HSE CONTRACT RESEARCH REPORT No. 60/1993

SAFETY MANAGEMENT OF PROCESS FAULTS:
A POSITION PAPER ON HUMAN FACTORS APPROACHES
FOR THE DESIGN OF OPERATOR INTERFACES TO
COMPUTER-BASED PROCESS CONTROL SYSTEMS

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There is a growing concern that the introduction of computer-based control into process plants has created a supervisory role for the operator which is not adequately catered for in the current approaches to the design of control room interfaces. In response HSE has recognised the need to provide process companies with practical guidance on safety related aspects of the design of the operator interface. As an initial step this paper provides a review of the current status of human factors techniques, standards, guidelines and research relating to the operator interface in process control plants. This includes a comparative review of the design process for computer-based systems adopted in seven UK process companies. Recommendations are provided to improve the application of human factors principles to the operator interface including support for standards, development of guidance, technology transfer, training and further research. These recommendations do not necessarily represent HSE views, but are intended to stimulate interest and to obtain responses on the suggested recommendations.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION
   1.1 Background to Paper
   1.2 Objectives
   1.3 Scope

2. HUMAN FACTORS DESIGN AND EVALUATION TECHNIQUES
   2.1 Introduction
   2.2 Conceptual Design
   2.3 Outline Design/System Procurement
   2.4 Detailed Design and Acceptance Testing
   2.5 Commissioning
   2.6 Operation
   2.7 Conclusions

3. HUMAN FACTORS STANDARDS, GUIDELINES AND HANDBOOKS
   3.1 Introduction
   3.2 Human Factors Standards
   3.3 Human Factors Guidelines and Handbooks
   3.4 Conclusions

4. A SURVEY OF CURRENT DESIGN PRACTICE
   4.1 Introduction
   4.2 Description of Survey
   4.3 Results
   4.4 Conclusions

5. THE SCOPE AND DIRECTION OF CURRENT RESEARCH
   5.1 Introduction
   5.2 Global Issues
   5.3 VDU System Design
   5.4 Panel Display Design
   5.5 Conclusions

6. CONCLUSIONS AND RECOMMENDATIONS
   6.1 Conclusions
   6.2 Recommendations

7. REFERENCES

8. ACKNOWLEDGEMENTS

APPENDIX 1: SUMMARY TABLES OF STANDARDS AND GUIDELINES

APPENDIX 2: SUMMARY OF INTERVIEWS WITH PROCESS COMPANIES

APPENDIX 3: PROPOSED SAFETY ASSURANCE FRAMEWORK

I
LIST OF TABLES

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Page No</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Summary of Standards Applying to Workplace Design</td>
<td>29 - 30</td>
</tr>
<tr>
<td>3.2</td>
<td>Summary of Standards Relating to VDU Interface Design</td>
<td>31</td>
</tr>
<tr>
<td>3.3</td>
<td>Summary of Standards on Information Coding and Presentation</td>
<td>32</td>
</tr>
<tr>
<td>3.4</td>
<td>Summary of Standards on System Documentation</td>
<td>33</td>
</tr>
<tr>
<td>4.1</td>
<td>Overview of Companies Included in Survey</td>
<td>38</td>
</tr>
<tr>
<td>4.2</td>
<td>Decision Processes Adopted for Deciding Levels of Automation</td>
<td>39</td>
</tr>
<tr>
<td>4.3</td>
<td>Human Factors Considerations Applied in the Selection of Control Room Interface Hardware</td>
<td>40</td>
</tr>
<tr>
<td>4.4</td>
<td>Design Processes Applied in Determining the Number of VDU Displays Required in a Control Room</td>
<td>40</td>
</tr>
<tr>
<td>4.5</td>
<td>Processes Applied in the Design, Checking and Revision of VDU Displays</td>
<td>42 - 43</td>
</tr>
<tr>
<td>4.6</td>
<td>Design Processes for Control Rooms</td>
<td>44</td>
</tr>
<tr>
<td>4.7</td>
<td>Application of Guidelines and Standards to Human Factors Aspects of Design</td>
<td>46</td>
</tr>
<tr>
<td>4.8</td>
<td>Primary Roles of Operations Personnel in the System Design Process</td>
<td>47</td>
</tr>
<tr>
<td>5.1</td>
<td>Summary of Adequacy of Research Coverage</td>
<td>62</td>
</tr>
</tbody>
</table>

LIST OF FIGURES

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Page No</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Example of Hierarchical Task Analysis Format</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>Example of Tabular Task Analysis Format</td>
<td>11</td>
</tr>
<tr>
<td>2.3</td>
<td>Example of a Timeline Analysis Format</td>
<td>14</td>
</tr>
<tr>
<td>2.4</td>
<td>Example of Link Analysis Diagram</td>
<td>14</td>
</tr>
<tr>
<td>2.5</td>
<td>Example of Human Error Analysis Tabular Format</td>
<td>16</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION

1.1 BACKGROUND TO PAPER

Computer-based systems are being increasingly applied in the instrumentation and control of industrial process plant. The primary impetus for such technological advance is the economic benefits that can be obtained through closer and more reliable control. This has partly been achieved by replacing many aspects of human control of process flow, sequencing and dynamics by computer-based control systems. The human operator is therefore required to monitor the performance of largely automatic systems, initiate and coordinate key stages of system operation and respond to any malfunctions that cannot be handled automatically. The supervisory and scheduling aspects of the operator's job are not intrinsically difficult and there is a tendency to allocate these functions to the computer where it is both technically feasible and cost effective. At the same time, it is recognised that the response to unanticipated events with safety consequences cannot be left entirely to automatic systems. The human operator, therefore, retains a key role in the detection, diagnosis and recovery of process malfunctions.

For a number of reasons, the task of the process operator in responding to fault situations is not at all straightforward. Increased automation has resulted in operators being required to monitor larger plants of growing complexity and sophistication. The operator's appreciation of process dynamics and the details of plant design is further affected by the passive nature of supervisory tasks. Operators have little opportunity for practising the fault finding skills and developing the plant knowledge required for handling a fault when it occurs. The design of the operator interface can also contribute to the difficulties encountered. The operator can be hindered from developing an overall appreciation of plant dynamics through VDU displays which are poorly designed and difficult to access. During a fault situation, the operator may be subjected to a flood of alarm messages which contain a large degree of redundant information, complicating the task of identifying the root cause of the event. There is a real danger that under such circumstances the operator will either fail to act in time or will act to make the situation worse rather than better.

The design of the systems that the process operator uses to monitor and intervene in plant operations is therefore a vital component in the safety management of process faults. The Health and Safety Executive (HSE) recognises the importance of companies effectively managing human factors as a part of maintaining safety. The guidance booklet "Human Factors in Industrial Safety" (HSE, 1989) is intended to alert managers to the issues involved by use of pertinent examples and by suggesting a control strategy to reduce risks. This booklet identifies the need for more specific guidance on human factors issues in specific areas, which includes the design of the operator interface. The need to provide guidance in the design of operator interfaces in computerised process plants has also been identified by the Chemical Manufacturing National Interest Group of the Field Operations' Division of HSE. They had become aware of an increasing trend of accidents from deficiencies in the operator interface, particularly operators having difficulty in identifying and interpreting
information about plant status. Such difficulties have been found to be implicated in accident causation.

In response to the above, the Control Systems Group of HSE's Technology and Health Sciences Division requested a position paper to describe and summarise the available human factors techniques, relevant standards work, current practices in designing installations and relevant recent and ongoing research programmes applying to the operator interface in computerised process plants. The HSE would welcome comments on this report, particularly concerning views about the way forward on this topic. The address for correspondence is given at Section 6.2.6.

1.2 OBJECTIVES

The detailed objectives of this paper are as follows:

1. To provide a review of current practices employed across a range of process industry sectors during the design of control room interfaces for process plants.

2. To summarise the available design and evaluation techniques that may be employed in the development of control room interfaces.

3. To review recent and ongoing research programmes related to aspects of control room interface design.

4. To summarise relevant work on standards applicable to the design of interfaces to computerised process plants.

5. To identify those aspects of current practice and human factors theory which are sufficiently definitive to be incorporated in a guidance document.

6. To identify any major research topics which remain unresolved and which need to be covered before more comprehensive guidance can be given.

1.3 SCOPE

The focus of the study is on the operator interface in computerised process plants. This is taken to primarily involve Visual Display Units (VDUs), alarm annunciator panel displays and panel mimics. Whilst it is recognised that computer controlled plants can be operated partly or wholly via discrete instrumentation and controls, the detailed human factors design and layout issues raised by such interface technologies are not addressed here. This paper is intended to provide a representative rather than exhaustive treatment of each of the main areas identified in this study.

This study excludes a number of other key human factors issues that will also have an impact on the safety management of process faults. These include the selection and training of operators, the provision of job aids (e.g. emergency operating procedures), the quality of supervision, the management of plant maintenance, the reliability of communications between operating staff, and the overall safety culture within the company concerned.
As a matter of necessity, the paper examines human factors methods and techniques outside of the normal contractual and managerial framework of system design. It is recognised that in order for such approaches to be applied in a cost effective manner, there is a need for both the technical and human factors to be addressed in an integrated approach to design. Such a design approach would begin by identifying which operator activities might have potential consequences for plant safety, in a manner similar to that recommended in the guidelines for programmable electronic systems (HSE, 1987). A proposed approach along these lines is given in Appendix 3.
2.0 HUMAN FACTORS DESIGN AND EVALUATION TECHNIQUES

2.1 INTRODUCTION

Human factors considerations exist throughout the design lifecycle of computer-based control systems as they do during the whole lifecycle of the plant. These include decisions on the level of automation of a process, the numbers and responsibilities of operations staff, the design of the workplace and the design of the operator interface. Many decisions that are made regarding the automated control and instrumentation of a process have an implicit impact on the nature of operator tasks, which in turn can affect the overall safety and reliability of process operations. If human task requirements and characteristics are not explicitly considered, it is possible to build plants which are difficult to operate, particularly under fault conditions.

A variety of human factors techniques exist which address human aspects at each stage of the system design lifecycle. It is unfortunate that not all of these techniques are well documented or widely available outside of specialist circles. HSE could play a valuable role here in bringing details of and information about these techniques to a wider audience.

Human Factors techniques support the design process by providing information on task requirements, human physiological and human psychological characteristics. Similar information may also be used in evaluating designs at various states of completion. The systems approach taken by human factors practitioners also recognises that human performance is not only affected by equipment design, but by other interacting factors such as the calibre of personnel selected, their training and their management. As indicated in Section 1.3, the scope of this paper excludes consideration of these other human issues, though their importance needs to be borne in mind.

This section provides an overview of potential human factors activities during the implementation of a computer-based control system in a process plant. A simplified five-stage model of the design lifecycle of a computer-based control system is utilised as a framework in which to present the various human factors activities:

(i) Conceptual design
(ii) Outline design/system procurement
(iii) Detailed design and acceptance testing
(iv) Commissioning
(v) Operation.

Whilst the various activities are introduced within the context of particular lifecycle stages, it should be recognised that some activities will be carried out across a number of stages. Evaluation of displays, for example, may begin during detailed design, but continue through commissioning into the early phase of operations. The allocation of activities to lifecycle stages is therefore intended to be illustrative rather than definitive.

2.2 CONCEPTUAL DESIGN

The primary goal at this stage is to make explicit the safety-related functions of the various operational personnel. The key activities involved in achieving this goal are: defining who will use the system; allocation of control functions; the description and the assessment of
operational tasks (refer to 2.2.1 to 2.2.4 below). Inevitably, this will be an iterative process as task assessment may reveal the need to modify an initial conceptual design. Such assessment activity is also likely to become more detailed as design progresses.

2.2.1 Defining Target Users

As an initial step in developing any control system, it is important to define who will use the information and interfaces provided. It may be assumed, for example, that the only user of a set of displays will be the shift process operator, when in fact during normal daily operations and during the response to an incident the displays are also utilised by supervisory staff, managerial staff and engineering personnel. The information requirements of each of these groups may differ in subtle ways, and the design of the system needs to take account of this.

The definition of target users should be an important part of the overall activity of defining the operational philosophy for a plant. A key output from this process is a description of the outline staff structure for the new plant. This should define the roles and responsibilities of each of the personnel in the staff structure and identify who will directly access information or perform control actions via the control system interface.

Key aspects in defining target users are as follows:

(i) It is important to ensure that all potential target users are identified and listed.

(ii) These target users should be identified by job title, grade, etc. It is important to establish the depth of plant knowledge and experience of the persons who are going to use the computerised system.

(iii) Appropriate representatives for the key target user groups should be identified. For example, operators or supervisors from an existing, similar facility. These personnel will be vital in the consultation process as described in Section 2.3.2.

In terms of specific methods of performing such analyses or representing the output, the process is relatively straightforward. The HUSAT Human Factors Guidelines (HUSAT, 1988) embodies the task of defining target users within the wider process of 'stakeholder analysis'. A stakeholder analysis identifies all the people who have a legitimate 'stake' in a system, the target users and the scenarios which the system will be designed to cope with. The concept of stakeholder recognises that the individuals who have a legitimate stake in a system such as a new process plant will be much wider than just the personnel concerned with daily operations (e.g. plant management, maintenance). The process of stakeholder analysis encourages the explicit consideration of the needs and requirements of all the stakeholders.

2.2.2 Allocation of Functions

In the design of any process plant, decisions are made regarding the scope and sophistication of its automated control systems. Options may range from complete automation to manual control, though in most cases feasibility and cost considerations will limit the extent of the options available. Decisions to automate or not to automate particular plant control functions involve an implicit 'allocation of functions' between the control system and its operators. It
is an important principle in human factors that such allocation of function decisions should be made explicitly and be subjected to careful evaluation.

There are a number of possible consequences of a sub-optimum allocation of functions between an operator and plant control systems. At one extreme, highly automated plants may operate under normal circumstances without operator intervention. However, under fault conditions or following control system failure, the operating staff may be required to perform actions which they have had little opportunity to practice, utilising a knowledge of the process which they have not had the opportunity to develop due to being denied active involvement with the process by the largely automated operations (Bainbridge, 1987). At the other extreme, the operators may be overloaded by an excessive requirement for manual control actions, preventing them from maintaining a necessary watching brief of important trends within a process. Functions may also be sub-optimally allocated between the members of an operating team, for example relying upon the process knowledge of supervisory staff to diagnose fault conditions whilst only the operators have sufficient direct operating experience to develop the necessary knowledge of process state and dynamics.

Whilst the need to carefully consider allocation of function questions is well established, current techniques tend to be limited. Early approaches focused on making allocation decisions based on a comparison of human and machine strengths and limitations (eg. Fitts, 1951). However, it was recognised that such comparisons tended to favour the machine element and did not properly reflect the unique contributions that could be made by human operating personnel. In addition, it is rarely possible to allocate functions entirely to either an automated system or an operator, since the operator still needs to monitor automatic processes at some level of abstraction, and plant protection systems may be required to 'monitor' and limit the impact of human errors (eg. interlocks and trips). At the two extreme ends of the scale, rapid events or highly repetitive events are clear candidates for automation, whilst there will be decision-making functions and some complex control functions that must reside with the human operator. The remaining allocations require the application of heuristics to achieve one or more candidate designs for a process. Bastl et al (1990) report on a workshop convened by the International Atomic Energy Authority (IAEA) to attempt to arrive at a consensus approach to the allocation of functions in nuclear power plant design. They acknowledge that even recent control room design standards (eg. IEC Standard 964, Appendix 1, Table A1.2) which address the issue of allocating functions in some depth, have not made any attempt to define a methodology for the process. They concluded that a single, fully deterministic solution to the task allocation problem is not possible. They then describe a general approach to the allocation of functions which divides system functions into four classes:

(i) **Functions which must be automated:** these exceed human capabilities to perform them.

(ii) **Functions which are better automated:** these could be performed by an operator, but may be better assigned to a machine because, for example, they are lengthy and repetitive or involve a degree of risk to the operator.

(iii) **Functions which should be allocated to humans:** these require heuristic or inferential knowledge, or a requirement for flexibility. Other functions may need to be allocated for reasons of practical or technical constraints.
(iv) **Functions which should be shared.**

The emphasis in this process is in documenting the basis for decisions and acknowledging the real constraints and influences that determine each allocation. The involvement of operational staff from similar plants is encouraged for the purpose of evaluating allocation decisions. It is possible that a number of alternative schemes could be generated and then compared. The output of the allocation of function process should be operator task specifications and outline specifications for automated systems. The feasibility of the tasks allocated to operating staff are then open to evaluation and may be redefined a number of times through the design process as the safety implications of particular allocation strategies are made clear.

The HUSAT Human Factors Guidelines (HUSAT, 1988) provide a range of heuristics for guiding the allocation of function process. They also describe diagrammatic techniques for documenting allocation of function decisions.

In summary, the key principles in the allocation of functions within plant design process are that such decisions should be made explicit and that the resulting allocations should be evaluated. The decision process can be assisted by a range of available heuristics and principles, though these could be better publicised and documented to make them more generally accessible. The allocation and evaluation processes can capitalise upon past operational experience to assess what are reasonable, practical and potentially satisfying allocations of tasks to operators. Further evaluations are possible through task assessment (see Section 2.2.4) and later through simulation or commissioning trials (Section 2.4.2).

2.2.3 **Task Description**

Following initial decisions regarding the allocation of process control and safety functions, it is possible to produce a set of formal descriptions of operator and supervisor tasks. These task descriptions can provide an important source of information during the design process. They can also be used as the basis for assessments (Section 2.2.4) and for identifying operator information requirements (Section 2.3.1).

Task descriptions represent formal statements of human goals, plans and actions in process control terms. Where an existing plant is to be automated or extended, task descriptions of existing operator activities can be a very valuable source of data for feeding into the initial allocation of functions for the new design. For entirely new plant designs, task descriptions have to be 'synthesised' from a knowledge of operating goals, temporal and physical constraints. The output from the process are task description documents which can then form the basis for various detailed analyses.

The predominant task description techniques for process control applications are Hierarchial Task Analysis (HTA) and Tabular Task Analysis (TTA). HTA was originally developed for application to training analysis and has been subsequently developed for more general task description purposes (Shepherd, 1989). HTA descriptions primarily utilise a hierarchical tree diagrammatic format, representing a top-down structure of operator goals (refer to Figure 2.1 from Whalley 1990). For example, the top goal of the tree might be 'operate mixer plant' subdivided at lower levels into sub-goals such as 'fill mixer vessel' and 'maintain correct mixing speed'. The tree format incorporates plans that indicate the sequencing and combination of the sub-goals to meet the super-ordinate goal within a sub-tree.
HTA is widely used in the description of both production and safety-related tasks in the process industries. It has the benefit that an initial, very global task description can be produced early in the design process, restricted to only the top levels of the hierarchy, which can then be expanded as the design progresses. It is most appropriate when applied to procedural types of tasks, becoming more unwieldy for representing the details of complex decision-making tasks, parallel and possibly conflicting goals, and for representing event-driven behaviour (e.g., responses to faults). It should be noted that whilst the HTA tree format has become accepted as a standard approach to describing operator tasks, there is nothing particularly unique about its diagrammatic notation. The hierarchical diagrammatic notation, for example, is functionally equivalent to entity life history diagrams that form part of the Jackson Structured Design Method (Jackson, 1983) used in software engineering. HTA, however, also consists of a method of analysing human activities which extends beyond its notational format.

TTA utilises a simple, columnar table format, that can be adapted to a number of purposes (refer to Figure 2.2). It is possible, for example to represent hierarchical task descriptions within a tabular format (Miller 1962), though often HTA’s and TTA’s will be used in combination, the tasks listed in the first column of the TTA representing tasks at a particular level in the HTA tree. A valuable aspect of a TTA description is that it enables tasks to be annotated by textual comments in a separate column. Further columns can be used for human error analyses or information requirements analysis as described in Sections 2.2.4 and 2.3.1. The TTA format may also be utilised for representing the particular steps in an operational scenario. In this case, the sequential task steps throughout a chosen scenario dictate the ordering of the tasks down the columns of the tables.

HTA and TTA are both well established techniques though not very well documented or widely known. As indicated previously, they are best suited to routine, procedural tasks. However, one of the major challenges posed by increasing automation of processes is that the key human activities from a safety perspective tend to depend upon complex, cognitive processes such as status monitoring and fault diagnosis. Some form of description of these tasks is also required in order to ensure that relevant information is provided and that the sensitivity of such tasks can be evaluated. This has led to the development of cognitive task analysis techniques over recent years, though their development is still largely in its infancy (Carey and Whalley, 1990).

Cognitive task analysis techniques proceed beyond the description of comparatively simple procedural tasks to incorporate the analysis of more complex decision making tasks, possibly incorporating conflicting goals (Roth and Woods, 1988), and application of complex knowledge to plan and carry out tasks (Johnson et al 1988). The major difficulty with such techniques is deriving a general method for generating the task descriptions or task models. Where an existing task is to be described, sophisticated methods of data collection have to be applied (Diaper, 1989). Such techniques are highly resource intensive and subject to bias. Even then, how to map the collected data on to the structures provided by a particular descriptive technique is on the whole poorly specified. The task of synthesising cognitive task descriptions for a new system is intrinsically even more difficult. This requires an analysis of the cognitive demands of a particular operation to determine the resulting goal structure required of a human operator. An initial step is to analyze the dynamic interactions within the system to be controlled or monitored (e.g., Sanderson et al, 1989; Roth and Woods,
1988). The most appropriate structures for modelling such task related knowledge is still a matter for debate.

Whilst comprehensive task descriptions can provide a valuable resource during system design, it is clear that problems exist in their implementation. Techniques such as HTA and TTA are well proven and practical, though poorly documented for use by non-specialists. This is currently being addressed by a guide to task analysis being generated by the Human Factors in Reliability Group (Kirwan and Ainsworth, 1992). This document, currently in production, will provide outline descriptions of a wide variety of task analysis techniques in a readily accessible format. The main problem lies with the description and subsequent analysis of highly cognitive tasks such as fault diagnosis and surveillance monitoring of complex systems. Further research is required in this area to produce techniques which are reliable and cost effective to apply.
FIGURE 2.1: EXAMPLE OF HIERARCHICAL TASK ANALYSIS FORMAT
TASK 2.0: RE-ESTABLISH STEAM

<table>
<thead>
<tr>
<th>Staff</th>
<th>Task Step</th>
<th>Information or Control Required</th>
<th>Action and Equipment</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCR Operator</td>
<td>2.1</td>
<td>Close V25</td>
<td>C: Control loop for V25</td>
<td>Select display L3:REACOUT via hierarchy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Open V25 on Manual</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mimic available from reactor overview display</td>
</tr>
<tr>
<td>CCR Operator</td>
<td>2.2</td>
<td>Ensure V26 Open</td>
<td>D: Status of V26</td>
<td>Check status of V26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V26 shown on L3:REACOUT (Check labelling distinct)</td>
</tr>
<tr>
<td>CCR Operator</td>
<td>2.3</td>
<td>Open V24</td>
<td>C: Control loop for V24</td>
<td>Set V24 to Manual</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Open V24 on Manual</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Return V24 to Auto status</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V24 must be returned to auto to enable main recipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sequence to run</td>
</tr>
</tbody>
</table>

FIGURE 2.2: EXAMPLE OF A TABULAR TASK ANALYSIS FORMAT

2.2.4 Task Assessment

Given that task descriptions have been generated for a system design, it is possible to perform various forms of task assessment such as timeline analysis, link analysis, workload analysis and error analysis. The purpose of these analyses are to establish the feasibility of the proposed tasks and to highlight any design features that might impinge upon the safety or effectiveness of operations.

Timeline Analysis

Timeline analysis is useful where the scheduling or time to complete a set of operations is particularly crucial. For example, a safe operator response to a particular process fault may require a series of manual control actions to be completed within a set time period from the onset of the incident. A timeline could be employed to demonstrate how this might or might not be achieved. A timeline may also be used purely to represent task operations and their duration within a shift. This data could then be employed for workload analysis (see below). A safety-related use of a timeline analysis such as described would also need to consider the impact of likely errors, adding on the time for self-detection and recovery. This would be assisted by a human error analysis (see below).

The timeline analysis technique provides a graphical representation that shows how the component times for individual component sub-tasks are combined together to give an overall time for an operation. The usual format utilises the horizontal axis to show elapsed time and component sub tasks are listed along the vertical axis (Figure 2.3). Parallel operations, either performed by the same operator or by multiple operators can easily be shown using this format, indicating any dependencies where completion of a set of parallel activities are paced by the completion time of the longest activity.

The main difficulty in constructing such a timeline is obtaining accurate estimates or actual data for the task times. Any diagnostic components can prove to be the most difficult aspect on which to obtain accurate time estimates. For example, in the critical set of operations following the onset of a fault, the first task might be to diagnose that the particular fault has
occurred. With appropriate indications and the full attention of the operator this could be virtually instantaneous. However, where uncertainty exists and there are competing demands upon the operator, the time for diagnosis could stretch from seconds to minutes. For elementary operations such as scanning a display or pressing a key, data can often be generated from models based on psychological research (Carey, 1984). Where times are variable in a predictable way (eg. normally distributed around a mean value), then modelling programs are available that allow time estimates to be generated by Monte Carlo sampling techniques.

The value of timeline analysis clearly lies in the analysis of tasks which are time constrained. Unfortunately, the most crucial tasks with automated processes are often those monitoring and diagnostic tasks for which the time available is not the key determinant of task success.

**Link Analysis**

Link analysis provides a method of optimising the layout of a display, the structure of a set of displays or the physical layout of a control room. It achieves this by describing and analysing the physical or visual movements required between controls and displays in a particular set of tasks. The input to the analysis is a detailed task description, preferably with frequency data on individual tasks, and a schematic or plan layout of the relative positions of displays/controls. From this data, a link matrix can be created which indicates the number of links between pairs of controls/displays. This then forms the basis for a link diagram (Figure 2.4), where the nodes indicate particular displays, controls, VDU pages or panels and the links the number of transitions between them. Where panel instrumentation is used, such a diagram may be overlaid on top of a plan of the control room, such that the lengths of the link directly indicate the distance to be travelled between displays or controls. High frequency linkages between distant displays or controls would then become self-evident. A similar diagram might be generated for VDU displays, where the length of the links indicates the number of intervening displays that would have to be traversed to move from one display to another.

As with timeline analysis, link analysis relies upon having available accurate input data, in this case, data on the predicted frequency and priority of the constituent tasks. This is most easily obtained for existing control rooms where activities may be sampled over a period of time. The links between tasks also need to be clearly defined, suitig highly procedural tasks or activities specified in emergency response procedures rather than the rather more opportunistic nature of diagnostic and monitoring activity.

Link analysis is most effective where the number of nodes (ie. displays/controls) are small and spatially distributed (eg. on separate panels). The link diagram can then be a very powerful indicator of layout problems. Where the number of nodes is large and the number of inter-node links is also large, link diagrams rapidly become cluttered and difficult to interpret. However, the link analysis matrix can still be effective in such cases. It is also possible to concentrate on analyses based around sub-tasks to reduce the complexity of an analysis. There can be further problems when applying the technique to sets of multiple VDU displays, where the same item may be represented on more than one page (which one would the operator consult?) and where there are multiple possible access paths between two displays (what method of page access will be used?). The principle behind such an analysis is valuable but would benefit from further development if it is to be used effectively to analyse information access via VDU-based control room interfaces.
Workload analysis

Workload analysis attempts to predict the level of operator physical or mental workload generated by a particular set of tasks. For the estimation of workload, the most generally adopted measure is the percentage of time available utilised in task or job related activity. Therefore, if in an eight hour shift, the operator is on duty for six hours (ie. discounting time for rest breaks), during which time routine logging operations take one hour in total and control actions on the process two hours, then operator scheduled activity would utilise three out of the six available hours giving a workload estimate of 50%. Such an analysis may also differentiate between the types of work undertaken and their relative proportions. The boundaries of what are considered acceptable workload levels can vary, but it is normal to define both lower and upper limits to desirable workload levels (eg. between 50% and 70% overall), avoid inefficiency through either boredom or overwork.

Workload analysis of the type described depends on the availability of the same type of timing information required for timeline analysis. It may be used both at an earlier stage of design when only gross task data is available and only the most global time constants of a process can be estimated. In this capacity, it can be used in evaluating initial allocation of function decisions. However, current methods of workload estimation have limited use in estimating mental workload for example during a complex control task or fault diagnosis. The underlying theoretical issues in predicting mental workload are complex and the subject of debate. At present, the only effective techniques for mental workload are measuring techniques based on questionnaires or physiological data.

Human Error Analysis

Human Error Analysis is an umbrella term for a number of techniques that can be applied to a task description to identify potential errors, consequences of errors, error recovery routes and the underlying causal factors for the errors identified.
FIGURE 2.3: EXAMPLE OF A TIMELINE ANALYSIS FORMAT

FIGURE 2.4: EXAMPLE OF A LINK ANALYSIS DIAGRAM
A number of techniques are available for error identification, based upon taxonomies of error types, flowchart style algorithms and sets of keyword prompts such as used in hazard and operability studies (HAZOPS). A useful comparative review is given in Whalley and Kirwan (1989).

Human error analyses are usefully represented in a tabular format similar to that used for tabular task analysis (Figure 2.5). The tasks from the task description or a particular scenario are listed in the first column, the identified errors in the second column etc. An exhaustive error analysis is time consuming, so it is frequent practice to limit the errors shown to only those with significant consequences for system safety or productivity. In general, human error analyses do not incorporate specific considerations of the probability of particular errors occurring. Such data may be generated if the output from the analysis is fed into a quantitative risk assessment. However, in constructing the analysis, qualitative decisions may be made to exclude highly improbable errors where the consequences are limited. A second table may be utilised to identify the underlying causal factors for errors identified and the relevant ‘performance shaping factors’. From this recommendations may be made to alter task design, provide additional training, develop procedure or modify the system design.

Current developments in human error analysis are addressing the modelling of psychological error mechanisms. This is of assistance in identifying the particular types of errors that can occur in highly cognitive tasks such as complex control tasks or fault diagnosis. Lists of typical human biases and error modes have been generated and are being incorporated into practical techniques of error analysis for such tasks.

Task complexity analysis

Research into the psychological aspects of human-computer interaction have given rise to a small number of task analysis techniques which can provide comparative measures of task complexity. Techniques such as Task Action Grammar (Green et al, 1988) and Cognitive Complexity Theory (Kieras and Poulson, 1985) operate by describing the knowledge required to perform a task in the form of a set of rules and then counting the number of rules. These are primarily comparative measures in that, for example, two or more competing command dialogues for a system can be compared in terms of the amount of knowledge required for their operation. Since there is no standardised means of determining how complex a particular item of knowledge is to acquire in isolation, the figures produced by such techniques cannot be taken as absolute measures of complexity.

Such techniques are still in the early stages of development. It may be possible to develop techniques that enable the complexity of a particular process monitoring or control task to be quantified and compared against acceptable bounds. This would have similar aims to those of mental workload estimation methods discussed in Section 2.2.4. The currently available techniques can be applied to interaction dialogues on computer-based systems and could be used for comparing different methods of accessing, selecting and controlling plant items on VDU displays. The need for such analyses, however, are limited in process control where interaction dialogues are at present comparatively simple and the greatest source of complexity is involved in interacting with the plant itself.
2.3 OUTLINE DESIGN/SYSTEM PROCUREMENT

The main output from this stage is a detailed human factors requirement specification or 'user requirements specification'. This will include fairly well defined requirements concerned with the physical aspects of display equipment (e.g. screen resolution and refresh rate). In addition, a number of more complex issues have to be resolved during this stage including:

(i) What information should be shown on panels and what on VDU displays?
(ii) How many VDU display screens should be provided?
(iii) What type of VDU display formats need to be provided (i.e. mimics, tabular, trends, bargraph)?
(iv) What level of detail and amount of information should be shown on each VDU display?
(v) How should the plant be grouped and sub-divided for display purposes?
(vi) How should the VDU displays be structured and linked to provide rapid and easy access to information?

As discussed later in Sections 5.2.2 and 5.3.1, a number of these issues require further research in order to provide definitive guidance. However, there are a small number of useful techniques that can be applied to resolve some of these questions, including information requirements analysis, utilising operational knowledge and prototyping of interface designs (see Sections 2.3.1 to 2.3.3). The output from these techniques can be fed into the user requirements specification (Section 2.3.4).

Task 3.1 MAKE PUMP CONNECTIONS

<table>
<thead>
<tr>
<th>Sub Task</th>
<th>Staff Code</th>
<th>Error</th>
<th>Consequence</th>
<th>Staff Code</th>
<th>Detection</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.3.2 Close pump inlet valve to stop flow.</td>
<td>Operative A</td>
<td>Not Done Less Than; Valve not completely closed.</td>
<td>Water could syphon through line even with pump off.</td>
<td>Operative A</td>
<td>Excess of water in pumphouse. Valve appears to leak.</td>
<td>Close valve fully</td>
</tr>
<tr>
<td>3.1.3.3 Stop Pump</td>
<td>Operative A</td>
<td>Not Done</td>
<td>Wasted fuel Possible build up of fumes</td>
<td>Operative A</td>
<td>Hear pump running</td>
<td>Stop pump</td>
</tr>
</tbody>
</table>

**FIG 2.5 - EXAMPLE OF HUMAN ERROR ANALYSIS TABULAR FORMAT**

2.3.1 Information Requirements Analysis

As with the assessment techniques described in Section 2.2.4, information requirements analysis is based upon detailed task descriptions. For each task, the information required by
the operator, the control to be activated and cues for further actions are identified. This analysis may be carried further to indicate the type of information required by the operator (e.g. absolute value, deviation, trend, alarm). This is usually carried out using a tabular task analysis format.

The tables then provide an indication of the key items of information required by operators in the performance of their duties. Furthermore, the tables indicate the temporal and task-related grouping of information required by the operator. This enables rational decisions to be made for selecting the key indicators to show on overview displays and the grouping of information to support operator task activities.

A formalised process of 'mapping' derived information requirements onto an integrated structure of displays of various types has yet to be developed. Research is currently in progress towards developing structured approaches (Astley, 1991; Shepherd, In Press).

2.3.2 Utilising Operational Knowledge

A key principle in human factors is to utilise user participation in system design. There are a variety of ways that operations personnel can contribute to the design of a plant:

(i) **Authorisers**: Where operations management have budgetary control or powers of veto, they can act as authorisers of design decisions.

(ii) **Task experts**: Members of operations staff on the same or similar plants may act as sources of information on operational tasks and requirements.

(iii) **Interface experts**: Operations personnel can also be a key source of information on the weaknesses and strengths of systems that have been implemented on other plants.

(iv) **Designers**: Operations personnel may be allocated to design sub-teams and given particular tasks to complete, such as display design or workplace layout.

(v) **Opinion providers**: Operations staff may act in a consultative role, being asked to provide their opinions on design options.

(vi) **Evaluators**: Operations staff have an important role as evaluators through their participation in evaluation trials and through use of the system.

It should be noted that all of the above roles have the potential to contribute positively to system design. Consulting operators for the purpose of making them feel involved but without granting them any influence is actively discouraged. Effective user participation does not necessarily occur naturally and must be carefully planned and controlled. Where plant operations have some degree of ownership of a plant design process, the impetus already exists to provide the personnel required and the necessary authority to influence the course of design. Where ownership resides within an engineering or corporate planning function within a company, active steps may have to be taken to achieve the required level of input from operations personnel.
The management of the participation process requires consideration of who should be represented, the structuring and regulation of the operator teams, the particular tasks that will be given to these representatives, their reporting routes during the design process and the boundaries of their authority. The selection of the correct personnel is particularly important. Whilst managerial personnel may provide a steering function, input on plant operations, operator tasks and interface design requires staff with current operating experience, probably at a supervisory level.

A comprehensive and structured method for consulting users during the design of displays is described by Van der Schaff (1989). This consists of two main stages; a detailed general procedure which is applied to a representative sample of displays followed by a set of specific guidelines generated on the basis of the first stage, which are utilised by operations staff to redesign the remaining displays.

The general procedure has four steps involved in generating VDU graphic formats:

(i) Teams of operators from different shifts are asked to define the logical grouping and ordering of plant functional elements. This is achieved through structured discussions within shifts, consensus being sought between shifts. The output is a general description of how the display pages will be structured (e.g. hierarchy of three levels) and a 'paging sequence' at each level (i.e. horizontal connections between displays using page forward and backward keys).

(ii) Operators are then asked to rate each piece of information in terms of its value for providing process overview. They are also asked to indicate the required precision of any information they have judged to be important for overview. At the same time, a questionnaire is used to gather information on operator preferences for display design.

(iii) From the information generated in the previous steps, a set of prototype displays is now generated and coupled into the process. Operators are encouraged to use these new formats.

(iv) The new formats are then evaluated by checklists based on the responses given to the questionnaire in step (ii), a questionnaire aimed at measuring subjective preferences, and a set of test exercises. The new formats are then amended in correspondence with the results of the evaluation.

Following the completion of the general procedure, a set of specific guidelines is generated, codifying the rules used whilst constructing the final design versions of the prototype displays. These guidelines can then be used to generate the remaining displays.

This procedure provides a means of redesigning existing and presumably poorly designed mimics on a plant. It may not be so easy for operators to answer some of the questions posed if the current interface or task design is radically different from that proposed with the redesigned mimics. However, the overall approach is valuable in demonstrating the role that operations staff can play in determining interface design and in suggesting a structured method by which this information can be obtained.
2.3.3 Prototyping Interface Designs

As indicated in the previous section, there is considerable value in developing and evaluating prototype interface designs at an early stage of the design process. Even static mockups displays can be employed to refine design concepts and to act as a focus for consultations with operations staff. Once finalised, such example displays provide useful role models for the development of the remaining displays either in-house or by an external contractor.

The prototyping process may begin during the concept design stage or even earlier if establishing and evaluating advanced concepts for operator information provision. For operator interfaces being retrofitted to existing plants, fully operational prototype displays may be constructed and installed alongside existing instrumentation in the control room. This is a particularly valuable means of providing early operational evaluation of the display designs. For entirely new plant designs, the comprehensive evaluation of the design concept is likely to prove more difficult unless there is the opportunity to utilise a plant simulation model.

The value of utilising prototyped displays at an early stage of design is to reveal potential problems both in the use and the construction of the full set of displays prior to their development. The most obvious application is to evaluate new graphic display concepts, such as windowed displays or special purpose schematic displays (e.g. Duncan et al, 1989). The key aspect in the prototyping approach, however, is not the development of the displays, but the systematic evaluation of the underlying concepts through structured gathering of opinion and performance data. Actual use of the displays can reveal aspects of operator tasks not previously established and result in further revisions to task descriptions and allocations of function. In other areas of computer systems development, prototyping is either an established practice (e.g. military systems) or is rapidly becoming a standard design approach. Large computer systems manufacturers have built usability laboratories where prototype systems can be evaluated by potential users in a controlled environment whilst performance data is captured on video tape for later analysis.

2.3.4 User Requirement Specification

 Whilst it is standard practice to issue a technical specification for all aspects of a system design, the non-functional user requirements are often loosely defined or limited in scope. This problem has been recognised and various approaches to the specification of user requirements are under development. Chapanis and Budurka (1990) point out the problems than can exist when user requirements are stated in very general terms (e.g. 'ensure consistency') and the degree of unwelcome latitude still provided by even the most carefully defined general design guidelines for human-computer systems. Recent research work has demonstrated this problem empirically, revealing the problems that designers can have in attempting to achieve conformance with user interface style guidelines (Tetzlaff and Schwartz, In press). Chapanis and Budurka propose a solution to this problem through the drafting of a project specific Human Computer Interface Requirement Specification (HCIRS). The standard structure of the HCIRS indicates what must be specified for each design. This is then constructed in accordance with the specific features of a design. For example, MIL-STD-1472C has the following statement on error correction:

 "Where operators are required to make entries into the system, an easy means for correcting erroneous entries shall be provided. "

19
This gives the designer considerable scope for individual judgement and interpretation. The guidelines for constructing a HCIRS restate this as follows:

"Specify user actions needed to correct each form of error."

This would lead to the following type of interface requirement stated in the project-specific HCIRS:

"Errors made in typing an input shall be correctable by positioning the cursor under the incorrect entry with one or more of the four cursor control keys, and retyping the correct entry."

The resulting requirement is a design specification, compliance with which is easily checked.

The very restricted nature of the requirements in the HCIRS approach are not practical in all circumstances. For example, if the user requirements specification is to form part of the tender documentation for selecting a packaged control system for a new plant, each such system is implemented with its own specific approach to operator interaction. Definitive statements can be made on issues relating to the visual performance of display hardware, colour coding standards etc. but there would be little scope for enforcing requirements for the details of operator interaction. The document should incorporate definitions of display concepts to be adopted, page structures and operator information requirements as necessary. In order to ensure the overall implementation meets user requirements, two possible approaches are gaining in popularity: specifying usability goals and specifying a required human factors development process.

Usability goals are formal statements describing a target level of performance that must be achievable on critical tasks. For example, it might be stated:

"From any display within the display hierarchy, operator X should be able to access a layer 3 display page containing the most recent high priority alarm within Y seconds."

Operator X in this statement would be carefully defined in terms of experience with the system and demographic characteristics. The contractor for the system would need to demonstrate that this task could be performed within this criterion time. As pointed out in the HUSAT Human Factors Guidelines (HUSAT, 1988) a formal specification for such goals should include:

(i) What is to be measured.
(ii) How it is to be tested for compliance.
(iii) What level of performance is provided by the current system (if applicable).
(iv) What is the best level of performance that could be achieved.
(v) What is the minimum level of performance that would be acceptable.
(vi) What is the planned level of performance.
Such usability goals may cover more subjective measures such as user satisfaction measured by questionnaire. Attempts are currently being made to develop standard usability metrics (e.g. task effectiveness, task efficiency, problem rate and productivity; Rengger, 1990) that are rigorously defined and can be widely applied across different systems.

A general concern with the application of usability goals is that they may distort the design process by an undue emphasis on those attributes of a system that are most easily tested. For example, speed of access to information may be provided at the cost of other usability characteristics of a system. A more central concern in process control applications is that the attributes that could be measured are only peripheral to the key attributes of a system relating to process monitoring and responses to process upsets.

An alternative or complementary approach to usability goals involves specifying required human factors activities by a contractor during the system development process. For example, this may require a design contractor for the VDU displays formats for a particular plant to carry out a programme of consultations with operations staff, to construct prototypes for review, to perform design auditing and finally to carry out trials with operators for final acceptance testing. The process description would define the deliverables to be generated, including formal reports on each stage. This is the approach underlying the HUSAT Human Factors Guidelines (HUSAT, 1988), which specifies an extremely detailed integrated human factors programme for use as a supporting document during system procurement (Note: the HUSAT guidelines are wider in scope than a user requirements specification, covering the entire design process from conception to operation).

In summary, a specification of user requirements, how these are to be met and how compliance is to be tested, is gaining general favour as an approach to ensuring that systems are designed with an appropriate focus on the needs of their users. Elements of this approach could be utilised in process control applications to ensure that the vendors of control systems take proper account of their ultimate customers, in Plant Operations.

2.4 DETAILED DESIGN AND ACCEPTANCE TESTING

Having developed the specification for the operator interface, displays are designed, coded and tested during this lifecycle stage. The detailed design activity may be guided by the provision of detailed display design standards or guidelines (Section 2.4.1). As display designs are completed, a range of evaluation techniques may be applied to ensure that they comply with the user requirements specification, with any mandatory standards or guidelines, and that they provide the overall level of safety performance required. These are outlined in Section 2.4.2.

The detailed design of the control room may also be carried out during this stage. In common with the design of operator interfaces, the process of designing the control room needs to begin in the conceptual design phase. However, the bulk of the design work will be carried out during the detailed design phase. Section 2.4.3 describes those aspects of control room design that are particularly pertinent to the effective use of VDU display systems and discusses how these aspects may be evaluated.
2.4.1 Guidelines and Standards

Whilst the overall design process may operate within a framework of general design and quality assurance standards, (eg. IEC 964 as described in Section 3), there will be a need early in the design phase of a plant to establish any guidelines or standards that are to be applied during the detailed design phase. Apart from the current activity in the international standards area (see Section 3), a number of companies are developing their own in-house guidelines and standards relating to human factors aspects of system design. British Nuclear Fuels, for example, have developed and established a company standard which provides coverage of most aspects of control room and interface design (Kirwan et al, 1990). In a similar manner, RMC have been involved in producing comprehensive sets of company guidelines for the food processing and offshore oil industry. In general, such standards address the physical aspects of control room, workstation and display design. They may also state how compliance is to be checked or tested (eg. checklists, usability trials).

2.4.2 Evaluation of the Operator Interface

Once detailed display designs and panel layouts are finalised, it is possible to apply a number of techniques to evaluate their adequacy, particularly in relation to safety-related tasks. This evaluation phase may be required for three particular reasons:

(i) It cannot be assumed that even when great care has been taken to devise an appropriate conceptual design for an interface and appropriate design specifications in the form of user interface requirements (Section 2.3), that the designs produced will be without faults or design inadequacies. Evaluation may therefore be carried out both for quality assurance purposes and as a final check that the interface will meet its design objective.

(ii) Evaluation may be necessary for contractual reasons as part of a customer acceptance testing procedure. Customer acceptance tests are already established practice in procuring plant control software and they may be extended to cover the formal acceptance of the displays provided.

(iii) Evaluation may form part of an independent safety auditing process. This particularly applies in certain industries such as nuclear power, where there is a requirement for independent evaluation of operator facilities during the production of a safety case.

The main approaches that can be utilised for evaluation are as follows.

Checklists

Checklists are closely related in content to interface design guidelines. They consist of a set of requirements that can be checked by an independent assessor and columns or boxes that allow compliance with each requirement to be classified as adequate or less than adequate. They can be particularly useful where a set of guidelines has been issued for a design and the checklists provide an exhaustive and auditable means of checking compliance. NUREG 0700 provides a very extensive and detailed checklist that covers not only the operator interface but all aspects of the control room environment and organisation (NUREG 0700 is described in Appendix 1).
Scenario Analysis

As described in Section 2.2.4, task descriptions can be used as the basis for detailed task assessments. As the design process progresses, it is possible to examine in detail the operator actions and possible errors/difficulties that could be encountered during critical emergency scenarios. This may employ link analysis as a means of examining display navigation requirements, workload analysis to determine the demands that would be made upon the operator and error analysis to identify key errors and possible recovery paths (Section 2.2.4).

There are problems with such forms of analysis when applied to monitoring or fault diagnosis tasks. It is rarely possible to provide conclusive proof that the interface will be adequate for such tasks from a paper-based analysis. For monitoring tasks the best that can be achieved is to determine the key information requirements (Section 2.3.1) and to show how these are met by the display design. The evaluation of diagnostic tasks can only be based on an indication that the information required is available or accessible on operator displays. A fully conclusive formal evaluation will require the development of appropriate cognitive task analysis methods.

Operator evaluation

In the same way as described in Section 2.3.2, operators may contribute formally or informally to evaluating an interface design. This is achieved by collecting their subjective opinions, through evaluation trials, or through formal reviews by an operations steering group.

The opinions of operators need to be collected in a systematic manner, either in a carefully controlled panel session or using evaluation questionnaires. There are potential pitfalls when applying either of these approaches. These are addressed in human factors methodology handbooks.

Evaluation trials may be carried out using designs on paper, static displays or with fully functional prototypes driven by a plant simulator. Again it is important to ensure that appropriate experimental controls are applied in order to collect valid data.

The role of an operations steering group in reviewing and signing-off systems can be a particularly effective means of ensuring design quality. However, this should be supplemented by other forms of evaluation to ensure that assessments are rigorous and comprehensive.

Theoretical evaluation

For many aspects of the operator interface, particularly in relation to VDU systems, it is not possible to evaluate all aspects of the interface on the basis of precise empirically derived principles or task-based evaluation. The justification for the system can only be given on theoretical grounds based on established human factors principles and research findings. Such evaluations would be given by subject experts, and may be commissioned as an independent peer review of a system.
2.4.3 Design and Evaluation of the Workplace

A number of aspects need to be considered with respect to the design of control rooms and consoles in order to ensure operational effectiveness. Poor design of the working environment can increase the risk of operator error through fatigue and the inefficient location of displays and equipment. The introduction of VDU’s in the workplace requires consideration of a number of particular aspects:

(i) For the layout of the workplace, consideration must be given to the communication and movement links of the personnel involved. This will affect the proximity of items of equipment and the interrelationship of operator and supervisor consoles.

(ii) Consoles and panels need to be designed to be compatible with the physical characteristics of the full range of potential users. Consideration therefore has to be given to the heights of work surfaces, the reach and visual dimensions of console/panel equipment and the field of view of the operator. Maintenance access to panels and equipment also needs to be considered.

(iii) VDU systems make particularly stringent demands on the control room environment. Careful consideration has to be given to lighting design and the provision of natural lighting in order to avoid glare that if present can render VDU displays difficult, if not impossible, to use. Such display systems also often give off heat and electrostatic radiation that can affect the overall comfort of the control room environment unless properly compensated for.

All of these considerations are covered by human factors methods, data and guidelines (e.g. Invegard, 1989; Kinkade and Anderson, 1984; Gilmore, 1985; Cakir et al, 1980; Panero and Zelnik, 1979). An initial prerequisite is some form of task description to feed into an analysis of control room staff activities and interactions. From this, link tables can be constructed indicating the physical or communication links between personnel and operating positions. Initial layouts may be made on the drawing board, or in some cases using sophisticated computer packages for workplace evaluation (e.g. Porter et al, 1990). An important constraint will always be the size and shape of the overall control room. Irregularly shaped spaces and columns within control rooms are particular problems.

As in the design of operator interfaces, some problems with a workplace layout will not reveal themselves until the control room is completed. One solution to this is to build a full scale mockup and evaluate its performance using operational staff. This approach is strongly advocated by specialists in this area (e.g. Wood, 1984).

The design of natural and artificial lighting in a control room is covered by guidelines, formulae and evaluation techniques (e.g. NUREG 0700 described in Table A1.7, Appendix 1; CIBS, 1984). Guidelines address the type and positioning of light sources and formulae enable the direct and reflected lighting levels at points within a room to be calculated. If a relatively flexible lighting scheme is installed, a lighting survey may be performed in the completed control room to identify any repositioning of light sources that might be necessary. In a similar manner other environmental aspects such as thermal comfort and humidity are covered by guidance, analysis and empirical measuring techniques. Further information on current standards and guidelines are given in Section 3.0.
2.5 COMMISSIONING

The commissioning stage provides the first opportunity for commissioning engineers and future plant operators to use operator interfaces and other control room facilities. Individual displays can be further evaluated and modified, if required, during the various commissioning phases (Section 2.5.1). User documentation and training will also tend to be developed during this stage (Section 2.5.2), though wherever possible, the processes of drafting operator documentation and defining training needs should begin early in the detailed design phase.

2.5.1 Operational Assessment

Operational assessments can be performed once the plant is being commissioned and it is possible for the operations staff to gain their first experience of using the interface facilities to control the functioning plant. Such assessments may be formalised as operational safety assessments of particular safety-related activities and scenarios. It is important during such exercises that measures are taken to ensure that appropriate information on the performance of the operator interface can be collated. This may include post exercise questionnaires, debriefings, logging of operator input actions, observation or video recording of activities. The analysis of some of this data can be very time consuming but particularly valuable (eg. Woods, 1984).

2.5.2 Development of User Documentation and Training

The provision of well designed documentation and training can be an important determinant of the effective use of the facilities and displays provided by VDU-based operator interfaces. Most proprietary DCS systems, for example, offer a wide variety of functions for accessing displays and manipulating data. However, the operator interface manuals are often unsuitable for regular use by operations personnel. Without appropriate reference material or comprehensive training, many features of such systems will remain unused.

A limited amount of guidance is available on the design of effective user documentation (eg. Simpson & Casey, 1988). The theory and practice of training design is a well developed discipline in its own right. In addition, it is possible to formally evaluate both documentation and training during commissioning. This may be carried out in conjunction with evaluations of the operator interface.

2.6 OPERATION

Once a plant becomes operational, the scope for further change is clearly limited. Yet, important problems with the design of the operator interface or the workplace may not become apparent until in routine, operational usage. There is benefit, therefore, in continuing to collect information on the operational performance of control room facilities as outlined in Section 2.5.1. Incident investigations and near-miss reporting schemes can also be utilised to provide indications of deficiencies in interface design (Section 2.6.1). Where such deficiencies are not critical to safe operation, the collection of such information in a systematic manner can be valuable for directing the development of the next generation of plants, avoiding the repetition of mistakes and identifying the opportunities for improvements.
2.6.1 Incident Investigation and Reporting

Useful information may be provided by incident records during operation though it is important to ensure that the incident reporting methods cover details of any contributory effects of the operator facilities. In addition, a very valuable source of information can be provided by Confidential Incident Reporting Systems which enable operators to record near accidents, that otherwise would not be reported and observations on the performance of control room systems. These are now being implemented in a number of areas within the nuclear industry after their success in civil aviation applications (Van der Schaaf et al, 1991). The essence of these is the confidentiality guaranteed to their contributors through the use of an independent agency to collect and abstract data from the reports.

2.7 CONCLUSIONS

This section has provided a wide ranging review of human factors techniques and approaches that may be applied to the design of operator interfaces and control room facilities in process plants. Few projects will employ all or even a majority of the techniques described. Practicality and cost/benefit considerations will place strong constraints on what may be realistically attempted. It is clearly important to select the appropriate level of systematic human factors input to ensure that the required level of operational safety is achieved.

A recurring theme throughout this section has been the limitation of analysis and evaluation techniques for highly cognitive tasks such as monitoring plant status and fault diagnosis. Unfortunately, as indicated in the introduction to this paper, with increasing levels of automation, such tasks are becoming crucial in ensuring system safety. As will be indicated in Section 5.0, this area is one of the key-priorities for research.
3.0 HUMAN FACTORS STANDARDS, GUIDELINES AND HANDBOOKS

3.1 INTRODUCTION

This section provides a survey of currently available human factors standards, guideline documents and handbooks that may be applied during the design of the operator interface for computerised process plants. This includes standards and guidelines on control room layout, the working environment, console design, VDU interface design and human factors design approaches. Details of each of the documents referred to are provided in Appendix 1.

3.2 HUMAN FACTORS STANDARDS

3.2.1 The Current Status of Human Factors Standards

A large proportion of the currently available standards in human factors have been developed over the last ten years. There are a number of underlying reasons for this:

(i) There has been increasing recognition of the importance users or operators have in ensuring the safety and effectiveness of systems. Standards are therefore being developed to establish baseline requirements for good human factors practice during the development of systems.

(ii) There has been concern regarding the health risks arising from the continuous or frequent use of VDU-based systems. These risks include physical fatigue from poor workplace anthropometrics, visual fatigue from continuous use of VDU displays under inappropriate lighting conditions, and the subtle organisational impact of introducing computerised working practices. There is also a recognition that unduly complex software interfaces can lead to stress and lowered job satisfaction. With regard to the physical aspects of VDU system design, standards have been developed that lay down rigorous minimum requirements for the performance of system components (eg. a colour CRT display) and for their implementation in the working environment. These will form the core of the move towards mandatory regulations on the human factors aspects of VDU systems.

(iii) The gradual move towards removing barriers to international trade has provided a general impetus to the standardisation process. The European standards bodies (eg. CEN, CENELEC) are highly active in the development of a European standards infrastructure and in the adoption of international standards prior to the planned liberalisation of European trade in 1992. A cohesive framework of standards is intended to ensure competitiveness through establishing common working practices in the development of products and a high degree of commonality between the goods produced by different member countries.

There is considerable activity at the present time in the field of human factors standards. This includes the development of general standards covering the design and use of user interfaces to computer systems and some standards specific to control room design. A summary of current standards related to human factors and ongoing standards work is given in Tables A1.1 to A1.6 of Appendix 1.

The BSI is actively involved in all the European and International human factors standardisation activities, adopting relevant standards as British Standards where required (British Standards Committee PSM/39 covers most areas).
3.2.2 The EEC Safety Directives

Two recent EEC directives are predicted to have a major impact upon the implementation of human factors standards within the UK. The VDT directive (90/270/EEC) specifies minimum safety and health requirements for work with display screen equipment. The directive requires all member countries of the EEC to put into place regulations enforcing certain minimum standards for display screen equipment, the immediate working environment around VDT work and for the usability of computer software. This directive applies from 1st January 1993 for new installations and from 1st January 1997 for all existing installations. The scope of this directive includes VDU systems implemented in control rooms. A further directive (89/392/EEC) on machine safety specifies minimum safety requirements for items of machinery. This includes a requirement that "interactive software between the operator and the command or control system of a machine must be user friendly". The extent to which the machinery directive will apply in the process control context is still unclear.

The mechanism for implementation of the EEC directives will be via regulations issued and policed by the HSE. A draft version of these regulations relating to the VDU directive has been published by the HSE for comment (HSE, 1992). The consultative document includes both the draft regulations and a draft guidance document that would be published in conjunction with the regulations. The draft regulations primarily address issues such as the visual demands of working with VDU's, postural requirements and the need for rest breaks. The schedule to the draft regulations does address issues of usability in an outline form. Reference is made to ISO 9241 and the interim British Standard BS7179. Guidance relating to the machinery directive should also refer to ISO 9241 or to its European equivalent EN29421, as well as to specific ergonomics standards being developed currently by CEN/TC/22/WG6 (Table A1.3, Appendix A) and to ISO11064 (Table A1.2, Appendix A).

Considerable debate is likely to ensue with regard to the implementation of the requirements of the VDT regulations in the context of the process industries. For example, clause 4(d) of the schedule to the draft regulations requires that "systems must display information in a format and at a pace which are adapted to operators" (HSE, 1992). The difficulty will come in establishing which types of display format are considered well adapted to the needs of an operator in a particular process context, and how does the pacing requirement impact upon acceptable minimum display response times and upon the rate of alarm presentation during an incident? It seems inevitable that one of the main consequences of the implementation of these Directives will be an increased interest in the human factors aspects of the operator interface for process control, particularly with regard to the design of VDU-based operator interfaces. Similarly, the type of VDU format that is implemented in a process control room for status monitoring purposes will depend to some extent upon the nature of the plant (eg. size, complexity, slow/fast response process) and the experience of the operators in controlling the plant.

3.2.3 Standards Relating to Control Room and Workstation Design

The theoretical basis underlying the physical design of workplaces is relatively well developed. Standards in this area give explicit advice on the minimum and maximum physical dimensions of operator consoles, the precise visual performance requirements of VDU displays and give measurable minimum comfort requirements for the working
environment. Key standards in this area are summarised in Table 3.1. Of these, IEC 964 and ISO 11064 are of particular relevance. IEC 964 specifies the functional requirements of control rooms for nuclear power plants, though most of the principles described could equally be applied in other types of control room. The design guide provided as an appendix to IEC 964 is particularly useful. Details of the one currently available part of ISO 11064 suggests that this standard will provide a comprehensive and detailed specification for control room design, though work on developing this five-part standard is still at an early stage.

3.2.4 Standards Relating to VDU Interface Design

Effective standards relating to the usability of computer-based systems are difficult to develop. This is partly due to the limited established theoretical basis for determining the factors that affect system usability in a given context. Detailed design requirements for one task context and user group can be inappropriate when applied during a different task context or by a different group of users. For example, the interface requirements of a skilled typist differ from that of an infrequent non-typist user of a wordprocessing package.

In the former case, keyboard-orientated commands may be substantially quicker to use than a pointing device for text and command selection, whereas the infrequent user would benefit from the lower memory demands involved in selecting items from pull-down menus with a mouse. A summary of currently available standards is presented in Table 3.2.

ISO 9241, which is currently under development, will represent the main standard for application to the software interface of computer-based systems. The German standard DIN 66234 covers a similar area but it is intended to replace it with ISO 9241 when the International standard is complete. Also, as mentioned in Table A1.2 in Appendix 1, a joint ISO/IEC technical committee is working on standards for keyboard layout, dialogue interaction and symbols. All these standards activities have office tasks as their primary focus.

Parts 10 to 19 of ISO 9241 provide an overview to software ergonomics principles stating detailed requirements for the presentation of information on displays, user guidance and for a variety of different forms of interactive dialogue (refer to description in Table A1.2 in Appendix 1). Part 11 is central to the approach to software ergonomics being envisaged for ISO 9241.

<table>
<thead>
<tr>
<th>STANDARD</th>
<th>TABLE CROSS-REF</th>
<th>COVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 7179</td>
<td>A1.1</td>
<td>Parts 5 and 6 over VDT work environments, primarily in office contexts</td>
</tr>
<tr>
<td>BS 5940</td>
<td>A1.1</td>
<td>Provides a specification for office furniture</td>
</tr>
<tr>
<td>ISO 9241</td>
<td>A1.2</td>
<td>The early parts of this standard specify in some detail physical, visual and office environmental requirements</td>
</tr>
<tr>
<td>ISO 11064</td>
<td>A1.2</td>
<td>Part 3 of this standard is currently under development providing a detailed specification for the physical design of control room workplaces</td>
</tr>
<tr>
<td>IEC 964</td>
<td>A1.2</td>
<td>Defines functional requirements for the design of the control room in nuclear power plants. This covers the physical and environmental requirements at a general level</td>
</tr>
</tbody>
</table>

**TABLE 3.1 SUMMARY OF STANDARDS APPLYING TO WORKPLACE DESIGN**
TABLE 3.1 SUMMARY OF STANDARDS APPLYING TO WORKPLACE DESIGN (CONT'D)

The current draft of Part 11 of ISO 9241 outlines the requirements for a ‘usability statement’ which may be issued for one or more of the following purposes:

(i) As a statement of usability requirements, issued either by a developer in order to establish a systematic basis for the consideration of usability issues during the development process, or by a customer/consumer to specify the levels of usability required.

(ii) As a statement of usability to accompany a product or work system which has been developed.

(iii) As a statement of conformance to particular standards which contribute to usability in a specific context. This might be completed by a developer or by a test house.

The usability statement may consist of statements describing the particular features of a product or work system that influence the effectiveness, efficiency and satisfaction of its users, and/or may describe measures taken of the effectiveness, efficiency and satisfaction of its users whilst performing criterion tasks. The usability statement can also describe the process that has or will be undertaken during system development to enhance usability. The standard will therefore allow either or both of two main complementary approaches to be taken to the human factors design of VDU interfaces; usability assurance based on a description of the design principles and practices employed or usability assurance based on empirical testing.

The remaining parts of ISO 9241 (Parts 12 to 19) will provide specific design requirements for VDU information presentation, user guidance and various forms of interactive dialogue styles. Two approaches are being investigated in the development of these standards; a top-down approach based on cognitive theory and models and a bottom-up approach based upon the empirical literature (Holdaway and Bevan 1989). The current committee draft of part 14 on "menu dialogues" presents a large number of design requirements for a variety of types of menu dialogues. Each individual requirement is accompanied by one or more examples of its application, a reference to the general usability principles it aims to fulfil, notes on conformance testing and references to source literature upon which the requirement is founded.
<table>
<thead>
<tr>
<th>STANDARD</th>
<th>TABLE CROSS-REF</th>
<th>COVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 9241</td>
<td>A1.2</td>
<td>Standard will cover the definition of usability statements, presentation of information on VDUs, user guidance and a number of specific dialogue styles. Orientation is towards office systems.</td>
</tr>
<tr>
<td>ISO/IEC JTC1/SC18/WG9</td>
<td>A1.2</td>
<td>Standards work in progress covers keyboard layout, user interface and symbols. Orientation is towards office systems.</td>
</tr>
<tr>
<td>IEC 964</td>
<td>A1.2</td>
<td>Defines functional requirements for the design of control rooms in nuclear power plants. Provides some outline recommendations on display design.</td>
</tr>
<tr>
<td>ISO 11064</td>
<td>A1.2</td>
<td>Part 4 of this standard is planned to cover the topic of 'visual displays for process control'.</td>
</tr>
<tr>
<td>DIN 66234</td>
<td>A1.4</td>
<td>This covers the coding of displayed information, and provides five general principles to be applied in dialogue design.</td>
</tr>
<tr>
<td>DefStan 00.25 (MOD)</td>
<td>A1.6</td>
<td>Military standard with some limited information on VDU display and dialogue design.</td>
</tr>
<tr>
<td>MIL-STD-1427C (DOD)</td>
<td>A1.6</td>
<td>Military standard providing a useful set of requirements for command dialogues and display management.</td>
</tr>
</tbody>
</table>

**TABLE 3.2 SUMMARY OF STANDARDS RELATING TO VDU INTERFACE DESIGN**

Based on the level of detail provided in currently available parts of ISO 9241, the standard should give detailed and relatively comprehensive coverage of VDU dialogue design. The concept of usability statements as described in part 11 may be usefully employed in the process industries. However, as mentioned previously, the focus of the latter parts of ISO 9241 and of the other related standards is on office tasks and they are unlikely to cover all of the specialised design issues of concern within the process control room.

There does not appear to be any detailed standards that apply specifically the display and interactive dialogue requirements of VDU display systems for process control applications. IEC 964 specifies some outline functional requirements for VDU display formats, but includes few detailed requirements. Part 4 of ISO 11064 is planned to cover the topic of 'visual displays for process control', but since work on this part of the standard has not yet begun, it is not possible to state whether this will provide a more detailed set of requirements.

**3.2.5 Standards on Information Coding and Presentation**

A number of detailed standards exist which specify standard symbols, colour codes and other display attributes of value when designing operator interfaces. These are summarised in Table 3.3. These are of varying degrees of use for application in the design of VDU-based displays. BS 381C, for example, is more directly usable than other more sophisticated methods of colour specification, but is essentially a specification method for reflected colours rather than for the emitted colours of a VDU display.

The standards relating to graphical symbols (BS 553, BS1646, ISO 3511) are primarily intended for use on process and instrumentation drawings not VDU displays. In most cases, the fine graphic details and distinctions between valve and pump types would detract from
the clarity of a VDU presentation. The ANSI standard (ISA-85.5-1985), however, is intended for use on process displays.

The number of standards that are of direct use in specifying VDU-based displays is therefore limited. It would be necessary in a project context to define project specific standards or guidelines that abstract the most useful information from such standards.

<table>
<thead>
<tr>
<th>STANDARD</th>
<th>TABLE CROSS-REF</th>
<th>COVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 381C</td>
<td>A1.1</td>
<td>Defines 84 standard colours which may be of use in specifying colour coding schemes.</td>
</tr>
<tr>
<td>BS 1523 Part 1</td>
<td>A1.1</td>
<td>Provides a standard glossary of terms for the automatic control aspects of a system.</td>
</tr>
<tr>
<td>BS 553</td>
<td>A1.1</td>
<td>Defines standard Graphical symbols for piping, power generating and compressor plant.</td>
</tr>
<tr>
<td>BS 1646</td>
<td>A1.1</td>
<td>Defines standard symbols for process measurement, control functions and instrumentation (Based on ISO 3511)</td>
</tr>
<tr>
<td>BS 1710</td>
<td>A1.1</td>
<td>Defines standard colours for identifying pipelines and services conveying fluids in liquid or gaseous condition.</td>
</tr>
<tr>
<td>BS 4099</td>
<td>A1.1</td>
<td>Defines standard colours for indicator lights, push-buttons, annunciators and digital readouts.</td>
</tr>
<tr>
<td>BS 5378</td>
<td>A1.1</td>
<td>Provides a specification for safety signs and colours, including the definition of standard colours for specific safety meanings.</td>
</tr>
<tr>
<td>ISO 3511</td>
<td>A1.2</td>
<td>Defines standard symbols for process measurement, control functions and instrumentation. Adopted with changes by BSI as BS 1646.</td>
</tr>
<tr>
<td>ISO 1503</td>
<td>A1.2</td>
<td>Defines standard for the direction of movement of controls and motion indications on signs.</td>
</tr>
<tr>
<td>ISO 3864</td>
<td>A1.2</td>
<td>Provides a specification for safety signs and colours, including the definition of standard colours for specific safety meanings. Adopted with changes by BSI as BS 5378.</td>
</tr>
<tr>
<td>IEC 73</td>
<td>A1.2</td>
<td>Defines standard colours for indicator lights, push-buttons, annunciators and digital readouts. Adopted by BSI as BS 4099 Part 1.</td>
</tr>
<tr>
<td>ISA-85.5-1985  (ANSI)</td>
<td>A1.5</td>
<td>US standard on symbols for use on process displays.</td>
</tr>
</tbody>
</table>

**TABLE 3.3 SUMMARY OF STANDARDS ON INFORMATION CODING AND PRESENTATION**

3.2.6 Standards on System Documentation

Two sets of standards are available that particularly cover the design and development of the technical and user documentation for computer-based systems. These are summarised in Table 3.4.
<table>
<thead>
<tr>
<th>STANDARD</th>
<th>TABLE CROSS-REF</th>
<th>COVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 4884</td>
<td>A1.1</td>
<td>Specifies the required content and presentation of technical manuals for a system.</td>
</tr>
<tr>
<td>BSI Tech. Committee IST/18</td>
<td>A1.1</td>
<td>Specifies the process that should be followed when creating user documentation for software products.</td>
</tr>
</tbody>
</table>

**TABLE 3.4 SUMMARY OF STANDARDS ON SYSTEM DOCUMENTATION**

### 3.3 HUMAN FACTORS GUIDELINES AND HANDBOOKS

There is a wide range of sets of human factors guidelines and handbooks available. Those listed in Table A1.7 in Appendix 1 are restricted primarily to those that have specific application to process control. These cover a wider area than that covered by current standards and generally provide more detailed advice. However, there are still areas of operator interface design such as display design and alarm presentation which have limited, or generalised coverage.

#### 3.3.1 Guidelines and Handbooks Relating to Control Room and Workstation Design

A number of the guidelines and handbooks cover the design of control room layout and consoles. Invégard's handbook (Invégard, 1989) provides the best coverage of control room and console design for VDU-based systems, though this has insufficient detail to be used as a single source reference during design. Gilmore et al (1989) also covers console design for VDU's and provides useful diagrams to illustrate the guidance. The nuclear power related guides and checklists (Kinkade and Anderson, 1984; NUREG-0700) give only limited coverage of the specific requirements for VDU-based systems, though they do address comprehensively the design requirements for panel displays and controls. Woodson (1986) provides some coverage of VDU-console design but this is limited in detail and extent. HFRG (1991) provides a useful outline of required console dimensions and visual requirements of VDU's. Gilmore (1985) is an extremely useful source document for detailed guidance on the visual aspects of VDU systems. The VDT Manual (Cakir et al, 1980) is a standard source reference for the implementation of VDU's in the workplace, providing useful background information and guidance. In general, the most direct guidance for implementing VDU systems in a control room context is provided by the DIN standard (DIN 66234, parts 6 and 7), covering the detailed vertical dimensions recommended for console design and both horizontal and vertical sightlines requirements. When completed similar information should be provided in part 3 of ISO 11064.

#### 3.3.2 Guidelines and Handbooks on VDU Interface Design

As indicated in Section 3.2.4, there is very limited coverage of the design of VDU displays and operator interaction for process control contexts in existing or planned standards. Current sets of guidelines and human factors handbooks supply a lot of the detail required, but there are still gaps in this coverage.

NUREG-0700 provides some specific checklist entries relating to VDU-based systems. This gives useful detailed guidance in some areas (eg. recommended VDU viewing angles, blink rates for flashing information). However, the coverage is far from comprehensive, providing
only outline guidance on display format design and navigation. In contrast, Kinkade and Anderson (1984) describes a generic approach to the process of designing control rooms, but provides little specific information on VDU information system design.

Useful overview information is given by the Human Factors in Reliability Group Guides (HFRG, 1987 and HFRG, 1991). These guides provide lists of questions on the design and implementation of control room facilities. The extended version (HFRG, 1991) also provides cross-references to useful background literature and case study examples. These guides are written for human factors non-specialists to prompt detailed consideration of the safety aspects of VDU interface and workplace design in process control applications. They do not, however, provide detailed guidance on display design etc.

The most comprehensive coverage of VDU interface and workplace design is given by Gilmore et al (1989). This covers details of screen design, coding, information formats, input devices and dialogue issues. The guidelines are referenced directly to background research support where available. The handbook also includes an extensive checklist. A number of the guidelines as presented are open to debate. There are clearly situations in which some guidelines are not applicable or appropriate. The handbook does not assist the reader in making such value judgements or tradeoffs. Also, there are weak areas in the coverage of the guidelines such as the presentation of alarm information on VDU displays. It is, however, an extremely valuable reference source and a good starting point for the development of company project specific guidance.

The Computer Display Designer's Handbook (Wagner, 1988) is also a useful source reference for application to VDU system design. It contains background information on user psychology relevant to the display design process and covers detailed aspects of display design for process applications. It is particularly useful in the coverage it gives to the design of mimic displays, providing numerous examples. Some of the advice given is open to debate, and is not supported by empirical research findings. The handbook is not in the form where it could be directly used by display designers.

The design guidelines produced by Smith and Mosier (1986) provide a large amount of detailed advice on general aspects of human-computer interface design. Where appropriate, examples are given to illustrate the application of a guideline, cross references are given to similar guidelines or comments are provided on its use. The Smith and Mosier guidelines have emerged as a standard reference for human-computer interface design, though it is recognised that there can be severe problems in their application. In particular, they can give advice which is conflicting or in some cases contradictory when applied to a specific design. The authors suggest that the guidelines should be reviewed in a particular project context to generate a set of agreed design rules specific to a project. Versions of these guidelines are also now available on disc for IBM PC and Apple Macintosh Computers considerably simplifying the task of consulting and cross-referring the guidelines. The guidelines have limited applicability to process control systems, being primarily aimed at office type systems, but provide a useful model for the type of guidelines that may be generated for process control applications.
The HUSAT Human Factor Guidelines for the Design of Computer-Based Systems (HUSAT, 1988) takes a different approach to the provision of design guidance. The set of six volumes of the guidelines provide a detailed specification of a human factors design process for a computer-based system:

| Part 2 - Human Factors in Project Initiation |
| Part 3 - Human Factors in Requirements Specification |
| Part 4 - Human Factors in Full Development and Build |
| Part 5 - Human Factors in System Integration, Test and In-Use Support |
| Part 6 - Human Factors Quality Assurance |

They indicate the activities to be performed at each stage of the design lifecycle, the deliverables to be produced and the managerial control required. At appropriate points, specific guidance is provided on aspects such as workplace dimensions and interaction design. The document is designed to enable it to be used as the basis of a requirement specification when procuring a system. As with the Smith and Mosier guidelines, the HUSAT guidelines are aimed at general computing systems covering the requirements of both office and military systems. As would be expected, precise guidance is not given on the detailed aspects of display design for process control applications. The recommended design process is very rigorous and would be cost intensive to apply to its full extent. The authors do suggest, however, that sub-parts may be selected and applied as appropriate.

The coverage of published sets of guidelines and handbooks is therefore limited with regard to the design of VDU displays. However, there is a considerable volume of detailed information available, primarily intended for panel and hardcopy displays, scattered throughout the human factors research literature as published papers and reports. These sources have been collated in specific company contexts (e.g. the BNFL and RMC guidelines mentioned in Section 2.4.1), but are not widely available. The weakest area relates to issues of display clutter, page structure design (i.e. incorporating operator information requirements) and navigation between displays. As indicated in Section 5, a number of these areas require further basic research.

3.4 CONCLUSIONS

There are a wide range of standards, guidelines and handbooks relating to the human factors aspects of computer-based systems. There is sufficient information available on the design of the workplace for VDU-based control systems, though it is not summarised in a single, comprehensive document. The physical design of the workplace may be covered by the final issued version of Part 3 of ISO 11064. The visual aspects of implementing VDU displays in a control room are covered by handbooks and the recently issued parts of ISO 9241.

Information on the design of displays and interactive dialogues with VDU-based systems in the control room is less readily available being largely contained within the research literature. The major efforts in developing standards are directed towards office-type systems of which only a limited proportion of the requirements are applicable to process applications. Gilmore et al (1989) provides a lot of useful information and source references, but requires careful interpretation in some areas. The Human Factors in Reliability Group guide (HFRG, 1991) identifies key points in this area but is likely to require detailed
supplementary information on a number of areas. The most useful form of guidance might
be to bring together statements of principle with illustrated examples. For example, the
principle of avoiding 'cluttered' displays could be described and then illustrated by example
screen displays. As indicated when describing the Smith and Mosier design guidelines, such
guidelines should lend themselves to being redefined within a project or company specific
context. Consideration would also have to be given regarding any tradeoffs that may need to
be made during design.

Precise and prescriptive standards will be less easy to develop for VDU-based operator
interfaces. There are few principles of interface design that can be specified unambiguously,
are supported empirically and have universal application. The most promising approach to
standards development would be to aim for minimum requirements for human factors
activities in the design and evaluation of operator interfaces. This would be similar to IEC
964 but cover more specifically the design process for computer-based systems. Specific
documentation requirements could be indicated, similar to the 'usability statement' forming
part of ISO 9241. Detailed design advice would still be required, but with the present state
of knowledge, this is best presented as advisory guidance rather than a mandatory
requirement.
4.0 A SURVEY OF CURRENT DESIGN PRACTICE

4.1 INTRODUCTION

It is suspected that few companies are employing human factors techniques across the spectrum of design as outlined in Section 2.0. It is also uncertain the extent to which currently available guidelines and standards are applied in practice. The eventual intention of the HSE is to develop human factors guidance for process companies which avoids duplicating existing practice and offers help where it is most clearly required.

In order to provide objective information, a survey was carried out of a sample of UK-based process companies to determine current design practice relating to the operator interface to computer-based control systems, particularly in relation to operator displays and control room design.

4.2 DESCRIPTION OF SURVEY

The objective of the survey was as follows:

"To provide a review of current practices employed across a range of process industry sectors during the design of control room interfaces for process plants".

This includes issues such as; the allocation of tasks to operating personnel, design of VDU displays, control room layout and environment.

Within the limitations of this project, it was recognised that the survey would need to be restricted to a small number of companies. The results provided, should be treated as useful case study material rather than as providing a fully representative survey of design practice across the UK.

Initially a candidate list of possible contributors was drawn up including companies from the nuclear, chemical processing, oil and gas, pharmaceutical and food processing industries. These were then individually approached to invite them to participate in the project. The results presented in this section are based upon interviews held with seven companies from various industrial sectors as described in Table 4.1.
<table>
<thead>
<tr>
<th>Company Reference</th>
<th>Industrial Sector</th>
<th>Types of Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Nuclear industry</td>
<td>Nuclear reactors</td>
</tr>
<tr>
<td>B</td>
<td>Chemical Processing</td>
<td>Small batch to large continuous</td>
</tr>
<tr>
<td>C</td>
<td>Offshore exploration and production</td>
<td>Offshore drilling and production platforms</td>
</tr>
<tr>
<td>D</td>
<td>Pharmaceuticals</td>
<td>Medium to large fine chemicals batch plants</td>
</tr>
<tr>
<td>E</td>
<td>Food products</td>
<td>Wet and dry batch production plants</td>
</tr>
<tr>
<td>F</td>
<td>Petrochemicals refining</td>
<td>Large refineries</td>
</tr>
<tr>
<td>G</td>
<td>Oil and gas production</td>
<td>Oil and gas terminals and processing</td>
</tr>
</tbody>
</table>

**TABLE 4.1: OVERVIEW OF COMPANIES INCLUDED IN SURVEY**

As can be seen from the entries in Table 4.1, the companies cover a diverse range of industrial sectors. The inclusion of one or more contributors from the nuclear industry was particularly important, as the safety-critical aspects of operations in the nuclear industry has led the development and application of sophisticated human factors programmes. Some of these are reported in the open literature (e.g. Kirwan, 1989; Kirwan et al, 1990; Williams and Storey, 1987), though not in the level of specific detail required for this project.

The participants were contacted initially by telephone and then sent a letter outlining the objectives and scope of the overall project. The information was gathered either by face-to-face or telephone interviews. A standard questionnaire format agreed with the HSE Technology Division was used as the basis for the interview. In general, the interviews were structured around obtaining information on design activities during the following five project phases:

(i) Conceptual design  
(ii) Outline design/system procurement  
(iii) Detailed design and acceptance testing  
(iv) Commissioning  
(v) Operation

The responses obtained were summarised and returned to the contributors for checking. An important aspect of the survey process was ensuring the confidentiality of the contributions provided. For this reason, each of the companies are referred to by an anonymous reference letter and some of the details relating to the identity of the respondents have been disguised.

**4.3 RESULTS**

The validated transcripts of the information obtained from the contributing companies are included in Appendix 2. These include notes on the design activities carried out by each of the seven companies during the five project stages. Summaries of the main findings are given below.
4.3.1 Design Processes Adopted for Deciding Levels of Automation (Table 4.2)

Most of the companies interviewed indicated that they have clear company policies on process automation. In general, primary safety hazards are handled by automatic trip systems and the primary role of the operator is to act as a production manager. The philosophies on the level of automation of process operations varied between companies and industrial sectors. In some cases, there is a clear drive towards increased automation (companies B and D) for commercial reasons. In company F, automation was applied to those control tasks where clear economic benefits could be demonstrated. The sequencing of operations is still retained as a largely manual task. In none of the companies participating in the survey were operators seen as fulfilling a primary safety role, with primary responsibility for preventing serious hazards. However, the operator will still have a role in the early detection of hazardous events, in checking that trip systems have operated correctly and in carrying out any residual actions. Operators involvement will also be particularly important in monitoring maintenance activity to ensure automatic protection systems are not compromised.

4.3.2 Human Factors Considerations Applied in the Selection of Control Room Interface Hardware (Table 4.3)

Varying approaches are taken to the human factors considerations in the selection of control room interface hardware. Companies C, D and E for example, include precise requirements in the specification sent to system vendors. Company F involves its operations personnel in the review of alternative interface facilities. Company B, however, tends to use a limited number of hardware vendors and so is able to build up experience with the interface options offered by each vendor. Company A has to meet detailed requirements laid down by their client. These include human factors requirements for interface hardware.

<table>
<thead>
<tr>
<th>Company Reference</th>
<th>Outline of Decision Process for Levels of Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Levels of automation defined by client at present, though intention is to adopt more formalised approach to allocating functions.</td>
</tr>
<tr>
<td>B</td>
<td>Policy is to automate control tasks wherever possible for productivity reasons. Where staff are already available in an existing control room, then some tasks may be left manually operated. For safety reasons, all trip functions are fully automated.</td>
</tr>
<tr>
<td>C</td>
<td>Safety trip systems are largely automated, with control staff primarily concerned with early intervention and with production tasks.</td>
</tr>
<tr>
<td>D</td>
<td>Plants designed to be fully sequenced batch operations apart from manual handling needed with powder products. This is for commercial reasons.</td>
</tr>
<tr>
<td>E</td>
<td>Decisions on the level of automation are largely based on previous operational experience. The operating staff are primarily given the role of production managers, since potential safety hazards are guarded against by automatic trips.</td>
</tr>
<tr>
<td>F</td>
<td>Decisions on the level of automation are generally based on economic factors. Sophisticated automation may underpin financial case, though in general, plants are not highly sequenced, leaving the task of production scheduling to the operator.</td>
</tr>
<tr>
<td>G</td>
<td>Details not available to interviewee.</td>
</tr>
</tbody>
</table>

**TABLE 4.2: DECISION PROCESSES ADOPTED FOR DECIDING LEVELS OF AUTOMATION**
<table>
<thead>
<tr>
<th>Company Reference</th>
<th>Conceptual Reference</th>
<th>Outline</th>
<th>Detailed</th>
<th>Commissioning</th>
<th>Operation</th>
</tr>
</thead>
</table>
| A                 | * Conceptual research studies | * Prototypes evaluated | * Detailed design on paper/PC's  
+ Simulation studies carried out | * Operational trials  
+ Operator surveys | * Operator surveys |
| B                 | * Types of displays decided | | * Displays designed from P & ID's by control engineers  
+ Style of graphics influenced by operations  
+ Graphics generated in-house  
+ Graphics discussed by control system engineers and process chemists  
+ Problems sometimes revealed during simulation testing of control software | * Operators involved in commissioning plant  
+ Any subtle problems with graphics are dealt with at this stage  
+ Modifications are carried out at site | * Modifications to graphics may still be made, but these will tail off |
| C                 | * Types of displays decided | | * Display design performed by senior operator seconded to project  
+ Screens constructed by external contractor  
+ Screens are reviewed and changed if problems identified  
+ Screens also in use during factory acceptance testing | * Software is tested through operator interface during commissioning, giving opportunity for further check on displays | * Modifications still possible through formal change procedures |
| D                 | * Types of displays decided | | * Graphics constructed in-house from P & ID's  
+ Accuracy of displays checked by process engineers  
+ Displays may be examined during acceptance testing, if displays available | * Operations staff are involved with commissioning of system  
+ Problems with displays may be detected and rectified at this stage | * Further changes may be made on basis of formal change procedures |

**TABLE 4.5: PROCESSES APPLIED IN THE DESIGN, CHECKING AND REVISION OF VDU DISPLAYS**
<table>
<thead>
<tr>
<th>Company Reference</th>
<th>Conceptual Design</th>
<th>Outline Design</th>
<th>Detailed Design</th>
<th>Commissioning</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>* Types of displays decided</td>
<td>* Display designs incorporated in functional design specification, drawn up by vendor and operations</td>
<td>* Limited opportunities for operations to request changes to displays during this stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Displays generated by vendor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Displays checked by control engineering and formally reviewed during acceptance test using checklist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>* Types of displays decided</td>
<td>* Displays designed by a senior operations person and a control engineer</td>
<td>* Operations staff are involved with commissioning of system</td>
<td>* There is still scope for further changes to be made on basis of formal change procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Displays coded by contractor</td>
<td>* There is scope for changes to be made on basis of formal change procedure</td>
<td>* Investigating reasons for success of particular system implementations on existing plants</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Displays reviewed by designer once completed (in batches)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>* Types of displays decided</td>
<td>* Graphics displays designed by engineering contractor using P &amp; ID diagrams</td>
<td>* Minor changes possible to mimmics</td>
<td>* Operational feedback collected by nominated member of operations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Displays reviewed in batches by operations (teams of operators)</td>
<td></td>
<td>* Expert review of mimmics commissioned</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>* Comments fed into full revision of mimmics after one year of operation and into design of mimmics for further systems</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4.5: PROCESSES APPLIED IN THE DESIGN, CHECKING AND REVISION OF VDU DISPLAYS (CONT'D)**

4.3.5 Design Processes for Control Rooms (Table 4.6)

As with the design of displays, there is a clear distinction between the approach applied in the nuclear-related company and the companies from other process industry sectors. Apart from company A, all the other companies develop and agree control room designs 'on the drawing board'. The initial decision on the overall space to be allocated to the control room
will depend on inherent space limitations, particularly if a new control room is to be sited in an existing building. In a number of cases, operations have the responsibility for deciding control room layout in negotiation with project management. Only in the case of company A (nuclear industry) is a full-scale mockup of the control room constructed for evaluation purposes.

4.3.6 Application of Guidelines and Standards to Human Factors Aspects of Design (Table 4.7)

The results of the survey indicate that most of the companies in the survey do not apply guidelines or standards in the design of operator interfaces and control rooms. In most cases, a de facto standard exists within the company for aspects such as colour coding and symbols on displays but this is not formalised. The main exception to this is Company A operating in the nuclear industry, where the respondent, a human factors specialist, is aware of and makes use of the guidance given by human factors standards and guidelines. Furthermore, in-house guidelines on graphic display design are under development for future projects.

<table>
<thead>
<tr>
<th>Company Reference</th>
<th>Design Process for Control Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Size constraints of control room specified by client. General layout and environmental requirements stated and use may be made of 3D workplace simulators. Design mockups and full scale prototype constructed to evaluate performance.</td>
</tr>
<tr>
<td>B</td>
<td>Control room design by instrument engineering department on basis of wiring requirements and budgetary constraints.</td>
</tr>
<tr>
<td>C</td>
<td>Control room size determined early in design process, on basis of cost and space constraints. Size requirements extrapolated from previous designs. Design of control room layout decided through negotiation between the engineering team and operations. Desk layout and panel influenced by operations preferences. Modular console units used to enable some flexibility.</td>
</tr>
<tr>
<td>D</td>
<td>Operations decide upon the control room layout. Normally the vendor will suggest number of options which operations select between. Dimensions of consoles, etc, depend upon vendor products. Try to provide horseshoe arrangement and pay attention to lighting.</td>
</tr>
<tr>
<td>E</td>
<td>Initial layout of control room performed by operations and then negotiated with control engineering. Cost is an important constraint and issues such as sophisticated lighting design will be determined by budgetary constraints.</td>
</tr>
<tr>
<td>F</td>
<td>Operations drive the process of control room layout design in negotiation with projects. Normally working within space constraints in existing building. May make use of lighting standards.</td>
</tr>
<tr>
<td>G</td>
<td>Operations given input into control room layout proposals and collaborate during detailed design. Current operational control room being reviewed and lessons learnt being applied to new design.</td>
</tr>
</tbody>
</table>

**TABLE 4.6 : DESIGN PROCESSES FOR CONTROL ROOMS**

4.3.7 The Role of Operations Personnel in the System Design Process (Table 4.8)

Where a new plant design is similar to an existing plant or a computer-based control system is being implemented in an existing plant, there is particular value in involving appropriately qualified operations personnel in the system design process. Section 2.3.2 identifies six distinct roles which operations personnel can fulfil:
(i) **Authorisers:** Where operations management have budgetary control of powers of veto, they can act as authorisers of design decisions.

(ii) **Task experts:** Members of operations staff on the same or similar plants may act as sources of information on operational tasks and equipment.

(iii) **Interface experts:** Operations personnel can also be a key source of information on the weaknesses and strengths of systems that have been implemented on other plants.

(iv) **Designer:** Operations personnel may be allocated to design sub-teams and given particular tasks to complete such as display design or workplace layout.

(v) **Opinion Providers:** Operations staff may act in a consultative role, being asked to provide their opinions on design options.

(vi) **Evaluators:** Operations staff have an important role as evaluators through their participation in evaluation trials and through use of the system.

The information given in the interviews suggests that operations staff are widely involved in systems design within the various companies. In fact, the entries in Table 4.8 only represent those roles which were explicitly mentioned by the interviewees and it is likely that operations involvement is actually wider in practice than that shown. In particular, operations personnel are given the role of authorisers of design decisions in most companies.

A number of the companies choose to involve members of operations staff in the design of displays or control room layout. In company F, operations staff collaborate with the engineering contractor to generate a detailed functional specification for a plant design including the displays that are to be provided.

In various companies, operations staff also contribute their experience with existing operator interfaces to guide the selection of a new system. Shift staff are brought into the decision making process in a consultative role, providing their opinions on design options such as display designs and control room layouts.

A major role played by operations personnel is in the evaluation of displays during the commissioning and early operational phases. Unfortunately, at this stage of the design process there are practical limits on the scope of changes that can be made. Major flaws or inadequacies in the displays can usually be rectified.

Only in company A does there appear to be any intention to directly use operations knowledge of their major task activities during the design and evaluation of the operator interface and control room workplace. This is the basis of the task analysis approach described earlier in Sections 2.2.3 and 2.2.4.
<table>
<thead>
<tr>
<th>Company Reference</th>
<th>Application of Guidelines and Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Use made of variety of human factors guidelines and standards to guide development process. Detailed guidance on mimic displays under development within company.</td>
</tr>
<tr>
<td>B</td>
<td>Style of graphics displays based on style used in other company installations. De facto standards on colour coding and symbols therefore exist but are not formalised.</td>
</tr>
<tr>
<td>C</td>
<td>No particular use made of human factors standards or guidelines, though displays are designed to be compatible with other designs within company. This style 'standard' is not formalised.</td>
</tr>
<tr>
<td>D</td>
<td>Written standards exist within company for screen colours, though other aspects of graphics displays are based on 'house style'. This style 'standard' is not formalised.</td>
</tr>
<tr>
<td>E</td>
<td>Display colours and symbols are standardised within the company. Display design based on operational experience.</td>
</tr>
<tr>
<td>F</td>
<td>Decisions on colours and style of graphics made on a project basis, though there essentially exists de facto company standards on colours and symbols. There are no company standards addressing issues such as information density.</td>
</tr>
<tr>
<td>G</td>
<td>Details on past design process not available to interviewee. Current reviews will result in de facto standards for future designs.</td>
</tr>
</tbody>
</table>

**TABLE 4.7: APPLICATION OF GUIDELINES AND STANDARDS TO HUMAN FACTORS ASPECTS OF DESIGN**

### 4.4 CONCLUSIONS

From the results of the survey, a number of general conclusions can be drawn:

(i) Whilst most of the companies interviewed have clear policies on the scope and future direction of process automation, the specific role of operators is not so explicitly defined. There would be benefit in clearly establishing the role of the control room operator in ensuring the safety of highly automated processes.

(ii) Many human factors aspects of the operator interface are determined by the facilities offered on available packaged control systems. Various approaches to the selection of control room interface hardware were found amongst the sample of companies. There is scope for provision of advice to assist in the human factors aspects of the selection process.

(iii) The number of VDU displays implemented in a control room is often decided on the basis of past operational experience and cost constraints. There is no guarantee that this process takes adequate account of the needs for safety-related monitoring and emergency response. Advice in deciding upon the appropriate number of displays would be useful.
<table>
<thead>
<tr>
<th>Company Reference</th>
<th>Authorisers</th>
<th>Task Experts</th>
<th>Interface Experts</th>
<th>Designers</th>
<th>Opinion Providers</th>
<th>Evaluators</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>D</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>G</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

**TABLE 4.8: PRIMARY ROLES OF OPERATIONS PERSONNEL IN THE SYSTEM DESIGN PROCESS**

(iv) The variety of approaches to display design amongst the companies interviewed is a reflection of the different organisational and commercial influences on the system design process. No one particular method is 'correct', but companies could be assisted in developing individually tailored approaches which make use of a wider range of useful human factors related techniques.

(v) The control room design process could be greatly improved by the availability of appropriate guidance and standards relating to layout, physical dimensions, lighting and other environmental aspects.

(vi) Company experience in previous design projects is an important factor in determining the shape of future designs. However, formal feedback, particularly regarding the human factors performance of an operator interface and control room design, is often not provided, reliance is placed upon the opinions and experience of particular individuals.

(vii) The effective involvement of operations staff during the system design process has an important part to play in ensuring that due consideration is given to human factors considerations. However, a strategy of operations involvement is needed so that subjective opinion is balanced against objective human factors requirements.

(viii) As expected there is very little use of human factors guidelines and standards. This is probably partly due to simple lack of awareness of their existence. However, as indicated in Section 3.0, current guidelines and standards still require some further development to meet the main needs of process companies.

There is a marked difference between the range of human factors techniques and guidance indicated in Sections 2.0 and 3.0 and the actual design approaches adopted by most companies. The main exception is company A from the nuclear industry. Other companies in this same industry also apply similar detailed and wide-ranging human factors programmes. They each employ full-time human factors professionals and recruit expertise from human factors consultancies. This reflects the safety-critical nature of the human factors aspects, regulatory requirements and the scale of the resources available. The other process industry sectors are highly unlikely to adopt the same exhaustive and extensive approach to human factors.
Current design approaches in the non-nuclear process sectors do give implicit consideration to a wide variety of human factors issues. In some cases, current approaches are probably adequate when viewed from a safety-perspective. For example, where it is believed that the safety integrity of a process can be assured through automatic trip protection systems and where operating rules will not allow these levels of protection to be disabled or circumvented, then operator interface design considerations may be considered to have only have production-related consequences. (Nb. The actual impact of operator performance on process safety may be greater than believed). In addition, where processes are relatively simple to control and monitor, great attention to the grouping and presentation of process information may not be needed. As a result, it is important that whatever guidance is given it is flexible such that existing approaches to design may be incorporated if appropriate and can be adjusted to the complexity and safety-criticality of operator tasks. This could be similar to the approach being adopted by working groups 9 & 10 of IEC/65A in the current development of IEC standards on the Safety of Programmable Electronic Systems (Table A1.2, Appendix A). The working groups have defined four levels of safety integrity or safety performance, with the appropriate level being applied dependent on the level of risk and on other factors such as the type of industry and the safety assurance regime.

Overall the results of the survey indicate that there is scope for improvement of the human factors aspects of the system design process for computer-based control systems. Any guidance provided needs to recognize the commercial constraints inherent to the introduction of a comprehensive human factors programme and therefore needs to be clearly targeted at the safety-critical aspects of operator tasks. The approach to providing guidance needs to be flexible to fit a wide variety of commercial contexts and to capitalise on existing practices where appropriate.

A number of conclusions can be drawn about the scope of such guidance:

(i) It should cover the identification of safety-critical tasks and the evaluation of the resulting 'allocation of function'.

(ii) It should provide advice on the specification and evaluation of human factors requirements during the selection of a control system. This needs to include issues such as the number of display screens that will be required.

(iii) A range of approaches to display design should be suggested supported by specific guidance on detailed design aspects such as colour and symbol coding. This must allow the companies concerned to tailor the advice to their own organisational and commercial context.

(iv) Readily available guidance on control room design would be helpful.

(v) The value of the experience gained whilst operating existing plants needs to be generally recognized and advice given on means of feeding this information back into future designs. This should include effective strategies for involving operations personnel during the design process.

There is a general awareness that the human aspects of system design could be improved and evidence has been found of a number of current initiatives within process companies to evaluate human factors approaches. As a result, the majority of the companies contacted
expressed an interest in the eventual outcome of this project and in assisting in the development of the guidance.
5.0 THE SCOPE AND DIRECTION OF CURRENT RESEARCH

5.1 INTRODUCTION

This section examines the current state of research knowledge and research activity related to the operator interface for computer controlled process plants. Such knowledge is important for three reasons:

(i) It provides a theoretical framework for describing operator activities and requirements which can be applied when developing an overall interface design philosophy (eg. information required for effective safety monitoring, the role of alarms).

(ii) It forms the basis for detailed guidance on aspects of the design of the operator interface (eg. display design, use of colour).

(iii) It provides information that enables trade-offs to be made between interface design alternatives (eg. panel vs VDU displays, the effectiveness of speech interaction in the control room).

Within some of these areas, current knowledge is sufficiently well developed to provide the basis for clear prescriptive advice and analytic techniques. However, there are still areas where research questions remain unanswered, whilst advances in computer technology continue to generate additional areas of uncertainty. The primary purpose of this review is to distinguish between those aspects which have a mature research basis and those where further research would be beneficial.

The design of the human-machine interface is one of the primary areas of research activity within human factors. There is a vast amount of information potentially available for application to the design of the operator interface in process plants. This can be drawn from the domains of cognitive psychology, human factors and more recently, human-computer interaction. In particular, the events surrounding the near-catastrophic accident at the Three Mile Island nuclear reactor in March 1979 prompted a large programme of applied research in the USA into safety-related aspects of the operator interface.

The following sections review the current state of knowledge relating to VDU-based interfaces and particular aspects of panel display design. The initial section examines a number of global research issues which underpin the overall philosophy that may be adopted when designing operator interfaces for process plants.

5.2 GLOBAL ISSUES

5.2.1 Modelling of Operator Cognition

Investigations into the way process operators "think" has a long history within human factors. Initially, researchers were concerned with modelling the nature of the closed-loop control of processes by human operators, particularly in circumstances where there is a long response lag between a control input and process response. For example, the classic experiment reported by Crossman and Cooke (1974) examined subject behaviour controlling the temperature of a bath of water given delayed temperature indications. It is possible to
model such behaviour mathematically utilising control theory and then to use such models as
the basis for specifying augmented displays to optimise operator behaviour.

The changing role of the human operator from closed-loop control of process parameters to
supervisor of automatic systems has introduced new problems and has required new
approaches to the investigation and modelling of operator behaviour. In order to describe the
supervisory activities of an operator, it is necessary to model the mental processes that drive
the sampling of information and anticipatory control actions. Such models predominantly
assume that the operator utilises a combination of different types of process specific
knowledge including:

(i) Dynamically updated knowledge of the current operating state of the plant and values
of key variables.
(ii) Specific knowledge on the criterion values of particular plant parameters.
(iii) Procedural knowledge regarding the control actions required to achieve particular
process goals.
(iv) A variety of types of causal and structural knowledge about plant functioning. This
may be referred to as the operator's 'mental model'.

This raises three particular problems during the investigation and modelling of operator
behaviour. Firstly, the majority of the processes of interest to the researcher take place
within the head of the operator, giving few overt behavioral cues which can be directly
observed. Operators can be asked to give a continuous verbal report on their thought
processes, but this provides a partial and easily distorted source of data. Such methods are
also extremely time consuming to apply and to analyse.

The second problem results from the apparent complexity of the underlying mental
processes. It is not certain, for example, how operators develop, maintain and apply their
knowledge of the causal relationships within a process or indeed how important such
knowledge is compared with the more superficial knowledge related to the expected values
of key process variables. Such questions have practical implications. For example, whereas
an appropriate display design for supporting causal reasoning during fault diagnosis might be
mimic displays, a summary display of trends or bargraphs could be more effective in
supporting process monitoring tasks.

Finally, the detailed knowledge and mental strategies employed by an operator tend to be
specific to the particular process and possibly, form of interface concerned. Whilst there
have been a number of detailed studies reported on the behaviour of process operators, it is
difficult to generalise from these context specific findings to produce a representative model
of supervisory behaviour for use during system design.

Similar problems apply with the development of models of operator diagnosis of process
faults. The consensus view given in current models of human diagnostic behaviour suggest
that if the fault possesses similar symptoms to faults experienced previously, the operator
will diagnose the fault by recognising the pattern of symptoms. However, if the fault is new
to the operator or novel, then diagnosis will involve deeper reasoning based upon the
operator's knowledge of causal relationships within the process. However, as indicated by
Rasmussen (1980), an operator may utilise a complex combination of diagnostic strategies
during the analysis of a single fault. The nature of diagnostic behaviour in any context is
heavily dependant upon the nature of the process, the experience of the operators and the
time available in which to respond. So, whilst general models of diagnostic strategies are available, further development is required to ensure that these models are robust and can be applied to determine the types of displays and operator aids needed to support the accurate diagnosis of faults within particular contexts.

The development of widely applicable, consensus models of operator cognition should be viewed as an important research objective. Framework models, such as the skills/rules/knowledge-based behavioral taxonomy developed by Rasmussen (1980), have been widely applied, but these provide little specific guidance on the types of information that should be provided to support the supervisory and diagnostic skills of process operators. It is not certain, for example, how or indeed, whether, process overview information is utilised by operators. There may also be important differences between the type of information that is useful to the operator of a small, slow moving batch process in comparison with that required to effectively supervise a large, highly-automated continuous process plant.

5.2.2 The Trade-offs between Panel and VDU Displays

The introduction of sophisticated computer control into process plants has resulted in a widespread shift away from the use of panel displays to the use of VDU displays as the primary interface for process operation. This has not occurred, however, without some note of concern having been expressed. The primary trade-offs between VDU and panel presentations have been widely stated (eg. van der Schaff, 1989). The main advantage of panel displays is that all the process information is available simultaneously, whilst on VDU display systems the degree of parallel information display is limited and related information frequently has to be accessed serially by changing display pages. Even from a distance, a large proportion of the process parameters on a panel display can be quickly scanned for significant deviations. The same procedure can take considerably more effort via a VDU display system.

A number of comparative studies have been carried out to assess the performance differences resulting from these different forms of display. For example, van der Schaff (1989) surveyed operator opinion in three chemical process plants where panel displays had been replaced with VDU displays. The results indicated that the operators felt that their overview of the process was poorer with the VDU display system when dealing with multiple major disturbances.

It should not be concluded from the results of this research that VDU display interfaces are necessarily a retrograde step in the provision of operator information. The serial nature of VDU information provision requires explicit decisions to be made regarding the grouping of information and the selection of information for representation on process overview displays. If this is carried out well, then the need for changing display pages will be limited. The flexibility of information display on VDU interfaces also offers positive advantages over the limited and rigid nature of panel information presentation. Furthermore, panel and VDU display systems can be used effectively in combination. For example, for rapid access, information on key safety parameters can be repeated on a wall panel display.

Further comparisons between VDU and panel presentations of process information would have limited value. It is clear that both forms of presentation have strengths and weaknesses. The most suitable form of presentation or combination of forms of presentation will vary
between processes in accordance with a variety of situation dependent factors (e.g. amount of information, importance of shared information displays between control room operators). The studies described above, however, do serve to highlight the importance of providing rapid and easy access to key process information. This is an important issue when designing VDU display systems and is discussed further in Section 5.3.1.

5.2.3 Alarm Handling Philosophy Issues

In most process plants, alarm systems form a vital part of the strategy for detecting and averting incidents with safety consequences. Their purpose is to alert the operator to deviant conditions in sufficient time for preventative actions to be taken. In computer controlled plants, it is possible to attach alarms to most of the hundreds, possibly thousands of measurement points throughout the process. Under severe upset conditions, a large number of alarms can be generated in a short period of time. There is a real danger, that unless careful consideration is given to the handling of this information, the operator can become quickly overloaded with alarm indications of which only a small proportion have potential safety consequences, resulting in important information being overlooked.

The key issues in alarm system design are as follows:

(i) Selection of the minimum set of alarm points necessary.
(ii) Separating alarm indications from plant status indications.
(iii) Effective prioritisation of alarms.
(iv) Selection of grouped alarms.
(v) Preventing frequent spurious alarms.
(vi) The use of ringback or return-to-normal indications.
(vii) Altering alarm settings according to plant mode of operation.
(viii) Suppression of cascade alarms.
(ix) Selection between or combination of different modes of presentation (Panel, VDU and printer).
(x) Design of audible alerting signals.
(xi) Design of the operator alarm acknowledgement procedure.
(xii) Provisions for handling multiple alarm floods.

A number of these issues are technical in nature and depend upon the alarm handling capabilities of the computer control systems concerned. The research programme commissioned in the USA following the near disaster at the Three Mile Island power plant in March 1979 generated useful advice on the selection, prioritisation and grouping of alarm indications (Fink, 1984; Kinkade and Anderson, 1984). The trade-off between panel and VDU display of alarms has not been resolved, though it is possible to utilise both forms of display in combination, with just the highest priority alarms being repeated on a panel display. Advice is available on the design or selection of auditory alarm sounds (e.g. Patterson 1989). Provisions for handling multiple alarm floods may include a facility to silence audible alarm signals to minimise distraction and group acknowledgement of related alarms. One of the most important aspects in being able to handle such events is an effective alarm prioritisation scheme.

In terms of the overall philosophy for handling alarms, current theoretical knowledge is still limited. Whilst a host of technical approaches are available to assist in the presentation of alarm information there is a lack of clear design principles that can be readily employed. A
research priority should be the generation of a reliable psychological model of operator alarm handling, particularly under alarm flooding conditions. This would need to fit into the general models of fault diagnosis as discussed in Section 5.2.1. Research along these lines is currently in progress (Stanton & Booth, 1991; Stanton et al, In Press) and the results of this research should be evaluated when they are available. Further areas for consideration include alarm analysis and reduction (covered in the following Section) and the detailed design of VDU and panel alarm schemes (covered in Sections 5.3.6 and 5.4.2 respectively).

5.2.4 Operator Aids for Incident Response

In recent years, a considerable amount of effort has been directed towards the development of expert systems and other forms of diagnostic systems to assist operator response to an incident. The main developments in this area are:

(i) Alarm processing systems that utilise logical rules to reduce the number of secondary alarms to a minimum or to prioritise the presentation of alarm information.

(ii) Real-time expert systems that utilise plant data, expert knowledge and knowledge about the process to diagnose the root cause of an incident. Some systems can also suggest and/or evaluate possible recovery routes.

(iii) Critical Function Monitoring Systems (CFMS) that monitor the availability of critical safety functions following an incident.

It is not clear to what extent such systems are in operational use, though there are examples of current implementations of some of these technologies in the UK energy production industry.

Expert systems in particular raise important human factors issues. These are in the areas of control (i.e. how does the operator control the diagnostic process) and evaluation (i.e. how does the operator evaluate the accuracy of a diagnosis). With regard to safety validation, the process of evaluation is particularly important, as the operator needs to be in a position where he can detect wrong diagnoses. This is currently being tackled in the computer science discipline by research into the trustworthiness of expert systems and, at the same time, a number of human factors research programmes are currently underway utilising plant simulators to study in some detail the effectiveness of such expert system applications.

5.3 VDU SYSTEM DESIGN

5.3.1 Access to Information across Multiple VDU Displays

As indicated in Section 5.2.2, an important issue related to the design of VDU display systems is the access provided to key process information, particularly to those parameters which are important for safety purposes. There are three primary factors which interact to determine the ease of access to such information:

(i) The number of display screens provided.

(ii) The relevance of the information content on each overview and detailed display page.
(iii) The ease of navigation through the display structure.

The choice of the number of display screens is primarily determined by the number of subprocesses an operator would need to monitor simultaneously. Consideration also needs to be given to the requirement for consulting alarm displays alongside process displays during an incident. An alternative approach has been proposed by Umbers et al (1985) in the form of a mathematical function which calculates the number of monitors required based on a number of key plant parameters.

The organisation of information across multiple displays depends upon being able to identify the key information required for each of the main tasks performed by an operator and then mapping this on to appropriate displays (as described in Section 2.2.5). The mapping of the information on to displays raises a number of important issues:

(i) What should the displays be based around (i.e. the process structure, process functions, the task or a combination of one or more of these types of display).

(ii) What form of representation is most appropriate for each variable (i.e. a numeric value, bargraph, trend)?

(iii) What form of overview or summary display should be created? Is there a need to create a safety parameter display?

The issue of what types of display should be provided are a matter of debate and the subject of research. A widely used form of display is the mimic format based upon the engineering flow diagram for a process. This is not necessarily the best format for ensuring effective anticipatory monitoring of a process and for use during the response to an incident. Whilst it is recognised that task-based displays are useful during operations such as start-up and shutdown, there are arguments against their over use (Bainbridge, in press). Functional flow diagrams that represent the mass and energy flows within a process have been suggested as a means of assisting during fault diagnosis. There is scope for further research in this area to establish the comparative benefits and drawbacks of these and other forms of information display formats.

The final issue associated with providing ease of access to information concerns the complexities involved when navigating around a structure of interlinked displays. A poorly organised structure can delay access to information or even render it unusable as the operator is unable or unwilling to search for it. The basic parameters of what makes a display structure easy or difficult to use have not yet been defined. Work has been carried out to generate a predictive model of the time required to access information within an hierarchical display system (Carey, 1984a). However, there appears to be little other research work carried out into this topic. This represents a gap in research coverage which needs to be addressed.

5.3.2 Design of Mimic Style Displays

There are a number of guidelines available which can be applied to the design of mimic display formats. These cover aspects such as ensuring a consistent direction of process flow across or down a mimic display, avoiding crossing flow lines and the positioning of measured values on a process diagram. Few of these guidelines have clear empirical support
at the present time, resulting in an uncertain basis upon which to make trade-offs between design approaches.

A series of experiments at BNFL are examining various in-house design recommendations for mimic design. These include the importance of avoiding crossing mimic lines and the need to ensure that flow lines leaving one mimic enter the adjacent mimic display at corresponding positions on the edge of the display (Hubbard, 1990). Research elsewhere is examining issues of display clutter and evaluating alternative mimic display formats (Mayfield, 1988). This is useful research, which will assist in identifying those mimic design recommendations which should be mandatory (i.e. non-compliance has been demonstrated to have potential negative effects on performance) and those which are advisory.

The current advancements in windowing and direct-manipulation user-interfaces utilising high resolution colour graphics displays is certain to have an impact upon the future design of displays in process control applications. Exploratory research is currently underway into advanced forms of mimic displays which consist of a single large mimic that can be 'panned' across to scan plant variables and zoomed into in order to view the details of plant indications (Elzer et al, 1989). This particular demonstration system also uses a small overlay window to present a plant overview display. The evaluations planned for this particular style of mimic display presentation and for other advanced designs in this area will be important in ensuring that such technological innovations actually bring benefits for the safety of process operation.

5.3.3 Design of Sequence Control Displays

Many batch operations and mechanical areas of plant are driven through automatic control sequences, initiated and monitored by a process operator. The design and evaluation of display facilities for the supervision and control of sequences is a neglected area. It is not certain whether this is because the operations involved tend to be relatively benign or that current display designs have proved to be adequate. The author is aware of one research project that examined the issues underlying the design of sequence displays (Visick, 1986). It is recommended that the need for additional research in this area is considered.

5.3.4 Design of Trend and Bargraph Displays

Trend and bargraph displays are direct VDU descendants of the pen recorder and faceplate displays of control equipment. These forms of presentation have particular value in representing analogue information about long-term variable trends and parameter deviations (Hanson et al 1981).

The detailed design of these display elements has been subjected to a limited amount of experimental evaluation. Koch et al (1982), for example, have compared the use of the abscissa and ordinate axes for the time scale of a trend graph. They have also examined whether the time base should move towards or away from the trend origin. White and van der Meijden (1987) examined the effect of the amplitude and number of points given on a trend graph on prediction accuracy. Wagner (1988) reports an experiment by Verhagen which compared alternative forms of bargraph designs for the detection of parameter deviations.
For both forms of data presentation, there are still a number of detailed design parameters which could be examined empirically. However, there exist a number of established principles of scale and graph design which need little empirical justification and which could be implemented now. For example, with multiple trend graphs on the same axis, a problem can occur when one trend line overlays and masks another. This could be resolved with appropriate design features but many of the trend packages offered by vendors provide only a partial solution to this problem. The emphasis in this area should be on the publication of existing design guidance rather than on further empirical work.

5.3.5 Design of List Displays

The use of lists of process values is now rapidly being replaced by interactive graphic mimic displays, apart from their continuing use in alarm list presentation. The general design issues for legibility and efficiency of use are well established and covered by standard texts on screen design (Galitz, 1981). The only area where there remains some uncertainty is in the presentation of scrolling information on alarm list displays. The problem arises from the competing requirements to present static text for ease of reading, but at the same time the need to allow new or higher priority alarms to be added to the top of the list as they occur. It is also not certain whether 'paging' or 'scrolling' provides the best mechanism for moving through such lists. This is discussed in detail by Rankin et al (1985).

5.3.6 Alarm Information on VDU Displays

Alarm information can be presented in a number of ways on VDU displays. As mentioned in Section 5.3.5, most display systems provide alphanumeric lists of alarms organised in order of priority or order of chronological occurrence. This can be a useful way of scanning or reviewing alarm history. Embedded alarms in mimic displays are generally considered to be the most effective way of presenting alarm information in context. The general requirement with such alarm displays is that the operator must access the relevant mimic display that shows the alarm in order to acknowledge it. This is essentially a serial form of alarm presentation. This has the advantage that it increases the probability that operators will correctly identify individual alarms, but has the danger that under multiple alarm conditions operator response will be slowed down and their appreciation of the wider pattern of alarm occurrence hindered.

One possible solution to the need to retain a plant wide overview of alarm conditions is to provide an alarm overview display. This may be a single overview VDU mimic display showing a summary of the alarms received across plant areas or a panel mimic or annunciator array. There is some debate that where a VDU alarm overview display is provided, whether this should occupy a separate, dedicated display unit or be accessed through the general purpose VDU display structure. A useful alternative is a dedicated multiple key alarm display keyboard, providing alarm indicators for high priority alarms through embedded and single key access to the relevant process display.

Only a limited number of observational studies have examined the performance of computer-based alarm presentation systems (eg. Koch and Richardson, 1984; Thompson et al, 1989) compared with a larger number that have examined panel annunciator systems (eg. Kortlandt and Kragt, 1980; Kragt and Bonten, 1983; Zwaga and Veldkamp, 1984). Anecdotal evidence from process companies suggests that problems do exist with computer
presentation of alarm indications. Many of these issues will be resolved once a clear philosophy of alarm system design is developed as discussed in Section 5.2.3.

5.3.7 Use of Colour on Displays

The use of colour on process displays has received a lot of attention. It is recognised that colour is a powerful coding medium for identifying and distinguishing between items on a display. However, it is easily misapplied resulting in displays which are hard to read and visually fatiguing.

Most empirical work has focused on the value of colour as a coding medium in comparison with other coding methods such as shape and alphanumerics. On most process displays, it is now standard practice to use colour primarily for coding the operating status of plant and for distinguishing between priorities of alarm messages. Colour can also be used to code flow lines and to provide backgrounds and shading that can enhance the overall visual performance of a display.

Colour is certainly an important issue, and colour selection and specification have received considerable research attention. Guidance is therefore available on a number of key aspects (Davidoff, 1987; Long, 1984; Smith, 1988; Sapita, 1987). These include the selection of a maximally contrasting set of colours, screening out of colour vision deficient operators, and unadvisable colour combinations and uses. There are also technical issues related to the gradual fading of colours on VDU displays over a long period of continual use. With appropriate guidance, it should be possible to ensure that the main pitfalls in the application of colour are avoided.

5.3.8 Use of Symbols, Text and Numerical Information on Displays

Most of the key information provided on process displays is presented either by dynamic symbols, strings of text or numeric value fields. It is therefore vital that attention is paid to the detailed design and implementation of these features.

Fortunately, these aspects of display design have been researched in depth and form the basis of relevant guidelines (e.g. Bailey, 1982). There is, however, a need for the existence of this guidance to be brought to the attention of designers within process companies.

5.3.9 Selection of Input Devices

A wide range of input devices and combinations of devices can be applied to the task of process operation. Until recently, most commercially available control systems made predominant use of keyboard devices of one type or another for VDU operation. However, current generations of such systems offer a variety of forms of pointing devices such as trackerballs and touchscreens. In many cases, these are offered as options and the process company is required to select the device which they believe best suits their operational purposes.

There are a range of considerations that have to be addressed when selecting the most appropriate device for an application:
(i) The way that the device will integrate into the workplace of the operator and can be integrated with the range of other activities he/she is responsible for.

(ii) The comparative performance of the device in terms of its accuracy and speed of operation.

(iii) The simplicity of the form of interaction which the input device makes possible.

(iv) The physical reliability of the device under control room conditions.

The correct selection and implementation of an input device can be important. Poorly chosen devices may increase error rate, slow down the response to an incident and reduce operator satisfaction, which in itself may result in a lower level of voluntary interaction with the system.

The comparative performance aspects of input devices have been studied widely and some general conclusions can be drawn (Carey 1985). The trade-offs between the keyboard and the various forms of pointing device are fairly well documented. Continuous technical developments, particularly in the area of touchscreen technology, will result in some changes in the balance currently established. The value of speech interaction as an input medium in process control has also been recently studied in depth resulting in some clear conclusions on the potential scope of applications of such technology (Baber 1991). Whilst there is a need for widely available guidance, this area does not merit further empirical study.

5.3.10 Interaction Dialogue Issues

The forms of human-computer interaction in process control tend to be fairly simple and limited in number. These generally involve simple selection of objects on a screen, the entry or ramping of numerical values and the issuing of simple commands (e.g. open valve, start pump). The existing guidelines on the design of such dialogues are sufficient to cover most of the types of interaction encountered (e.g. Smith and Mosier, 1986).

The likely move towards the use of more sophisticated windowing and direct manipulation techniques will require careful handling. Fortunately, a number of industry standards are emerging for the 'look-and-feel' of such interfaces (e.g. Windows, Open Look, OSF-Motif) which should go some way to ensuring that good practice is adhered to. However, it is still possible to produce interfaces which are complex and confusing to use. Some guidance would be of benefit to ensure that interfaces are constructed which are effective for control room applications.

5.3.11 System Response Time

The speed of response of a control system to an operator input or request can be an important component when determining the operator's speed of response to an incident and overall level of satisfaction with the system. The most crucial response times tend to be the speed at which the display system can generate a display when it is requested. Consideration also needs to be given to confirmatory feedback on a control request (i.e. the feedback that the control request has been received rather than the feedback that the control request has been complied with).
Control system manufacturers are generally aware of the need to achieve and maintain short system response times (Carey, 1984b). However, the technology required to achieve this is not cheap and clear guidance on the acceptable level for response times is required.

The number of empirical studies on system response time specific to process control tasks are limited (eg. Stanton et al, 1987). An earlier literature review (Carey et al, 1986) concluded that the empirical data at the time was insufficient to provide reliable statements on maximum response time requirements. Target figures can be extracted from various sets of guidelines and applied with discretion. There is generally sufficient guidance available to be able to state both a preferred and an absolute maximum system response time for most operations.

5.4 PANEL DISPLAY DESIGN

5.4.1 Design Issues for Panel Mimic Displays

Wall panel mimic displays can have a useful role in a control room providing overview information alongside VDU displays that give detailed information about a process. The main important requirements relate to the size and positioning of the mimic such that its key indicators fall within the primary field of view of the operators. There exists clear guidance on these aspects and upon the size of any textual legends. Similarly, if the mimic has embedded push buttons or other controls, there is guidance available on the height, separation and physical characteristics of such controls.

5.4.2 Panel Annunciator Displays

As with other panel information displays, panel annunciator displays have the advantages of parallel and continuous information display over VDU alarm information displays. These attributes are particularly important when considering the key safety role of alarm indications. There is a strong case for utilising a panel annunciator array as an alarm overview display for the highest priority alarm indications. These may be repeated indications taken from the computer control system or hardwired digital alarms for prompting safe shutdown or recovery during possible computer failure.

The design requirements for panel annunciator displays are well documented (eg. Fink, 1984; Kinkade and Anderson, 1984; Benel et al, 1981). These form a ready basis for clear guidance on the assessment and design of such displays and further research work is not necessary.

5.5 CONCLUSIONS

In general, current theoretical knowledge is most clearly defined for the physical and perceptual aspects of control room and operator interface design. Therefore, it is possible to be very precise about the required physical dimensions of a workstation, the maximum forces that should be required to operate a control or the sizes and styles of character fonts on VDU displays. As indicated in Section 3.0, it is these attributes of interface design which can be specified to a fine degree of detail within human factors standards. Aspects which involve the higher levels of operator cognition, such as the design of displays to assist in status monitoring and operator aids for fault diagnosis, are far more difficult to research and to provide reliable prescriptive advice.
Table 5.1 provides a summary of the research areas reviewed and the current status of research coverage. Areas where current knowledge is sufficient to provide largely adequate guidance are classified as being adequate. The remaining areas are classified into two categories:

(i) **Deficient**: Current research knowledge in these areas is deficient and needs to be improved. However, existing information is sufficient to provide the basis for outline guidance in the short-term.

(ii) **Priority**: The information available in these areas is poor, such that it is insufficient to provide adequate support either for the design or evaluation of particular aspects of VDU display systems. Research effort should be focused on these areas initially.

The need for robust consensus models of operator cognition in monitoring and fault diagnosis tasks is of key strategic importance. Such tasks are central to the operator's safety assurance role in highly automated process plants. The current state of knowledge is insufficient to provide the basis for guidance on the most appropriate forms of interface design or for the development of robust analysis techniques. It follows that research into VDU formats to support monitoring and diagnosis tasks is also identified as a priority area for research.

Navigation within VDU display structures is identified as a priority area for research because of the concern that an inability to locate key process information may inhibit an operator in detecting or responding to a process malfunction. This is coupled with the structuring of information across a display system, since well defined overview displays should minimise the need for navigation whilst allowing monitoring of process status. As indicated in Table 5.1, current knowledge on methods for developing appropriate structures is deficient, but research work is proceeding in this area.

Finally, there is very little clear research guidance on the most appropriate ways of displaying and handling alarms on VDU displays (beyond their physical appearance). This can have direct safety consequences in delaying responses to incidents and in some faults remaining undetected. A priority is to develop clear guidance on the philosophy of alarm system design for VDU interfaces. Current research work may go a long way to providing the theoretical underpinning that is required, but there is still likely to be the need for further detailed research in order to provide clear principles and to develop specific guidance for VDU alarm presentation.
<table>
<thead>
<tr>
<th>RESEARCH AREA</th>
<th>RESEARCH COVERAGE</th>
<th>ADEQUATE</th>
<th>DEFICIENT</th>
<th>PRIORITY</th>
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<tr>
<td>Operator cognition in supervisory and fault diagnosis tasks</td>
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<td>Panel/VDU tradeoff</td>
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<td>Alarm handling philosophy</td>
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<td>Design rules for mimic style displays</td>
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<td>Design rules for sequence control displays</td>
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<td>Design of list displays</td>
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**TABLE 5.1 SUMMARY OF ADEQUACY OF RESEARCH COVERAGE**
6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

For ease of reference, a summary of the conclusions from each of the main parts of this study are repeated here.

6.1.1 Section 2 : Design and Evaluation Techniques

This section reviewed a wide range of human factor techniques and approaches that can be applied to the design and evaluation of operator interfaces and control room facilities in process plants.

Techniques and approaches reviewed included:

- Defining target users
- Allocation of functions
- Task description
- Task assessment (Timeline, link, workload, human error, and task complexity analyses)
- Information requirements analysis
- Utilising operational knowledge
- Prototyping interface designs
- User requirements specification
- Guidelines and standards
- Design evaluation (Checklists, scenario analysis, operator evaluation, and theoretical evaluation)
- Design and evaluation of the workplace
- Operational assessment
- User Documentation and training.

Only those projects with very high safety requirements would need to use all of the techniques mentioned. For other projects, the usual "reasonably practicable" considerations would limit the extent of their application. There can also be a tradeoff between employing analytic methods in the early stages of a design and the use of an iterative evaluation approach once displays are developed.

The review showed that there is a lack of analysis and evaluation techniques for highly cognitive tasks such as monitoring plant status and fault diagnosis. This type of task is becoming increasingly important as the routine aspects of tasks are automated.

6.1.2 Section 3 : Human Factor Standards, Guidelines and Handbooks.

The following areas were reviewed: Control room and Workstation Design, VDU Interface Design, Information Coding and Presentation, and System Documentation.
Control Room and Workstation Design

This area is concerned with the dimensions of operator consoles, visual performance criteria for VDU displays and comfort requirements for the working environment.

There is sufficient information in standards, guidelines and handbooks on this topic, although it is not summarised in a single, comprehensive document.

IEC 964 "Design for Control Rooms to Nuclear Power Plants"; and ISO 11064 Pt. 3 "Arrangements and dimensions of control stations" are the most relevant standards although ISO 11064 is still at an early stage of development. The handbook by Invegård (Invegård, 1989) provides the best coverage of the issues involved, whilst Gilmore et al (1989) provides some useful diagrams to illustrate the guidance. Information is at present fragmented over a number of guidelines and handbooks. (N.b. seven are identified in main body of Report).

VDU Interface Design.

This area is concerned with the design of the interface from the "usability" viewpoint. This includes the design of the interface so as to minimise the chance that operators will make mistakes when, for example, interpreting process status from a display or when entering a command on a keyboard. This is clearly related to safety.

The review found that there were no standards in place specifically targeted at process control applications. The most relevant standard was found to be ISO 9241 "Ergonomic Requirements for Office Work with Visual Display Terminals". However as its title indicates this is concerned with the office environment and it requires interpretation for process control applications. Part 4 of ISO 11064 "Visual displays for process control" is planned to cover this topic but is at an early stage of development.

Useful overview information can be found in the Human Factors in Reliability Group Guide (HFRG, 1987) and in the Computer Display Designer's Handbook (Wagner, 1988). The most useful single source of information is provided by Gilmore et al (1989), though there are weaknesses in the coverage of this handbook.

Information Coding and Presentation.

This area is concerned with symbols, colour codes and other display attributes. Twelve standards were identified but only one standard ISA-85.5-1985 "Graphic Symbols for Process Displays" was found to be directly relevant to VDU-based displays. Gilmore et al (1989) has an extensive section on information coding.

System Documentation.

Two standards were identified that gave requirements on technical and user documentation. These were: BS 4884 "Specification for Technical Manuals" and a draft standard being developed by BSI committee IST/18" Recommendations for the Design of User Documentation for Software Products for Text and Office Systems".
Section 3 - Overall Conclusions

The overall conclusions are:

(i) There is sufficient information in both standards and Handbooks to deal with the physical and perceptual aspects of the operator interface and the control room, information coding and presentation, and documentation. However this information is not always readily accessible and HSE could "add value" by drawing together and publicising relevant material.

(ii) Information about VDU interface design for process control is at present inadequate. No standards exist and current Handbooks and guidelines are of limited assistance. More detailed and relevant information is available in the human factors literature, but certain issues (e.g. navigation between displays) needs further research before robust guidelines or standards can be created.

6.1.3 Section 4: A Survey of Current Design Practice.

A survey of seven companies was carried out to see to what extent they used human factors techniques and guidance.

The overall conclusion was that, with the exception of a company from the Nuclear industry, the adoption of human factors techniques and guidance was limited. With regard to human factors guidance, it was felt that this was mainly due to lack of awareness. Wider usage may be made of systematic human factors approaches if appropriate descriptive guidance was made available.

The companies mainly used past experience and the facilities offered on packaged control systems to "design" the interface.

On the whole the companies wished to improve existing practices and were interested in any Guidance that HSE could produce on this topic.

It is suggested that this guidance should cover the following:

(i) The safety role of operators in automated plant. This should include the identification of safety-critical tasks and criteria for evaluating "allocation of function".

(ii) Specification and evaluation of human factors requirements during the selection of a control system, particularly for packaged control systems.

(iii) Determining the number of VDU displays required

(iv) Drawing together and, where necessary, re-publication of existing standards and guidance on control room layout, physical dimensions, lighting and other environmental aspects so as to make this material more readily accessible.

(v) Information on the benefits of involving operations personnel; and of obtaining feedback from previous designs. This should include effective strategies for involving operations personnel during the design process.
6.1.4 Section 5: The Scope and Direction of Current Research.

This section examined the current state of research knowledge and research activity related to the operator interface. The areas examined were: Modelling of Operator Cognition; The Trade-offs between Panel and VDU displays; Alarm Handling; Operator Aids for incident response; VDU System and Panel Display design.

The primary purpose of the review was to identify those areas where further research would be beneficial. In addition, those areas where better guidance material rather than research would be the way forward were indicated.

Areas identified as requiring priority research action included:

(i) Operator cognition in supervisory and fault diagnosis tasks.
(ii) Alarm handling philosophy, particularly under alarm flooding conditions.
(iii) VDU display formats for monitoring and diagnosis.
(iv) Navigation within VDU display structures.

Areas identified as having deficient research coverage included:

(i) Effectiveness of operator aids for incident response.
(ii) Appropriate structuring of information across a set of VDU display pages.
(iii) Design rules for mimic, sequence control and alarm displays.

Areas identified as requiring the development of guidance rather than the development of new "theory" included:

(i) Trend and Bargraph displays.
(ii) Symbols, text and Numerical information.
(iii) Input devices.
(iv) Interaction dialogue issues.

6.2 RECOMMENDATIONS

The following actions are recommended to improve the application of human factors principles to the operator interface in process control rooms. These recommendations do not necessarily represent HSE views, but are intended to stimulate interest and to obtain responses on the suggested recommendations.

6.2.1 International Standards

No standard currently exists that covers the operator interface for computer-based process control.

ISO 11064 - "Ergonomic design of control centres" seems to be the most directly relevant standard. In particular part 4 of the standard will cover Visual Displays for Process Control. This standard is at an early stage and it is not clear whether it will adequately deal with safety issues.
(i) The scope of this standard should be further investigated to see whether it will fit in with other standards work on the safety of programmable electronic systems and software.

(ii) If the standard is appropriate then the actions that might be taken to influence its timely production and to establish liaison arrangements with those producing safety standards for programmable electronic systems should be considered.

(iii) Liaison arrangements with other standards committees working in this area should be reviewed eg. ISO 9241, CEN/TC 122/WG6.

6.2.2 General Guidance

A number of human factor techniques and principles are not well documented nor accessible. A number of existing standards/guidelines are not that well known.

(i) The actions that might be taken to publicise their existence and benefits should be considered.

(ii) One way to pull together this disparate advice and information would be to provide general guidance in the form of a safety assurance framework based on objectives and goals to be achieved. Appendix 3 gives further details which might form the basis of guidance.

(iii) There is a need to clearly articulate the relationship between "good" human factors practices in the design of the operator interface and safety.

Topics that should be included in this general guidance include: control room layout, physical dimensions, lighting, environmental aspects, role of operations personnel in design, and the use of feedback from previous designs.

6.2.3 Specific Guidance

Guidance is weak in the following areas and it would be beneficial if specific guidance could be developed on:

(i) Allocation of functions
(ii) Human Factors Requirement Specification
(iii) Approaches to display design including colour methods and symbol coding
(iv) Safety-related monitoring and response
(v) Trend and bargraph displays
(vi) Symbols, text and numerical information
(vii) Input devices
(viii) Interaction dialog issues.

6.2.4 Guidance from Trade Associations and/or Suppliers

Many human factor aspects of the operator interface are determined by the facilities offered on packaged control systems.

(i) It would be beneficial if Trade Associations and/or suppliers produced appropriate advice.
6.2.5 Technology Transfer and Training

The survey of design approaches used in industry indicated that the level of expertise on human factors issues is variable, being strongest in the Nuclear industry.

(i) The steps that would be appropriate to improve skills in human factor techniques should be considered.

(ii) Steps that might be considered include technology transfer activities, eg demonstrator projects, and consideration of education and training requirements.

6.2.6 Research

The research of key strategic importance is to improve the understanding of operator cognition in monitoring and fault diagnosis tasks. Such tasks are central to the operator's safety assurance role in highly automated process plants.

Other priority research areas include:

(i) Alarm handling philosophy
(ii) VDU display formats
(iii) Navigation within VDU display structures.

Contact for Correspondence:

J Brazendale
Control Systems Group
Health and Safety Executive
Magdalen House
Stanley Precinct
Bootle
Merseyside
L20 3QZ
7.0 REFERENCES


<table>
<thead>
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<th>Author(s)</th>
<th>Year</th>
<th>Title</th>
<th>Location/Publisher</th>
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<tr>
<td>Carey M.S.</td>
<td>1984b</td>
<td>The operator interface in process control systems; Report on visits to U S process instrumentation manufacturers, December 16th - 22nd 1983.</td>
<td>(Report funded under extra-mural research contract RD150/017). (Stevenage, Herts: Warren Spring Laboratory, DTI).</td>
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<tr>
<td>Davidoff, J.</td>
<td>1987</td>
<td>The role of colour in visual displays.</td>
<td>International Reviews of Ergonomics, 1, 21-42.</td>
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Panero J. & Zelnick M. (1979) 


Rasmussen J. (1980) 

Rengger, R.E. (1990) 


Shepherd, A. (In Press) 


Cognitive aspects of alarm handling. Journal of Health and Safety, 6, 47-56.


76
8.0 ACKNOWLEDGEMENTS

The assistance of the following individuals in compiling this paper is gratefully acknowledged:

Dr. L. Ainsworth, Synergy Ltd
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Dr. L. Bainbridge, Dept. of Psychology, University College of London
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Mr. J. Brazendale, Control Systems Group, Technology and Health Sciences Division, HSE
Mr. P. J. Crabbe, British Standards Institute
Mr. B. J. Kirwan, School of Engineering Production, University of Birmingham
Ms. J. Reed, British Nuclear Fuels PLC
Mr. D. Ridley, Hatfield Polytechnic
Dr. R. B. Stammers, O.S. & A.P. Division, Aston University
Mr. N. Stanton, O.S. & A.P. Division, Aston University
Dr L. Tetzlaff, IBM, USA
Mr. T. Waters, British Nuclear Fuels PLC
Mr. R. White, Sension Ltd
Mr. D. J. C. Whitfield, Nuclear Installations Inspectorate, HSE
Mr. D. Wilson, Control Systems Group, Technology and Health Sciences Division, HSE
Dr. J Wood, CCD Ltd

The assistance of those individuals and their companies who contributed to the survey in Section 4.0 is also gratefully acknowledged. In order to maintain confidentiality, those companies are not listed.
APPENDIX 1: SUMMARY TABLES OF STANDARDS AND GUIDELINES

The following tables give outline details of human factors standards, guidelines and handbooks with application to the design of the operator interface to computer-based systems in the process control room. The tables included are as follows:

A1.1 British Standards
A1.2 International Standards
A1.3 European Standards Work
A1.4 Standards in other European Countries
A1.5 US Standards
A1.6 Military Standards
A1.7 Guidelines and Handbooks
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
</table>
| BSI, UK| Ergonomics of Design and Use of Visual Display Terminals (VDT's) in Offices.  
Part 1: Introduction  
Part 2: Recommendations for the Design of Office VDT Tasks  
Part 3: Specification for Visual Displays  
Part 4: Specification for Keyboards  
Part 5: Specification for VDT Work Environments  
Part 6: Code of Practice for the Design of VDT Work Environments | BS 7179: Parts 1-6 | 1990                | Parts 1, 2, & 3 superceded by Parts 1, 2, & 3 of European version of ISO 9241  
Issued Standard  
Issued Standard | Standard specifically addresses office environment and office tasks.  
Limited applicability to process control environments. |
| BSI, UK| Specification for Colours for Identification Coding and Special Purposes | BS 381C            | 1988                | Issued Standard | Specifies 84 standard colours. May be useful in specifying reference colours for screen displays. However, CIELAB system of colour specification may be preferable. |
| BSI, UK| Glossary of Terms used in Automatic Controlling and Regulating Systems:  
| BSI, UK| Specification for Graphical Symbols for General Engineering:  
Part 1: Piping Systems and Plant  
Part 2: Graphical Symbols for Power Generating Plant  
Part 3: Graphical Symbols for Compressing Plant | BS 553: Parts 1-3  | 1977                | Issued Standard (all parts) | Provides standard graphical symbols for piping, power generating and compressor plant |

**TABLE A1.1 BRITISH STANDARDS**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
</table>
| BSI, UK| Symbolic Representation for Process Measurement Control Functions and Instrumentation  
**Part 1:** Basic Requirements  
**Part 2:** Specification for Additional Basic Requirements  
**Part 3:** Specification for Detailed Symbols for Instrument Interconnection Diagrams  
**Part 4:** Specification for Basic Symbols for Process Computer, Interface and Shared Display/Control Functions | BS 1646: Parts 1-4 | 1979  
1983 | Issued Standard  
Issued Standard | Primary British Standard for symbols to be used on process displays (Related to ISO 3511) |
| BSI, UK| Anatomical, Physiological and Anthropometric Principles in the Design of Office Chairs and Tables | BS 3044 | 1990 | Issued Standard | Possible source reference for console seating design principles. Recently updated to cover VDU workplates. |
| BSI, UK| Colours of Indicator Lights, Push-buttons, Annunciators and Digital Readouts  
**Part 1:** Specification for Colours of Indicator Lights and Push-buttons  
**Part 2:** Specification for Flashing Lights, Annunciators and Digital Readouts | BS 4099: Parts 1 and 2 | 1986  
1986 | Issued Standard  
Issued Standard | Adoption of IEC 73 |
| BSI, UK| Office Furniture:  
**Part 1:** Specification for Design and Dimensions of Office Workstations, Desks, Tables and Chairs | BS 5940: Part 1 | 1980 | Issued Standard | Specifies limits and basic ergonomic and functional requirements for chairs, tables and worktops |

**TABLE A1.1 BRITISH STANDARDS (Cont'd)**
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<th>ORIGIN</th>
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<th>YEAR OF PUBLICATION</th>
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<tr>
<td>BSI, UK</td>
<td>Recommendations for the Design of User Documentation for Software Products for Text and Office Systems</td>
<td>BSI Technical Committee IST/18 (Doc Ref 90/66493)</td>
<td>-</td>
<td>Draft issued for comment</td>
<td>This draft standard describes the process that should be followed in creating user documentation for software products. The same general development process and considerations could be applied to system manuals or user guides for the control room context.</td>
</tr>
<tr>
<td>BSI, UK</td>
<td>Specification for identification of pipelines and services</td>
<td>BS 1710</td>
<td>1984</td>
<td>Issued Standard</td>
<td>Specifies colours for identifying pipes conveying fluids in liquid or gaseous condition in land installations and on board ships. Whilst intended for paint marking of physical pipework, the same colour codes would be translated to VDU displays.</td>
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**TABLE A1.1 BRITISH STANDARDS (Cont'd)**
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<tr>
<td>ISO,</td>
<td>Process Management Control Functions and Instrumentation - Symbolic</td>
<td>ISO 3511</td>
<td>-</td>
<td>-</td>
<td>ISO standard on process symbology. This is relevant to the selection of</td>
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<tr>
<td>International</td>
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<td></td>
<td></td>
<td></td>
<td>symbols for use on mimic displays. The later parts provide details on</td>
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<td></td>
<td>Part 1: Basic Requirements</td>
<td></td>
<td></td>
<td></td>
<td>the representation of complex computer control functions.</td>
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<td></td>
<td>Part 2: Extension of Basic Requirements</td>
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<td></td>
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<td>Part 3: Detailed Symbols for Instrument Interconnection Diagrams</td>
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<tr>
<td>ISO,</td>
<td>Geometric Orientation and Directions of Movements</td>
<td>ISO 1503-1977</td>
<td>1977</td>
<td>Issued Standard</td>
<td>This establishes standards for the direction of movement of controls, and</td>
</tr>
<tr>
<td>International</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>the representation of directions of motion on signs/displays. Useful</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>guidance when representing moving machinery/equipment on remote or adjacent</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>VDU workstations.</td>
</tr>
<tr>
<td>IEC</td>
<td>Software for computers in the application of industrial safety related</td>
<td>IEC 65A (Secretariat) WG9</td>
<td>-</td>
<td>Working Draft</td>
<td>Draft Standard under development dealing with safety related software.</td>
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<tr>
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<td>systems</td>
<td></td>
<td></td>
<td></td>
<td>Complimentary to that below.</td>
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<td>Systems: Generic Aspects</td>
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<td>Part 1: General Requirements</td>
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**TABLE A1.2 INTERNATIONAL STANDARDS**
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<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
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<tr>
<td>IEC, International</td>
<td>Design for Control Rooms to Nuclear Power Plants</td>
<td>CEI/IEC 964:1989</td>
<td>1989</td>
<td>Issued Standard</td>
<td>Standard for the design of control rooms for nuclear power plants. It covers the methods of design and specifies various aspects of the interface. It contains little specific guidance on VDU based systems. (Written in French and English)</td>
</tr>
<tr>
<td>IEC, International</td>
<td>Functional Design Criteria for a Safety Parameter Display System for Nuclear Power Stations</td>
<td>CEI/IEC 960:1988</td>
<td>1988</td>
<td>Issued Standard</td>
<td>Outlines functional criteria for safety parameter display systems. This includes required location, staff training, instrumentation design standards and require reliability. Gives little information on the actual display design requirements. (Written in French and English)</td>
</tr>
<tr>
<td>ISO, International</td>
<td>Ergonomic Principles in the Design of Work Systems</td>
<td>ISO 6385</td>
<td>1981</td>
<td>Issued Standard</td>
<td>General outline of ergonomics principles in systems design. For example, it identifies the need for task analysis and consideration of the anthropometric dimensions of users. Forms basis for a number of national standards, particularly in the Scandinavian countries.</td>
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TABLE A1.2  INTERNATIONAL STANDARDS (Cont'd)
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<th>YEAR OF PUBLICATION</th>
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<td>International</td>
<td>(VDT's) Part 1: General Introduction</td>
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<td></td>
<td>Part 2: Guidance on Task Requirements</td>
<td></td>
<td>1990</td>
<td>Issued Standard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 3: Visual Display Requirements</td>
<td></td>
<td>1990</td>
<td>Issued Standard</td>
<td>Parts 3 &amp; 4 relate to the hardware and environmental aspects of VDU work.</td>
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<td>Part 4: Keyboard Requirements</td>
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<td>Draft Standard</td>
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<tr>
<td></td>
<td>Part 5: Workstation Layout and Postural Requirements</td>
<td></td>
<td></td>
<td>Draft Standard</td>
<td>Parts 5 to 19 address the usability of the software. A key aspect of the approach to usability will be a requirement for a 'usability statement'. This is being developed in part 11 of the standard.</td>
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<tr>
<td></td>
<td>Part 6: Environmental Requirements</td>
<td></td>
<td></td>
<td>Committee Draft</td>
<td>The orientation towards office tasks will limit the applicability of this standard to the process control context</td>
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<td></td>
<td>Part 7: Display Requirements with Reflections</td>
<td></td>
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<td></td>
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<td>Part 9: Requirements for Non-keyboard Input Devices</td>
<td></td>
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<td>Working Draft</td>
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<td>Part 10: Dialogue Principles</td>
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<td>Part 11: Guidelines on Specifying and Measuring Usability</td>
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**TABLE A1.2  INTERNATIONAL STANDARDS (Cont'd)**
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<th>YEAR OF PUBLICATION</th>
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<tr>
<td>ISO, International</td>
<td>Ergonomic Requirements for Office Work with Visual Display Terminals (VDT's)</td>
<td>ISO 9241</td>
<td>-</td>
<td>Working Draft</td>
<td>Current standards work aiming to produce an international standard on control room design. Work is proceeding on part 3, which is based on DIN 66234.</td>
</tr>
<tr>
<td></td>
<td>Part 12: Presentation of Information</td>
<td></td>
<td></td>
<td>Working Draft</td>
<td>Publication of all parts apart from part 3 is imminent.</td>
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<td></td>
<td>Working Draft</td>
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<td>Part 15: Command Dialogues</td>
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<td>Part 19: Natural Language Dialogues</td>
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<td>ISO, International</td>
<td>Ergonomic Design of Control Centre;</td>
<td>ISO 11064</td>
<td>-</td>
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<tr>
<td></td>
<td>Part 4: Visual displays for process control</td>
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<td>Under Development</td>
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<td>Part 5: Principles for the evaluation of control stations</td>
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<td>Under Development</td>
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**TABLE A1.2 INTERNATIONAL STANDARDS (Cont'd)**
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<th>YEAR OF PUBLICATION</th>
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<tr>
<td>ISO, International</td>
<td>User system interfaces and symbol joint working group</td>
<td>ISO/IEC 9995</td>
<td>-</td>
<td>-</td>
<td>Standard to ISO/IEC 9995 applies primarily to keyboard and symbol design</td>
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<td>Part 1: General principles covering keyboard layouts</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>Part 2: Alphanumeric section</td>
<td>-</td>
<td>-</td>
<td>Draft</td>
<td></td>
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<td>Part 3: Common primary and secondary layout of the alphanumeric zone</td>
<td>-</td>
<td>-</td>
<td>Draft</td>
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<td>-</td>
<td>-</td>
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<td>Part 5: Editing section</td>
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<td>Part 6: Function section</td>
<td>-</td>
<td>-</td>
<td>Draft</td>
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<tr>
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<td>Part 7: Symbols used to represent functions</td>
<td>-</td>
<td>-</td>
<td>Started</td>
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<td>Part 8: Allocation of letters to the keys of a numeric keyboard</td>
<td>-</td>
<td>-</td>
<td>Draft</td>
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<td></td>
<td>Icons standard</td>
<td>WI 18.21.02</td>
<td>-</td>
<td>Under Development</td>
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<tr>
<td></td>
<td>User guidance standard</td>
<td>WI 18.30.01</td>
<td>-</td>
<td>Under Development</td>
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<td></td>
<td>Dialogue interaction</td>
<td>WI 18.30.01</td>
<td>-</td>
<td>Under Development</td>
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<td>Names for objects/actions</td>
<td>WI 18.30.03</td>
<td>-</td>
<td>Under Development</td>
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**TABLE A1.2 INTERNATIONAL STANDARDS (Cont'd)**
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<tr>
<td>CEN</td>
<td>Ergonomic Principles and Data for the Design of Displays and Control Actuators</td>
<td>CEN/TC 122/WG6</td>
<td>-</td>
<td>Working Draft</td>
<td>This standard applies to discrete control and display devices (e.g. dials, numeric displays, knobs, levers). Part 1 outlines general principles whilst Parts 2 and 3 will give detailed ergonomics standards.</td>
</tr>
<tr>
<td></td>
<td><strong>Part 1</strong>: Human Interactions with Displays and Control Actuators</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td><strong>Part 2</strong>: Displays</td>
<td></td>
<td></td>
<td>Draft</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Part 3</strong>: Controls</td>
<td></td>
<td></td>
<td>Under Development</td>
<td></td>
</tr>
<tr>
<td>CEN</td>
<td>Ergonomic Principles in the Design of Work Equipment</td>
<td>EN 614</td>
<td>-</td>
<td>Draft</td>
<td>Part 1 defines general principles of ergonomics and an approach to incorporating ergonomics principles into the design process. Not specific to VDU systems.</td>
</tr>
<tr>
<td></td>
<td><strong>Part 1</strong>: Terminology and General Principles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEN</td>
<td>Safety of Machinery - Indicating, Marking and Actuating Principles</td>
<td>EN 50099</td>
<td>-</td>
<td>Draft</td>
<td>This standard defines general principles for visible, audible and tactile safety signals for machinery. Principles are not directly applicable to VDU systems, though there will be a need to ensure that VDU display signals are compatible with the requirements of this standard.</td>
</tr>
<tr>
<td></td>
<td><strong>Part 1</strong>: Visual, Audible and Tactile Signals</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td><strong>Part 1</strong>: Specification for General Requirements</td>
<td></td>
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</tr>
</tbody>
</table>

**TABLE A1.3 EUROPEAN STANDARDS WORK**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEN/CENELEC</td>
<td>Ergonomics and Human Factors in Advanced Manufacturing (AMT) Task Force</td>
<td>CEN/CLC/AMT/ERG-WG</td>
<td>-</td>
<td>Work ongoing</td>
<td>This task force has been set up to review existing human factors standards and determine their applicability to Advanced Manufacturing Technology. An initial draft report of the review has been produced.</td>
</tr>
<tr>
<td>CEN</td>
<td>Ergonomics requirements for office work with visual display terminals</td>
<td>EN 29241</td>
<td>-</td>
<td>Work ongoing</td>
<td>CEN working group shadowing development of ISO 9241.</td>
</tr>
</tbody>
</table>

**TABLE A1.3  EUROPEAN STANDARDS WORK (Cont'd)**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON, Austria</td>
<td>Ergonomics Design of Control Rooms</td>
<td>ONORM A800</td>
<td>1977</td>
<td>Issued Standard</td>
<td>General guidelines on the vertical dimensions and location of control room consoles. Covers console physical dimensions and visibility of related displays. (In German)</td>
</tr>
<tr>
<td></td>
<td>Concepts; Dimensions and Constructions.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Characteristics of Work Places for Seated Positions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIN, Germany</td>
<td>Ergonomics Design of Control Rooms</td>
<td>DIN 33414</td>
<td>1985</td>
<td>Issued Standard</td>
<td>Part 1 details required design principles and dimensions for seated workstations. Also provides detailed information on the operator's horizontal and vertical fields of view for the appropriate positioning of controls and displays. Part 4 describes process involved in laying out panels, controls and designs within a control room. (In German only at present)</td>
</tr>
<tr>
<td></td>
<td>Part 1: Seated Work Stations, Terms and Definitions, Principles, Dimensions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 4: Ergonomic Design of Control Rooms:</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Arrangement and Layout Principles</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ORIGIN</td>
<td>TITLE</td>
<td>REFERENCE</td>
<td>YEAR OF PUBLICATION</td>
<td>STATUS</td>
<td>COMMENTS</td>
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<tr>
<td>DIN, Germany</td>
<td>VDU Workplaces; Part 1: Terminology</td>
<td>DIN 66233</td>
<td></td>
<td></td>
<td>(In German only at present)</td>
</tr>
<tr>
<td>DIN, Germany</td>
<td>VDU Workplaces; Part 1: Geometrical Design of Text Symbols</td>
<td>DIN 66234</td>
<td>1980</td>
<td>Issued Standard</td>
<td>German standard on the ergonomics of VDU workplaces. This will be largely superseded by ISO 9241. (All parts in German. Those marked with 'E' are also available in English).</td>
</tr>
<tr>
<td></td>
<td>Part 2: Perceptibility of Symbols on VDU Workstations</td>
<td></td>
<td>1983</td>
<td>Issued Standard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 3: Grouping and Formatting of Data</td>
<td></td>
<td>1983</td>
<td>Issued Standard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 5: Coding of Data</td>
<td></td>
<td>1988</td>
<td>Issued Standard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 6: Design of the Workstation</td>
<td></td>
<td>1984</td>
<td>Issued Standard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 7: Ergonomic Layout of the Room Illumination and Arrangements</td>
<td></td>
<td>1988</td>
<td>Issued Standard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 10: Minimum Information for VDU Specification</td>
<td></td>
<td></td>
<td>Draft</td>
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</tr>
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</table>

**TABLE A1.4  STANDARDS IN OTHER EUROPEAN COUNTRIES (Cont'd)**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI, USA</td>
<td>Human Engineering for Control Centres</td>
<td>ISA-RP60.3-1985</td>
<td>1985</td>
<td>Issued Standard (Adopted by ANSI)</td>
<td>Provides information on human dimensions and a limited set of standards for control room and interface design practice. Limited amount applies directly to VDU systems.</td>
</tr>
</tbody>
</table>

**TABLE A1.5 US STANDARDS**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOD, UK</td>
<td>Human Factors for Designers of Equipment</td>
<td>Def.Stan. 00.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 1: Introduction</td>
<td></td>
<td>1983</td>
<td>Issued</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 2: Body Size</td>
<td></td>
<td>1985</td>
<td>Issued</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 3: Body Strength and Stamina</td>
<td></td>
<td>1984</td>
<td>Issued</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 4: Workplace Design</td>
<td></td>
<td></td>
<td></td>
<td>UK military standard on human factors. Part 7 provides a limited set of guidelines on VDU display formats. Of limited application to process control.</td>
</tr>
<tr>
<td></td>
<td>Part 5: Stresses and Hazards</td>
<td></td>
<td></td>
<td>Under Development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 6: Vision and Lighting</td>
<td></td>
<td>1986</td>
<td>Issued</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 7: Visual Displays</td>
<td></td>
<td>1986</td>
<td>Issued</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 8: Auditory Communication</td>
<td></td>
<td>1989</td>
<td>Interim</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 9: Voice Communication</td>
<td></td>
<td></td>
<td>Under Development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 10: Controls</td>
<td></td>
<td></td>
<td>Under Development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 11: Design for Maintainability</td>
<td></td>
<td>1988</td>
<td>Interim</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 12: Systems</td>
<td></td>
<td>1989</td>
<td>Issued</td>
<td></td>
</tr>
<tr>
<td>DOD, USA</td>
<td>Human Engineering Design Criteria for Military Systems, Equipment and Facilities</td>
<td>MIL-STD-1472C</td>
<td>1981</td>
<td>Issued Standard</td>
<td>Extensive and detailed standard addressing human factors design requirements for a wide range of display and control technologies. Addresses general requirements of VDU systems of which a large proportion would have valid application to process control systems.</td>
</tr>
</tbody>
</table>

**TABLE A1.6   MILITARY STANDARDS**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRC, USA</td>
<td>Guidelines for Control Room Design Reviews</td>
<td>NUREG-0700</td>
<td>1981</td>
<td>Issued Standard</td>
<td>Comprehensive set of guidelines in the form of a review process supported by associated checklists. Covers physical layout of control room, operator/computer dialogue, input devices, CRT display characteristics, coding of information and printer characteristics. The guidance given is restricted to general principles, with detailed guidance given only where a parameter can be directly measured.</td>
</tr>
<tr>
<td>NRC, USA</td>
<td>Computerised Annunciator Systems (Authors: W L Rankin, T B Rideout, T B Triggs and K R Ames)</td>
<td>NUREG/C R-3987</td>
<td>1985</td>
<td>Report</td>
<td>Provides a variety of advice on the design of alarm annunciator systems on VDU displays. The report recognises that a number of the aspects of detailed design of VDU alarm presentation remain to be resolved. It does offer a number of tentative guidelines in these areas.</td>
</tr>
</tbody>
</table>

**TABLE A1.7 GUIDELINES AND HANDBOOKS**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAEA, International</td>
<td>Improving Nuclear Power Plant Safety through Operating Aids; Guidelines for Selecting Operator Aids Prepared by the International Atomic Energy Authority</td>
<td>IAEA-TECDOC-444</td>
<td>1987</td>
<td>Technical document</td>
<td>Describes a process of review and design that may be applied in nuclear power plants to identify the need for additional operator displays/information and to guide their development. Includes a limited number of specific guidelines on the desiging of computerised aids.</td>
</tr>
<tr>
<td>The Mitre Corp., USA</td>
<td>Design Guidelines for User System Interface Software (Authors: S L Smith and J N Mosier)</td>
<td>ESD-TR-84-190</td>
<td>1986</td>
<td>Company report (free issue)</td>
<td>This is a substantial set of guidelines covering aspects of the human-computer interface. Various forms of interaction styles are covered including form entry, menus and see of function keys. The document is extensively cross-referenced and subject to an updating service. Versions are available on disc for IBM and Apple Macintosh computers. However, the guidelines do not cover the specific types of displays and interaction in process control.</td>
</tr>
</tbody>
</table>

**TABLE A1.7 GUIDELINES AND HANDBOOKS (Cont'd)**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUSAT Research Institute, UK</td>
<td>Human Factors Guidelines for the Design of Computer-Based Systems (Published jointly by Ministry of Defence and Department of Trade and Industry)</td>
<td></td>
<td>1988</td>
<td>Published Document</td>
<td>This six-volume set of guidelines specifies human factors activities and deliverables through each stage of the design process for a computer-based system. It is primarily a 'process' description, included to form part of contractual arrangements in system procurement. It does include some guidelines on issues such as console and interaction design.</td>
</tr>
<tr>
<td>The Human Factors in Reliability Group, UK</td>
<td>The Guide to Reducing Human Error in Process Operations</td>
<td>SRD R347</td>
<td>1987</td>
<td>Published Document</td>
<td>Sometimes referred to as the 'short guide', this document presents a list of questions on the human factors aspects of operator facilities in process plants. These are meant to prompt the reader to evaluate their systems or designs.</td>
</tr>
<tr>
<td>The Human Factors in Reliability Group, UK</td>
<td>The Guide to Reducing Human Error in Process Operations (extended version)</td>
<td>SRDA-R3 ISBN 0-85356-357-8</td>
<td>1991</td>
<td>Published Document</td>
<td>This document is an extended version of the above guide. It presents more detailed questions and more information on good design practice. As before it provides a list of questions which prompts the reader to evaluate the detailed human factors aspects of a design. The guide also includes case studies relevant to the advice given and references to key source references.</td>
</tr>
</tbody>
</table>

**TABLE A1.7 GUIDELINES AND HANDBOOKS (Cont'd)**
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TITLE</th>
<th>REFERENCE</th>
<th>YEAR OF PUBLICATION</th>
<th>STATUS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charterl-Bratt Ltd, Sweden</td>
<td>The Computer Display Designer's Handbook (Author: E Wagner)</td>
<td>ISBN 0-86238-171-1</td>
<td>1988</td>
<td>Published Book</td>
<td>Covers background psychophysics and practical design principles related to the design of displays in process control. Though some of the advice it provides is open to debate, it is a very useful source reference.</td>
</tr>
<tr>
<td>BSI, UK</td>
<td>Ergonomics Standards and Guidelines for Designers (Author: S Pheasant)</td>
<td>ISBN 0-580-15391-6</td>
<td>1987</td>
<td>Published Book</td>
<td>Provides anthropometric data, environmental design data, guidance on the visual aspects of displays, symbols, building design and controls. Provides a useful starting point in each of these areas.</td>
</tr>
<tr>
<td>Academic Press, USA</td>
<td>User-Computer Interface in Process Control: A Human Factors Engineering Handbook (Authors: W E Gilmore, D I Gertman and H S Blackman)</td>
<td>ISBN 0-12-283965-x</td>
<td>1989</td>
<td>Published Book</td>
<td>The format of the guidelines have been considerably improved and the content extended for this published version of the original report (NUREG/CR-4227). The guidelines cover many aspects of VDU display design and are supported by illustrations. Still weak in some areas (eg alarm displays). Extensive checklists given at back of book.</td>
</tr>
</tbody>
</table>

**TABLE A1.7 GUIDELINES AND HANDBOOKS (Cont'd)**
APPENDIX 2: SUMMARY OF INTERVIEWS WITH PROCESS COMPANIES
1. Conceptual Design

1.1 Prior to beginning design of new system, conceptual research studies are carried out, focusing on the design of VDU interfaces in the control room. These are funded by the client and are delivered in the form of reports. This also involves technology evaluation to determine what forms of technology are worth pursuing (e.g. expert systems).

1.2 During the conceptual design phase, more specific development studies will be carried out on the details of interface design.

1.3 There are few standards or reference guides which are of assistance. A lot of the conceptual study work is aimed at producing a set of empirically based guidelines for VDU system design.

2. Outline Design / System Procurement

2.1 Outline requirements specifications are given by the client. At present this defines in detail the number of operators, their grades and qualifications. The physical constraints of control room size are also specified.

2.2 Allocation of functions and task analysis are not performed at present, though there is a long term objective to employ these techniques.

2.3 Prototypes of control room interfaces are constructed at this stage using both part task and full task simulators. These are evaluated using operators and reviewed by an operations steering group.

2.4 Agreed design concepts are recorded in design philosophy papers. The final design concepts are fed into the full design specification.
2.5 Guidance is provided by such documents as the HUSAT MOD/DTI guidelines, NUREG 0700, EPRI reports, IEC 964, NII guidelines on control room development, quality assurance and software development standards.

3. Detailed Design and Acceptance Testing

3.1 VDU format and panel layout design is carried out during this stage.

3.2 Panel design and the location of VDUs may already be constrained by cabling runs and the latitude for major changes is limited. Use may also be made of 3D workplace simulators for anthropometric and layout considerations (eg. SAMMIE; Porter et al 1990). Environmental requirements are also specified (eg. lighting, vibration, radiation).

3.3 Display designs are drawn up on PCs and passed on to software engineers for coding.

3.4 Various mock-ups and a full scale prototype control room are built during the design phase. Trial walkthroughs using emergency operating procedures are carried out. These feed into the final detailed design of the control room layout and environment.

3.5 Simulation studies are performed during this phase using the mock-ups. This may lead to a number of stages of iteration until the design is considered acceptable.

3.6 Human factors considerations are covered in the customer acceptance tests.

3.7 Use is made of the same standards etc. as described in 2.5

3.8 The outputs are in the form of reports and design specifications.

4. Commissioning

4.1 Full operational trials are carried out during commissioning. These check operation of reactor and control room. Operating procedures are also validated during this stage. Test reports are produced which may contain some feedback on operator facilities.

4.2 Operator surveys are carried out during this stage to identify problems and reactions to the interface facilities.

5. Operation

5.1 Human factors personnel are part of the review process for any design modifications which are also reviewed by reliability assessors and any significant changes to operator facilities are fed back for comment.

5.2 Information on operational performance is gathered from various sources. The full scale simulators are fitted with data loggers which can provide useful
information. Further operator surveys are also carried out over a period of time. Apart from existing incident reporting systems, a confidential incident reporting system is being introduced (log book) and workshops with operators will be arranged to discuss the findings. These activities are intended to feed into the human factors database for assistance to designers for future reactor designs.

5.3 Use is made of the section on post design reviews and operational reviews in NUREG 0700.
1. Conceptual Design

1.1 Size and cost limits on project determine size and scale of control system. Size of plant largely determines I/O requirements. Cost constraints may determine level of automation.

1.2 General policy is to utilise computer control wherever possible for productivity reasons.

1.3 DCS systems are used by default for reasons of ease of implementation, unless there is an existing control system that could be extended or there are severe cost constraints.

1.4 Extensive use is made of trip systems, such that any malfunction with potential safety consequences results in a process shutdown. The main role of the operator is in restarting the process post-trip and the most difficult aspect of their task tends to be the identification and resetting of trips in order to enable the process to be restarted.

1.5 The allocation of tasks to operating staff depends on a number of factors. If it is possible to fully automate a plant, they will do so. However, if there are operating staff already available (i.e. extension to existing plant or common control room), tasks may be manual to save on costs. For example, in a recent small batch plant design, cost constraints dictated that utility supply valves would be left manually operated, whilst the main process valves would be actuated.

1.6 Decisions regarding the scope and scale of plant control systems largely based on experience of what job will stand. Also influenced by awareness that design will be subjected to a HAZOP at a later stage.

1.7 A dossier will be produced at end of conceptual design study which primarily will cover costings. There may be a statement regarding the level of automation.
2. Outline Design / System Procurement

2.1 Outline design of system developed in more detail, identifying number of control boxes required, number of control points etc. A detailed estimate is produced for capital authorization.

2.2 Requirements specification document sent out to equipment suppliers for tendering purposes.

2.3 Tend to use a lot of interactive VDU graphic displays for batch plants, along with alarm and trend displays. Aware of operator interface facilities offered by suppliers on tendering list.

2.4 The number of VDU displays need not be finally decided at this stage. Normally two are specified as a minimum, though on very small projects, just one may be fitted.

2.5 All graphics and control software is produced in-house. So this is not covered in requirements specification.

2.6 Will decide whether new control room will be built or existing facilities extended.

3. Detailed Design and Acceptance Testing

3.1 The types of displays used depends upon the type of process. Would provide mimic type display for batch units and where routing required. In general, wherever it is considered that it would enhance operator communications, a graphic display is provided. However, building graphics displays add an overhead on a project, compared with standard format displays and this is borne in mind.

3.2 Design is based on P & ID diagrams. They may prototype designs on a PC prior to building them on the system. This work is carried out by control system engineers.

3.3 The style of the graphics is decided in discussions with operations personnel to fit in to existing systems on a site or within the company. Some de facto standards on issues such as colour coding exist within the company, but are not formalised.

3.4 The mimic displays are not formally reviewed, but are discussed between control system engineers and process chemists.

3.5 The complex elements of the control system software are proven using simulation testing. This utilises the operator interface and any obvious problems are revealed at this stage.

3.6 The control room is designed by the instrument engineering department on basis of wiring requirements and within budget provided.
4. Commissioning

4.1 Plant is commissioned in phases, first water tested and then using chemicals.

4.2 Process and chemical engineers drive plant on shifts. Operators are trained during this phase on plant design and use of the control system.

4.3 Any subtle problems with displays emerge during this stage. New mimics can be built (0.5 day per mimic) or small changes made to existing mimics on-line. There is not necessarily a formal design change notice issued unless logic changed.

5. Operation

5.1 Once plant in operation, modifications to mimics may be carried out, but these gradually tail off. After formal handover point, all changes are made by plant maintenance.

5.2 System developers may give an overview description of display system to plant operations as part of documentation delivered on handover.

5.3 Plants operate an incident reporting system, but there is no guarantee that comments related to control system performance will be fed back to designers.
HUMAN FACTORS IN SYSTEM DESIGN SURVEY: COMPANY C

Industrial Sector: Offshore exploration and production

Types of Plant: Offshore drilling and production platforms

Types of Control System: Hardwired ESD system, SCADA systems for drilling data collection, DCS for process plant control and monitoring. Separate fire and gas detection system.

Operator Interfaces: Panel displays and alarms for ESD, fire and gas. VDU displays to DCS and SCADA systems.

Interviewee: Electrical instrument supervisor on project team

1. Conceptual Design

1.1 Selection of control technology and levels of automation decided by production and safety assurance requirements. For example, are unwilling to use programmable systems for ESD functions.

1.2 Manning levels are determined early in design for purposes of estimating accommodation requirements. Control room staffing levels are therefore fixed.

1.3 The safety philosophy is based upon a hierarchy of engineering safeguards; mechanical design is overspecified such that the system will contain all temperatures and pressures likely to be encountered and pressure relief valves are fitted. The overall system is protected by the fully automatic ESD system and the DCS displays provide the operator with the means for the early detection of process faults.

1.4 Numbers and size of control rooms are determined by cost and space constraints. Once number of control locations decided, size requirements are determined based on extrapolation from previous designs.

1.5 On current design, space constraints as well as the amount and complexity of process controls required have dictated the use of a DCS system with VDU displays. Also previous operational experience from the operations steering group is brought to bear. For example, current design will use panel displays for operating fire and gas systems. They have found VDU fire and gas systems to be non-intuitive and therefore unsuitable for operation by non-trained personnel in an emergency.

2. Outline Design / System Procurement

2.1 Hardware package and control systems procured by competitive tender.

2.2 A specification is prepared which includes details on display requirements (eg. high resolution colour graphics displays required, minimum no. of pixels on display),
the types of displays that must be supported (e.g. graphics, trends), response time requirements, input devices required and accuracy of time clocks shown on displays.

3. Detailed Design and Acceptance Testing

3.1 Use both standard format displays (e.g. trends, overview, alarm displays) and graphic displays. The design of graphic displays is performed in-house and then may be sent out for coding.

3.2 A senior operator is seconded to project to design displays and decide alarm priorities. Operator applies experience on similar platforms to decide content and structure of displays. A de facto company standard therefore exists, though it is not formally documented. The operator also decides upon alarm priorities and any grouping of alarms.

3.3 Physical layout of CCR gradually emerges through a process of negotiation between the engineering team and the operations steering group. The layout of the desk and panels is decided by operations preferences (e.g. operations prefer to have panels behind operators for each of access. Any key indications are audibly annunciated and are repeated on VDU DCS displays). The final design of control room is defined 'on the drawing board'.

3.4 The number of VDU displays, telecommunication system requirements etc. is decided in negotiations with operations, determining the size of the console. The console is built out of standard vendor desk units and there is some limited scope for expansion. Panel sizes are left flexible until final allocation of controls and displays are made. This element of flexibility is written into contract with equipment vendors.

3.5 Exact split of responsibilities between operators also established during this phase on basis of past operational experience.

3.6 Throughout system construction phase, screens will be reviewed and changed as problems identified. A training simulator may be available during the latter stages of the construction phase, and this provides an opportunity for further problems to be identified. Screens are also in use during factory acceptance testing of the various software systems and further problems may be detected at this stage.

3.7 No particular use is made of human factors standards or guidelines.

3.8 Human factors consultant has been employed to review and comment on control room design.

4. Commissioning

4.1 Software systems are tested through operator interface throughout commissioning process, providing a further opportunity to detect and correct any problems.

4.2 Operations staff draft operating procedures at this stage.
5. Operation

5.1 Operators are trained and skills are upgraded through simulator sessions. This involves dealing with simulated faults and emergencies.

5.2 Operations feed back operational experience in three ways:

i) Through formal design change procedures

ii) Through design review team meetings throughout the design process

iii) Through the contributions of the senior operator seconded to the project
1. Conceptual Design

1.1 Company policy is to use computer control for all plants above a certain size. This is based on experience of what has proven to work well. Computers ensure close control and ensure repeatability.

1.2 The decision to use VDU interfaces follows on from the decision to implement computer control.

1.3 Plants are designed to be fully automatic, sequenced-batch operations apart from manual handling needed with powder products.

2. Outline Design / System Procurement

2.1 Decisions on issues such as the number of displays and printers are decided by operations steering group. This steering group is in charge of design decisions, advised by C & I.

2.2 The number of VDU displays required will depend upon the size and complexity of the plant concerned, though as a minimum specification, two operator VDUs will be provided with a further fixed status VDU display.

2.3 Standard philosophy is to make available two displays for each major batch unit, one display showing the sequence control information and a second display a graphic of the unit. Text messages prompt the operator regarding any other currently operating batch sequences.

2.4 During this phase a requirements specification is drawn up for tendering purposes. This indicates the number of VDUs that will be required, the minimum visual characteristics required from the displays (eg. high resolution, colour), the requirement for the system to support a display hierarchy and the types of displays or functions that are required (eg. trending, dynamic graphics)
3. **Detailed Design and Acceptance Testing**

3.1 All graphics and applications software is constructed in-house by the C & I section.

3.2 Graphics are constructed directly from P & ID engineering line diagrams. There are company de facto standards on the style of mimics but these are not written down. C & I personnel are familiar with these standards. There are written standards for colours.

3.3 Operations are not generally involved in the specification or checking of displays at this stage. However, the accuracy of the graphic displays will be checked by process engineers using display printouts.

3.4 C & I personnel may have opportunity to evaluate displays during factory acceptance testing of hardware, particularly if the applications software and database is ready for loading.

3.5 Operations decide upon the control room layout, consoles etc. The hardware requirements for the control room have already been established in the requirements specification. Normally, the vendor will suggest a number of options for layouts and console configuration and operations will discuss these and decide.

3.6 Console dimensions and other human factors aspects depend upon what the vendor has to offer. Normally try to provide a horseshoe arrangement, with console units facing windows (not behind or to side of operator for visual performance reasons). They also consciously try to ensure that there is a good lighting arrangement.

4. **Commissioning**

4.1 A further opportunity is given to check the displays during the on-site acceptance testing of the installed control system. Individual loops will be driven through the operator displays.

4.2 Throughout the stages of water and chemical testing there is an opportunity for problems with displays to be detected and rectified. This involves the issuing of software change requests.

4.3 Operations staff are involved during this stage, undergoing training on the system and assisting in the testing process. They are often required to manipulate the system from the control room to assist in field installation testing.

5. **Operation**

5.1 After final handover, there is a warranty period during which the design and commissioning engineers may be called upon to make changes to graphics. After this period, modifications will be made by a nominated engineer on site.
5.2 Feedback on system performance and any operability problems may be received informally, particularly where there are recurrent problems. There are no formal feedback routes.
HUMAN FACTORS IN SYSTEM DESIGN SURVEY: COMPANY E

Industrial Sector: Food Products
Types of Plant: Wet and Dry batch production plants
Types of Control System: PLC based control systems
Operator Interfaces: Largely VDU based, particularly for sequence control. Some plants have panel mimics for status information.
Interviewee: Electrical Engineering Manager

1. Conceptual Design

1.1 The level of automation to be applied in a new plant is decided by the project design team. This largely consists of operations, maintenance and project engineers.

1.2 Decisions on the level of automation are based on previous experience and awareness of current technology (ie. what works best), though the team will be advised by control engineers who will be responsible for implementing the control scheme.

1.3 Potential safety hazards are protected against by hardwired trips. These trips provide an input to the PLC system for operator display purposes (eg. via an alarm message). The role of the operators are seen therefore largely as production managers, though they may detect and prevent process disturbances in their early stages.

1.4 The output from the design team is in the form of a functional specification for the new plant. This covers aspects such as the number of operators that will be in the control room, the number of VDU screens that will be required, any graphic displays required and management information requirements.

1.5 The overall project management and documentation model is based upon the IEE recommended process in "Guidelines for the Documentation of Software in Industrial Control Systems" (ISBN 0 86341 0464)

2. Outline Design / System Procurement

2.1 The control engineering department receive the control philosophy part of the functional specification and incorporate this into a user requirement specification for the tendering process.

2.2 The user requirements specification will reference the control philosophy and will include aspects such as the size and resolution required for display screens and control input device requirements.
2.3 The selection of types of display formats will depend upon the need for overview information (ie graphic facilities required), or if only management and recipe information required, then only textual displays need be specified.

2.4 Consideration is given to the adequacy of safety monitoring and control facilities during the HAZOP process (if required).

3. **Detailed Design and Acceptance Testing**

3.1 Following the tendering process, the selected supplier is required to consult with the design team to draw up a detailed Functional Design Specification (FDS) for the system. This is submitted to the control engineering department for acceptance.

3.2 The functional design specification will cover the detailed design of displays. These are drawn up by the operations personnel or the design team.

3.3 Display colours and symbols are standardised within the company, including additional special purpose symbols not covered by normal standards.

3.4 The displays are generated by the supplier and will be examined by the control engineering department during the coding process as part of general design liaison.

3.5 The displays are formally reviewed during the factory acceptance test. Full test specifications are drawn up in a checklist format and each item is checked for compliance.

3.6 The control room design and procurement is carried out as a separate process. The initial layout is carried out by the operations design team and then negotiated with the control engineering department.

3.7 Cost is an important constraint on control room design. They try to position desks to enable operators to look out on to the plant. Sophisticated lighting design is considered if there is sufficient finance available.

3.8 All control room design is performed on the drawing board.

4. **Commissioning**

4.1 At various testing stages during the control system commissioning process, the control engineering department have the opportunity to check the displays. In particular, during the testing of individual sequences, display details will be checked using a checklist from a software acceptance test document.

4.2 Operations staff are involved during the stages of dry testing, water testing and testing with actual ingredients. During this period they will be learning about system and may detect problems with the displays. In general, it is expected that such problems should be very few, since operations were responsible for the original specification of the displays.
4.3 The control room design is fixed by now and there is rarely much scope for modifications at this stage.

5. Operations

5.1 Following the formal handover point, operations staff will generally maintain the system, unless there are any major problems.

5.2 If there are any difficulties in the operation of the plant, feedback may be received through informal routes. Operational experience will also be fed back through the operations design team for a new design.
1. Conceptual Design

1.1 Primarily concerned with re-instrumentation of existing refineries. First stage is to construct a financial case, looking at various economic factors.

1.2 Decisions on levels of automation generally based on economic factors. They identify important process aspects that need to be controlled and those aspects where automation will bring economic benefits.

1.3 Levels of manning decided at this stage. No particular desire to reduce manning levels, though trend away from distributed local control rooms towards a centralised control room does result in some reductions in manpower requirements.

1.4 Tend not to aim for a high level of process automation and consequential sequential control.

1.5 Decision on manpower made by operations department, who are represented on the project team along with control engineers. The decision is based on the number of plants to be controlled and the number of consoles. The final decision is based largely on pragmatic experience and to date, less than 200 loops per operator has been the norm.

2. Outline Design / System Procurement

2.1 A decision regarding the most appropriate DCS system tends to be made fairly early on to enable the financial case to be as detailed as possible. The first stage involves careful estimation of the size of the facilities that will be required (loops, control boxes, advanced control facilities). Estimates are then obtained form the various vendors and a short-list drawn up for more detailed examination.

2.2 A view on interface facilities is obtained from the operations representatives on the project team, which then seek endorsement from the operations department. They visit DCS vendors to view their systems and view implementations on other
sites. There is often a consultation process with the various shifts at a site to obtain their opinions. Some guidance is also given by control engineering personnel on the basis of previous projects.

2.3 They do not have any general human factors standards or guidelines to apply in this area, though there is a move towards the development of such documents.

2.4 The number of screens and keyboards tends to be decided in negotiation between operations and project management. There is a tendency for operations to want a larger number of screens and keyboards than strictly justified on cost-benefit considerations.

2.5 The final decision on a system is based upon both cost considerations and the facilities offered.

2.6 During this stage, an outline design of the control room layout will be decided upon. This is a drawing board exercise, operations driving the process in negotiation with projects. There is very often a consultation process with the various shifts at a site to obtain their opinions on a control room design. Often they will be working within the constraints of the available space in an existing building, though there has been a trend over more recent projects towards the construction of new control room facilities.

3. Detailed Design and Acceptance Testing

3.1 All display design is carried out in-house and then the designs sent out for coding by a contractor.

3.2 The displays are designed by a team consisting on a member of operations personnel on detachment to the project and a control engineer. The member of operations staff (supervisory grade) provides information on which graphics are required and the grouping of alarms etc.

3.3 Decisions on colours and style of graphics made on the basis of the experience of the personnel involved, such that there exists de facto standards on colours and symbols. There are no standards on issues such as information density.

3.4 Full factory acceptance test performed on system once software completed. This does not cover all graphics displays though it does involve operations staff. Graphics displays are checked and reviewed by the design team in batches as they are completed.

3.5 Decisions on detailed design of control room outside remit of person interviewed. Believed that they might have some objective standards on lighting installations in control rooms.

3.6 Decisions on details of decor etc. are in most cases referred to operations staff for their consideration.
4. Commissioning

4.1 Operations personnel are involved throughout commissioning process. Where possible, the new control system is commissioned utilising a 'hot changeover' from the existing control system. Operators are trained on new interface using a plant simulator or sent to the vendors for a training course.

4.2 There is scope throughout the commissioning process for changes and additions to be made to the graphics and other displays. This is administered by formal change procedures.

5. Operation

5.1 The project team maintains its involvement during the initial operation of the new control system. One of the operations representatives on the projects team is transferred as a permanent member of the operations system support team at the plant.

5.2 There is still scope for further changes to be made to displays, utilising the same formal change procedure controls.

5.3 The company has recognised that, though all their changeovers to new control systems have been completed without incident, there are distinct differences between the success of different implementations on refineries, even where the same DCS has been used. They are beginning a pilot project to investigate the factors underlying the success of different operator interface implementations.
1. **Conceptual Design**

1.1 Details of plant automation and type of control system taken by project team, which does not include operations input. Reasons for deciding upon DCS not clear, though other parts of site already have DCS installed.

1.2 Existing control room had conventional instrumentation and this has been transferred on to the DCS.

1.3 Continuing to run two control rooms, partly for historical reasons.

2. **Outline Design / System Procurement**

2.1 Two to three options were studied for a DCS and a decision made on the basis of cost, performance and reliability.

2.2 The design of the DCS and control room was largely project driven with operations involved to a certain extent.

2.3 Operations had an input into the control room layout proposals. They also made other suggestions for changes which were considered by the process engineers.

3. **Detailed Design and Acceptance Testing**

3.1 Operations personnel spent a lot of time with the design engineers during detailed design.

3.2 All graphic displays were designed by the engineering contractor on the basis of the P & ID diagrams.

3.3 The mimics were reviewed by operations in batches and changes agreed (Note: the mimics were supplied on disc so it was possible to examine the mimics on screen). The reviewers consisted of teams of operators who reviewed the displays one-by-one.
3.4 Decisions on numbers of monitors and other console facilities made on basis of experience.

3.5 A full factory acceptance test was carried out of all the equipment at the manufacturers premises, as it was not intended to test the equipment to this level on site. This included operations input though it is not certain the extent to which this covered the displays.

4. Commissioning

4.1 Operations input continued into the commissioning phase. Significant changes to the mimics were not made at this stage as the project included a full review of the system after one year's operational experience (see 5.1 below).

4.2 A senior member of operations personnel was seconded to the project, receiving detailed training on operating the DCS. He is responsible for training the other operators as well as for collecting feedback on operational experience (see 5.2 below).

5. Operation

5.1 The project was set-up to include a review after a year of full operations. This is intended to feed into revisions of the existing mimics and in to the design of mimics for future systems.

5.2 The feedback of operational experience was coordinated through a designated member of operations staff, specially seconded to the role.

5.3 An human factors review of the mimics was carried out by independent human factors consultants, examining issues of mimic design, colour coding, information requirements etc.

5.4 The review includes comments on control room design. Future development phases will include a totally new control room which will incorporate the operational feedback from existing facilities.
APPENDIX 3: PROPOSED SAFETY ASSURANCE FRAMEWORK
APPENDIX 3: PROPOSED SAFETY ASSURANCE FRAMEWORK

Table A3.1 provides an overview of the currently available standards, guidelines and handbooks within the system development lifecycle. The columns indicate the successive stages of the development lifecycle from conceptual design through to operation. The rows in Table 6.1 consist of the following:

(i) **Objectives and Goals:** This indicates the safety related objectives and goals that underly human factors activities during each stage of the design lifecycle.

(ii) **Standards/Guidelines/Handbooks:** This row lists the broad categories of guidance documents that are available to support human factors activities at each stage of the design lifecycle. Where appropriate, examples are given from Section 3.0. Remember that although guidance is available at each stage of the design lifecycle, it is not comprehensive or necessarily in a form that can be readily obtained and applied.

(iii) **Possible Activities:** The main categories of human factors techniques from Section 2.0 are listed in this row of the table against their most appropriate stage in the system development lifecycle.

(iv) **Deliverables:** This row suggests the types of safety-related documentation that could be generated at each stage of the lifecycle.

(v) **Reviews:** The types of review of human factors related activities that could be carried out are shown in the bottom row of the table.

The various entries in the Table are described in the following sections:

1. **Conceptual Design Stage**

The primary goal at this stage is to make explicit the safety-related functions of the various operational personnel. This should include the identification of possible human errors that may contribute to a safety-related incident (eg. opening wrong valve, errors whilst operating a process in manual mode) and include situations where operators are required to act to prevent a safety-related incident. In both cases, it is important to ensure that either high levels of human performance can be ensured through design, or automatic protection systems are implemented to provide protection.

The key activities required to achieve this goal are:

(i) Define who will be the users of the control room systems

(ii) Make explicit the allocation of functions to the operating personnel

(iii) Evaluate the resulting task allocation.

The process of identifying target users should in most circumstances be straightforward, including both who the users will be and what their capabilities can be expected to be. The initial allocation of functions will probably be driven by process automation requirements,
though if required, various heuristics may be applied in an attempt to optimise the allocation from the operator's perspective. The evaluation of the resulting task allocation may make use of global time estimates for the process in order to carry out a coarse grain workload assessment of operator activities to ensure that the operator is neither under nor overloaded. This may simply involve a subjective estimate of the likely workload on the basis of an extrapolation from existing task demands on the same operator.

The output from this process should be an operational safety philosophy document that indicates how the required level of safety protection is to be provided for, incorporating mechanical design, automated protection systems and human actions. For the human sub-system, the document should outline the staff structure and identify the safety-related functions of operations personnel, particularly with regard to emergency conditions. This should refer to any evaluations that have been performed at this stage in order to confirm that the allocation of functions is reasonable. Once complete, this would form an important source document during the remaining design stages. Later assessments, evaluation trials and efforts to support the design process should focus upon the range of functions identified in this document and may result in further revisions.

Existing standards and guideline documents provide a reasonable coverage of the activities identified to take place at this stage of the system design lifecycle.

2. **Outline Design/System Procurement**

There are two possible safety related objectives during this stage of system design. Firstly, as the design progresses beyond the conceptual stage, it is possible to evaluate operator task demands at a more detailed level, partly to identify the types of support that operators will require (eg. display formats, alarm systems) and partly to extend to a more detailed assessment of workload demands. The second objective is to develop the human factors component of the system requirements specification to ensure that the system that is procured provides the range and quality of interface facilities required to support safe operation.

The particular interface and workplace requirements may be extrapolated from existing provisions on the same or similar plants. However, where operator tasks or interface facilities vary to any great extent from any other comparable contexts, it would be necessary to generate formal task descriptions to identify the resulting task requirements. As was indicated in Section 2.2.3, this is complicated where tasks are highly cognitive in nature. New display design concepts may be prototyped and evaluated at this stage, both in consultation with operations personnel and in evaluation trials. Similarly, outline designs for the control room layout may be developed during this design stage then evaluated both in consultation with operations and using link analysis.

The main output from this stage should be a detailed human factors requirements specification, possibly forming part of a tender specification for the control system. This should include specific requirements on display visual performance (based on human factors standards) and outline the required interface functional requirements (eg. size of colour palette, maximum acceptable display build times). It may also be appropriate to define and incorporate particular usability goals which should be achievable by an operator when using the system, as described in Section 2.2.6. The various design and evaluation activities should
<table>
<thead>
<tr>
<th>SAFETY LIFECYCLE</th>
<th>CONCEPTUAL DESIGN</th>
<th>OUTLINE DESIGN/SYSTEM PROCUREMENT</th>
<th>DETAIL DESIGN AND ACCEPTANCE TESTING</th>
<th>COMMISSIONING</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECTIVES AND GOALS</td>
<td><em>To describe and evaluate task and demands of safety-related operations (initial)</em>&lt;br&gt; <em>To define human factors component of requirements specification for the system design under procurement.</em></td>
<td><em>To describe and evaluate task and demands of safety-related operations (detailed)</em>&lt;br&gt; <em>To ensure detailed design meets standards set in requirement specification and is compatible with overall safety goals.</em></td>
<td><em>To demonstrate that commissioned system meets safety requirements</em>&lt;br&gt; <em>To ensure user support facilities (e.g. procedures and training documentation) meet standards set in requirement specification and is compatible with overall safety goals.</em></td>
<td><em>To ensure safety design meets being complied with during operations, particularly following plant modifications.</em>&lt;br&gt; <em>To collect operational feedback on system performance to feed into future design.</em></td>
<td><em>Guidance on safety audit methods</em>&lt;br&gt; <em>Standards and handbooks on procedures and documentation design (e.g. HSE 4894)</em></td>
</tr>
<tr>
<td>STANDARDS/ GUIDELINES/ HANDBOOKS</td>
<td>*Standards and handbooks covering stakeholder analysis and allocation of functions (e.g. EC 1994, HSE, 1993) *&lt;br&gt; *Standards and guidelines relating to workplace design, panel design, and VDU visual and workplace requirements (e.g. ISO 9241, ISO 11944; CEN, 1989, BS 1646)  *&lt;br&gt; *Standards, guidelines and handbooks on interface design and user requirements specification (e.g. IFRG, In press: Wagner, 1998, ISO 9241; Chapter and Bakhita, 1999)  *&lt;br&gt; <em>Guidelines/handbooks on task analysis methods, interface design, workplace design, evaluation methods and user participation in design.</em></td>
<td>*Standards and guidelines relating to workplace design, panel design, and VDU visual and workplace requirements (e.g. ISO 9241, ISO 11944, CEN, 1989; BS 1646)  *&lt;br&gt; *Standards, guidelines and handbooks on interface design (e.g. IFRG, In press: ISO 9241; NUREG 0700, Claxton, 1985)  *&lt;br&gt; <em>Guidelines/handbooks on task analysis methods, interface design, evaluation methods and user participation in design.</em></td>
<td><em>Design and development of system user training and documentation</em>&lt;br&gt; <em>Operational safety assessments</em>&lt;br&gt; <em>Confidential reporting systems and questionnaire evaluation</em>&lt;br&gt; <em>Design and assessment of modifications to interface</em>&lt;br&gt; <em>Simulator trials of emergency response capabilities</em>&lt;br&gt; <em>Review and modification of task analysis</em>&lt;br&gt; <em>Modification of existing user documentation</em></td>
<td><em>Safety management audits and incident investigations</em>&lt;br&gt; <em>Safety audit reports</em>&lt;br&gt; <em>System assessment reports</em>&lt;br&gt; <em>Human factors assessment reports on modifications to interface</em>&lt;br&gt; <em>Simulator trial reports</em>&lt;br&gt; <em>Revised user documentation</em></td>
<td><em>Reviews by operations steering group</em>&lt;br&gt; <em>Internal safety review</em>&lt;br&gt; <em>Independent human factors peer review (optional)</em>&lt;br&gt; <em>Commissioning safety review (optional)</em>&lt;br&gt; <em>Corporate management reviews of audit reports and incident analysis</em>&lt;br&gt; <em>Operations management review of procedures and feedback on operational problems.</em></td>
</tr>
<tr>
<td>POSSIBLE ACTIVITIES</td>
<td><em>Define target users</em>&lt;br&gt; <em>Holds system functions between operator and control system</em>&lt;br&gt; <em>Describe and evaluate operator tasks at global level</em></td>
<td><em>Task description and evaluation</em>&lt;br&gt; <em>Definition of usability goals</em>&lt;br&gt; <em>Workplace layout design and physical mock-ups</em>&lt;br&gt; <em>Conceptual interface design and examination of prototypes</em>&lt;br&gt; <em>Establishment and consultations with operations personnel</em>&lt;br&gt; <em>Evaluation of interface conceptual design</em></td>
<td><em>Task description and evaluation</em>&lt;br&gt; <em>Contribution with operations personnel</em>&lt;br&gt; <em>Detailed assessment of design (against standards, requirement specification) possibly utilizing human factors checklists</em>&lt;br&gt; <em>Operate evaluation of prototype displays and control-room design</em>&lt;br&gt; <em>Acceptance testing of displays</em></td>
<td><em>Commissioning test reports</em>&lt;br&gt; <em>Design change requests</em>&lt;br&gt; <em>User documentation</em></td>
<td><em>Reviews by operations steering group</em>&lt;br&gt; <em>Internal safety review</em>&lt;br&gt; <em>Independent human factors peer review (optional)</em>&lt;br&gt; <em>Commissioning safety review (optional)</em>&lt;br&gt; <em>Corporate management reviews of audit reports and incident analysis</em>&lt;br&gt; <em>Operations management review of procedures and feedback on operational problems.</em></td>
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<tr>
<td>DELIVERABLES</td>
<td><em>An operational safety philosophy document describing human factors, emergency response philosophy, the target user population and supervisory plan</em></td>
<td><em>Detailed human factors requirements specifications (May form part of control system tender document)</em>&lt;br&gt; <em>Outline description of operator tasks</em>&lt;br&gt; <em>Outline workplace layout</em>&lt;br&gt; <em>Task assessment reports</em></td>
<td><em>Detailed task analysis document</em>&lt;br&gt; <em>Detailed human factors assessment reports</em>&lt;br&gt; <em>Operator evaluation reports</em>&lt;br&gt; <em>Simulator trial reports</em></td>
<td><em>Safety management audits and incident investigations</em>&lt;br&gt; <em>Safety audit reports</em>&lt;br&gt; <em>System assessment reports</em>&lt;br&gt; <em>Human factors assessment reports on modifications to interface</em>&lt;br&gt; <em>Simulator trial reports</em>&lt;br&gt; <em>Revised user documentation</em></td>
<td><em>Reviews by operations steering group</em>&lt;br&gt; <em>Internal safety review</em>&lt;br&gt; <em>Independent human factors peer review (optional)</em>&lt;br&gt; <em>Commissioning safety review (optional)</em>&lt;br&gt; <em>Corporate management reviews of audit reports and incident analysis</em>&lt;br&gt; <em>Operations management review of procedures and feedback on operational problems.</em></td>
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**TABLE A3.1: OVERVIEW OF HUMAN FACTORS INPUTS TO SYSTEM SAFETY LIFECYCLE**
also generate deliverables in the form of outline task descriptions, an outline workplace design and any reports on assessments carried out. These deliverables should be reviewed by the operations steering group and the safety-related documents subjected to an internal safety review. It may also be worthwhile subjecting the design at this stage to an independent human factors peer review.

Apart from the design of the workplace and the physical requirements of display hardware, the guidance for this stage of design is patchy and diverse. For example, there is very little guidance available at present on task analysis methods, though as indicated in Section 2.2.3, a guide to these methods in currently in preparation (Kirwan and Ainsworth 1992). Detailed guidance for the content of displays is also limited, though there is a reasonable coverage of issues such as symbols and colour specification in current standards.

3. **Detailed Design and Acceptance Testing**

The first of the two objectives suggested for this stage is a more detailed extension of the outline task evaluation performed in the previous design stage. This would make use of actual display designs to evaluate key safety-related scenarios in more detail.

The second objective relates to the quality control of the human factors aspects of the emerging interface and workplace designs. This process has two elements; the provision of project specific design guidance to set project design standards and the subsequent evaluations of designs, possibly utilising human factors checklists. Further evaluations of designs may be carried out by operations personnel. This may include the evaluation of prototype displays or the evaluation of a full size control room mockup. Human factors considerations can also be built into the acceptance testing of displays.

The primary output from the activities in this stage are further assessment reports for review by the operations steering group and by the internal safety review body.

As with the outline design stage, guidance is available on workplace design but current guidance on VDU display format design and human factors methods is very limited. The Human Factors in Reliability Group guides to error reduction (HFRG, 1987 and HFRG, 1991) can act as useful checklists for auditing a complete design. Further detailed guidelines and checklists are required to support this stage of the design process.

4. **Commissioning**

During the commissioning phase, it is possible to evaluate the performance of the interface and control room in-situ to verify the safety integrity of operator task design. At the same time system support documentation will be produced and user training carried out. A further safety-related goal, therefore, is to ensure that the operator training on the system and any safety-critical support documentation meets the required standards.

Current guidance on evaluation trials and on the development of appropriate user documentation is limited. It should be a relatively straightforward task to provide useful guidance in this area.

5. **Operation**

Once a plant is in operation, the primary safety-related objective is to ensure that the principles of safe operation established during the system design are maintained, particularly
following design modifications. This may involve re-evaluation of modified task
descriptions and documentation using similar techniques to those applied during the initial
design phase. There is also a move towards the implementation of safety management
auditing techniques, that enable the general standards of safety-related behaviour within an
organisation to be measured and controlled. Some of these techniques may also be applied in
the investigation of the root causes of incidents. These techniques may be beneficial in
revealing problems with the operator interface that have potential safety implications. In
addition, more direct approaches to the continuing safety auditing of the operator interface
may be implemented including:

(i) Confidential reporting systems for operations staff allowing near miss errors and
problems with the interface to be pointed out.
(ii) Questionnaire or interview evaluations based on operator experiences and views of
the operator interface.
(iii) Continuing examination of emergency response capabilities through exercises
possibly utilising a training simulator.

The outputs of all of these techniques can assist in the continuing review of operational
safety, highlighting any safety-related problems that may result in the need for modifications
to the operator interface.

The same outputs can also provide a valuable input for meeting the second safety-related
goal listed in Table A3.1, feeding back operational experience into the design of future
systems. A number of the companies interviewed during the survey have instituted studies
for this purpose, recognising that a lot of valuable experience resides within their own
installations to guide future design projects.

A variety of safety auditing techniques exist which could be applied for the purposes
described above. A general guide to successful health and safety management and auditing
methods can be found in a recent HSE publication (HSE, 1991).
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