THE DEVELOPMENT OF CANDU TECHNOLOGY AND TRAINING AT THE INSTITUTE FOR ADVANCED ENGINEERING IN KOREA

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ABSTRACT

This paper presents an overview of the cooperative agreement between the Institute for Advanced Engineering (IAE) and Atomic Energy of Canada Limited (AECL) to facilitate the transfer of CANDU technology in South Korea.

This paper will present those AECL technology program activities worked on by IAE staff with AECL support along with the associated issues which these activities addressed and the expertise nature of this work. The training methods utilized and an assessment of their success will be discussed to show the potential applicability of these methods to the nuclear power industry staff of other countries. The spin-off cooperative work initiated with other Korean organizations as part of this initiative will also be considered.

INTRODUCTION

The Institute for Advanced Engineering (IAE) in Yongin, South Korea was founded as an educational/industrial institution in 1992 to serve the research and development needs of its member companies in certain targeted core technology areas for the 21st century (e.g. automotive engineering, flexible manufacturing, integrated gassification-combined cycle technology, nuclear power engineering, communications and electronics), and to combine research and teaching in a laboratory/workshop environment for direct hands-on work experience based on a systems engineering approach. The idea is to funnel realistic, work-place engineering experience directly to the students, with the emphasis on seeking practical and implementable solutions to ill-posed problems, since in reality problems are rarely well-posed.

One of these core technology areas is the supporting technology required for the generation of nuclear power. To better develop this technology base, IAE has an on-going agreement with Atomic Energy of Canada Limited (AECL), dating back to 1992, to share resources in order to facilitate this transfer to IAE staff, students and their Korean industrial contacts. As a result of this successful collaboration, IAE can provide supporting technology for present and future CANDU stations together with a dedicated CANDU Technology related course credit in its Department of Systems Engineering, which is operated in affiliation with Ajou University.

IAE's host company, Daewoo, is currently constructing the Wolsong 3&4 CANDU Units in Korea, owned by KEPCO and designed by AECL. As a large scale construction consortium, Daewoo is very interested in the application of 3D CADDS technology for the development of cost effective CANDU construction methods. This is one example of a synergistic return to all participants where mutual benefit obtained is significant from the progress of this type of cooperative work.

There is also considerable interest in training Korean engineers in the design, operation and maintenance of CANDU reactors. Due to IAE's development of CANDU technology courses, the development of an engineering simulator, and the application of 3D CADDS modeling resulting from the technology transfer program, IAE has been able to help train Daewoo construction engineers to provide cost-effective solutions for construction planning of the Wolsong 3&4 reactors. IAE has been instrumental in supporting commercial engineering contracts between AECL and Daewoo in this regard. As a result of the example set by the Daewoo/IAE/AECL initiative, other Korean technical institutions are expressing their interest in expanding CANDU research and teaching initiatives.

BACKGROUND - IAE/AECL HISTORICAL SUMMARY

The foundations for the co-operative program between AECL and Daewoo/IAE began in 1992 by the first President of IAE, Dr. Kun-Mo Chung, and Dr. D.A. Meneley, AECL's Chief Engineer. The latter was responsible for developing and setting up the basic CANDU Technology Training courses at IAE, introducing the 3D-CADDS engineering system for the CANDU units under construction in Korea, and development of the CANDU engineering simulator by IAE engineers.

The initial motive for establishment of the IAE program was the education of engineers, as distinct from scientists. Engineering is a decision-making process with options and assigned values, whereas science is a problem-solving process. Dr. Meneley was concerned that this distinction often has been blurred in North American as well as in Korean university programs, at the expense of engineering education. An engineer must consider the whole task of providing nuclear electricity as a <u>system</u>, inside which many subsystems operate, including technical, economic, and social subsystems. This manner of thinking avoids the common technological problem of finding local optima for subsystems separately, and thereby sacrificing the global optimum or even choosing inconsistent subsystems which then interfere in the real world.

The CANDU technology program at IAE began with the systems approach - using operator training materials to illustrate the technical subsystems of a CANDU plant. Also, the AESOP/CANCAP73 optimization program was brought to IAE to show the importance of economics to engineering design optimization.

AECL then assigned Dr. A.P. Muzumdar to IAE who continued the development work on the engineering simulator in 1994, and in addition, focused on safety engineering, cost optimization and design methods. He was also responsible for obtaining formal agreement between AECL and IAE to collaborate on the further development of a CANDU engineering simulation package, to model certain normal operational transients not usually performed adequately by training simulators.

The present AECL/IAE attachment incumbent, Mr. M.J. MacBeth, formerly the Manager of CANDU 9 Control Engineering, continued with the formal CANDU related presentations. IAE credit courses and seminars were presented on CANDU control strategies, man-machine interface designs, human factors engineering and the use of simulation as a design tool.

COOPERATIVE IAE/AECL NUCLEAR SIMULATION TECHNOLOGY

The CANDU engineering simulator was developed at IAE to provide a tool that would be useful for training researchers and engineers in CANDU technology at IAE. However, these same researchers would also be involved with simulator model development, providing them with valuable hands-on experience as well as providing a better understanding of the product. Several interacting requirements led to this choice of teaching tool. First, a nuclear power plant is a dynamic system; the notion of steady-state is misleading. The simulator demonstrates this principle for the system as a whole and for its component parts.

Second, the simulator provides an inexpensive and practical alternative for the student's need to operate a real power reactor, which hardly any of them will have a chance to do. This brings the engineer's mind closer to the operator's needs – the operator being the most important human element in the overall system (not the engineer).

Third, the engineering simulator consists of subsystems which are the engineers' objects of study - the reactor itself, heat transfer and fluid flow systems, control systems, and so on. Each of these subsystems can be modeled by the engineer, these models can be verified against the performance of actual systems (using real plant data), and the models can then be improved as required. Finally, the designs of these subsystems can be improved by replacing component parts with better ones in a "plug-in" fashion to better serve the holistic objective – which is the economic, reliable, and safe production of electricity.

While then existing CANDU full scope simulator models were adequate for operator training, they did not possess the kind of detailed models required of an engineering simulator, which is much better suited to providing training in a research/ engineering/ education environment. The alternative of training using a set of highly detailed physics and thermal-hydraulics based tools, typically used in design and licensing analyses, is not only too cumbersome and impractical, but detracts from the "technology" based goals pursued at IAE, which require that there be some potential for commercial application. Such application requires a balance somewhere between the approaches adopted for a full-scope simulator and detailed analysis capability.

The starting vehicle of the CANDU engineering simulator project was a test version of a CANDU simulator model previously developed under Dr. Meneley, and modified at IAE to model various overpower and setback transients. The plant dynamic modules consisted of representations of the main systems, components, and physical processes in a CANDU plant. The CANDU engineering simulator model was used to predict plant operational transients such as reactor setback and reactor trip, and the results compared well against those of more detailed coupled neutronics/thermal-hydraulics models.

Since CANDU reactors have multiple inlet/outlet feeder connections with varying lengths and diameters of feeders, and hence, varying flow resistances, a method of representing these feeders using only a few groups of channels was developed. This method can potentially be applied to other types of analysis in which the overall behavior of the heat transport system is required, e.g., during LOCA analysis.

More recently, the AECL CANDU 9 nuclear power plant simulator was introduced to IAE as an example of the use of simulation early in a design process. This simulation is a low fidelity, near full scope capability simulator. It was designed to play an integral part in the design and verification of the CANDU 9 control center mockup man-machine interfaces. This simulation will also provide CANDU plant process dynamic data to the plant display system, the distributed control system and to the mock-up panel devices.

The CANDU 9 simulator was supplied to AECL by Cassiopeia Technologies Incorporated (CTI) and was developed using a simulation development tool under the trade mark title CASSIM (Reference 6.). IAE purchased a software license for the CTI simulation executive that would allow them to execute the CANDU 9 simulation code on one of the existing work stations in Korea. AECL donated the integrated model run-time code so that a fully functional version of the CANDU 9 PC based simulation was available at the IAE Yongin, Korea facilities by early 1997 for use by students and researchers. This platform was also selected as the basis for another, non-nuclear research project at IAE in 1997.

The simulation employs dynamic mathematical models of the various process and control components that make up the CANDU 9 nuclear power plant. This simulation tool provides the flexibility to add, remove or update the user supplied component models. The design strategy organized the simulation into three main function categories - the process models, control logic and the man-machine interfaces. Initially, the PC based CANDU 9 simulation would run in stand-alone mode, but as the distributed control system and the plant display system designs progressed, more and more of the control and display interfacing functions could be provided by those respective systems.

Although prepared as a design tool, the CANDU 9 PC based simulation provided an excellent means of supplementing technical lectures on CANDU operations and control topics as well as allowing hands-on technical exercises and operational assignments to be carried out. The simulation is a mechanism for improving an individual's understanding of system to system interactions (i.e. heat transport to boilers) as well as mastering the practical basics of system annunciation, display and control functional requirements.

The CANDU 9 PC based simulation at IAE has been used as an integral part of the CANDU technology credit courses. The simulation can as well be used by researchers or students who are tasked with man-machine interface development on other projects as a means of defining and reviewing basic requirements while allowing rapid prototyping to thoroughly assess concepts.

COOPERATIVE IAE/AECL CADDS TECHNOLOGY

The CANDU 6 3D CADDS Models were developed by AECL/Daewoo/IAE to provide technical support for the construction of the CANDU 6 units at Wolsong site, Korea by Daewoo. AECL and Daewoo/IAE shared the modeling works so that timely application of those models for construction would be possible.

AECL initially provided CADDS training for IAE/Daewoo engineers who were assigned to be familiarized with the new CADDS system and ultimately, to do the modeling work. Several AECL engineers were dispatched to Daewoo/IAE to help IAE set up the CADDS environment in Korea. IAE staff were responsible for ensuring that the CADDS equipment and software tools were functional, and that the Daewoo staff were trained. This is a very good example of a practical technology transfer implementation strategy. Then, cooperative and coordinated modeling works began at the Daewoo/IAE sites in Korea and at AECL Sheridan Park in Canada.

The development of 3D CADDS models for Wolsong CANDU resulted in a 3D electronic CADD database being available for project use so that necessary drawings could be extracted for site work. Component interferences, constructability, piping isometric extractions, equipment install simulations, construction sequence studies and so forth were now all possible by utilization of the 3D CADDS model files.

The resulting 3D model files were integrated by AECL/Daewoo/IAE to be sent to Wolsong site for construction staff use. This construction application of CADDS resulted in the achievement of a world record for the shortest installation time of a feeder piping system. This technique also contributed significantly to the recognized high quality of construction achieved for the Wolsong units.

The outcome of this work will be further enhanced and utilized for the Qin Shan China CANDU project to optimize that construction schedule. The model data for a target site will also be further developed and enhanced as part of the CANDU 6 Nuclear Power plant configuration management program under development by IAE. The application of CADDS models to Operation and Maintenance applications for cost reduction purposes is also under consideration for Wolsong units 2/3/4.

AECL CONTRIBUTIONS TO THE IAE TRAINING PROGRAM

In addition to the CANDU Technology Training courses initially introduced to IAE by Dr. Meneley, a set of five credit courses were also developed by Dr. Muzumdar during 1994-1996. These focused on the following CANDU reactor design related topics:

- Safety and Supporting Research Programs
- Design and Cost Optimization
- Control Systems Basics

- Plant and Systems Design
- Special Topics in CANDU Technology.

Regular seminars were given to IAE staff covering various topics such as reactor regulatory practice in Canada compared to the U.S., reactor safety research, containment design, acoustics of CANDU reactors, single channel behavior, unique aspects of CANDU behavior during severe core damage accidents, safety culture and the history of reactor accidents, lessons learned from a review of significant event reports, liquid relief valve related failures, and operating procedures in the event of various accidents. Some of these seminars were also provided to engineers of the Korean electric utility (KEPCO) by invitation.

The present (1997) AECL/IAE cooperative initiative focused on the operations, controls and instrumentation of power plants in general with application examples being taken from the CANDU 9 pre-project phase to enhance the IAE staff capability to provide such project support. In addition, design methodology and implementation insight training was provided for such topics as control application programming and man-machine interface design concepts and verification methods. Where possible, the application of such concepts to non-nuclear applications warranted consideration.

The lectures for the CANDU technology course were then supplemented by the use of the CANDU 9 plant simulation for concept clarification, control system performance, power maneuvering demonstrations, malfunction effects, operational assignment training exercises and commissioning related tasks such as loop tuning.

As well, a series of CANDU related seminars were conducted at IAE and with peer organizations in Korea to better share and utilize the AECL technology base applicable to those organizations on such topics as CANDU station system controls, Human Factors Engineering, plant software categorization, simulation applications and lessons learned from past commissioning or operations events.

A RESULTANT PROJECT

Daewoo Heavy Industry (DHI) had contracted to build two large liquid natural gas (LNG) carrier ships which are to be completed on a multi-year schedule separated by six months. These ships are to be powered by turbine control, which was an innovation for this class of ship, and the fuel for the boilers would come, in part, from the cargo LNG boil-off which required a more sophisticated combustion control strategy. The controls supplier did not have experience with this application and any delays in completion date or late discovery of design problems represented a very substantial economic risk. For these reasons (innovation, complexity, inexperience and risk), Daewoo investigated strategies which would help assure timely and successful project completion.

Since an AECL staff member familiar with the AECL CANDU 9 simulation design methodology was attached to IAE, and had presented an IAE seminar on this topic in January 1997, he was invited to present a similar seminar at the DHI Okpo shipyard and so was able to participate in this technology implementation opportunity from the onset.

One approach adopted as part of the final LNG controls project implementation was to use the AECL CANDU 9 simulation development and design integration methodology to allow design concept evaluation and control scheme functionality testing with confirmation of essential man-machine interfaces.

This initiative required a cooperative effort between the staff of the Institute of Advanced Engineering (IAE), Ajou University and DHI. Once the decision was made to proceed with the LNGC project, a development team was assembled with staff provided jointly by IAE and Ajou universities. This team was supervised by the responsible IAE and Ajou Professors with technical guidance, review and consultation input provided by the attached AECL staff member.

Related goals for this work assignment included a practical focus, the desire to work effectively and efficiently, work correctness, work completeness, well documented results, auditable work methods and application repeatability with the spin-off advantage of minimizing subsequent costs for repeat design versions. As well, the final simulation product and documentation set would be available at project completion for final client training use as may be required.

Early project discussions and presentations to help determine the suitability and extent of simulation support for the LNG carrier project were held. A justification criteria was proposed to assist in the decision making process and as well, an implementation framework plan was submitted for early discussion and steering purposes.

Once the formal approval to proceed was obtained, staff suggested first step activities and provided example documents to show the type of model reports, Phase I displays, manner of document approvals and tentative interaction meeting schedule with the client. This allowed the newly formed team to begin to focus on tangible deliverables that needed to be completed in a timely manner to allow achievement of the overall project schedule.

The LNG controls simulation team then worked in a progressively more independent manner to develop the detailed model reports and model codes, to conduct progress review meetings and as well as to complete the related code integration and testing tasks. This is a good example of cooperative technology transfer where work practices from the nuclear industry can be applied to other applications striving to instill higher levels of rigour and discipline in their engineering processes.

CONCLUSIONS

The cooperative work program approach described in this paper is one example of a very successful methodology to implement a systematic technology transfer program and would be recommended as a model for other organizations considering such technology transfer initiatives. As a result of the successful collaboration with AECL on CANDU technology, IAE can provide supporting technology and infrastructure guidance for present and future CANDU stations.

The CADDS technology transfer from AECL to Daewoo via IAE was seen as a crucial step in achieving the successful construction time and quality goals for the Wolsong project.

As described in this paper, the lectures for the CANDU technology courses at IAE were supplemented by the use of CANDU plant simulations to provide a hands-on ‘learn by doing’ environment which is a very powerful technical training technique.

The simulation can also be used by researchers or students who are tasked with, for example, man-machine interface development on other projects as a means of defining and reviewing basic requirements while allowing rapid prototyping to thoroughly assess concepts.

Equally important for the Korean technology transfer momentum were the series of CANDU related seminars and presentations conducted at several technical organizations in Korea to better share and utilize the CANDU technology base applicable to those organizations. This is a strong and diversifying mechanism which should be included when planning such technology transfer initiatives.

The use of the CANDU 9 design and simulation methodology for the LNG controls project is one positive example of the diverse spin-off results one can expect from a technology transfer initiative.

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