HUMAN FACTORS ENGINEERING (HFE) METHODS

Human Factors Engineering (HFE) is a ***systematic approach*** to guide the human interactions with a facility (say such as a control room) to ensure that all functional aspects of human involvement are ***achievable*** without introducing the opportunities for ***human error***. HFE is concerned with the user, the maintainer, the designer, manager, regulator, construction, commissioning staff, etc - all people who will be involved with this facility for the entire project life cycle.

Significant ***HFE design features*** that should be included in a systematic HFE design process include:

- Project ***HFE Program Plan*** (***HFEPP***) - intent, scope, timeliness and interfacing
- HFE aspects of ***design process*** - procedures and instructions
- ***Design Guides*** - project needs, the implementation and impact
- HFE pre-project ***licensing*** activities
- HFE guidance for control centre HSI ***standardization***.
- ***HFE analysis*** and specifications leading to plant display system requirements
- HFE considerations in support of ***automated safety system testing functionality***
- HFE analysis and ***on-going input/assessment*** using a mock-up. facility

This lecture will present some of these features of the HFE initiatives that have been implemented in support of the CANDU 9 Control Centre design as a way of introducing central HFE concepts.

PROJECT HFE PRINCIPLES

- At the start of the CANDU 9 project, the executive committed to implementing an ***HFE methodology*** for the ***design process*** in order to:
  - ***standardize*** the design activities and deliverables,
  - ***minimize*** the opportunity for ***human error***,
  - improve the ***visibility*** and ***auditability of HFE endeavours***,
  - while improving the ***operability*** and ***maintainability*** capabilities.

- The need for this ***design methodology*** came about due to gradually evolving ***HFE awareness*** in the technical community and increased nuclear ***regulatory HFE scrutiny*** as past power plant operations events had shown recurring instances of ***HFE root causes*** for significant ***plant outages*** or ***near misses.***

- CANDU 9 HFE staff defined ***two levels of HFE design effort*** - Levels **A** & **B**

- Level **A** HFE work represents intensive, ***high degrees of human interactions*** such as Control Centres, secondary control areas or field panel designs

- Level **A** HFE design tasks involve ***first-hand participation*** by the HFE specialists in the design activity

- Level **B** HFE work are those design activities which apparently have ***relatively low levels of human interactions***

- Level **B** HFE design tasks are more of a ***review*** or ***audit*** function for HFE staff (that is the HFE specialist does not contribute to the design product).

Flexible Level of Effort Assignment

- This level of HFE effort ***categorization can be revised*** as the design proceeds and a Level **B** area can be raised to a Level **A** design activity if supporting HFE activities prove to be ***more extensive*** than originally anticipated, as shown by a ***review finding*** or as a result of a ***designer requests*** for support (i.e. the process should be flexible or iterative in nature)

- AECL staff believe that the application of HFE to the design is best achieved by following a ***thorough***, ***systematic*** and ***traceable*** design methodology.

- Without such a ***structured process***, the application of design methods and criteria would be ***vulnerable*** to unique designer inputs which are dependent upon the individual designer's ***education***, ***experience***, ***knowledge***, ***judgement***, ***discipline preferences*** and ***perceived project goals***.

- We can minimize these ***potential design input variances*** by establishing ***an HFE design process basis*** (starting with the project HFE Program Plan - HFEPP) and ***integrating*** this HFE process into the project system design methods which are directly applicable to ***all*** project designers.

- The CANDU 9 project HFE staff also developed an ***HFE trade-off rationale*** to provide a ***mediating mechanism*** for those design issues for which technical necessity or constraints did ***not sufficiently address the HFE goal*** or principle. This was seen to be an essential design process strategy since HFE issues could now be ***dispositioned*** in a similar manner to other project technical, economic or layout clashes.

HUMAN FACTORS ENGINEERING PROGRAM PLAN (HFEPP)

- Initially, the CANDU 9 HFE staff prepared the project human factors engineering program plan (HFEPP) to provide the ***framework*** and ***guidance*** for the ***design and verification process*** to be used for the project.

- This plan was used by the nuclear regulator ***to assess the overall project design HFE strategy***. The HFEPP was reviewed and modified by project staff, management and executive prior to being submitted to the Atomic Energy Control Board (AECB), the Canadian Nuclear Regulatory authority.

- The CANDU 9 program director approved the HFEPP to apply the necessary ***administrative authorization*** so that the HFE intent would be implemented equally across ***all project disciplines***.

- Once the CANDU 9 HFEPP was approved, related ***project documents*** required by this plan were prepared.

- These underpinning documents are ***project wide*** in nature in that ***all designers*** for ***all disciplines*** can be affected to various extents.

- Documents such as ***project procedures*** governing the manner of ***documents preparation*** for design requirements and design descriptions were revised, reviewed and approved.

- These procedure modifications ***facilitated the incorporation*** of HFE design criteria throughout all relevant design documents (and hence the facility), and added a dedicated HFE section which summarized HFE aspects to improve peer ***reviewability***.

HFEPP IMPLEMENTATION...continued

- These revised project procedures provide a means of ***integrating HFE*** thinking and actions into the design process from the ***project start*** with the development of Design Requirements documents while also providing detailed design support ***guidance information***.

- For example, at the early stages of the project design, it is sufficient that the designer identifies and documents the ***high level functions*** and ***interfaces*** as well as the high level ***allocations*** for those functions. In many cases, simply asking the designer the HFE questions (via the checklist) initiated a very thorough and conscientious HFE effort.

- As the design progresses, this information can be revisited, reviewed and ***revised*** to a greater completion level of detail so that such information as the selection of ***automatic*** parameters, ***completeness*** of the parameter set, ***CRT*** based or ***hardwired*** display, and to which plant ***operating region*** CRT based HSI will be available can be addressed.

- Considering general project goals such as ***maintainability***, ***access***, ***inspection***, ***operability***, work control, communications, safety, etc ensures that necessary features are included in the design while such changes can actually be accommodated.

HFE ASPECTS OF THE DESIGN PROCESS

- HFE design process implementation must be ***practicable*** so that each designer can and will use HFE design criteria in their daily design work activities (i.e. make the ***functional integration*** of HFE a reality).

- The design process must follow a ***systematic analytical approach*** for ***all designers*** (e.g. involving designers from safety, process systems , controls, electrical, civil, control center, HFE, etc.)

- The HFE system design process provides ***requirements definition, function analysis, function allocation*** and ***task analysis***, combined within a ***verification and validation*** (V&V) ***cycle***, to define required operator and maintainer ***information*** and ***information presentation*** requirements.

- To assist in implementing the desired design process, the HFE staff also developed project ***HFE Assessment Documents*** and ***Design Guides*** as required by the HFEPP to provide further ***guidance*** to all project designers and to ***facilitate following*** the engineering procedural instructions (i.e. you should make it easy for the engineering staff to be succesful).

- These HFE guidance documents provide the ***specific detailed information*** necessary to implement ***particular aspects*** of the design.

CANDU 9 HFE design guides address design topics such as:

- Function Analysis
- Task Analysis
- Maintenance, Testing and Inspection
- Computerized Display & Monitoring
- Computerized Control Data Entry
- Annunciation
- Panel Layout & Device Selection

HFE Design Guides

- The system designers refer to these design guides for ***increasing levels*** of design detail or methodology ***guidance*** as the design for the application system proceeds.

- The designer has the reference ***plant Functional*** and ***Operational Basis*** documents, the ***operational feedback*** input, the ***project procedures***, and the ***HFE design guides*** as guiding mechanisms for the content and methodology for that portion of the design.

- Traditional discipline oriented design techniques are followed, but these are ***directed*** and ***standardized*** by the mechanisms mentioned above, to achieve a functional, ***consistent HFE design*** component across all disciplines.

- ***Function allocation*** is conducted early in the requirements definition stage as designers are guided to consider, for example, if the function should be performed ***automatically*** or ***manually*** (i.e., allocated to machine or human) and if automatic, should that function be performed by ***computer*** or ***hardwired devices.***

- The project ***procedures, design guides*** and the ***reference plant bases assessment documents*** aid the designers in this function allocation.

- Further function allocation details are defined as the system ***Design Description*** is prepared, as the design continues to progress and the method of implementing the design is prepared.

- A ***Function Analysis Design Guide*** is used by the Design Description document author to progress the on-going design review/evaluation process to ensure that required ***operational and/or maintenance sequences*** can be conducted ***effectively*** and ***efficiently***.

HFE Design Guides...continued

- ***Task analyses*** will be completed for those operational tasks which are identified as being ***problematic***, having ***high risk, high consequences*** and/or a ***high degree of difficulty*** for completion, or those tasks which are ***new in comparison*** to the reference plant.

- ***Not all operational sequences*** will be subjected to the task analysis process. Those tasks which have a proven operational success history will not be analyzed further.

- Any operational tasks from the reference plant for which ***concerns are raised*** during the validation process may be subjected to task analysis methods in order to determine the most appropriate solution.

- The resultant operator or maintainer display, annunciation and control information is ***verified*** against the system design requirements as well as being assessed against the operational task interfaces information set to provide a ***high confidence level*** that ***adequate*** and ***correct*** information is provided, necessary for the operational or maintenance task at hand.

- This verification process includes the traditional ***supervisory and peer document reviews, CADDS reviews, procedural walk-throughs*** moving to ***validation*** by utilizing the full scale control centre ***mock-up facility*** which is supported by the PC based CANDU 9 plant simulation.

HOW HFE FACILITATES PROJECT LICENSING ACTIVITIES

- A key CANDU 9 project goal is to significantly ***reduce schedule risk*** or uncertainty due to licensing issues.

- The project intention was to complete ***up-front licensing activities*** to ensure that the conceptual design was acceptable to the ***Canadian Nuclear Regulator*** (i.e. the AECB) as a basis for expediting foreign regulatory review and approval for the CANDU 9 design.

- Implementation of a sound ***HFE engineering methodology*** was agreed with the regulator as an enabling mechanism for achieving a substantial portion of this up-front licensing goal.

- Such pre-project licensing accomplishment is very desirable for both the regulator and the client utility in that all concerned parties have a ***firm*** and ***clear understanding*** of the intended ***action plan*** and ***schedule*** at the project onset.

In support of the CANDU 9 pre-project licensing goals, HFE staff undertook the following:

- Frequent ***informal*** information meetings with the regulator to provide on-going details and status on the HFEPP schedule and the associated design process
- Scheduled explanatory submissions of selected HFE and related design documents, with supporting documentation, for ***formal*** AECB review.
- ***Timely responses*** to AECB formal review comments followed-up with ***dispositioning meetings*** to clarify outstanding issues
- Conduct an ***internal project audit*** of HFE design processes and criteria
- Submit and discuss the results of the internal project HFE audit to the AECB
- Participated in the ***formal AECB audit*** of the CANDU 9 HFE design processes and criteria
- In general, the approach taken by HFE staff was ***to communicate more frequently*** with the regulator in a more issue oriented manner than had been the previous practice

- In this manner, regulatory staff understood very clearly ***what*** HFE work was being done, ***who*** was assigned the HFE work, ***when*** it was to be completed, ***how*** the was to be completed and ***why*** that HFE work was necessary.

PRACTICAL EXAMPLES OF PROJECT HFE IMPLEMENTATION

Standardization of Human System Interface Requirements

- ***Standardization*** of the ***operator*** and ***maintainer interfaces*** to the plant systems is crucial for an ***efficient*** station design.

- During ***plant manoeuvring*** conditions, it must be possible for an operator to move from ***system*** to ***system*** interface with a ***minimum of conflicting data presentation*** methods, alarm ***formats*** or control ***implementation methods***.

- Standard panels for the entire CANDU 9 plant (NSP,BOP,F/H) will be implemented with a ***standard display/presentation philosophy*** which provides operators with a ***consistent appearance*** across systems

- The ***design goal*** for this Human Systems Interface (HSI) aspect is that the general ***appearance***, ***meaning*** and ***operability*** of the key indicators and controls will be ***immediately apparent*** to the operator.

- HSI features such as device ***location*** on each panel, ***colours***, ***light status***, ***handswitch positions***, and VDU ***display features*** are standardized so that operator ***data assimilation*** and ***problem solving*** is completed with ***a minimum cognitive overhead*** and minimum opportunity for ***error***.

Plant Display System, Annunciation And Central Overview Display

- The basis for initiating the design of the CANDU 9 Plant Display System (PDS) was the ***well known information*** and ***operations requirements*** for the successful CANDU 6 single unit power plants.

- In addition, complementary ***operations features*** adapted from the more modern ***Darlington*** CANDU multiunit station were assimilated into the design.

- The design strategy is to ***preserve the functionality*** of the existing control/monitoring/annunciation systems while providing ***enhancements*** which will result in an ***improved operating & maintenance staff awareness*** of the plant operational state, provide for ***better detection*** and ***diagnosis*** of faults and ***improved*** operational ***reliability***.

- The CANDU 9 ***Plant Display System*** application will be based on HFE principles and criteria that are distilled for use in project specific design guides for such aspects as ***Video Display content***, ***navigation aspects***, ***control interactions***, ***annunciation*** and interface ***device selection***.

- Due design consideration has been given to the ***functional relationship*** between parameters of ***operationally related systems*** so that operators can ***easily navigate*** laterally or vertically through the display hierarchy to call-up the ***desired display***.

- The operator can navigate from plant ***overview*** to ***system*** to ***parameter/device*** levels directly in a ***system based hierarchy***, as well as move between selected systems, parameters and devices in a ***functional hierarchy*** (i.e. heat sinks, controls, chemistry, etc).

- Display action points are presented as device ***icons***, ***menus***, ***flowsheet connectors***, flagged ***parameters*** or ***action buttons*** in a standardized display format.

- The utilization of a flexible navigation system for the VDU-based plant display system allows ***custom information displays*** to be accessed in a ***simple***, ***direct***, ***repeatable***, ***convenient*** and ***logical*** manner by operations staff.

Automated Safety Systems Testing

- Automatic Safety System Testing encompasses ***computer assisted testing***, full ***automation of test signal generation***, ***application*** and ***switching*** of the test signal, ***test result comparison*** with test specifications and the ***approval*** or ***rejection*** of test results.

- The operator has the freedom to ***step through the test in any order***, provided that the necessary ***prerequisites are satisfied*** - which are also checked by the computer program. All ***calculations*** and ***scaling*** are provided by the testing software as well as the generation of textual/graphical ***displays*** and ***test records***.

- The testing HSI is further improved by ensuring that test information is provided in an ***easy-to-read format***.

- The test prompts are equipped with conditioning delays, which ***eliminate anticipated operator errors*** due to the incorrect timing of the commands, such as a typical valve test which requires the evacuation of a valve interspace to be completed before a second valve is tested .

- The screen displayed menus list ***all legal commands*** and ***possible choices*** for that display. The system responds positively only to acceptable commands while ignoring predefined illegal selections with appropriate feedback messages.

- All test signals are provided with selected trajectories that are ***automatically ramped***, so that operators and/or technicians can easily confirm the trip level or equipment calibration status.

- The test data values are ***automatically stored*** in the database, which enables the ***convenient issuing*** of automated ***periodic reports***, statistical ***evaluations*** etc. to completely unload the operator from these administrative tasks.

Full Scale Mock-Up Assessment

- A mockup of the CANDU 9 Control Centre panels and consoles in the AECL design facilities will be used for ***verification*** and ***validation*** (V&V) of the Level A HFE Control Centre features, displays and operator interactions.

- The functionality of the Control Centre mockup provides a ***practical mechanism for V&V design activities*** such as the panel or console ***attributes***, ***displays***, ***annunciations*** and operator/ maintainer ***interfaces***.

- The CANDU 9 system designers will utilize the mockup throughout the entire project design life-cycle.

- The CANDU 9 Control Centres ***HFE V&V*** was ***formalized*** in its own planning document that was based on several new standards for V&V such as the NUREG 0711 (HFE Program Review Model) and IEC 1771(Nuclear Power Plants - Main Control Room Verification and Validation of Design).

- This V&V plan identifies all the activities required to verify that alarms, displays and controls that have been ***specified*** in design documents ***are in fact present***, and ***validate their use*** in operational situations (e.g. plant startup and event mitigation).

- In CANDU 9, validation activities will include ***Subject Matter Experts*** (e.g. operators and shift supervisors) walking through panel and display designs for operability assessments as well as participating in walk-throughs and real time scenarios where a significant portion of the HSI and control centre staff are involved.

- The PDS facilities installed as part of the Control Centre mockup will be used to evaluate ***display/navigation concepts*** as the design proceeds. ***Dynamic plant data*** will be provided to the mock-up of the Plant Display System from the CANDU 9 mockup simulator.

SUMMARY

- The CANDU 9 project strategy for implementing HFE within the design process while ensuring that HFE is utilized in a ***pragmatic fashion*** on a day-to-day basis is a very successful technique.

- The HFE project structure provided the mechanism for ***assessment*** and ***review*** by the nuclear regulator while providing an ***auditable trail*** of design activities which could be used to demonstrate ***adequate*** and ***correct resolution*** of design issues.

- The use of the HFE methodology as a means of ***addressing*** and ***dispositioning*** the conceptual pre-project licensing design process issues has proven to be an invaluable and credible technique.

- The implementation of a structured HFE design process has provided many spin-off advantages (i.e. improved efficiency, standardization, timely input to structure design, improved operability, etc) to the project in the design phase and is expected to return even more (economy of scale) during the ensuing construction, commissioning, operations, maintenance and decommissioning stages.

- The careful consideration of the design process, interfacing design requirements and the diverse human needs within the total project will prevent the occurrence of some ***human errors***, improve the ***general quality*** of the final product and help to ***reduce project costs*** by eliminating rework or the creation of unexpected personnel workloads.