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ORNL FOREIGN TRIP REPORT

ORNL/FTR-3435

DATE: November 10, 1989

SUBJECT: Report of Foreign Travel of H. E. Knee, Group Leader, Cognitive Systems and Human Factors Group, Engineering Physics and Mathematics Division

TO: A. W. Trivelpiece

FROM: H. E. Knee

PURPOSE: To visit the Halden research facility in Norway and to discuss whether Halden's research would be useful for the Advanced Controls Program and man-machine interface collaborative research potential.

SITES VISITED: 10/18-20/89 OECD Halden Reactor Project Site, Halden, Norway — Mr. H. Smidt Olsen, Director of Man-Machine Systems, OECD Halden Reactor Project

ABSTRACT

The traveler and Mr. J.D. White, also of ORNL, met with management and research personnel at the Halden Reactor Project (HRP) in Halden, Norway to assess the potential for future collaborative research between ORNL and the HRP in the areas of advanced controls and man-machine interface. The travelers were provided with two-and-a-half days of briefings and demonstrations that addressed a number of computer-oriented support systems (COSSs) and an integrated surveillance and control system (ISACS). The purpose of the ISACs is to integrate the various COSSs into a "super" support environment for the human operator of a nuclear power plant.

The HRP has not only developed a number of COSSs over the past decade, it has also built an experimental environment in which to evaluate the emerging support systems, and to examine the impact on human performance. Most of their research has focused on nuclear-oriented informational displays for the operator, with little to no emphasis on control.

The Halden experimental environment and expertise in displays, coupled with ORNL's recognized expertise in the area of advanced controls, could provide strong control system/room design support for DOE's Advanced Reactor Designs, especially the Advanced Liquid Metal Concept.

HALDEN, NORWAY TRIP REPORT

Background Information

The HRP is a 20-MW(th) Boiling Heavy Water Reactor built more than 30 years ago to support nuclear fuel testing and operational measurements. During its lifetime, the HRP has put together a research capability in the area of advanced display/informational support for nuclear power plant operators. The Project is currently funded by ten "signatory" members (Norway, West Germany, Sweden, Italy, the United Kingdom, Finland, Denmark the Netherlands, Japan and the US [the USNRC is the US signatory]), who contribute agreed upon funding levels (not all equal) on an annual basis. Each member country is allowed to "suggest" research areas of their own interest for pursuance by the Project. Research is usually planned for a three year period by the Halden Board of Managers (Halden Management and Signatory representatives). Currently the research is coming to the end of the second of a three-year plan, and the Board meets at least once per year to discuss progress, problems and research directions (the next meeting is December 12, 1989). The Project currently supports over 200 staff members with a budget of about $14.5M. About 40% of the research is directed at the area on man-machine interface, especially with respect to the development and evaluation of advanced operator support systems.

The Project also accepts associate members who have specific research interests and provide specific funding to pursue such interests. In effect, by acceptance of associate memberships, the Project acts as a subcontractor to the associate member. The associate member's research is generally complimentary to the research interests of the signatory members. In the past, General Electric, Combustion Engineering and the Electric Power Research Institute have been associate members from the U.S.

Results of research by the Project get into the open literature primarily through presentation of the research at international conferences, and to a lesser degree, journal publications. The research reports generated by the project are generally considered proprietary to the signatory and associate members, and unfortunately do not receive wide circulation.

The traveler and Mr. J.D. White, Program Manager of ORNL's Advanced Controls Program, Instrumentation and Controls Division, had been asked by DOE to go to Halden to participate in discussions dealing with Halden research, and to assess the degree to which such research compliments DOE supported research in the areas of advanced controls and man-machine interface.

Meeting Highlights

General discussions concerning the HRP, man-machine interface design, and specific research projects at the HRP were held during the two-and-a-half day meeting. A general overview is presented below.

General HRP Overview: Mr. O. Berg (Manager of the Operator Support Systems Group, Man-Machine Systems Division) provided information that overviewed the development of the various COSSs at the HRP, and the plan for their integration into the ISACS. Some general questions/comments were raised concerning the experiments and interface design. They were:

1) What population of experimental subjects are used for the experiments, and is there a concern about biased data?

Mr. H.S. Olsen, Director of the Man-Machine Systems Division, indicated that there were about 18 operators from the Halden Reactor that functioned as the subject population. He stated that there is always the concern over biases in the subject population, but that obtaining nuclear-wise operators for experiments was difficult. He indicated further that since the Halden Reactor was so completely different from the experimental environment (e.g., there is no balance of plant (turbines) on the Halden Reactor), that carryover from previous operational experiences was minimized. He also emphasized that none of the HRP man-machine interface research has been ported to the Halden Reactor control room.

2) Mr. Olsen indicated that a properly designed interface raises the cognitive level of the operator in the system. He gave a good example related to representation of the motion of the planets and their oscillations and effects. He indicated that such data and information can be captured in tables, but that one dynamic physical representation conveyed much more to a student than the tabular form. He stressed that proper integration of data to support cognitive notions of the operator is the direction that man-machine interfaces is headed.

3) Mr. K. Haugsett, Laboratory Manager of the Man-Machine Systems Division, discussed the ISACS and the COSSs that will go into making up the ISACS. Several important points discussed by Mr. Haugsett were:

- The purpose of ISACS is to support operator performance in normal, disturbance and accident conditions.

- Support by ISACS is to be provided to the operator in the areas of status identification, action planning and action implementation.

- The following COSSs have been developed at the HRP:

  SCORPIO: Assists the operator in developing operational strategies associated with movements of control rods, fuel burn-up, Xenon oscillations, etc. It is also a forecasting tool for these areas. This COSS is intended to support status identification and action planning during normal reactor operation.

HALO: An Alarm Filter for the operator to assist in status identification during reactor disturbances.

EFD (Early Fault Detection): Gives an indication of feedwater system state changes (and physical location) in a single diagram that provides trend curves for modeled components. It was noted that the feedwater headers for GE's PRISM design have been modeled using EFD. This COSS will provide support to the operator for status identification during reactor disturbances.

Diskett: An alarm diagnosis expert system that will provide support to the operator for status identification during reactor disturbances.

DDP (Detailed Diagnosis and Prognosis): A COSS still under development but designed to support status identification during reactor disturbances.

CFMS (Critical Function Monitoring System): A COSS originally developed for Combustion Engineering to assist in the identification of critical functions during reactor accident situations.

SPMS (Success Path Monitoring System): A COSS originally developed for Combustion Engineering to assist in the identification of existing success paths during reactor accident situations.

COPMA: A procedure prompting aid that leads the operator through procedures for normal, disturbance and accident reactor states. It primarily supports the operator during action implementation.

- The only area for which a COSS has not yet been developed is action planning in support of a reactor disturbance.

- The design of the ISACS is applicable to nuclear as well as non-nuclear control rooms that deal with complex processes.

- Halden has not specifically carried out research in the area of Supervisory Control. It was indicated that Supervisory Control was felt to be good for normal operation and deviations from normal. Halden's emphasis is normal operation and all other phases of operation including accident situations.

- It was stated that the level of integration of controls and displays should be complimentary. That is, if emphasis is placed on "direct manipulation" capabilities for controls, emphasis should also be placed on "direct perception" capabilities for displays.

- Currently, the HRP does not conduct research in the controls area. This would be a new research direction for them which is felt to be a necessary if research is to be supportive of an advanced control room concept.

- In the use of the Diskett system at Halden, experimental evidence exists with respect to operators "blindly relying" on the diagnosis of the computerized system without subsequent verification for validity. It was suggested that this effect could be minimized through better training of the operator.

- The first version of ISACS to be completed in CY-1990, will be considered to be a prototype demonstration of its high-level concepts. Its evaluation will come almost entirely through experimentation.

- The Halden staff includes only one full-time psychologist.

4) Demonstration of the COPMA system was provided by Ms. M. Krogseter. It was noted that input for the development of COPMA differed significantly from one signatory member to another. The United Kingdom was very supportive of a system that dealt primarily with scrolling techniques, with effectively no imbedded intelligence. The Germans, on the other hand, supported advanced capabilities for procedure aiding. The demonstrated form of COPMA required approximately 9 person-years for development.

5) Demonstration of the Diskett system was provided by Mr. T. Karstad. The expert system was capable of displaying "why" certain rules were fired, but was felt by the traveler not to give such reasoning in an integrated manner. Integration, in the current form was left to the operator. The demonstrated form of Diskett required approximately 4 person-years for development.

6) Mr. G. Dahl, manager of the Software Reliability Group, discussed the Standardized Software Safety Assessment Tool (SOSAT) that is being developed at Halden. He indicated that this tool, when applied to an existing piece of software, provides a number of measures or characteristics that are important for a user interested in the reliability or safety of the software. Four primary areas were discussed: (a) Metrics Computation, consisting of characteristics such as the number of lines, a measure of complexity, etc., (b) Static Analyses, dealing with data flow characteristics, program flow characteristics, etc., (c) Dynamic Analyses, dealing with path convergence characteristics, input/output transfer functions, etc., and (d) Symbolic Execution, dealing with characteristics such as path predicates. Mr. Dahl indicated that the symbolic execution portion of the tool was still under development.

7) Mr. T. Silvertsen discussed an automated procedure verification and validation tool based on algebraic specification. Although he did not have the time to go into detail, Mr. Silvertsen indicated that the tool could find inconsistencies in procedures, where they could lead to unsafe plant states, and where operations would be impossible or difficult. He

hinted that such an approach could also be applied to control software. He stressed however that the results did not reflect possible human error, were not necessarily optimal, and did not consider qualitative information.

8) Mr. Bill Nelson, independent consultant to the HRP, discussed the overall approach to experimentation at the Project, emphasizing the man-machine interface research. He indicated that the experimental efforts were one of a four-step approach taken to generate information/data of interest to analysts: (a) COSS Development and System Integration, (b) Experimental Evaluation, (c) Development of Data Supported Models of Operator Performance, and (d) the Generation of the Technical Bases for Man-Machine Interface Guidelines. It was stressed that the four steps were highly iterative, and that work has just been initiated in the latter two steps.

Mr. Nelson indicated that most of the ideas for the COSSs come from within the HRP, and that experimental evaluation is carried out in their laboratory. He indicated further that the

models of step (c) come from the interpretation of the experimental results. Currently, only a small effort is directed in this area. For step (d), it was suggested that utilization of the data and information by the signatory members would require identification of the types of data needed. Intentions were to design and circulate a questionnaire among the members.

Mr. Nelson pointed out that the HRP carries out one-to-two experiments per year, and that each experiment (excluding the actual running of the experiments and the analyses) requires about one person year of effort. He indicated that the evaluation of Diskett had just been completed. The experiment resulted in the collection of subjective input from operators and data pertaining to verbal protocol, including time and accuracy measures. Currently, experiments are being designed for the COPMA system, however, they will not be focused on cognitive elements.

It was the observation of the traveler that the experimental approach taken at the HRP is primarily bottom up. That is, the experiments are designed to support COSS evaluation rather than supporting a more general understanding of human performance (a top down approach). From the scope and application of their experiments, it would be difficult to make generalizations about human performance outside of relatively specific applications. Although the experimental environment is potentially very good, its application and use, in the opinion of this traveler, is relatively narrow. It is believed by the traveler that the experimental design could benefit from some additional expertise in the area of human factors or experimental psychology.

9) Mr. Nelson described HRP efforts in the area of early fault detection (EFD). He indicated that it provides a state history of components that use models of component operation as reference. Thus far, the system addresses only mechanical components, and

that the EFD effort on-going at GE for their feedwater headers will have imbedded intelligent, diagnostic capabilities. The system being developed for GE effectively gives conclusions and advice to the operators.

10) Mr. J.D. White provided an overview of the Advanced Controls Program to the HRP staff members in attendance at the meeting. When the discussion centered on levels of automation, a number of interesting comments were provided. They included the following:

o German reactors have multi-variate control, have a number of automated interlocks, and have a number of layers of automation. Their automation, however, is probably not digitally oriented; it was felt that perhaps it was mostly analog.

o The French N-4 Concept is more advanced than the Germans, and is very procedure-oriented. It has been observed that digital technology is abundant in their design, however, questions have been raised concerning effective utilization of the digital technology.

o The HRP staff seemed to be impressed by the research within ORNL's Advanced Controls Program. Mr. Olsen indicated that a systems approach to advanced control room design would require a more integrated controls and display research; one that might be achieved by a more closely aligned research focus between Halden and ORNL.

11) Mr. T. Vik, director of the HRP, indicated positive support for ORNL (as a representative of DOE) being an associate member of the HRP. Since the U.S. was already represented as a signatory member by the NRC, initial discussions assumed an associate membership for ORNL. He indicated that cooperative efforts could be initiated as soon as the start of CY-1991 (note: CY-1990 is the last year of the current three year plan).

12) Mr. J. Kvalem described the HRP configuration of their laboratory. He indicated that their full-plant simulator models were running in real time on a NORS ND 5920 computer. The COSSs are functional through two NORS computers (ND 570 and ND 120CX) and a TI Explorer machine, all linked via Ethernet to the 5902 machine. The laboratory workstations are supported by two Symobilcs 3640 machines and a VAX 2000. These are connected via Ethernet to five HP Unix-based work stations (9000 series) and another TI explorer. The laboratory also has audio and video capabilities and is observable from a separate instructors workstation via a glass partition. He indicated further that their Man-Machine interface involved Unix-based servers, X-Windows, and advanced graphics (based on X-Windows).

Future research will involve the implementation of a new data base management system (most likely Sybase because of its real time relational capabilities). The system will be implemented in CY-1990.

Mr. Kvalem also discussed a new system under development that is intended to help experimentalists prepare, conduct and analyze experiments. The system entitled HOPES has the following characteristics: (a) menu driven, (b) predefined display formats and function buttons, (c) some direct choice keys, (d) "help" on all levels, and (e) clear error messages. The system will be capable of (1) controlling the state of the simulator, (2) displaying dynamic variables, (3) advanced malfunction handling, (4) scenario control, (5) debriefing functions, and (6) simulator configuration control.

13) Lastly, the travelers were given a brief demonstration of the Rankin Cycle operator aid under development at the HRP. Its concept is very similar to the steam/entropy concept developed at the Experimental Breeder Reactor-II (Mr. L. Beltracchi of the NRC is the champion of both). The aid builds on first-principal notions of pressure, temperature and entropy in order to display to the operator a pictorial that is rich with information related to plant state. With such an aid, the operator is not required to integrate a large number of diverse information sources to understand the state and direction of the plant. It would be interesting to investigate the effects of such a system on overall reactor system functionality.

Observations and Conclusions

1) The HRP has much expertise in the area of informational displays and aids for the operator. A research program that could bring together such expertise with ORNL's expertise in the area of advanced controls would provide an extremely supportive environment for the design of advanced control rooms.

2) The HRP has acknowledged experience in the area of conducting bottom-up human performance experiments focused on evaluation of operator aids. The principal drawing point in their experimental efforts however is the existence of a well-networked architecture of hardware and software. What would be very beneficial is the application of such an environment to well-designed and controlled top-down human performance experiments. Such experiments would not only provide system performance metrics, but would also provide insights into human performance, especially from a cognitive functioning perspective. Since ORNL has demonstrated a research interest in the area of experimental human performance research (both within the Advanced Controls Program and other human factors programs at the laboratory), cooperative experimental research between Halden and ORNL seems potentially fruitful. Specific areas might include the evaluation of the Advanced Controls Program products, e.g., supervisory control, design workstations, etc., and experimental validation of the Advanced Controls Program's human operator model - INTEROPS.

3) The HRP research in support of ISACS is an extremely good area for cooperative research. Although initially the ISACS will have limited applicability, its ability to address man-machine interface concepts (e.g., communication, content, degree of

transparency of controls/displays, operator roles, etc.) would provide an opportunity to design and conduct experiments that would be supportive of data and informational needs of the advanced reactor design concept communities.

Recommendations

In many ways the Halden Project has characteristics of being what an "Advanced Displays Program" might be. Furthermore, the experimental environment is something that should be developed for/within the ORNL Advanced Controls Program. It is felt that at least initially, there is a positive benefit from having a closer cooperative research effort with Halden. It is recommended that if DOE feels similarly, that contact prior to the next Board meeting scheduled for December 12 should be pursued.

APPENDIX 1

Itinerary

October 16-17, 1989	Travel from Knoxville, Tennessee to Halden, Norway
October 18-20, 1989	Meeting With Halden Reactor Project Personnel
October 20, 1989	Travel to Frankfurt, Germany, for weekend
October 21, 1989	Personal time at traveler's expense [Saturday]
October 22, 1989	Travel from Frankfurt, Germany to Knoxville, Tennessee

APPENDIX 2

Persons Contacted

Meeting With the Man-Machine Systems Division (MMSD)

Mr. O. Berg, Manager of the Operator Support Systems Group

Mr. G. Dahl, Manager of the Software Reliability Group

Mr. K. Haugsett, Man-Machine Laboratory Manager

Mr. T. Karstad, MMSD Staff - Diskett Demonstration

Ms. M. Krogseter, MMSD Staff, COPMA Demonstration

Mr. J. Kvalem, MMSD Staff, Discussion of Laboratory Configuration

Mr. W. Nelson, Independent Consultant Under Contract to the HRP

Mr. H.S. Olsen, Director of the Man-Machine Systems Division

Mr. T. Silvertsen, MMSD Staff Algebraic Specification

Mr. T. Vik, Director of the HRP

U.S. Nuclear Regulatory Commission - Office Of Nuclear Regulatory Research

Mr. L. Beltracchi

APPENDIX 3

Literature Acquired

"OECD Halden Reactor Project, 1958-1988, "brochure from Institutt for Energiteknikk, Norway, undated.

"OECD Halden Project, 1985-1987 Achievements," brochure from Institutt for Energiteknikk, Norway, undated.

"Draft Halden Reactor Project Programme; Proposal for the three year period 1991-1993," Institutt for Energiteknikk, Norway, April, 1989.

"Halden Reactor Project Programme; Proposal for 1990, Institutt for Energiteknikk, Norway, HP-805, October, 1989.

"SOSAT User Guide for Programs Developed at IFE, Halden, Institutt for Energiteknikk, Norway, HP-SYSDOC-8, undated.

Valisuo, H. and Silvertsen, T. "Verification of Discrete Event Control Systems Using Algebraic Specification, Institutt for Energiteknikk, Norway, unpublished, undated.

Dahll, G. and Sjoberg, J. :SOSAT - a Set of Tools For Software Safety Assessment," paper submitted for the Second European Conference on Software Quality Assurance, May 30-June 1, 1990.

Ness, E., Berg, O., and Sorenssen, A., "Early Detection and Diagnosis of Plant Anomalies Using Parallel Simulation and Knowledge Engineering Techniques," Institutt for Energiteknikk, Norway, undated.

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