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ENCLOSURE

HUMAN RELIABILITY STUDY

Past Studies Survey

Some work on human reliability was done for the Reactor Safety Study (References 1 and 2). This work basically involved an extrapolation of data obtained from other programs (e.g., aerospace, weapons) with some on-site observation of the human operators. While the work that was done was undoubtedly adequate for the purposes of the Reactor Safety Study (RSS) it is worth noting that RSS (Reference 1) states:

> "An actuarial data base for human error rates in nuclear power plants does not exist."

and

> "In general, the design of controls and displays and their arrangements on operator panels in the nuclear plants studied in this analysis deviate from human engineering standards specified for the design of man-machine systems and accepted as standard practice for military systems."

Specific problems included possible errors in operating similarly designated control functions or valves. Reference 2 cited some specific examples of improper human engineering in nuclear plants:

- use of similar appearing control displays
- lack of practice in simulated emergencies
- poor format for operating procedures
- too many auditory/visual panel displays competing for operator attention
- side-by-side location of valves (which might cause both not to be operated)
- occasional low degree of human redundancy in certain operations.

The RSS also noted the absence of data on how the operators might respond in a high-stress situation (e.g., LOCA) and stated that "to obtain more accurate evaluations, each particular situation must be individually analyzed to assess the specific human failure rate which is applicable." (Reference 1).

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Beyond the question of operator reliability, RSS stated that "human errors related to the testing and maintenance of components can also be important common mode contributors." (Reference 3). In addition "design defects" were noted as sources of common mode failures (Reference 3) and in a sense, this is also a human error.

There are, of course, a number of reference materials dealing with the general subject of human engineering especially as it relates to aerospace and military missions (cf., e.g., References 4-8). These reference materials highlight a number of general topics concerning human performance such as:

- working conditions (lighting, noise levels, temperature, spacing, stress and fatigue).
- equipment design (spacing of consoles; size and location of buttons, switches, etc.; need for standardization)
- definition of the appropriate man-machine interface
- selection and training of personnel
- maintainability
- application of decision analysis
  - What decisions must the operator make to accomplish each function?
  - What information is required for each decision?
  - What action is required to execute the decision?

Both NRC and NSIC regularly collect and disseminate information on safety-related occurrences in nuclear power plants (cf., e.g., References 9 and 10). While not directly applicable to establishing the desired data base on human error, they do provide a useful measure of the degree of human involvement in LWR safety-related occurrences. Tables 1 and 2 from Reference 9 and Tables 3 and 4 from Reference 10 show that design error, operator error, maintenance error and administrative error head the list of causes of these safety-related occurrences. The old adage about these occurrences being a means of the plants trying to tell us something is no doubt true; therefore, it would behoove us to collate and study these occurrences further. NSIC has provided me with the results of a literature search on human reliability in nuclear power plants. This is available in my office.

The Browns Ferry nuclear plant fire provides a recent and publicly visible test of reactor operator performance (references 13 and 14). The NRC Special Review Group stated that "the TVA operating staff .... behaved in exemplary fashion." (Reference 14). However, the NRC Special Review Group goes on to note:

1. There were lapses in quality assurance at Browns Ferry.

2. There is a need to develop standards and requirements for instrumentation required for operator information and action.

3. There is a need for periodic drills involving all onsite and offsite organizations which may be expected to respond to a fire. Reference 14 cites the NRC inspection report of the Browns Ferry fire (see Reference 13, pp. 218-685) to observe that there were "a number of examples where the actions taken by the plant operating staff during the fire are stated not to be indicative of a high state of training of plant personnel in fire fighting operations."

Present Studies

NRR has recently let a $100K/year contract with Aerospace Corporation to analyze reactor control room displays and operator performance. On February 19, 1975, I briefly discussed this study with Dominic Tondi, who is the NRR project manager for the study. He said Aerospace Corporation will study about five nuclear plants, specifically plants which have had "semi-major kinds of events."* He said he is interested in making decisions on how one can reduce operator errors particularly during postulated accident conditions (Attachment 1 is the scope of work for this effort.)

The RES Probabilistic Analysis Branch is also starting a study at Sandia on human reliability. The scope of this study is yet to be defined and RES/PAB is interested in any input RES/WRSR may have.

EPRI is funding some work on reliability and diagnostics ($3,576K in 1975) and operation and maintenance ($900K in 1975) but these studies appear to be related more to equipment and software (Reference 11).

Discussion with John A. Yoder

Per your recommendation I discussed the human reliability matter with John A. Yoder before he left NRC. A summary of Yoder's points as derived from his Navy and LOFT experience follows:

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* J. A. Norberg has observed that plants with good records should be studied also to determine where the differences are.

1. The operations personnel should review the design.*

2. The systems designers should write the procedures.** The procedures should not be cluttered with superfluous material, i.e., assume the operators are intelligent, well-trained personnel.

3. Human reliability is a function of the design and each design is different.

4. Early in the design process, the project should generate a document that sets forth the guidelines on how to consider the operational aspects in the design. Such a document would have to integrate all systems, e.g.,

   - How does the overall system work?

   - How do the parts fit together from an operations point of view?

   Designs which make operations so routine that an operator can err should be avoided.

5. Infrequent operations are the most likely cause of an accident. Dry runs should be performed prior to actually conducting an infrequent operation.

6. Certain critical functions should be designed such that it takes a two-step process to accomplish the function.

7. How an operator responds to a situation (e.g., an alarm) is a function of the status of the plant. Startup causes a lot of alarms and the operator may overlook some because they are not critical but merely an indication of a change in the plant condition. Thus there is a need to catalog what conditions cause alarms and what to look for when an alarm occurs and what to do about alarms. One idea to help the operator would be to have a computerized monitor which scans all signals, identifies which signal(s) caused the alarm and provides recommended courses of action.

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* J. A. Norberg recommends "that operators, and especially the key supervisors, should be involved as early as possible in the design and construction of nuclear power plants."

** J. A. Norberg and W. S. Farmer have recommended that the operators write the procedures.

Discussion with W. E. Vesely (2/23/76)

A summary of this discussion is as follows:

1. The utilities tend to design reactor control rooms to look much like fossil plant control rooms. (This permits them to use fossil plant operators at their nuclear plants.) The control board layouts can be grouped approximately by the utility.

2. The layout of a control room is determined to some extent by the manufacturers and the suppliers. The utility has the final say on labeling, although each plant within a given utility may have its own labeling. This difference in control board layouts implies different simulators would be needed and that the human reliability evaluation almost requires a plant-by-plant evaluation.

3. The location of valves is set according to drawings and not for the convenience of the operations personnel. Also there is often no positive indication whether a valve is open or closed. The color coding has been noted to be inconsistent within a plant (e.g., red can mean "open" and it can also mean "closed").

4. There are two basic areas to be studied:

   . existing plants - how to improve them

   . standard plants - how to standardize the control boards

5. In studying human reliability with the view of improving human performance, one must consider the critical areas (cf., e.g., WASH-1400), since it makes sense to concentrate on those operations where the human element is critical. (Sandia is familiar with these critical areas.) It should also be noted that changes in existing layouts or procedures can lead to accidents because of operator unfamiliarity with the new system.

6. Typically a plant will have two or three operators per shift. At times there may only be one operator in the control room with the other operators performing walk-through inspections (again possibly on an individual basis). Check lists are not always used.

7. At Zion there were an average of three to five alarms per hour. Usually the operators shut them off. (As an aside, ~95% of the SAC 16% error rate for air crews was caused by a failure to believe instruments.)

8. Sandia has a human reliability organization of at least 27 people who run a laboratory where actual human reliability tests can be performed and who maintain a data bank on human errors. The laboratory is not like a reactor control room. The laboratory is used to measure how long it takes to perform an operation as well as how well it is performed. (If an operator takes too long to perform it may be of no use.)

9. There is a need to establish an NRC-wide coordination of human reliability studies.

10. The RES/PAB study at Sandia will:

    - extend the present Sandia study of Zion (Reference 12) to other plants
    - study standard board layouts
    - establish a data bank on the functions humans actually perform by on-site investigations.

Recommended Future Courses of Action

Based on the foregoing discussion and my cursory review of the references, I think NRC should institute programs to address the following items:

1. A system of periodically testing operators under pre- and post-accident conditions should be established by the Office of Inspection and Enforcement. This may be done through actual tests (instrumentation only) performed on the operators in the plant and without their advance knowledge.*

   Some specific items which need to be addressed include response time, type of response, and whether the operators are overloaded by the types of alarms which can occur. Since performance effectiveness is a function of stress levels (see Figure 3), it might be worth establishing to the operators' satisfaction that they are "safe" no matter what the accident.

   An outcome of this work should be optimized methods of instruction, warning and communications not to mention improved procedures. In addition, regular training should improve the operator response time (References 1 and 2 note that disbelief and inaction would be the initial response to a major accident.)

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* Obviously there is no unanimity about using the plant itself as a testing ground. However, as Reference 13 brought out, something must be done about training reactor personnel on a regular basis to handle emergencies.

2. RSR should evaluate the recovery factors to determine the optimum degree of compensation for human errors, e.g.,

   . should immediate feedback be provided on the results of each operation?

   . how much personnel redundancy is required?

   . should there be immediate testing by a second party?

   In general an overall man-machine interface study needs to be performed for nuclear plants (see Tables 5 and 6).

3. The human aspect must be integrated into the design frum the very beginning. Appropriate guidelines for human engineering should be established by RSR to obtain equipment characteristics which facilitate error-free and safe performance of operation, control and maintenance tasks. Figures 1 and 2 illustrate this process. The designers must consider what tasks are to be performed because this determines the training. From this will come training plans, procedures and the appropriate testing and evaluation activities.

   Consideration may have to be given to the use of scaled mockups of control rooms and other critical plant features to determine how best humans can operate in the nuclear plant.

4. Supplementary to the NRR and RES/PAB programs there should be an overall program to establish the guidelines for control room and plant designs and information systems with the view of minimizing human errors through improved design practices and procedures.

5. OMIPC should establish a comprehensive, unified reference data base on human reliability as it relates to nuclear power plants. NRR and IE should be involved in the evaluation and interpretation of the data. This data base should include:

   . operator reliability

   . maintenance personnel reliability

   . test personnel reliability

   . administrative control personnel reliability

The data base may be developed through a combination of:

- data from safety-related occurrences
- data from related programs (only as directly applicable)
- experiments with operators under pre- and post-accident conditions (including allowance for psychological aspects and the "successive error" problem).
- evaluation of the differences in plant designs, operations and accident situations.

From the foregoing five items, it should be possible to set up three study programs as follows:

Study 1: Testing Procedures (item 1 above)(IE lead)

Study 2: Design, interfaces and guidelines (items 2-4 above) (RSR lead). This study could conceivably be a three-step process leading to the guidelines.

Study 3: Establish a data base (item 5 above) (OMIPC lead)

It is recommended that most or all of these studies be done by competent aerospace or military firms, using nuclear consultants as needed. The reasons for this recommendation are:

- These firms have more experience in the human engineering field.
- These firms would bring a fresh viewpoint to the studies.

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References:

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4. R. M. Gagné (ed.), Psychological Principles in System Development (N.Y.: Holt, Reinhart and Winston, 1962).

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6. W. E. Woodson and D. W. Conover, Human Engineering Guide for Equipment Designers, 2nd ed. (University of California Press, 1966).

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8. E. Grandjean, Fitting the Task to the Man, An Ergonomic Approach (London: Taylor and Francis, Ltd, 1969).

9. R. L. Scott and R. B. Gallaher, Annotated Bibliography of Safety-Related Occurrences in Nuclear Power Plants as Reported in 1973, ORNL-NSIC-114, November 1974.

10. R. L. Scott and R. B. Gallaher, Annotated Bibliography of Safety-Related Occurrences in Nuclear Power Plants as Reported in 1974, ORNL-NSIC-122, May 1974.

11. "A Summary of Program Emphasis for 1975", Electric Power Research Institute, 1975.

12. A. D. Swain, "Preliminary Human Factors Analysis of Zion Nuclear Power Plant", Sandia report (unpublished), February 1975.

13. "Browns Ferry Nuclear Plant Fire," Hearings before the Joint Committee on Atomic Energy, September 16, 1975, pp. 25-26.

14. Recommendations Related to Browns Ferry Fire, Report by Special Review Group, NUREG-0050 (February 1976).

ATTACHMENT 1

SCOPE OF WORK

ANALYSES OF CONTROL ROOM DISPLAYS AND OPERATOR PERFORMANCE

BACKGROUND

Study and functional analyses are needed of the human engineering features and related accessibility to control devices in control centers of nuclear power plants. Modifications to current practices may be needed to adequately accommodate the needs under the more extreme incident and accident conditions which require added human operator initiative and performance. An objective and thorough appraisal must include the desired performance of operators under postulated high stress conditions within a limited timeframe environment; attendant features of control centers that would enhance human performance under such conditions should be established. Such an assessment may be expected to provide recommended methods of control room design and operating procedures that will enhance significantly the effectiveness of the reactor operator during postulated accident conditions.

Studies and functional analyses shall be conducted to synthesize recommendations for the desired control room layout and design to better assure the desired performance of human operators under postulated accident conditions in nuclear power plants. These evaluations shall include factors such as control board layout, data acquisition, information display, operating procedures, and human operator performance requirements under conditions of high stress.

Specific items to be included in these evaluations are indicated below.

1. An assessment of control board layout of the controls for redundant engineered safety systems. With or without panel graphics, these controls may be located as discrete side-by-side fully separated display arrays, or as redundant superimposed arrays, or as widely separated discrete control panel arrays.

2. An assessment and trade-off of using single or dual purpose displays and controls for plant equipment used for both normal operation and during postulated accidents.

3. An assessment of the current trend from more conventional information display and full size controls compared to computer control and Cathode Ray Tube display and recall techniques for postulated accident conditions.

4. An evaluation of the desirability of using selected shape, size, array, color, and other physical features of controls for use under postulated plant upsets and accidents.

5. An assessment of the human factors relevant to operator performance requirements under postulated accident conditions; and establish the likelihood of human errors under these high stress conditions considering selected ambiguous displays of information.

The methods of systems analyses to be used in evaluating control room design and attendant human factors shall be selected with the approval of cognizant NRC staff.

TABLE 1 (REF. 9)

Classification of BWR problems by cause, deficiency, and time of occurrence

	Percent	Number
Cause		
Maintenance	33.7	119
Design	23.8	84
Operator error	12.2	43
Administrative error	11.0	39
Installation error	10.8	38
Fabrication error	5.9	21
Construction error	2.5	9
Deficiency		
Switch set-point drift	31.8	88
Lea	15.5	43
edures	13.7	38
Vibration	5.1	14
Fish kill	4.7	13
Radioactivity release	4.3	12
Welds	3.6	10
Dirt	2.9	8
License violation	2.5	7
Debris	2.2	6
Corrosion	2.2	6
Lubrication	2.2	6
Personnel exposure	2.2	6
Instrument calibration	1.8	5
Lightning	1.4	4
Quality assurance	1.1	3
Communication	0.7	2
Fuel densification	0.7	2
Water hammer	0.4	1
Loose fitting	0.4	1
Stress corrosion	0.4	1
Storm	0.4	1
Time of occurrence		
Testing	47.3	247
Operation	38.9	203
Inspection	10.5	55
Construction	1.9	10
Preoperational	1.4	7

TABLE 2 (Ref. 9)

Classification of PWR problems by cause, deficiency, and time of occurrence

	Percent	Number
Cause		
Design error	22.6	77
Administrative error	19.4	66
Operator error	17.1	58
Fabrication error	15.6	53
Maintenance error	13.2	45
Installation error	7.6	26
Construction error	4.4	15
Deficiency		
Welds	13.5	28
Quality assurance	13.0	27
Procedures	13.0	27
Leak	10.6	22
Personnel exposures	7.2	15
Radioactivity release	6.7	14
Fuel densification	6.3	13
Vibration	6.3	13
License violation	4.8	10
Corrosion	4.8	10
Weather	3.4	7
Fire	2.9	6
Stress corrosion cracking	1.4	3
Lubrication	1.4	3
Set-point drift	1.4	3
Storage	1.0	2
Communication	0.5	1
Geologic fault	0.5	1
Dirt	0.5	1
Water hammer	0.5	1
Earthquake	0.5	1
Time of occurrence		
Operation	39.2	161
Testing	23.9	98
Construction	17.6	72
Inspection	12.9	53
Preoperational	6.3	26

TABLE 3 (Ref. 10)

Classification of BWR problems by cause, deficiency, and time of occurrence

	Percent	Number
Cause		
Design error	23	154
Maintenance error	21	143
Equipment failure	16	105
Operator error	13	85
Installation error	10	65
Administrative error	8	54
Fabrication error	8	53
Construction error	1	8
Weather	<1	6
Lightning	<1	2
Tornado	<1	1
Deficiency		
Set-point drift	26	142
Leak	15	81
Procedures	9	48
Vibration	7	36
Debris	5	26
Failure to test	4	24
Radioactivity release	4	21
Calibration error	4	21
Welds	4	21
Loose screws	3	16
Corrosion	3	16
Coolant chemistry	2	13
Moisture	2	10
Lubrication	2	10
Stress corrosion	1	8
Erosion	1	8
Failure to follow procedures	1	7
Water hammer	1	7
Quality assurance	1	5
Detonation	1	4
Fatigue	<1	3
Personnel exposure	<1	3
Thermal pollution	<1	3
Loose connection	<1	2
Radiation damage	<1	1
Fire	<1	1
Time of occurrence		
Startup testing	31	284
Testing after going commercial	30	279
Operation	26	246
Inspection	10	97
Construction	2	17
Preoperational	1	12

TABLE 4 (Ref. 10)

Classification of PWR problems by cause, deficiency, and time of occurrence

	Percent	Number
Cause		
Design error	21	112
Operator error	18	96
Maintenance error	17	87
Administrative error	13	66
Equipment failure	10	53
Installation error	8	44
Fabrication error	7	37
Construction error	4	21
Weather	2	10
Deficiency		
Leak	15	69
Procedures	13	60
Radioactivity release	10	45
Welds	8	38
Set-point drift	7	34
Coolant chemistry	7	32
Vibration	5	25
Corrosion	4	19
Debris	4	18
Quality assurance	3	16
Fish kill	2	11
Failure to test	2	11
Calibration error	2	10
Personnel exposure	2	9
Loose screws	2	8
Fire	2	8
Lubrication	2	8
Water hammer	2	7
Fatigue	1	6
Citation	1	6
Erosion	1	5
Stress corrosion	1	4
Loose connection	1	4
Security	<1	2
Geological fault	<1	2
Explosion	<1	1
Improper storage	<1	1
Moisture	<1	1
Time of occurrence		
Operation	41	330
Startup testing	22	177
Testing after going commercial	20	157
Construction	8	67
Inspection	6	46
Preoperational	3	21

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TABLE 5 (Ref. 6)

MAN VS. MACHINE

MAN EXCELS IN	MACHINES EXCEL IN
Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Detecting signals in high noise levels	Exerting great force, smoothly and with precision
Ability to store large amounts of information for long periods — and recalling relevant facts at appropriate moments	Storing and recalling large amounts of information in short time-periods
Ability to exercise judgment where events cannot be completely defined	Performing complex and rapid computation with high accuracy
Improvising and adapting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (infrared, radio waves, etc.)
Ability to react to unexpected low-probability events	Doing many different things at one time
Applying originality in solving problems; i.e., alternate solutions	Deductive processes
Ability to profit from experience and alter course of action	Insensitivity to extraneous factors
Ability to perform fine manipulation, especially where misalignment appears unexpectedly	Ability to repeat operations very rapidly, continuously, and precisely the same way over a long period
Ability to continue to perform even when overloaded	Operating in environments which are hostile to man or beyond human tolerance
Ability to reason inductively	

TABLE 6 (Ref. 6)

LEVELS OF ANALYSIS AND SOME RELATED TECHNIQUES

LEVEL OF ANALYSIS	PURPOSE	APPLICABLE TECHNIQUE
System	To determine effectiveness of system in performing a specified mission	Operations-research methods[illegible]
Subsystem	To determine best way of meeting a specified requirement of the mission	System analysis Integration matrix
Function	To determine best combination of components required to make up subsystem	Man-machine system analysis[illegible] Function analysis
Task	To determine best allocation of man's capabilities to perform required functions	Task analysis Time-line analysis[13] Logic models[20, 27] Information theory[illegible]
Subtask	To determine best method of utilizing man's capabilities to perform the assigned tasks	Operator load analysis[illegible] Operator sequence diagrams Decision theory Information-flow analysis
Element	To determine best method of utilizing man's capabilities to perform assigned subtasks	Time-and-motion analysis Elemental task analysis

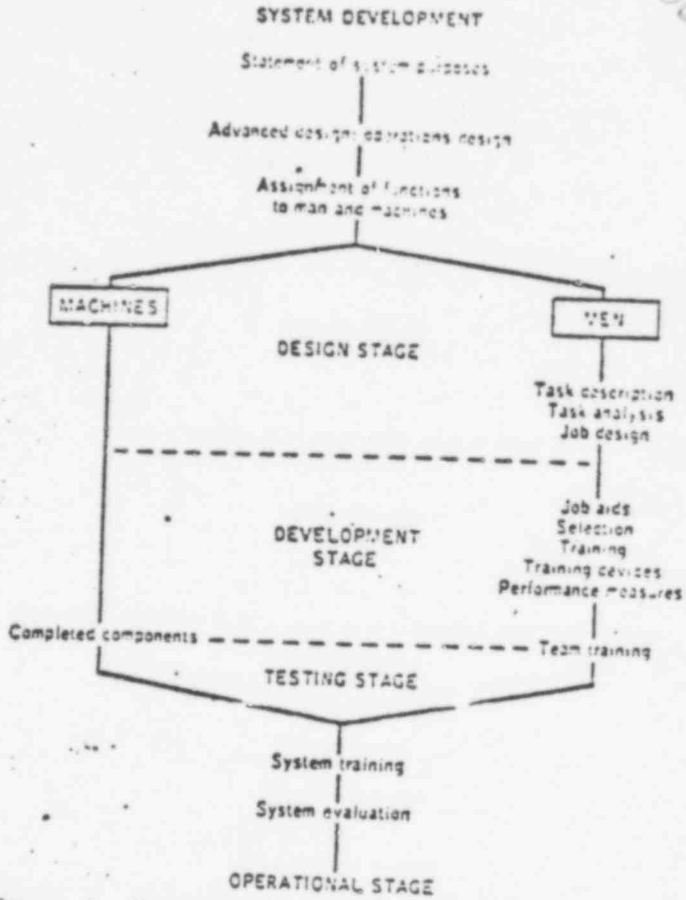

Figure 1. The procedures used in the development of human components of systems, and their order of initiation, in relation to the stages of system development. Procedures used for equipment development are not shown in detail. (Ref. 4)

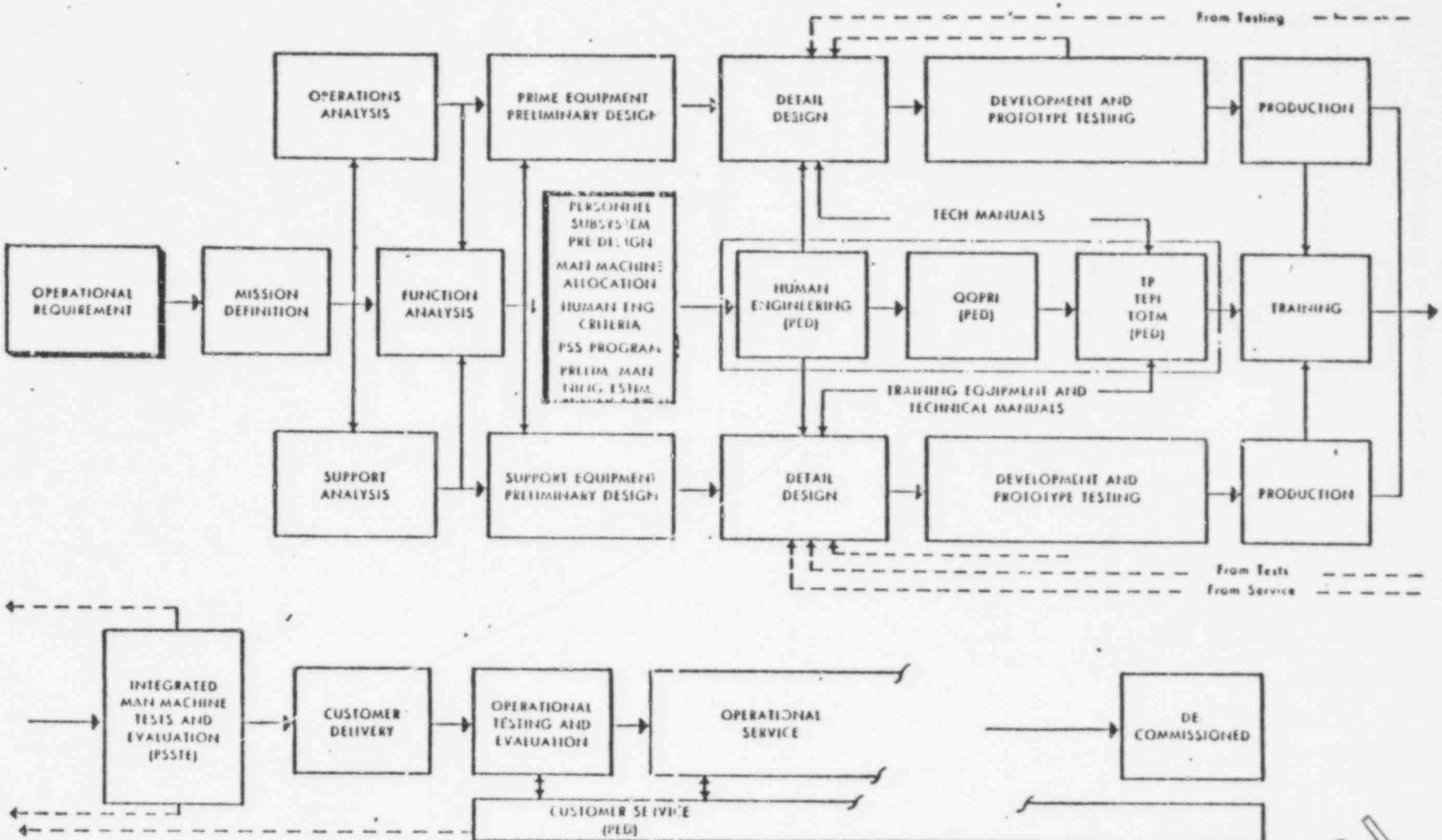

FIGURE 2. A TYPICAL MANNED WEAPON-SYSTEM DEVELOPMENT MODEL SHOWING THE PSS CONCEPT INTERACTION WITH EQUIPMENT DEVELOPMENT

(Ref. 6)

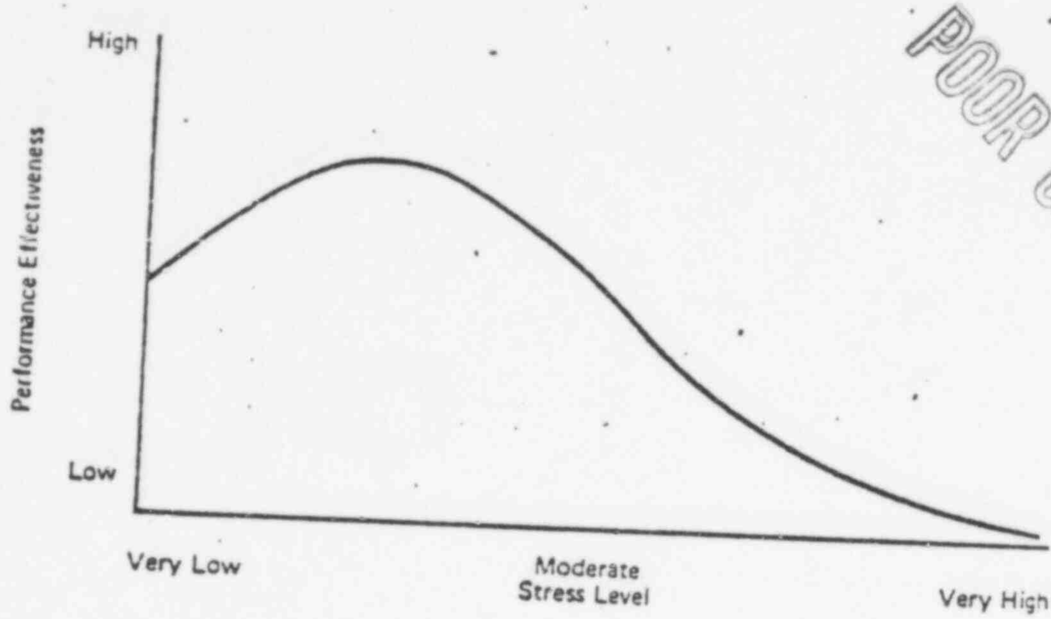

FIGURE 3 Hypothetical Relationship between Performance and Stress (ref. 1)