

Response to
Request for Additional Information No. 328, Supplement 3

11/17/2009

U. S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 18 - Human Factors Engineering
Application Section: FSAR Ch 18

QUESTIONS for Operating Licensing and Human Performance Branch
(AP1000/EPR Projects) (COLP)

Question 18-53:

It is the FSAR that the staff evaluates to make a safety determination. Therefore, the FSAR should contain all information (either directly or by reference) the staff uses in its evaluation. A reference to the submitted HFE Design Implementation plan (document no. 118-9047891-001) was not provided in the U.S. EPR FSAR. Include this reference in the FSAR, or clarify why a reference to this document is not, and will not be, included in the FSAR.

Response to Question 18-53:

The Response to RAI 322, Supplement 1, Question 18-52 revised U.S. EPR FSAR Tier 2, Chapter 18 to include references to the U.S. EPR Human Factors Engineering (HFE) Design Implementation Plan and the other referenced HFE implementation plans.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-54:

In the HFE Design Implementation Plan, various steps throughout the plan instruct the Responsible HFE Engineer to "audit" various documents. In some steps within each section, as in section 3.7.1 for instance, it explicitly gives guidance to "Audit all...", but in other sections it just says "audit." Clarify what the implementation plan is communicating with the word "audit", and indicate if there is a particular process associated with the audit that differs from any indicated in the implementation plan.

Also, when no particular audit process is specified (when the word audit appears by itself), does the Responsible HFE Engineer "audit all," or is a sample taken of the relevant material to be audited? If sampling is conducted, how is the sample size determined, and what process is used to determine the design aspects to be sampled? Provide clarifying information detailing the scope of the audit term within the implementation plan.

Response to Question 18-54:

For this implementation plan, "audit" means to compare design documentation with the as-built design to verify that the as-built design matches the plant design, including any design modifications resulting from verification and validation (V&V) activities. An audit confirms that the reviewed sample data is representative and that designs, including design modifications, have been appropriately implemented. There is not an audit process that is different from or represents a departure from the intent of the human factors engineering (HFE) Design Implementation Plan.

The term "audit all" is a misnomer for HFE design implementation because a carefully constructed representative sampling technique is used. HFE issue tracking system (HITS) items and the resolution of human engineering discrepancies (HED) are confirmed (audited) for resolution and implementation. The word "review" will replace "audit all" because the HFE issue resolutions are evaluated as a part of design implementation.

Because the term "audit" does not inherently mean all, the sampling process named operational conditions sampling (OCS) is described in the Response to Question 18-70 and in the latest revision of the U.S. EPR V&V Implementation Plan (IP), and is used to define the sample process. This verifies that the as-built design is reviewed to conform with U.S EPR plant design criteria.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-55:

Section 3.1.1 of the HRA Implementation Plan (IP) provides RAW and FV criteria for the risk-significant human actions (R-S HAs) relative to the Level 1 PRA. It further states that "Similar risk-importance metrics are produced by the Level 2 PRA results, except that the criterion for risk-significance is associated with large release frequency (LRF) instead of CDF." For clarity, provide the specific criterion for LRF risk-significance noted in the IP.

Response to Question 18-55:

The following information will be added to the U.S. EPR Implementation Plan for the Integration of Human Reliability Analysis (HRA) into the Human Factors Engineering (HFE) Program:

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The schedule for providing the revised U.S.EPR HRA Implementation Plan is provided below:

Document Number	Commitment Date
U.S.EPR Implementation Plan for the Integration of Human Reliability Analysis (HRA) into the Human Factors Engineering (HFE) Program	4/17/2010

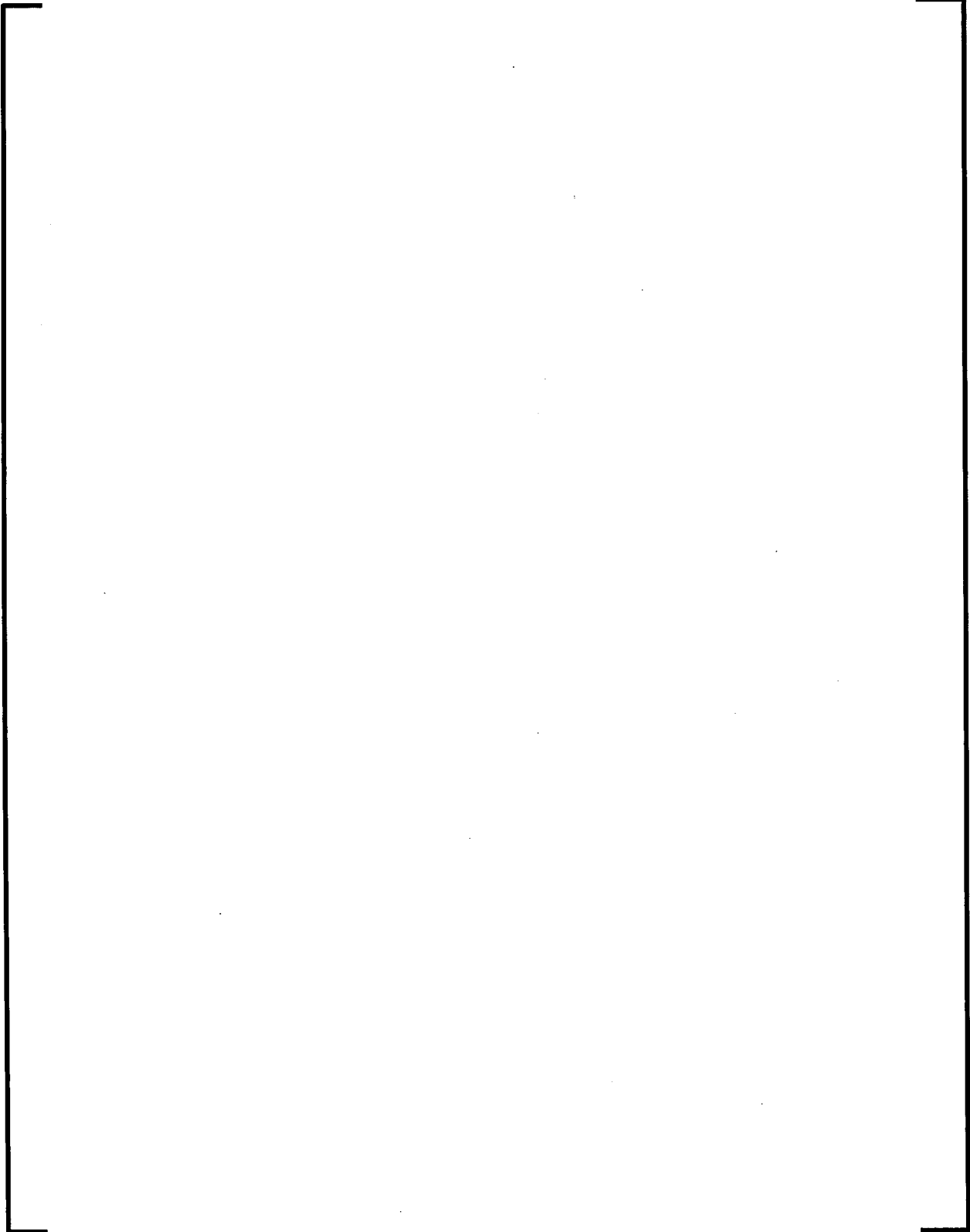
FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-56:

1. NUREG-0711 Section 7.4 (1) specifies that risk important actions be developed from the Level 1 (core damage) PRA for internal and external events. Section 3.1.1 of the HRA IP states that human errors are considered risk-significant if they meet defined RAW and FV values. Clarify that these will include human actions from both the "PRA for Operations at Power" and the "PRA for Other Modes of Operation," namely low power and shutdown operations.
2. NUREG-0711 Section 7.4 (1) specifies that risk important actions be developed from the Level 1 (core damage) PRA for internal and external events. Section 3.1.1 of the HRA IP states that human errors are considered risk-significant if they meet defined RAW and FV values. Clarify that these will include human actions from the external events PRA.
3. Section 3.1 of the HRA IP states that "The HRA will be performed iteratively during the design process." It also states that "New items analyzed during the design process determined through HRA to have *unacceptable risk* will be sent back through the HFE design process along with the applicable performance shaping factors as candidates for design changes." Provide the measure and threshold for *unacceptable risk* as used in this context.
4. NUREG-0711 Section 7.4 (1) specifies that risk important human actions should be identified. Section 1.5 of the HRA IP in the definition of risk-significant human actions states that the initial list of these actions is located in Appendix B; but App. B is not included in Rev. 2. Appendix A of the HRA IP contains a Table titled U.S. EPR HRA Risk-Significant Human Actions, but it is blank and notes that "list to be developed by PRA/HRA." It appears that there are currently HFE activities in progress that need the list as input. Review of FSAR, Chap. 19, Rev. 0 shows tables of HAs with RAW and FV values. Provide a copy of the most current consolidated list of risk-significant human actions.
5. NUREG-0711 Section 7.4 (2) specifies that risk-important HAs should be addressed in (among others) task analyses (TA). Section 1.2.1.4 of the HRA IP addresses input to TA from the HRA. Clarify the HRA IP to specify that there will be a task analysis performed for each R-S HA.
6. NUREG-0711 Section 7.4 (2) specifies that risk-important HAs should be addressed in (among others) procedure development. Clarify the HRA IP to specify that each R-S HA will be addressed in the EPR procedure system.
7. NUREG-0711 Section 11.4.1.2.1 (2) states that all risk-important HAs should be included in the operational conditional sample for developing V&V scenarios. Section 1.2.1.9 of the HRA IP only states that the R-S HAs will be "considered." The HRA IP, Section 3.4, item 3 states that V&V includes test scenarios that assess each R-S HA. Clarify Section 1.2.1.9 to agree with the other references and state that all R-S HAs will be addressed in V&V. Also, add to FSAR Section 18.6.2, last paragraph, that fact that all R-S HAs will be addressed in integrated system validation scenarios.
8. Section 1.2.1.10 of the HRA IP states that the U. S. EPR™ HFE program will require developing construction staging and commissioning plans, including use of a temporary control room during construction. Clarify any use of such a temporary control room and when it would be used.
9. Add the HRA IP as a reference to FSAR Section 18.6.4.

Response to Question 18-56:

A large empty rectangular box with a black border, intended for the response to Question 18-56. The box is currently blank, with no text or graphics inside.

The schedule for providing the revised U.S. EPR Implementation Plans is provided below:

Document Number	Commitment Date
U.S.EPR Implementation Plan for the Integration for Human Reliability Analysis (HRA) into the Human Factors Engineering (HFE) Program	4/17/2010
U.S.EPR HFE Procedure Implementation Plan	3/18/2010

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 18.6.2 will be revised as described in the response and indicated on the enclosed markup.

Table 18-56-1—Risk-Significant Human Actions (2 sheets)

Table 18-56-1—Risk-Significant Human Actions (2 sheets)

Question 18-57:

Section 13.4 of NUREG-0711 Criterion 1 outlines the expected scope for the human performance monitoring program. The criterion states that the performance monitoring strategy should provide reasonable assurance that:

1. The design can be effectively used by personnel, including within the control room and between the control room and local control stations and support centers
2. Changes made to the HSIs, procedures, and training do not have adverse effects on personnel performance
3. Human actions can be accomplished within time and performance criteria
4. The acceptable level of performance established during the integrated system validation is maintained.

Sections 1.3 and 1.4 of the U.S. EPR Human Performance Implementation Plan outlines the scope of the human performance monitoring (HPM) program, and states that monitoring of human performance continues throughout the life of the plant. HPM ensures that the results of the integrated system validation are maintained throughout the life of the plant and that operator performance does not degrade over time. HPM also ensures that issues discovered by personnel are noted, tracked and corrected before plant safety is compromised, and that changes made to the U.S. EPR design do not result in a degradation of human performance. The HPM implementation plan says that the HPM program will ensure that the design can be effectively used by personnel not only in the control room, but also between the control room and local control stations and support centers. The plan will also ensure that changes made to the HSIs, procedures, and training do not adversely affect performance. The plan continues to say that the program will ensure that human actions can be accomplished within the time frame and performance criteria defined in the HRA, and that the acceptable level of performance established during the integrated system verification is maintained. Additionally, the HPM program will ensure that degrading human performance is detected before plant safety is compromised and that identified errors in the design are resolved in a timely manner.

It is unclear to the staff how the implementation plan will ensure that the design can be used effectively over time, how the plan will ensure that changes made to the HSIs, procedures and training do not adversely affect plant performance, or how the HPM program ensures that human actions can be accomplished within the time frame and performance criteria defined in the HRA.

Clarify the scope of the HPM implementation plan and how the program will "ensure" the identified items.

Response to Question 18-57:

The schedule for providing the revised U.S.EPR Human Performance Monitoring Plan is provided below:

Document Number	Commitment Date
Human Performance Monitoring Implementation Plan	4/24/2010

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 18.12.1 will be revised as described in the response and indicated on the enclosed markup.

Question 18-58:

NUREG-0711 Section 13.4, Criterion 2 states that a human performance monitoring strategy should be developed and documented.

Section 18.12.2 of the U.S. EPR FSAR lists several tools which will be developed to track issues. One tracking tool is a corrective action program (CAP) combined with a means for tracking issues to allow design errors, issues, operator workarounds, operators burdens, and inefficiencies to be captured and addressed. Both the implementation plan and the FSAR describe an operational focus index that will be used to trend performance of an operator's day to day activities.

Several tracking programs are discussed throughout the implementation plan. These include a corrective action program, an HFE tracking system and the operational focus index.

1. The staff requires more information regarding the use of the operational focus index. It is not clear whether this tracking system is used in conjunction with the corrective action program, or if it is a separate tracking database.
2. Clarify the relationship between the operational focus index, the Appendix B CAP program, the QA database described in the V&V plan, and the HFE tracking system. Describe who uses them, how information is captured and what happens with the results.
3. Section 3.1 of the implementation plan implies that the U.S. EPR operators can "choose" to use a separate HFE tracking system or the current corrective actions database. These tracking systems are discussed interchangeably throughout the implementation plan. Section 3.1 also states that to ensure all issues are captured, plant personnel are encouraged to report errors, deficiencies, workarounds, and design inefficiencies. The Appendix B CAP would "require" rather than "encourage" personnel to report errors, deficiencies, workarounds, and design inefficiencies. It is unclear whether use of the Appendix B CAP is mandatory.
4. Clarify the difference between the required appendix B CAP and the HFE tracking system. If there is no difference between them, what is meant by the word "choose?"

Response to Question 18-58:

The schedule for providing the revised U.S.EPR Human Performance Monitoring Plan is provided below:

Document Number	Commitment Date
Human Performance Monitoring Implementation Plan	4/24/2010

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 18.12.2.5 will be revised as described in the response and indicated on the enclosed markup.

Question 18-59:

Criterion 2 of NUREG-0711 section 13.4 says that a human performance monitoring strategy should be developed and documented. The Human Performance Monitoring Implementation Plan refers in several places to both an operator focus index and an operational focus index.

Clarify the inconsistent use of this terminology, i.e., operator focus index vs. operational focus index.

Response to Question 18-59:

The term "operational focus index" and "operator focus index" are indications of plant performance from an operational perspective. These terms are being renamed to performance indication. U.S. EPR FSAR Tier 2, Section 18.12.2.5 and the U.S. EPR Human Performance Monitoring Implementation Plan will be revised to reflect the use of this information to form a performance indication (PI) terminology. The definition and outline of this is renamed in the U.S. EPR Human Performance Monitoring Implementation Plan, Section 3.3.

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 18.12.2.5 will be revised as described in the response and indicated on the enclosed markup.

Question 18-60:

Criterion 3 of NUREG-0711 Section 13.4 states:

The (HPM) program should be structured such that:

- human actions are monitored commensurate with their safety significance
- feedback of information and corrective actions is accomplished in a timely manner
- degradation in performance can be detected and corrected before plant safety is compromised

Section 3.1 of the HPM Implementation Plan discusses the role of the HFE tracking system and the corrective action program with regard to the HPM. Once an issue is identified and is entered into the database or tracking system, a cognizant engineer performs an analysis to determine safety-significance. Issues deemed to have high safety-significance are analyzed further and corrective actions are promptly generated to ensure plant safety isn't compromised.

Provide information as to the guidance and training the "cognizant" engineer will receive to perform this analysis, to include details on how the analysis will be performed.

Provide information as to the guidance and training the "cognizant" engineer will receive to perform this analysis, AND include details on how the analysis will be performed.

Response to Question 18-60:

The analysis is performed by the human reliability analysis (HRA) personnel. This is described in the U.S. EPR Implementation Plan for the integration of human reliability analysis (HRA) with the human factors engineering (HFE) program. The human performance monitoring implementation plan will be revised for clarification.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-61:

Section 11.3 of NUREG-0711 states:

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for HFE V&V. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's V&V evaluations using the criteria provided in Section 11.4 below.

The FSAR Revision 2 should incorporate an explicit reference of the V&V Implementation plan. The specific implementation plans, used as the basis of the staff's safety determination, should be referenced in the FSAR.

Response to Question 18-61:

The Response to RAI 322, Supplement 1, Question 18-52 revised U.S. EPR FSAR Tier 2, Chapter 18 to reference the U.S. EPR Human Factors Engineering (HFE) Verification and Validation (V&V) Implementation Plan (IP) and the other referenced HFE implementation plans.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-62:

This Question indicates insufficient information in the V&V Implementation Plan for the general principal derived from NUREG-0711. This is followed by specific examples that arose because the information provided was insufficient for the review. The examples provided do not comprise a complete set of issues for each category. Rather, they are used to illustrate the general issue caused by the missing information. It is the responsibility of the Applicant to apply the general principals illustrated by staff in the examples to determine the full-scope of issues affected by the missing information.

Level of Detail. Many of the details provided essentially restate NUREG-0711 review criteria. The staff cannot perform an implementation plan review when the plan simply restates the staff's review criteria. The NUREG-0711 criteria are used to review information provided by the applicant. For example, the plan should identify the operational conditions to be used for V&V and the process by which the sampling dimensions were used to identify them. The staff can then use the NUREG-0711 criteria to review the acceptability of the operational conditions that have been identified. In many cases, the information currently provided in the plan will be used to *finalize the plan* at a later date. Thus, the IP should contain, for example: an identification of the specific scenarios to be used, the detailed definition of each, the specific performance measures to be used for each scenario and the acceptance criteria to be used for each measure, the measures that will be used to validate or invalidate the design, and the ways in which the data will be analyzed to arrive at conclusions. Examples where more details are required include, but are not limited to:

1. Section 18.10.3.4.3 of the FSAR discusses situational related performance shaping factors. This section closely rephrases the guidance provided in NUREG-0711, provided above. The section does indicate that multitasking is an example of high workload conditions. Section 3.5.1.3 of the V&V Implementation Plan closely quotes NUREG-0711; however it neglects discussion of the affects of fatigue and circadian rhythms. Provide discussion of the effects of fatigue and circadian rhythms in this context. Expand discussion of all sections that quote NUREG-0711. In that discussion, place emphasis on factors that are critical to EPR or possibly unique. Staff requests more information describing the incorporation of situational factors into test scenarios.
2. Section 18.10.3.4.21 of the FSAR provides some information regarding certain of the personnel tasks to be assessed. The FSAR states that sample tasks will include those tasks that are found to be difficult to design into the HSI, require significant compromise during the HSI design, and have the potential to cause error because of complexity. Section 3.5.1.2 of the V&V Implementation Plan is quoted almost verbatim from NUREG-0711, Section 11.4.1.2.1, and does not provide more explanation of the information provided in the FSAR. The staff cannot perform an implementation plan review when the plan simply restates the staff's review criteria. The plan should identify the operational conditions to be used for V&V and the process by which the sampling dimensions were used to identify them. The Staff cannot perform an implementation plan review when the plan simply restates the staff's review criteria. The plan should identify operational conditions to be used and how the operational conditions were developed into scenarios. More information is requested that will link the criteria for selection of Operational Conditions to the EPR PRA.
3. The basis of the information required in Section 18.10.3.4.21 of the FSAR for the identification of tasks that are difficult to design into the HSI, require significant compromise,

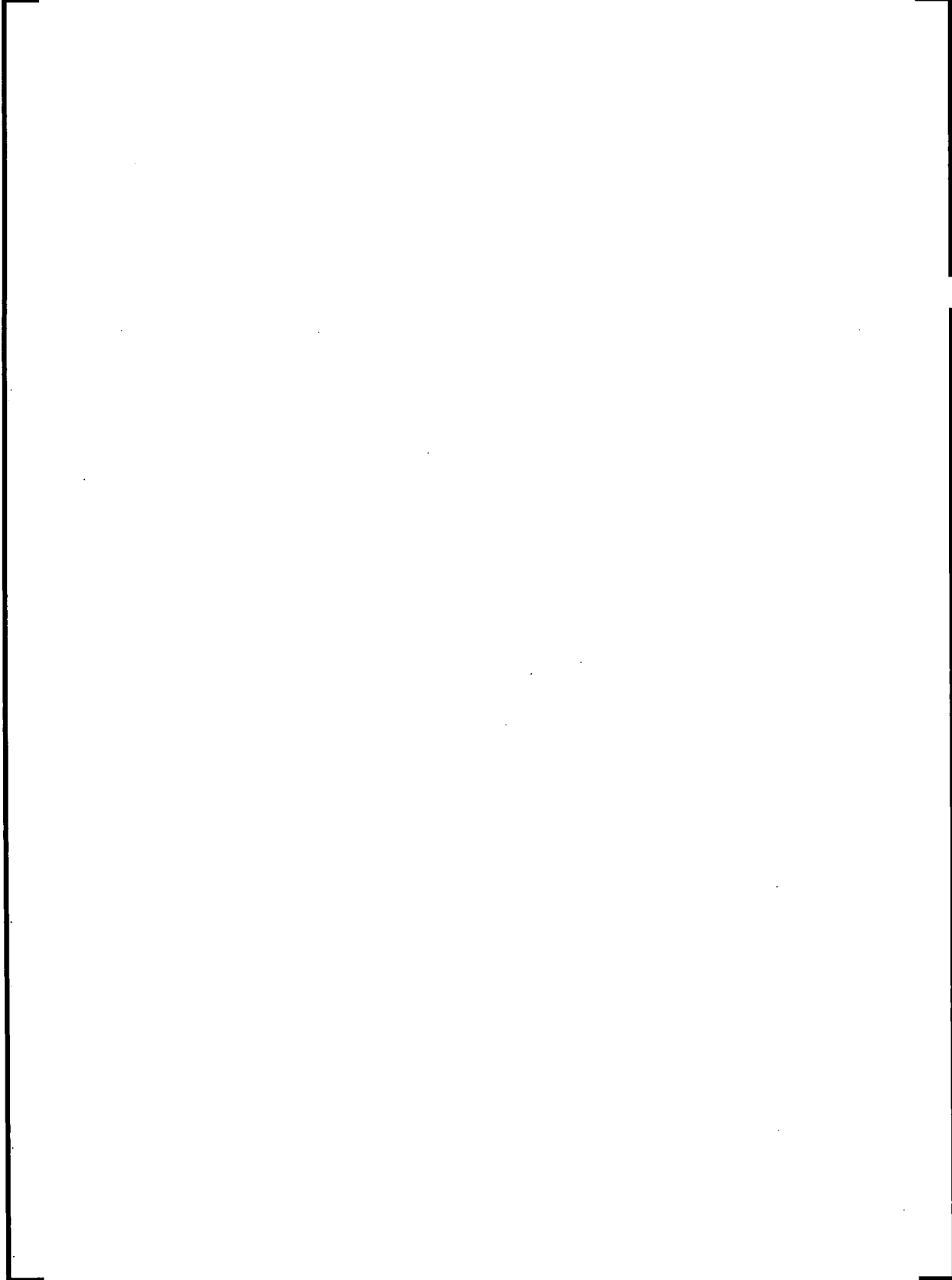
or are complex enough to cause errors is not clear to staff. The HRA Implementation plan is referenced; however, the section does not indicate how scenario development is related to the HRA Implementation Plan. It is not clear to staff which tasks will be used to assess the ability of the system to support a range of cognitive activities. More information is needed on these items. Staff also requires more information regarding the information shared during human interaction and communication methods of interest, the tasks being performed, and the complexity of the messages to be passed. Staff requires more information to determine how high frequency tasks will be identified.

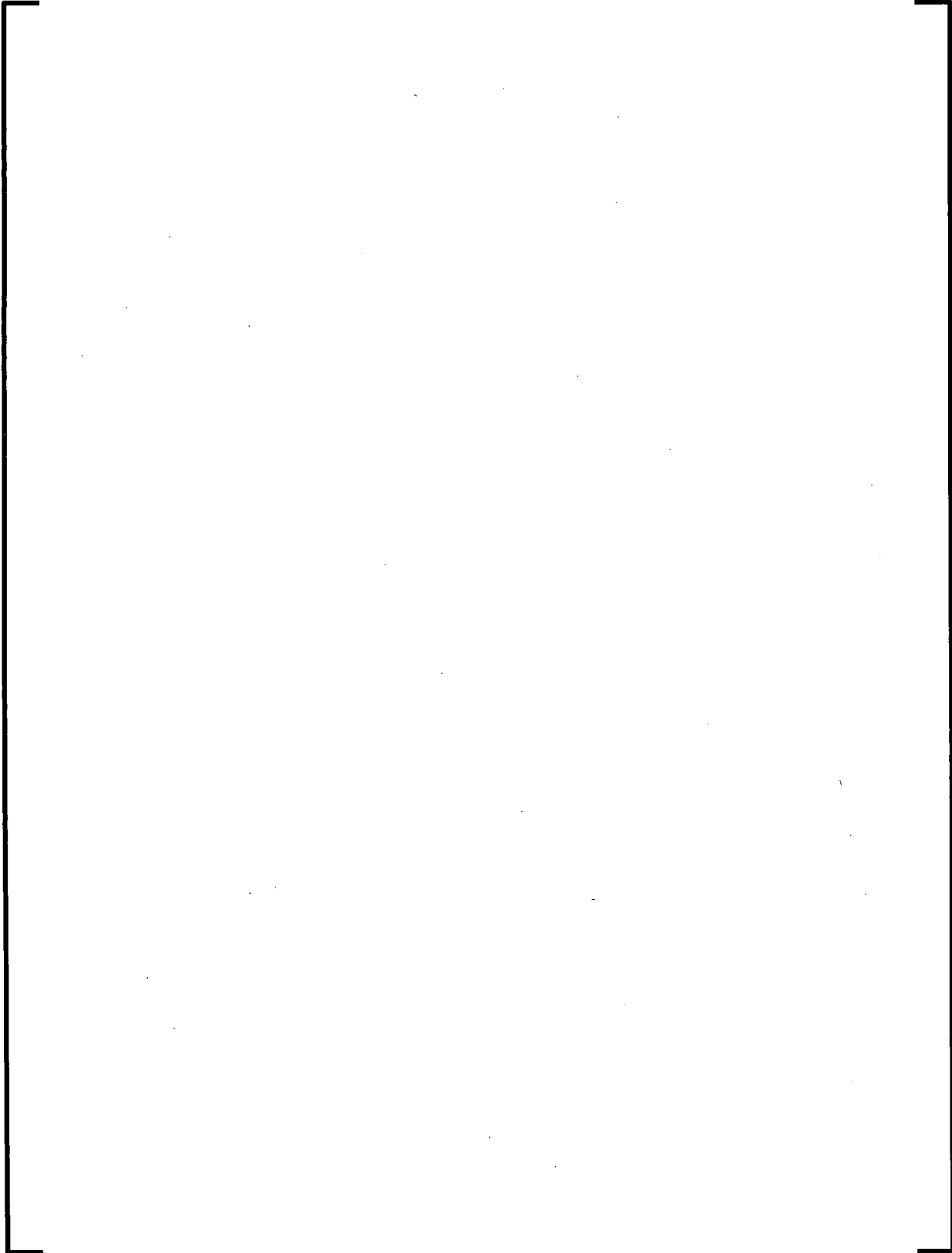
4. Determination and discussion of inclusion of environmental factors in scenarios are not provided with respect to the V&V Implementation Plan, beyond paraphrasing the NUREG-0711 guidance on environmental factors in Section 3.5.13 of the V&V Implementation Plan. Discussion of operations remote from or ancillary to actions in the control room is not provided with respect to scenario development. Staff request that the methods be expanded for inclusion of environmental effects, how they may be simulated, what may be simulated, the limitations of simulation, as well as evaluation of performance of operations remote from or ancillary to the main control room, and considerations relevant to that.

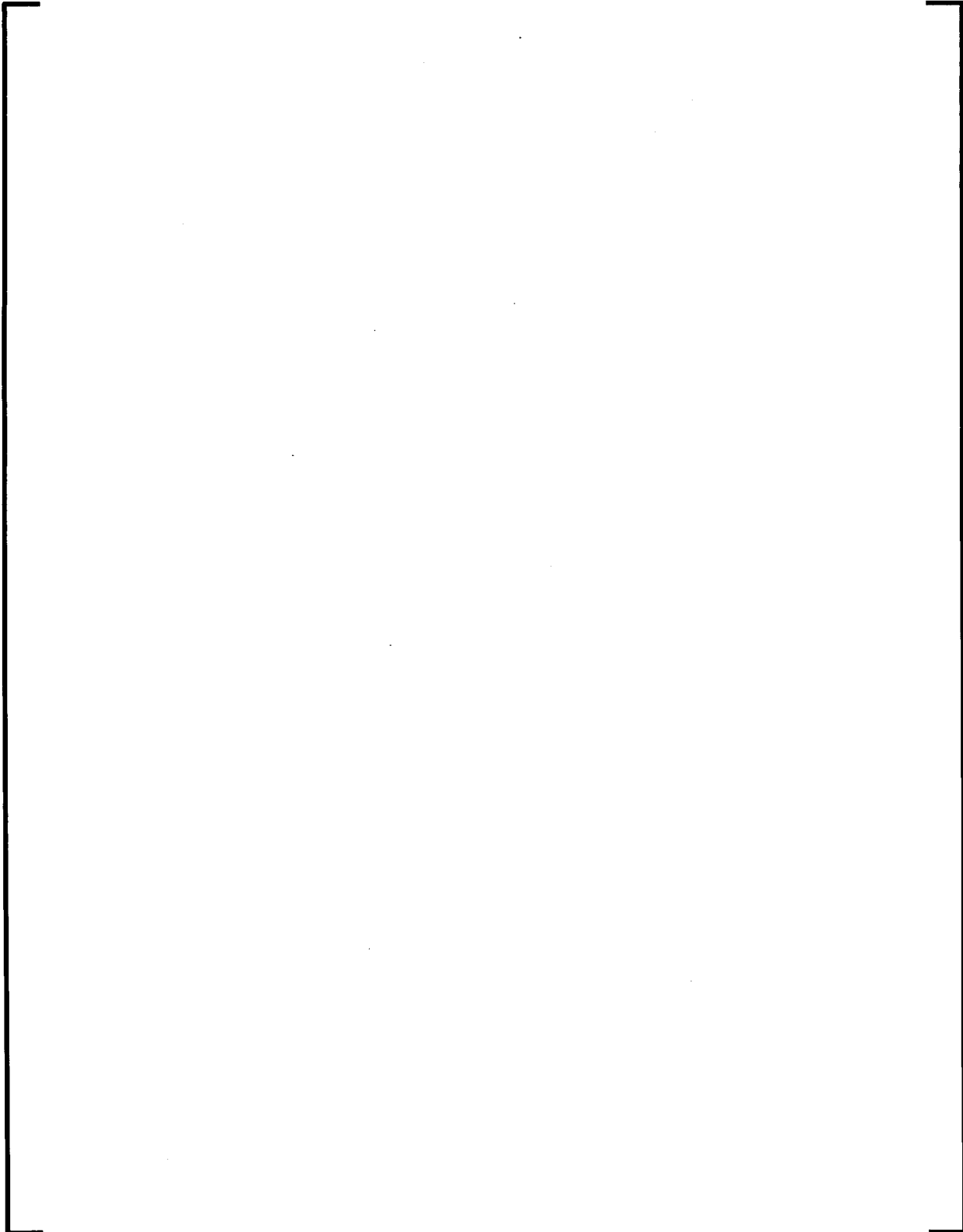
Response to Question 18-62:**Response to 18-62.1: *Situational Human Performance Shaping Factors***

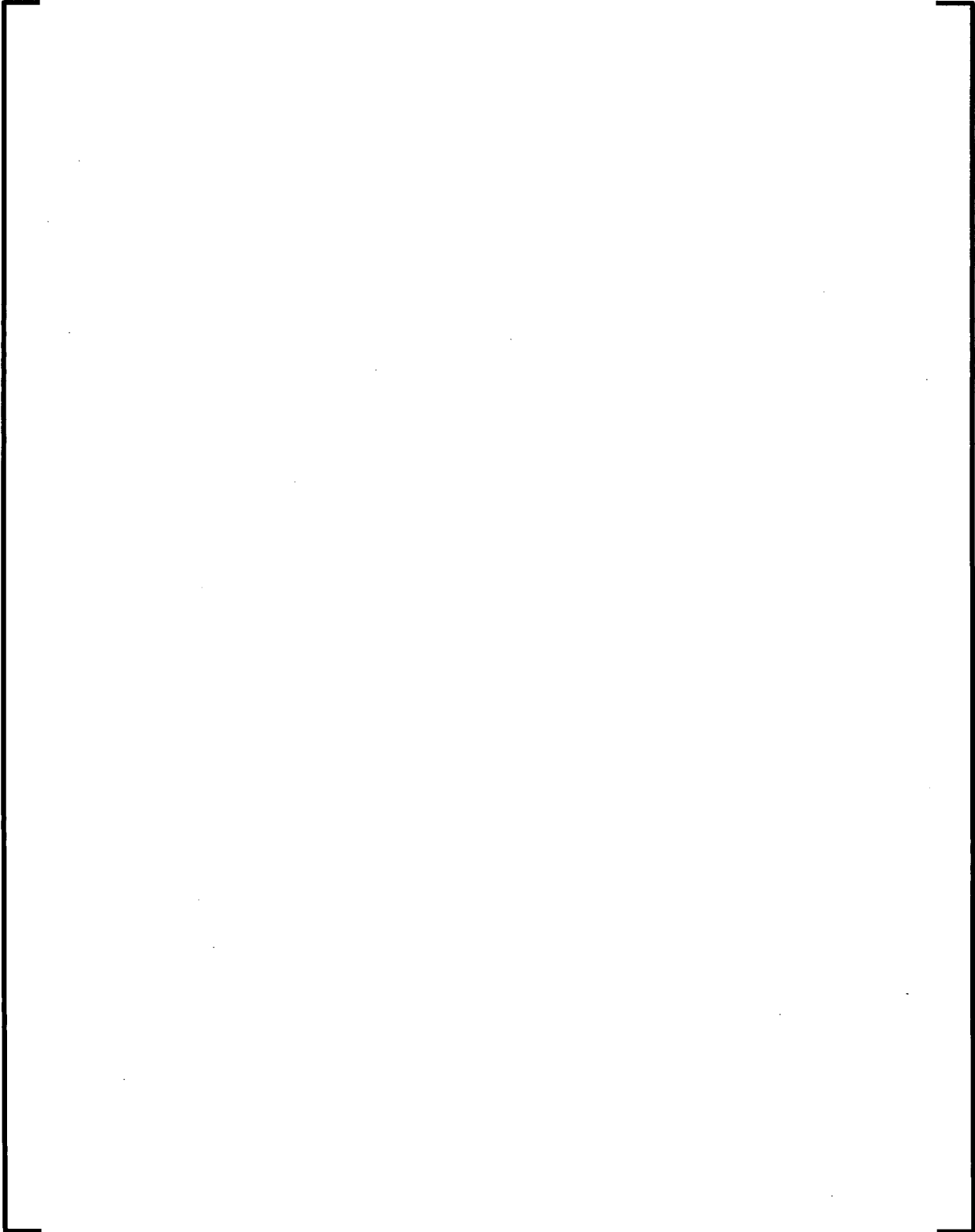
The six situational factors outlined by NUREG-0711 and incorporated into test scenarios are addressed individually. A brief basis and background are provided for each factor to support this response. The U.S. EPR's human factors engineering (HFE) and behavioral scientists recognize that at any time, these factors could be present or could emerge in conjunction with or is the result of other situational factors. These factors that challenge human performance can materialize at any time, in any plant mode, and may or may not be anticipated. [

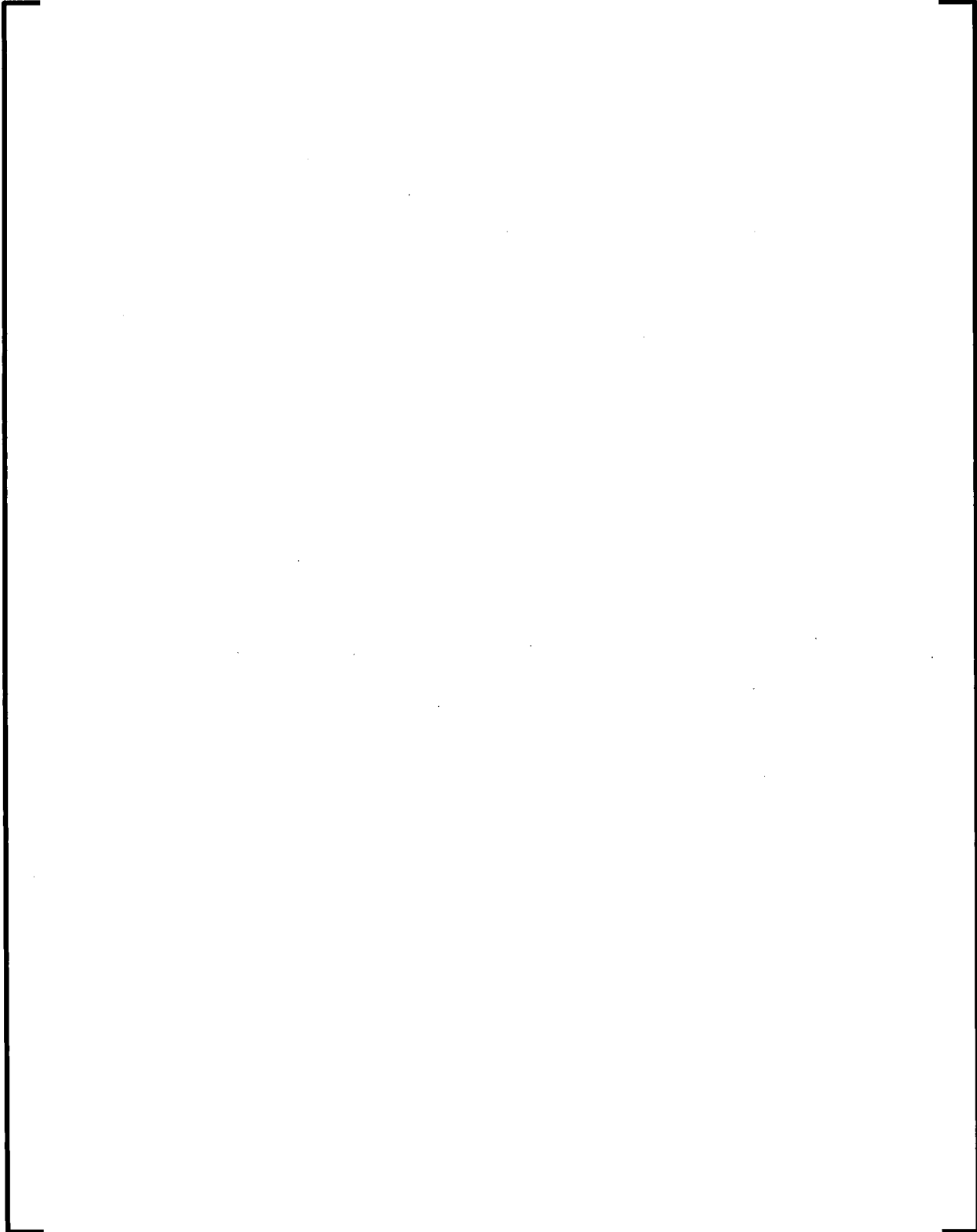
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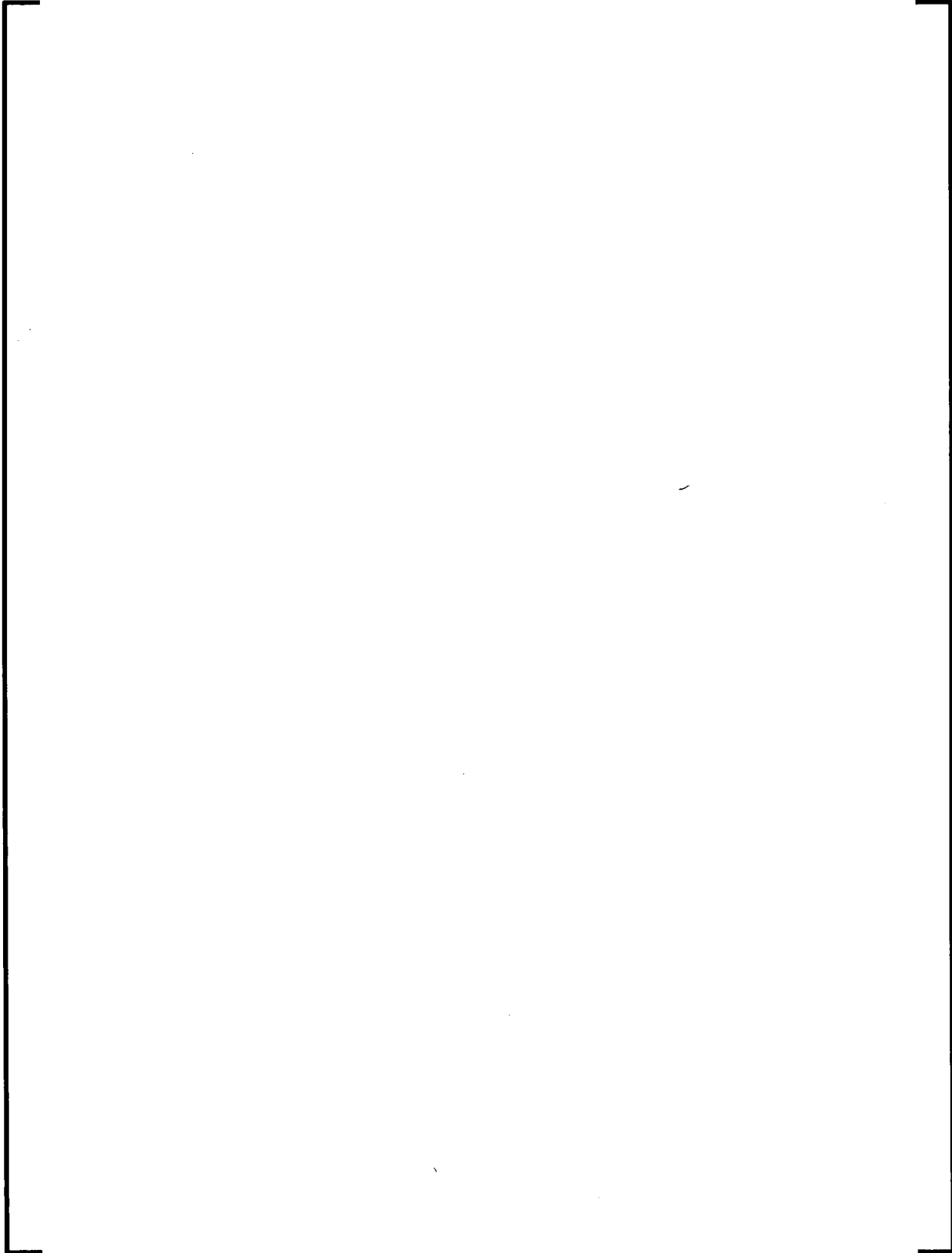


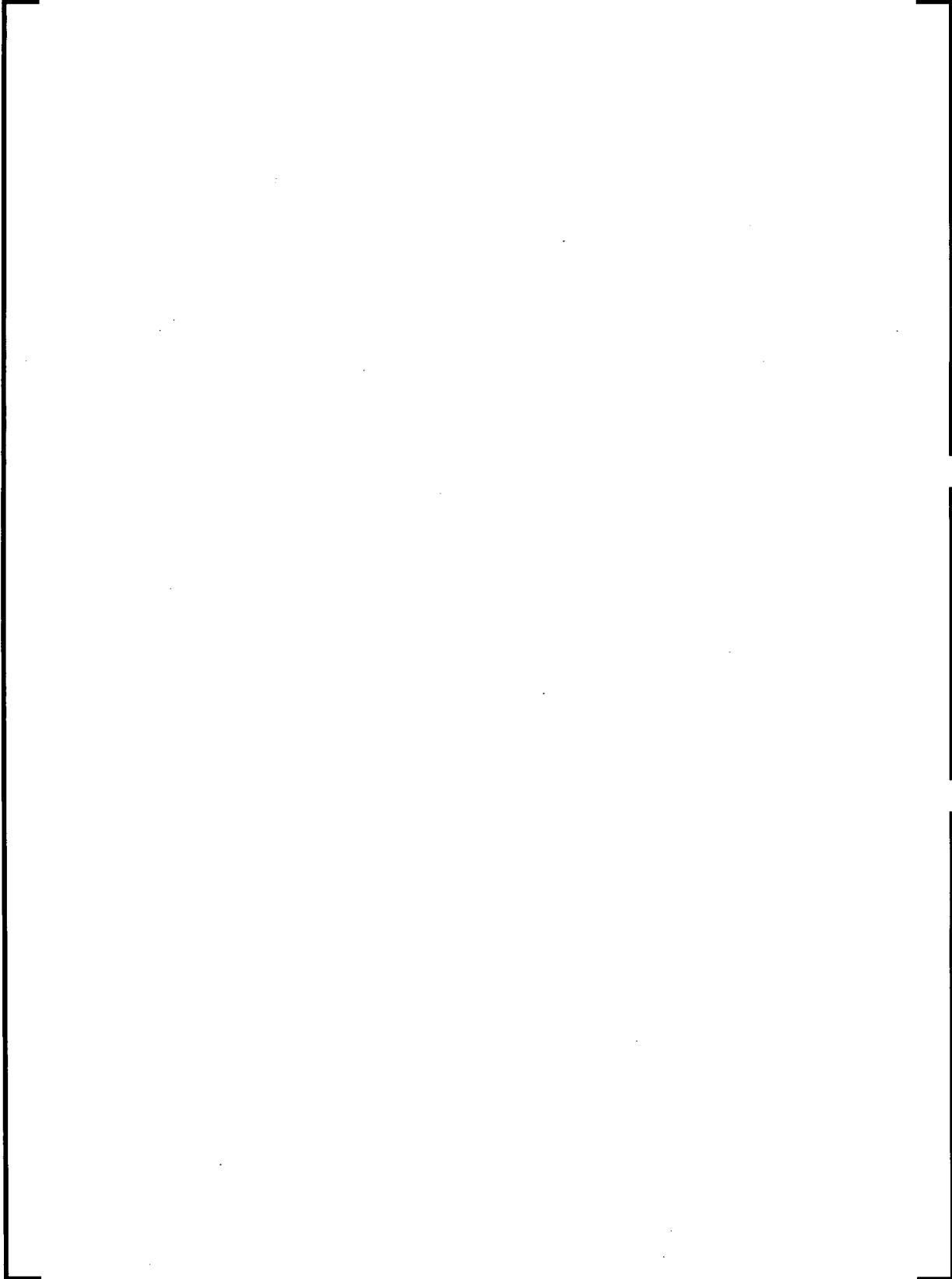


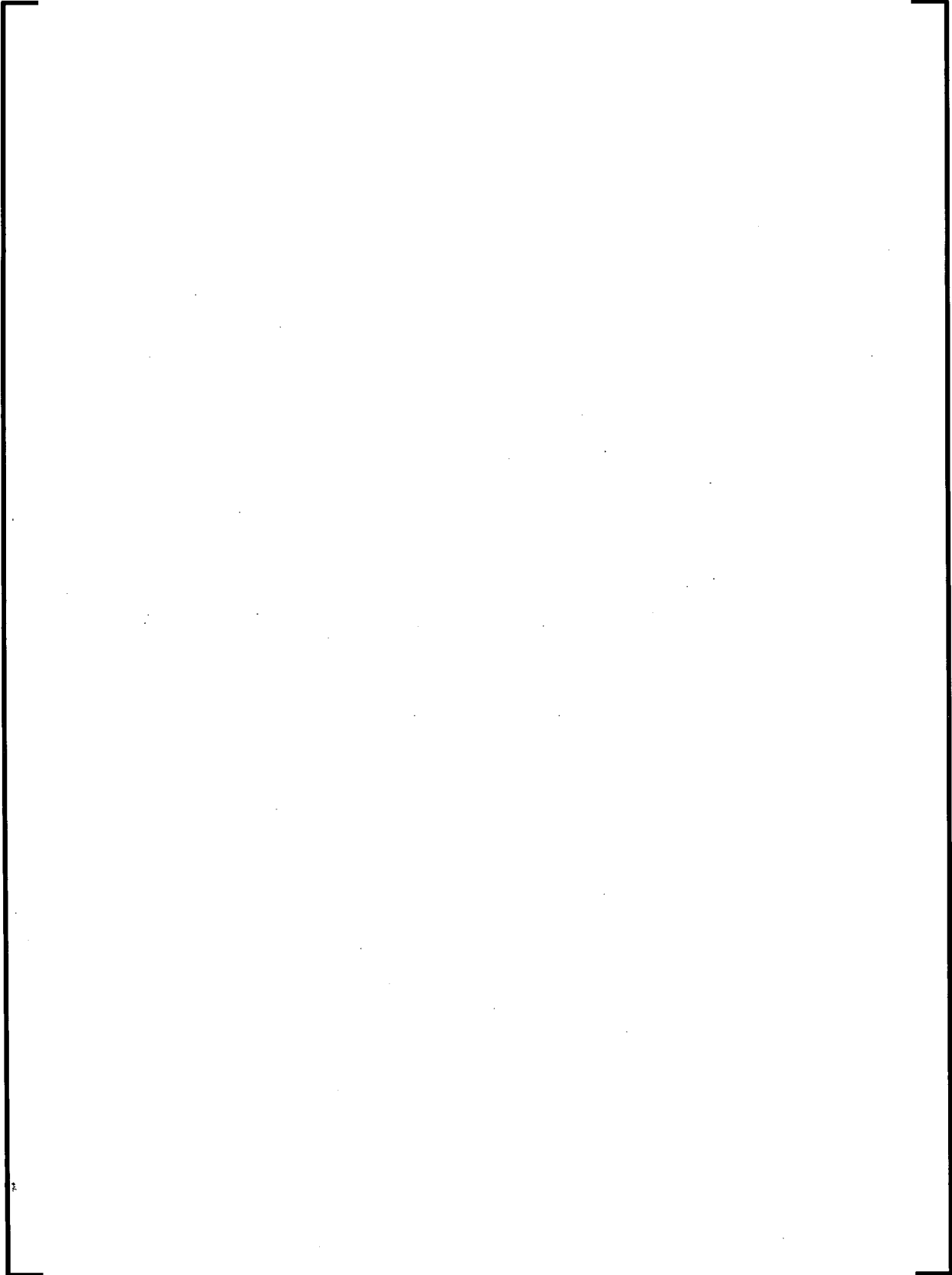


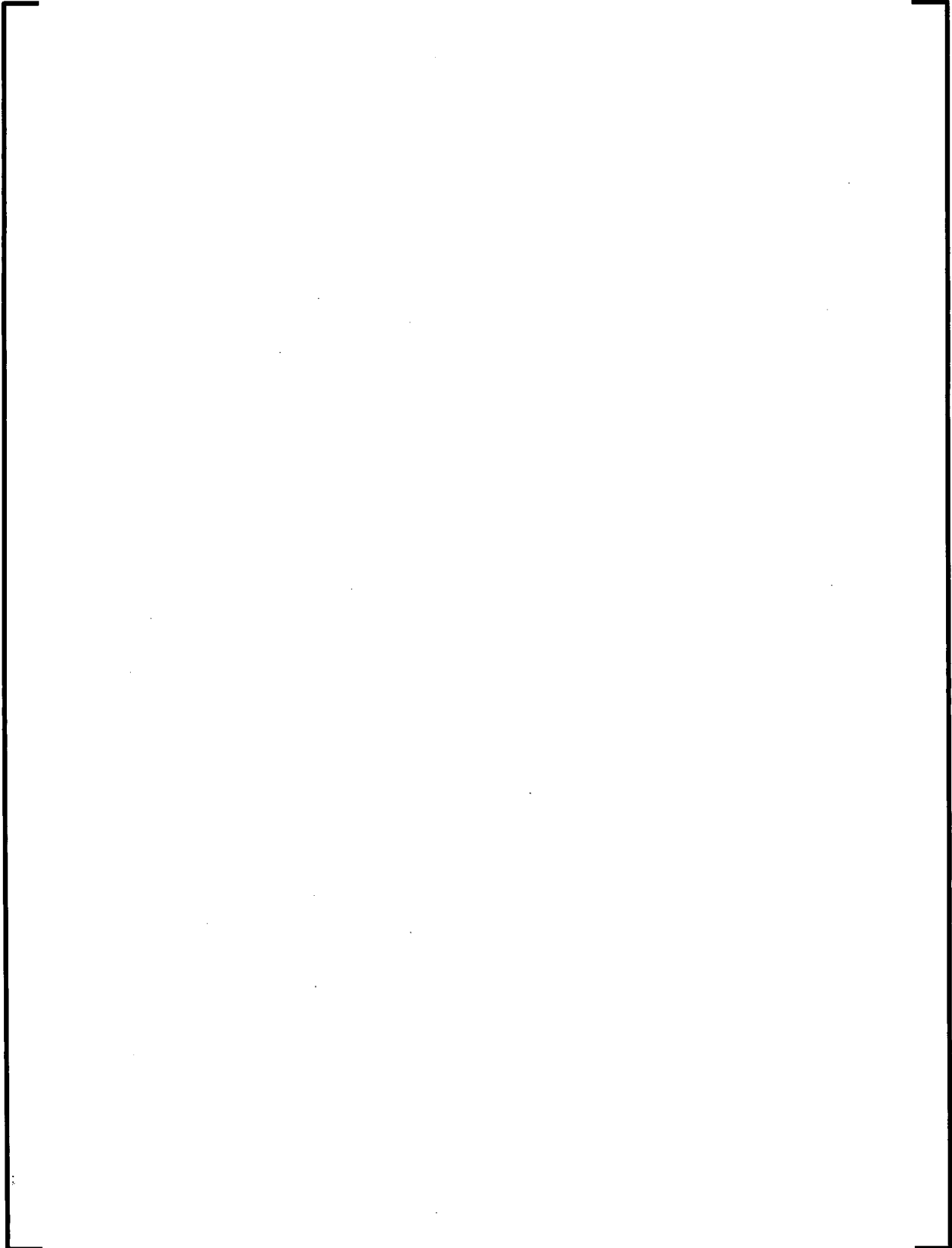


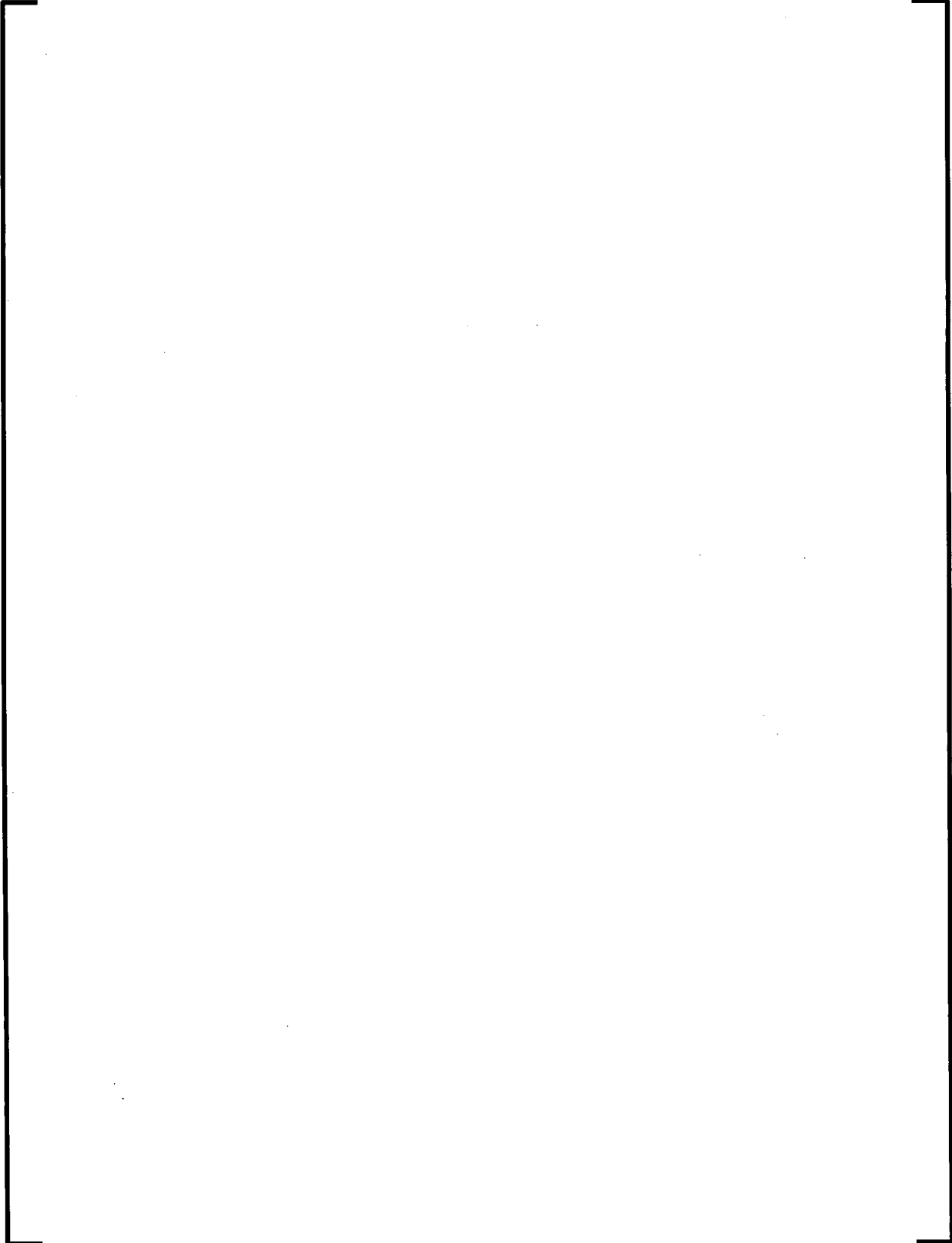


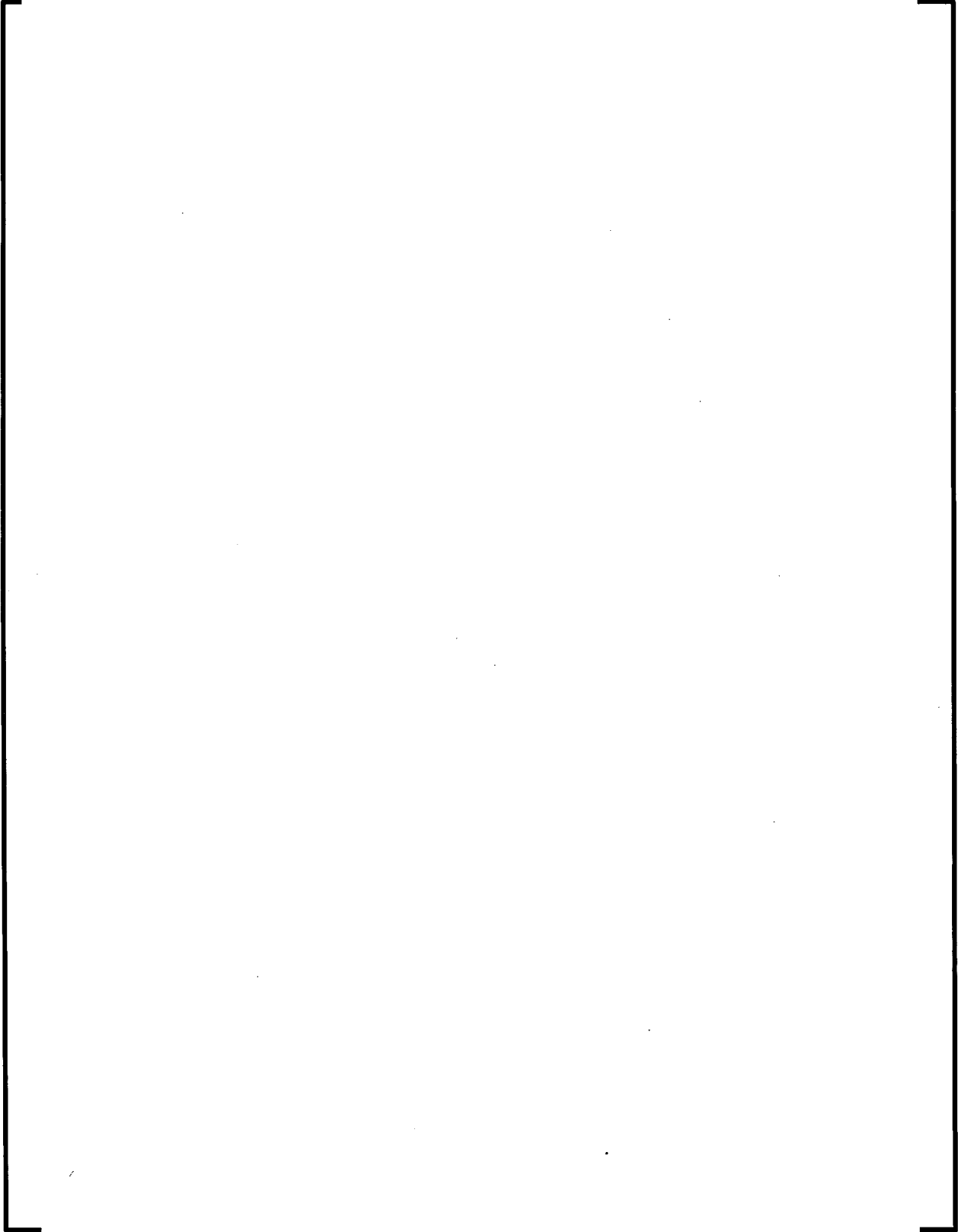


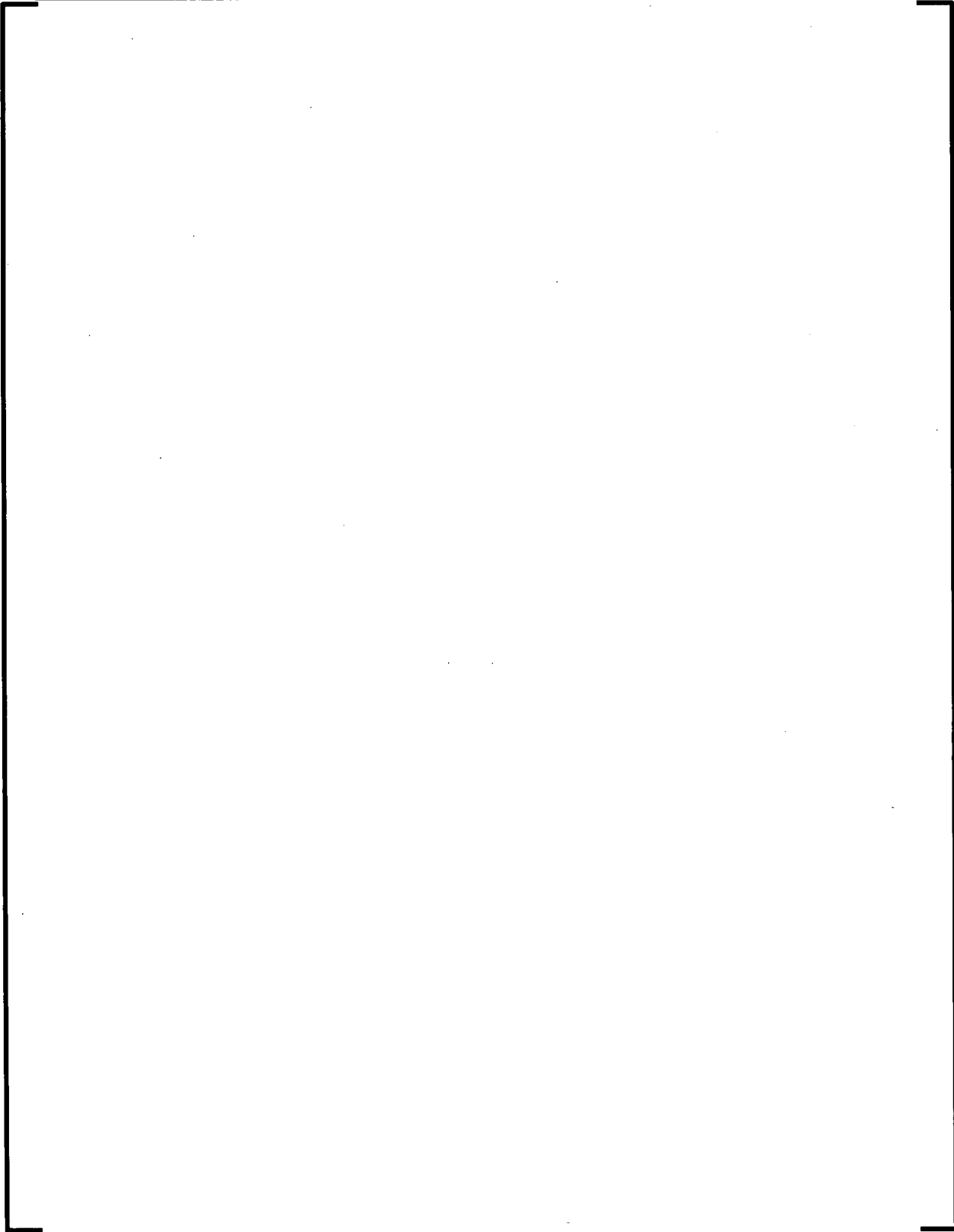


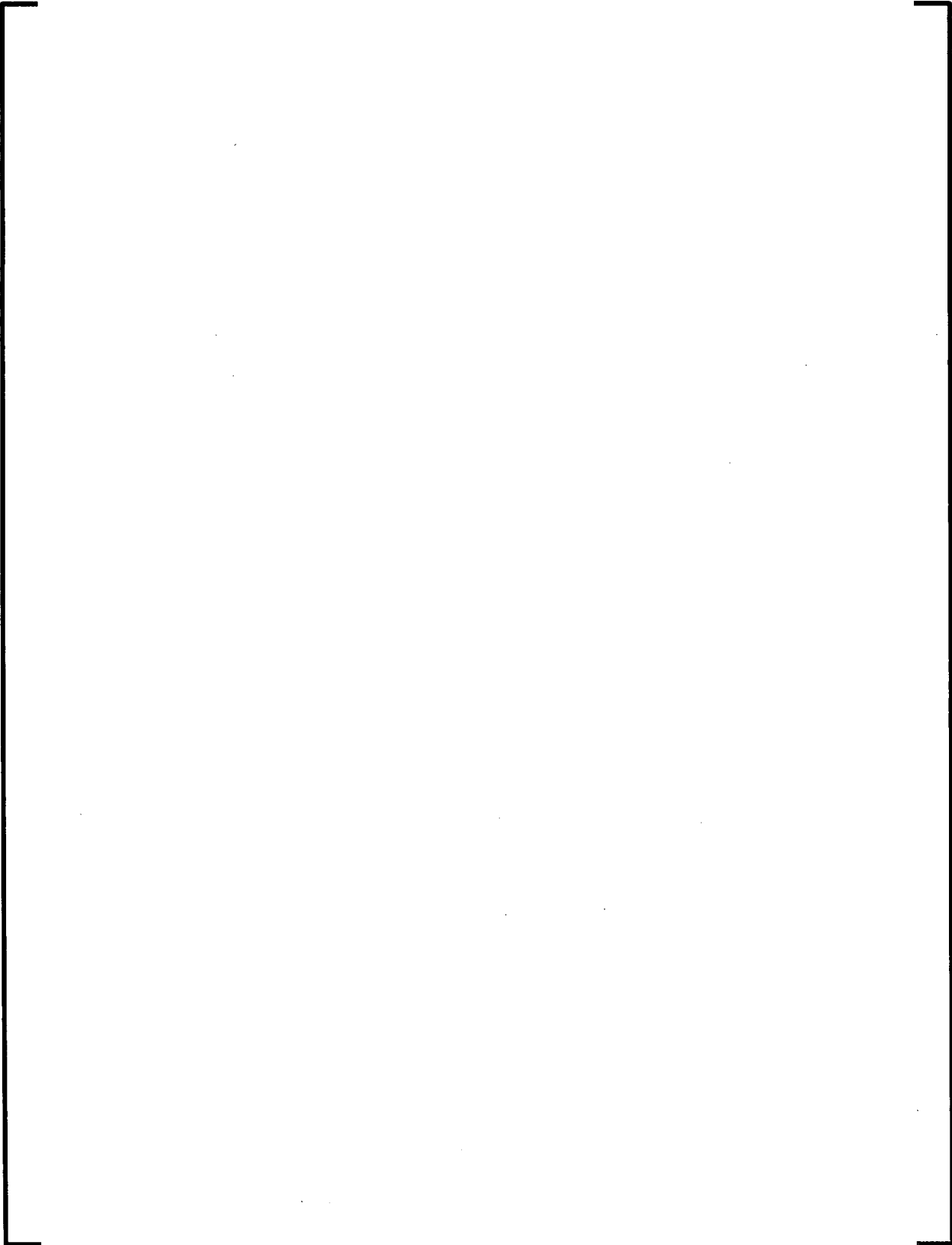


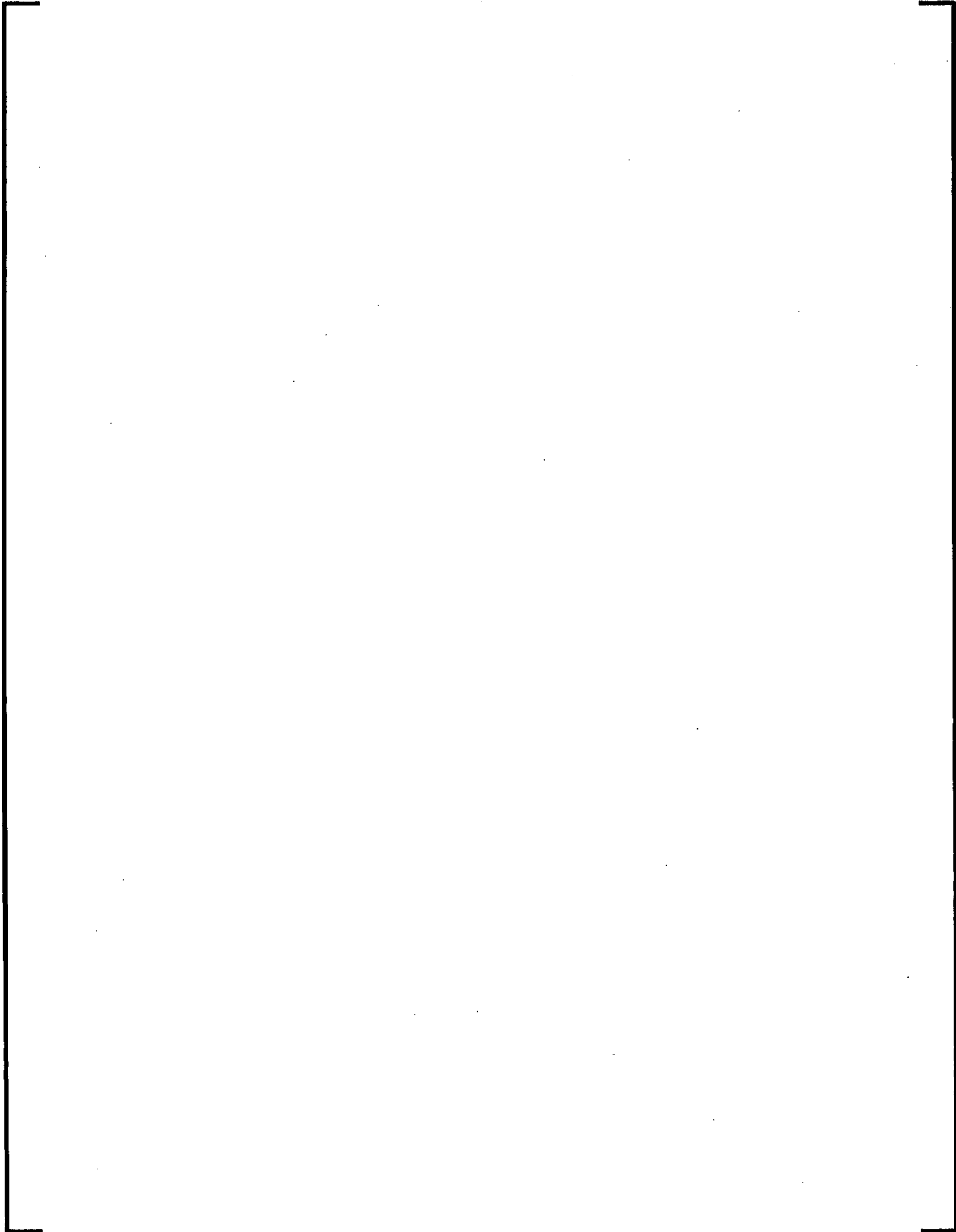


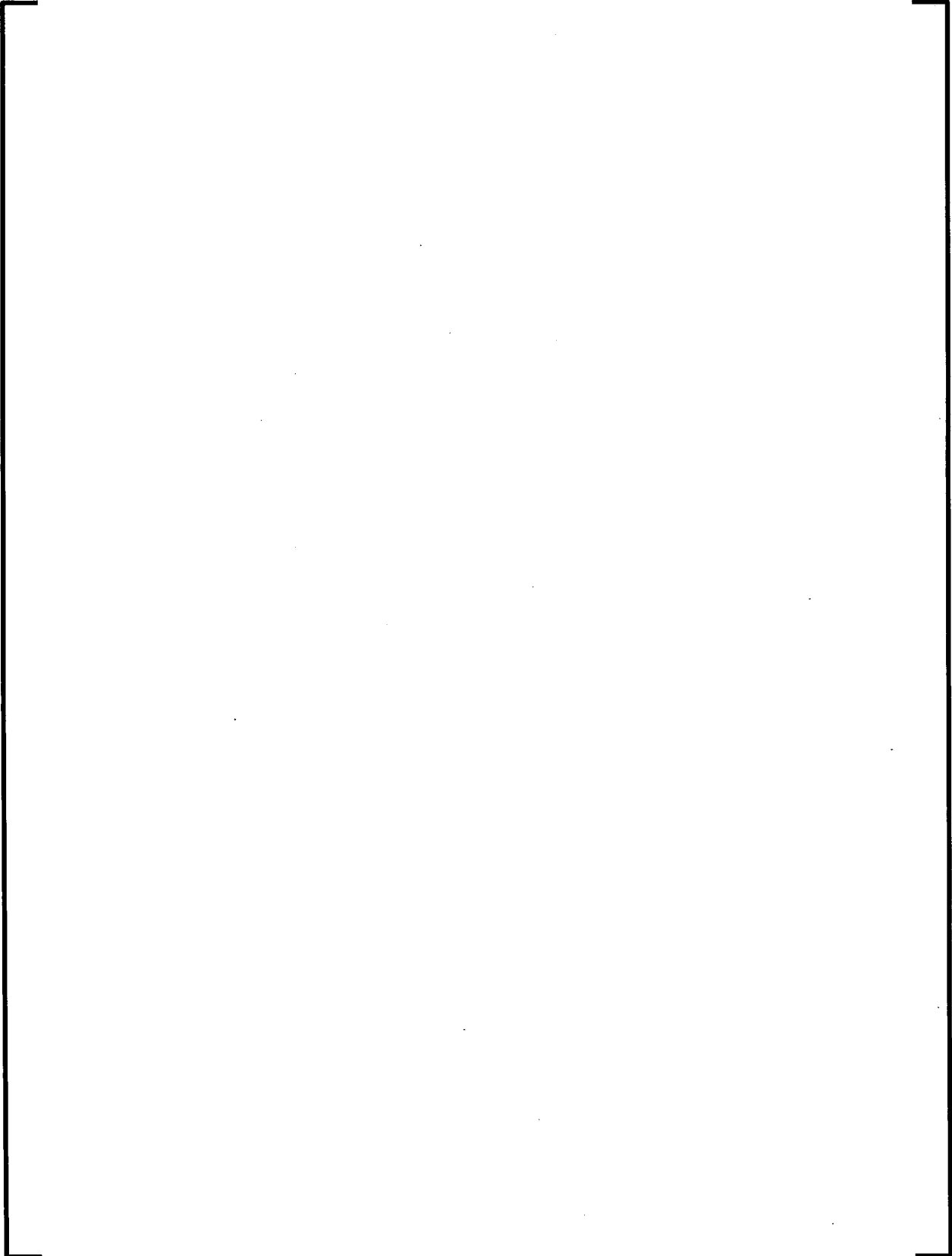


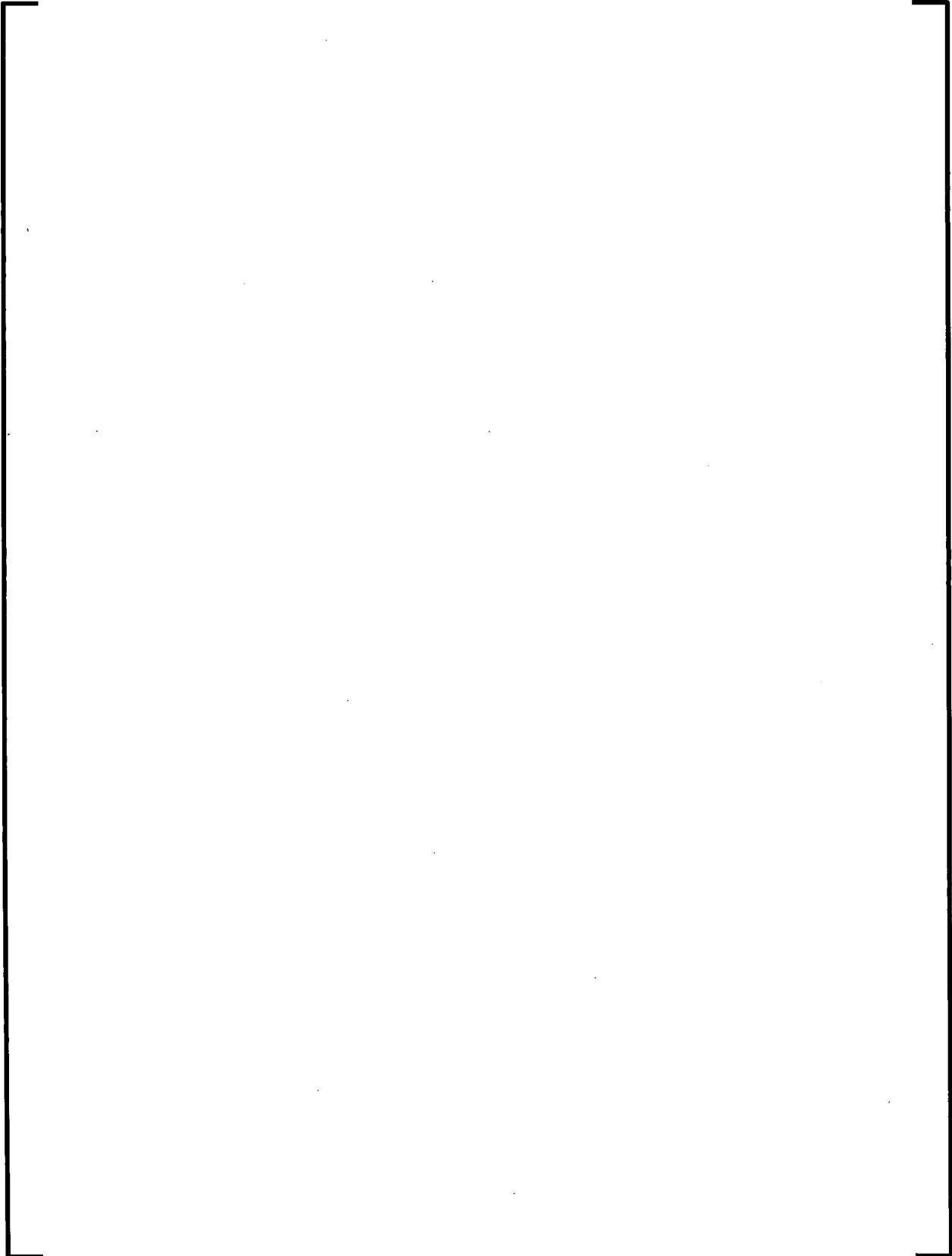


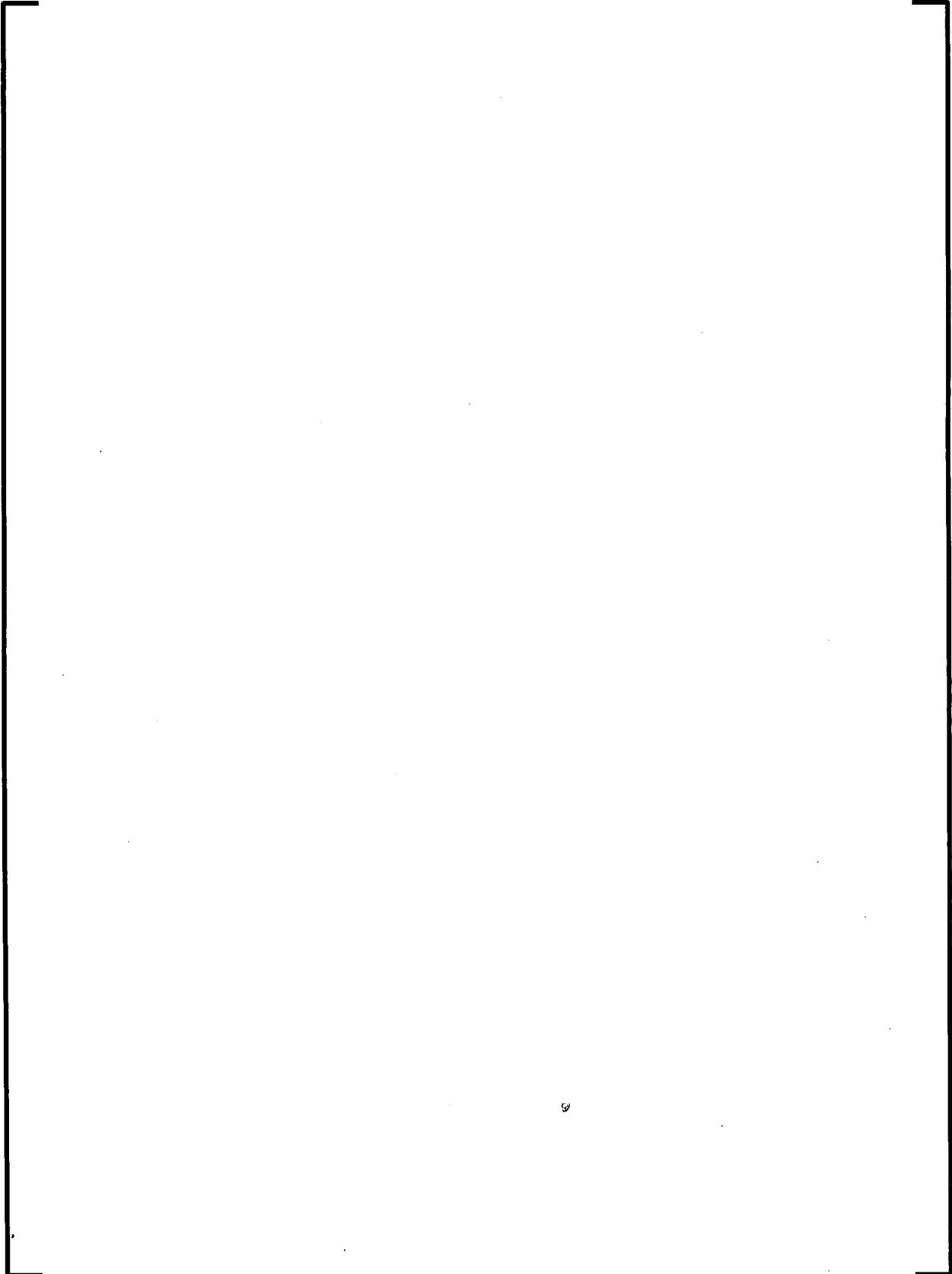


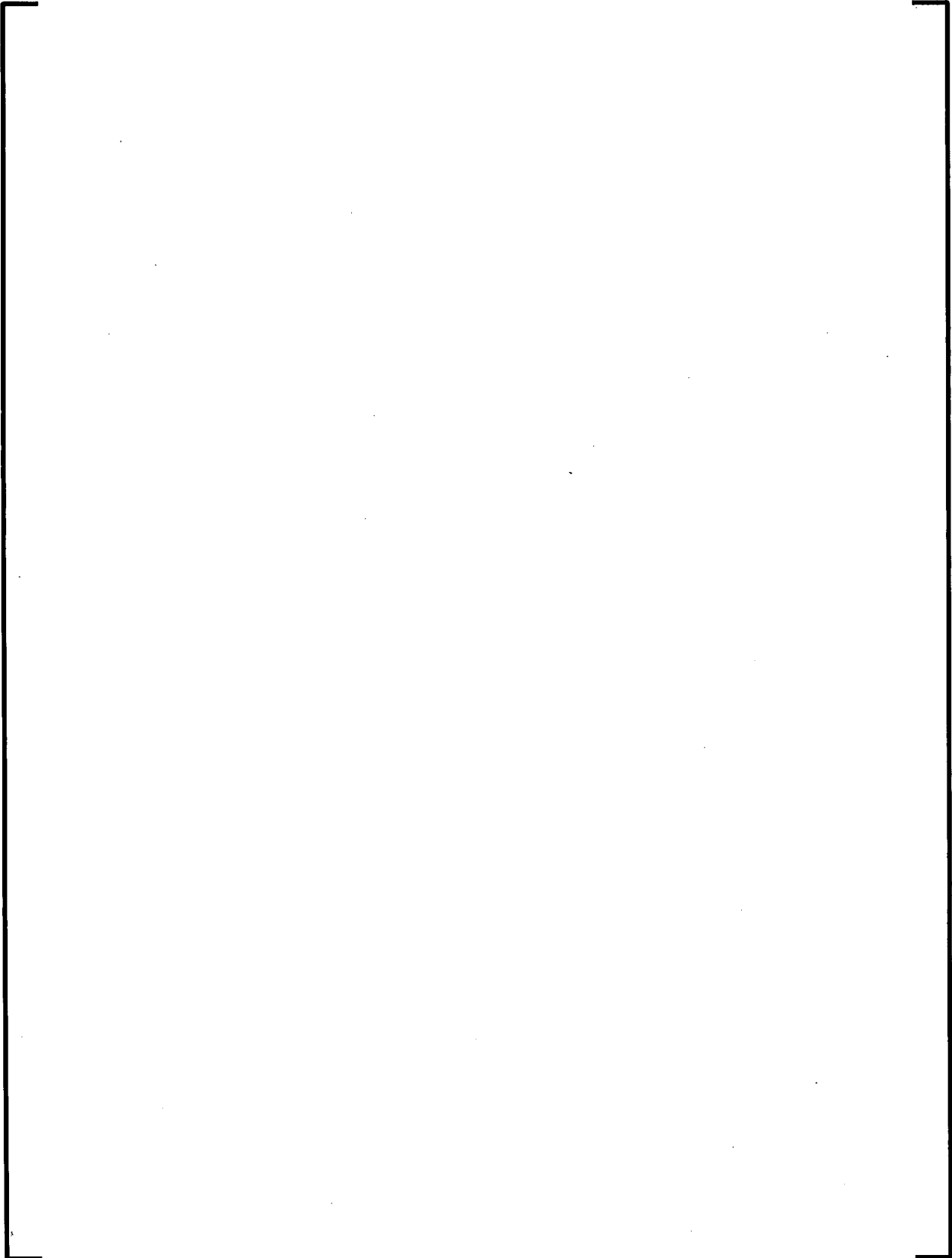


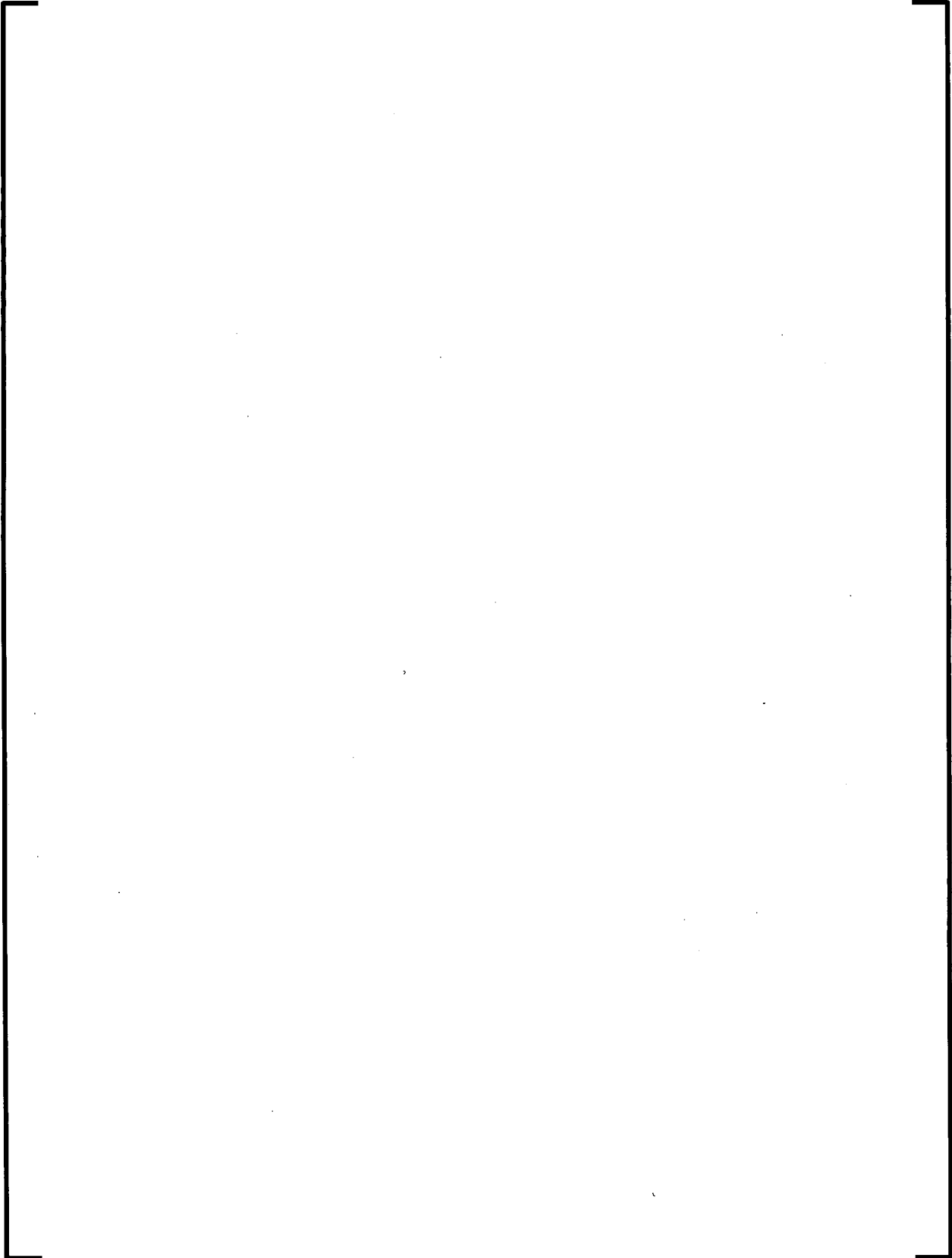


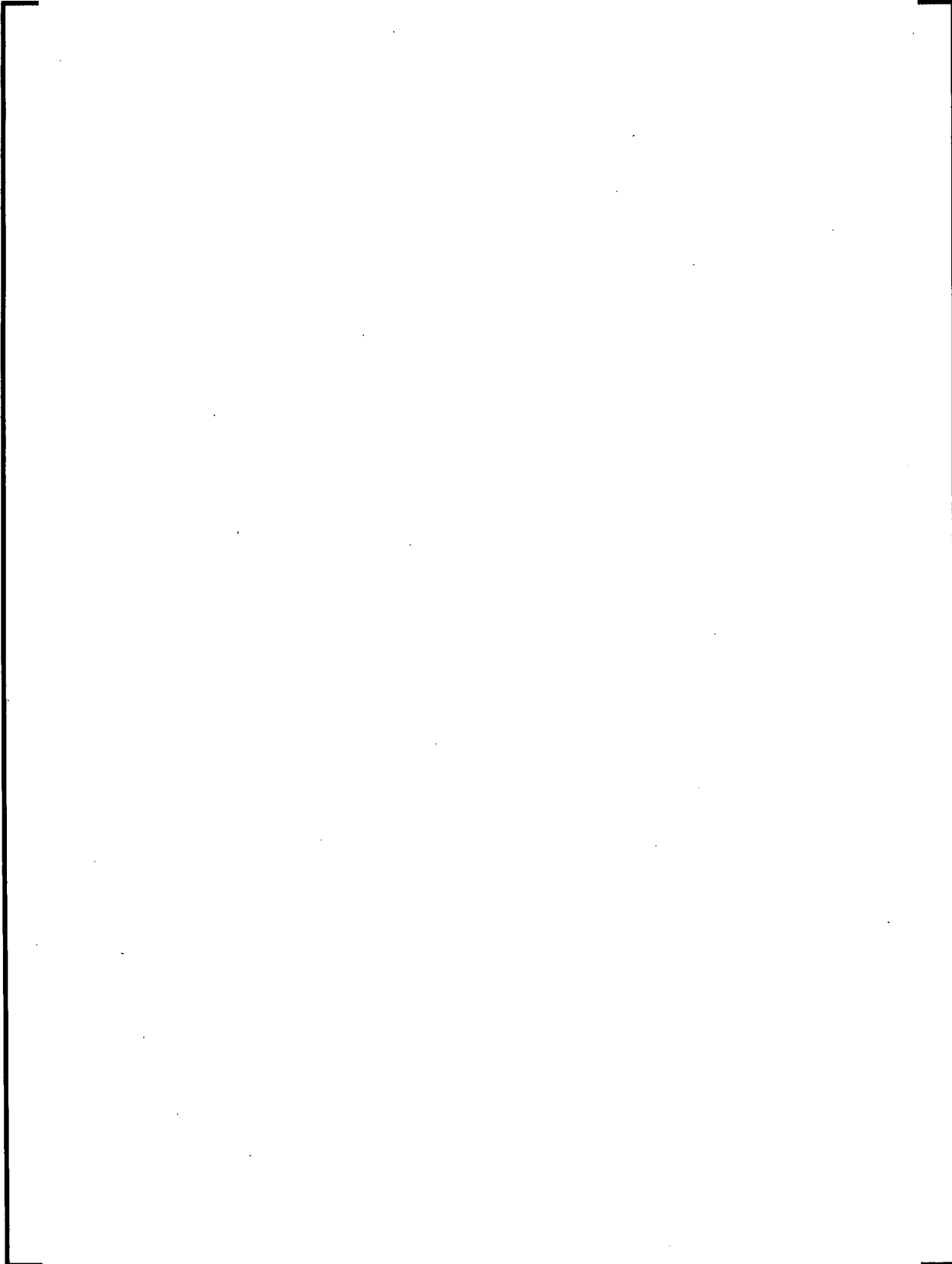


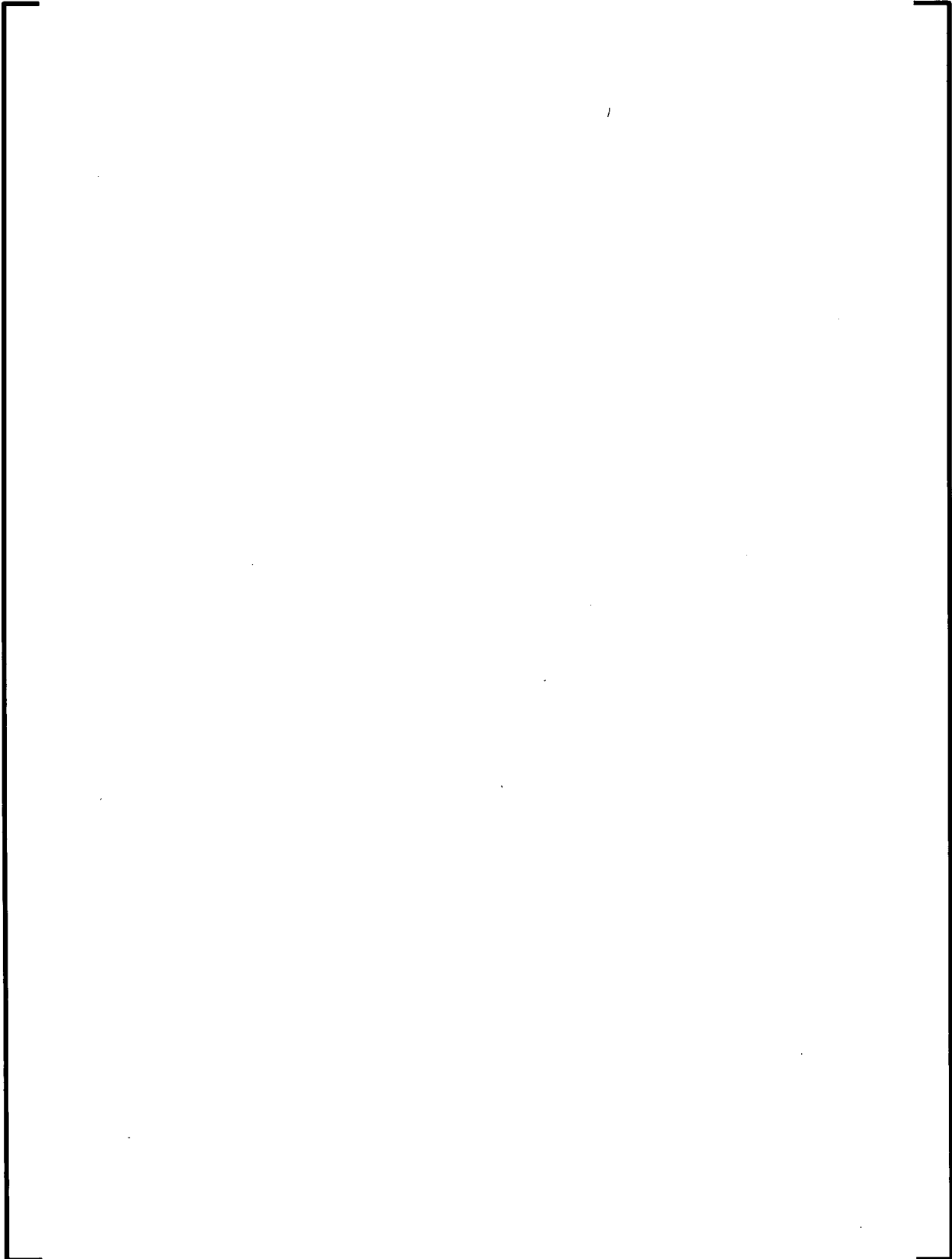


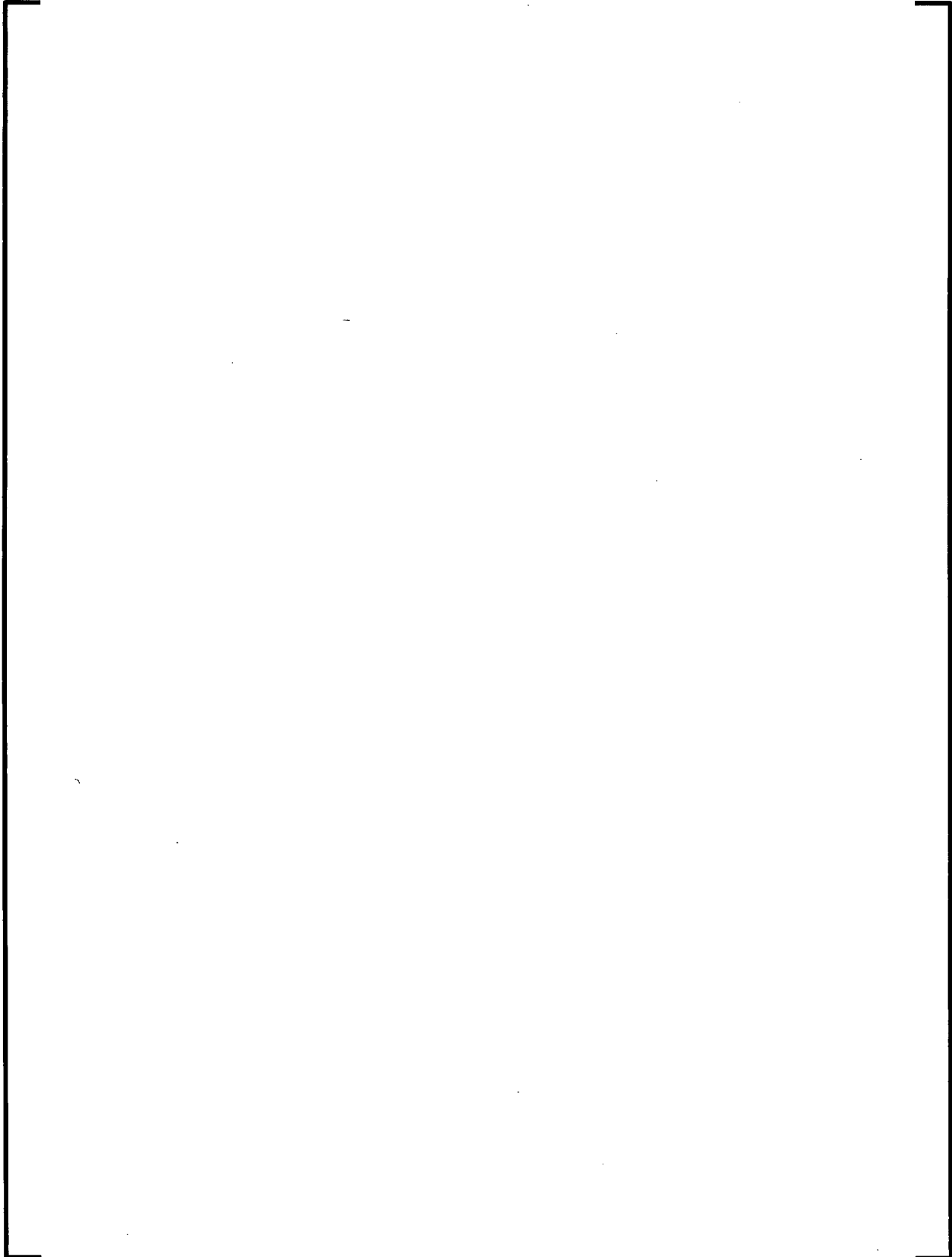


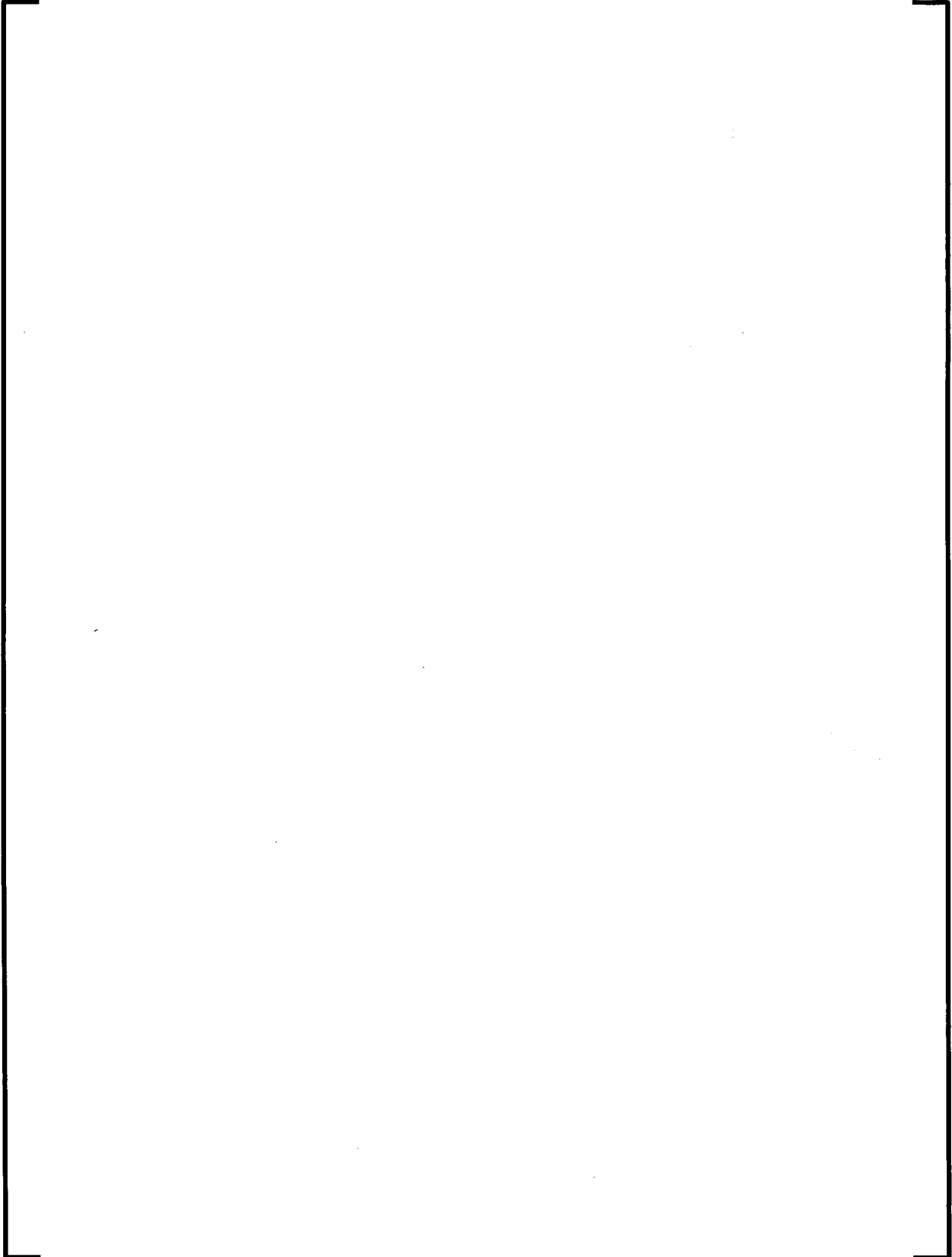


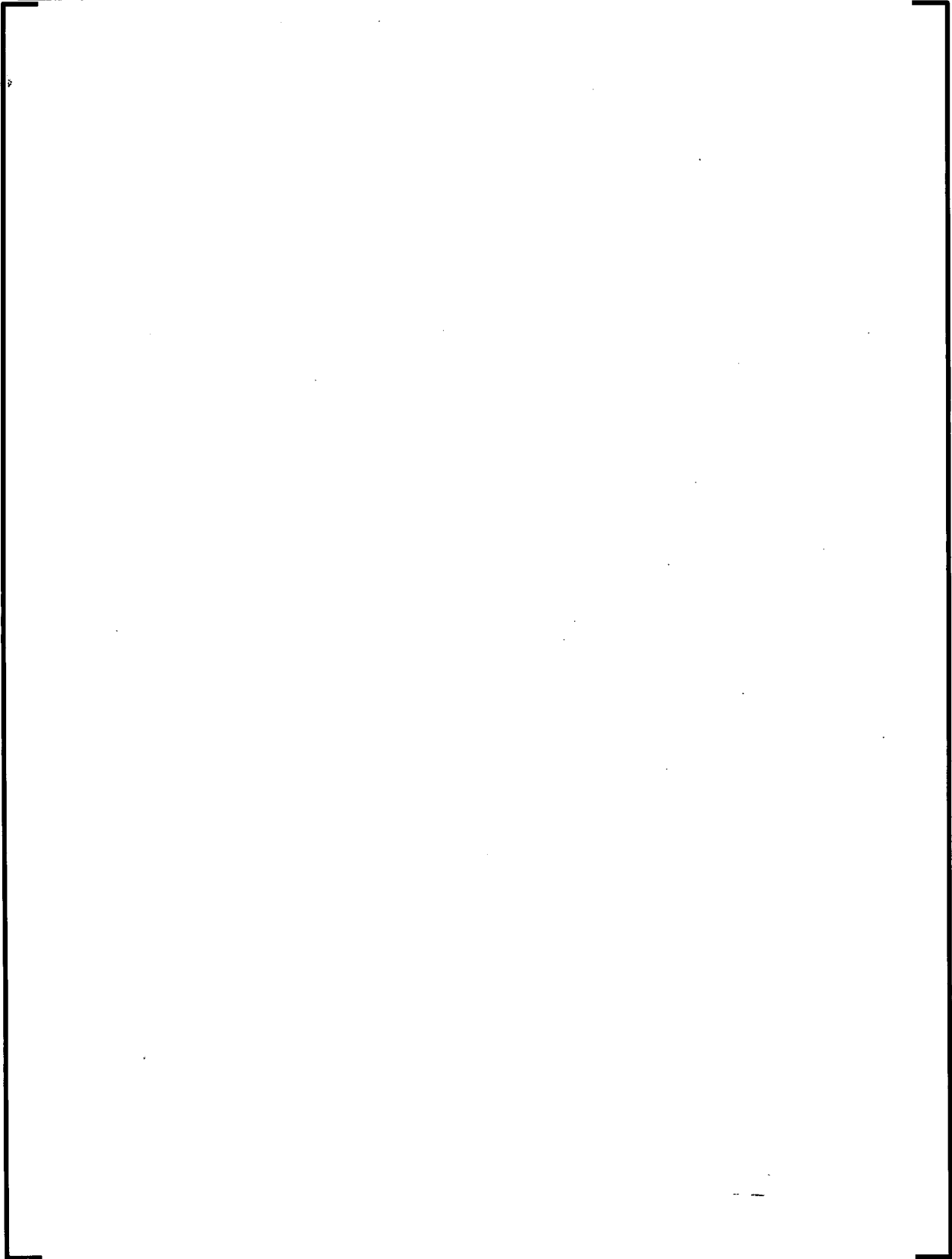


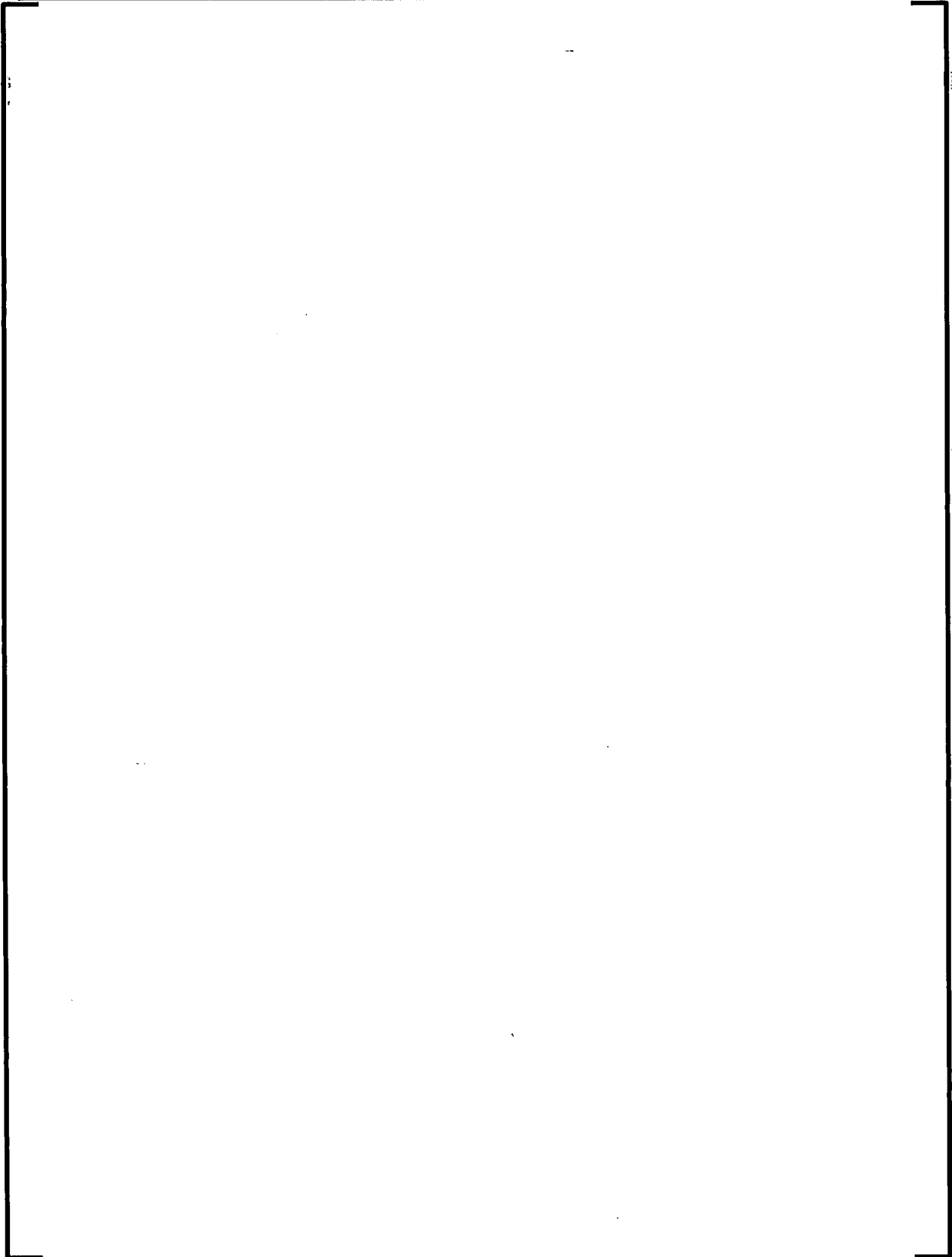


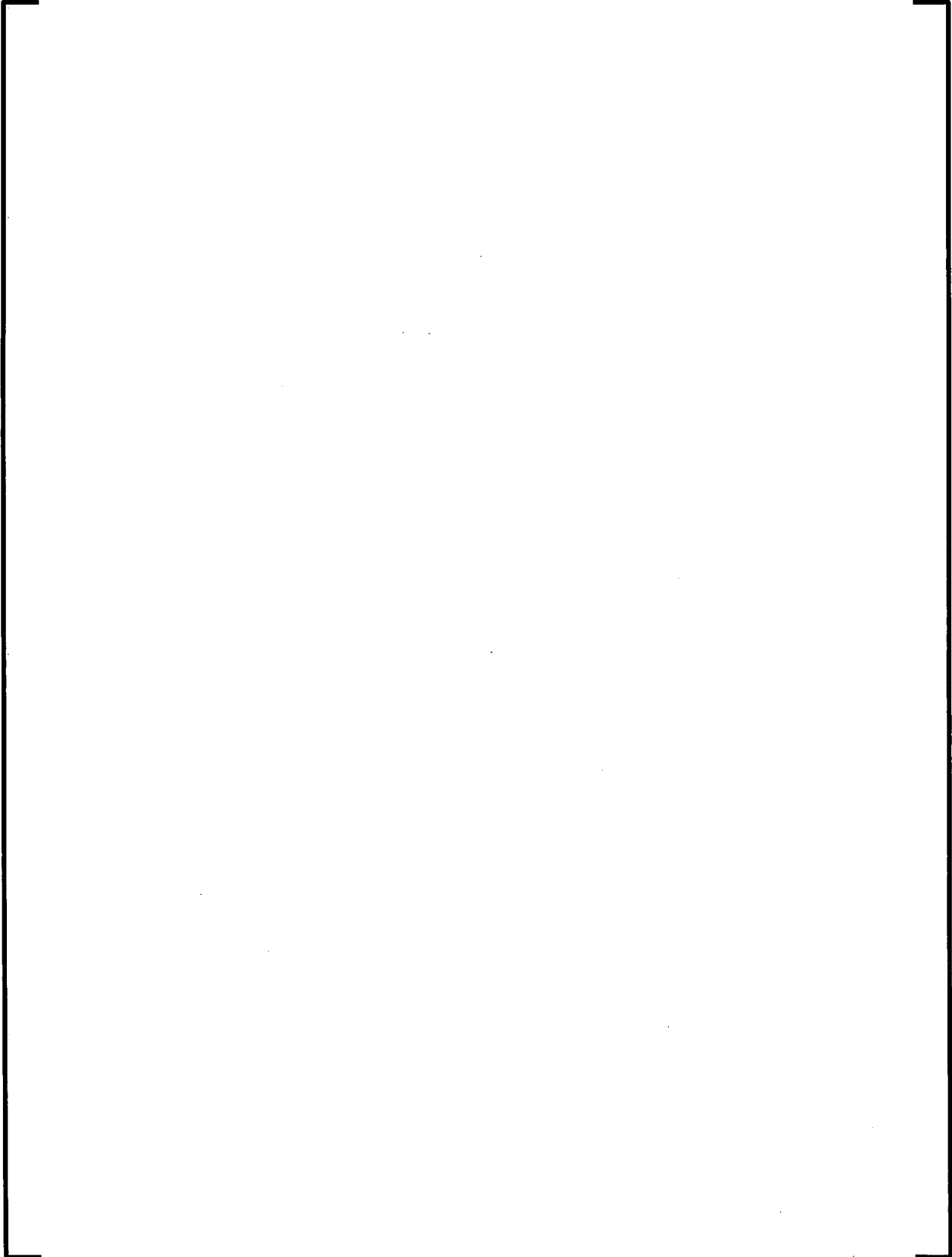


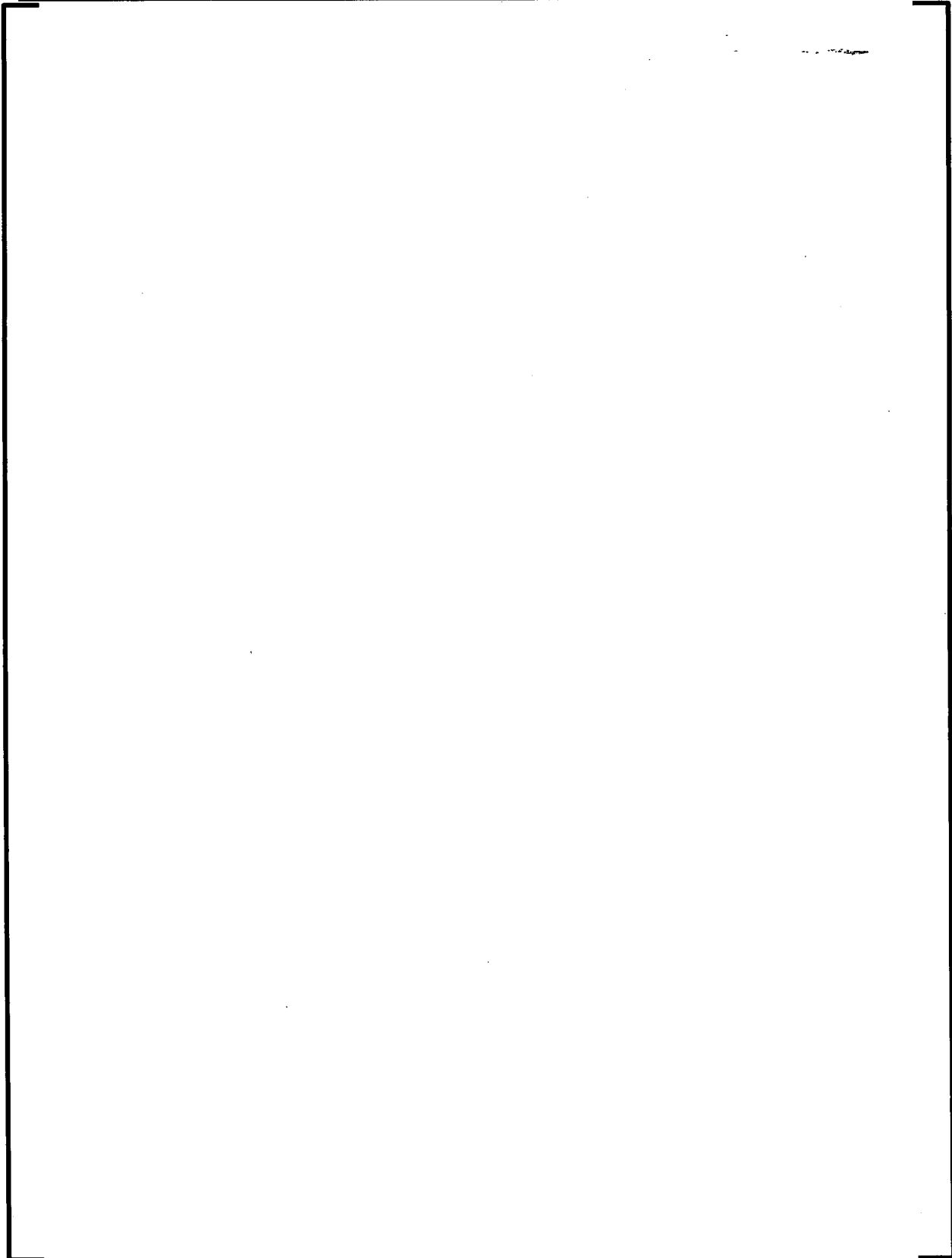


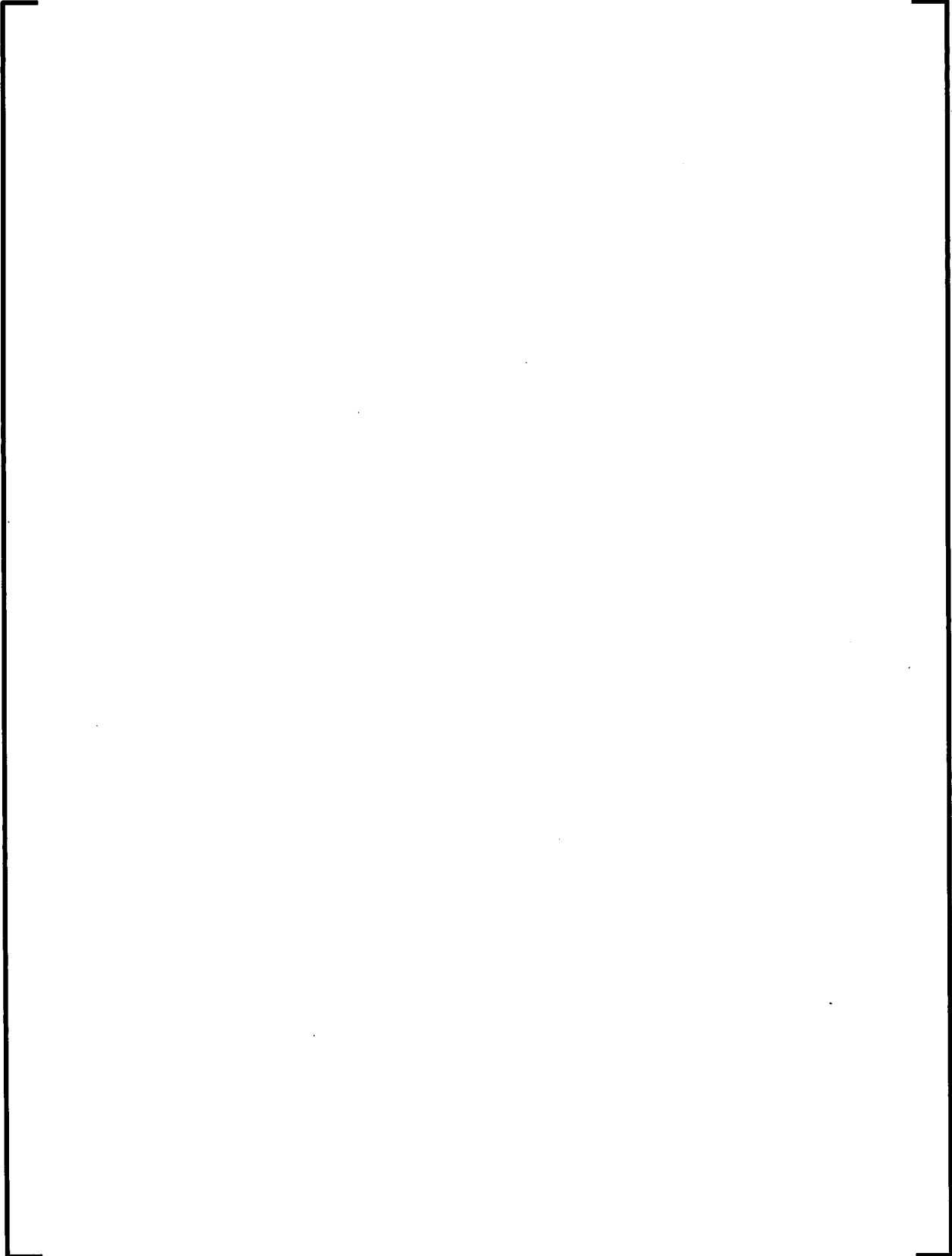


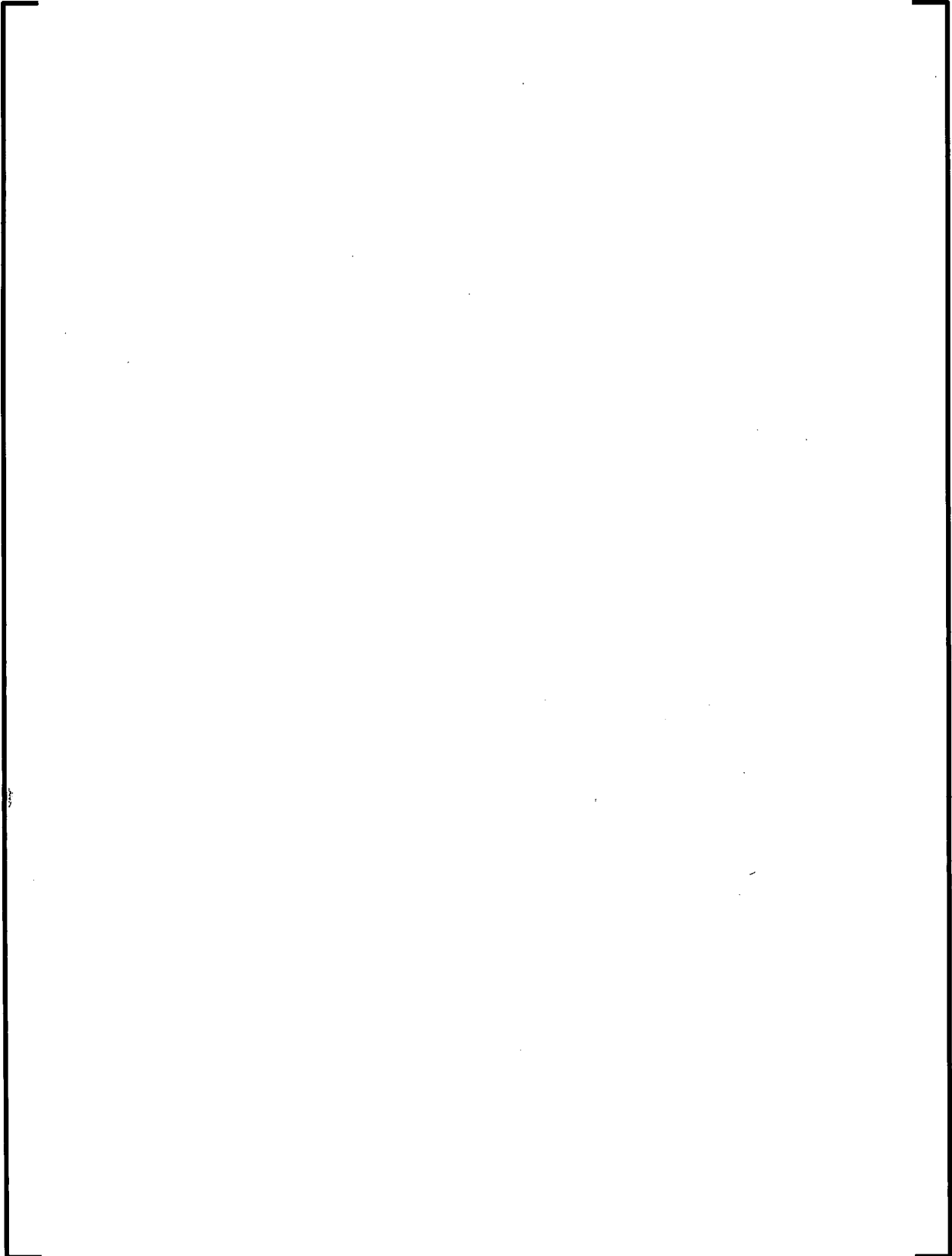


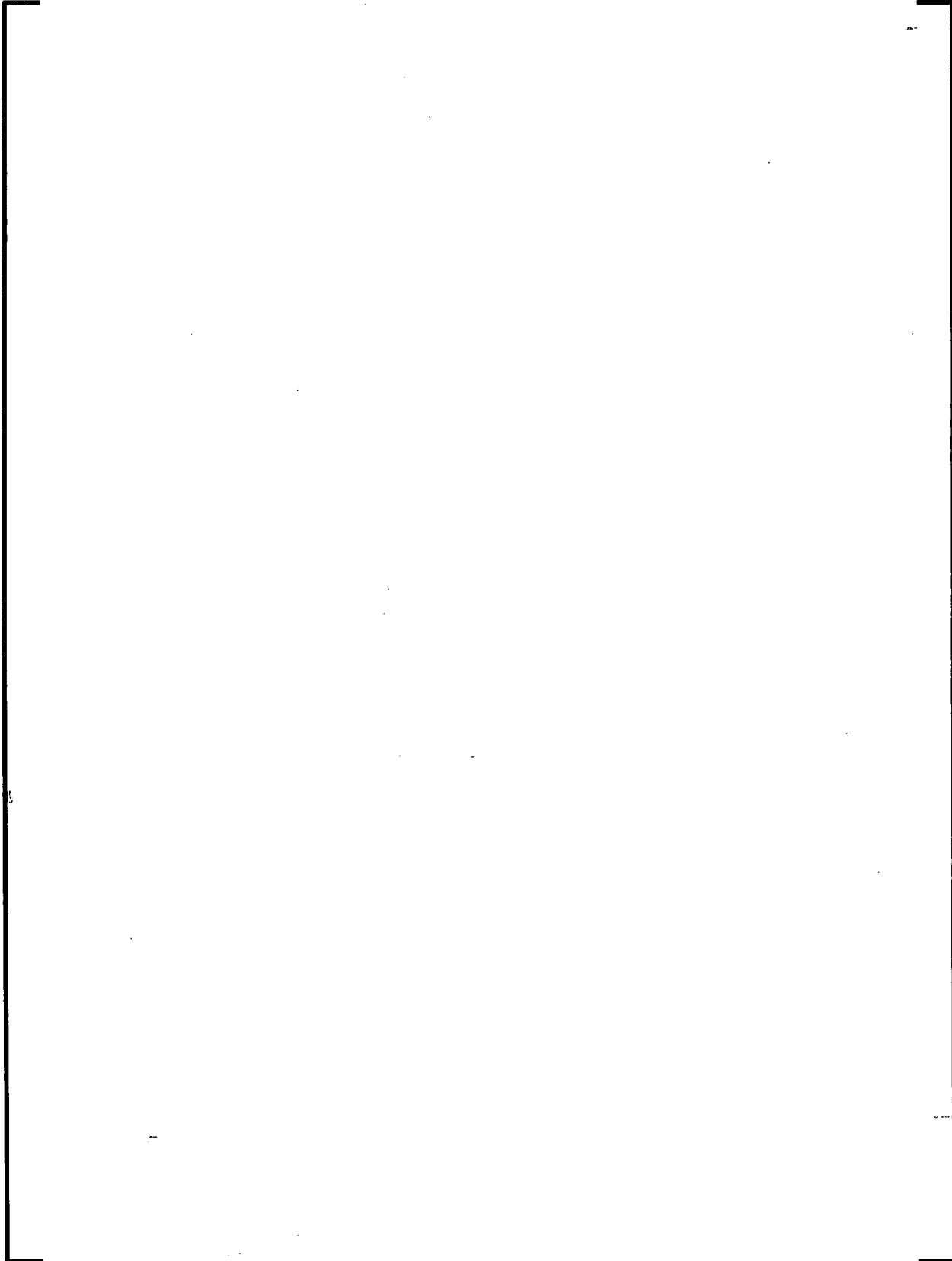


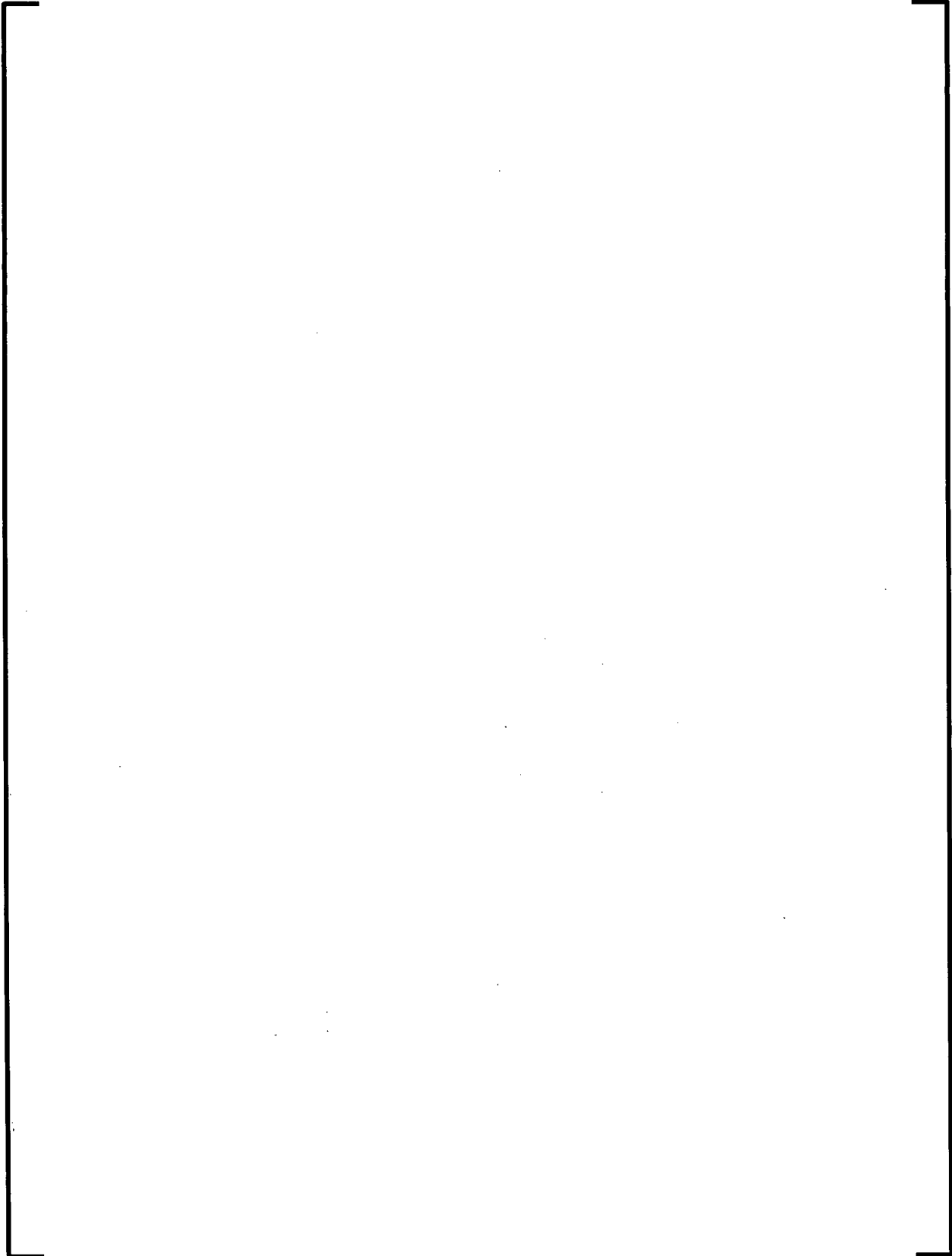


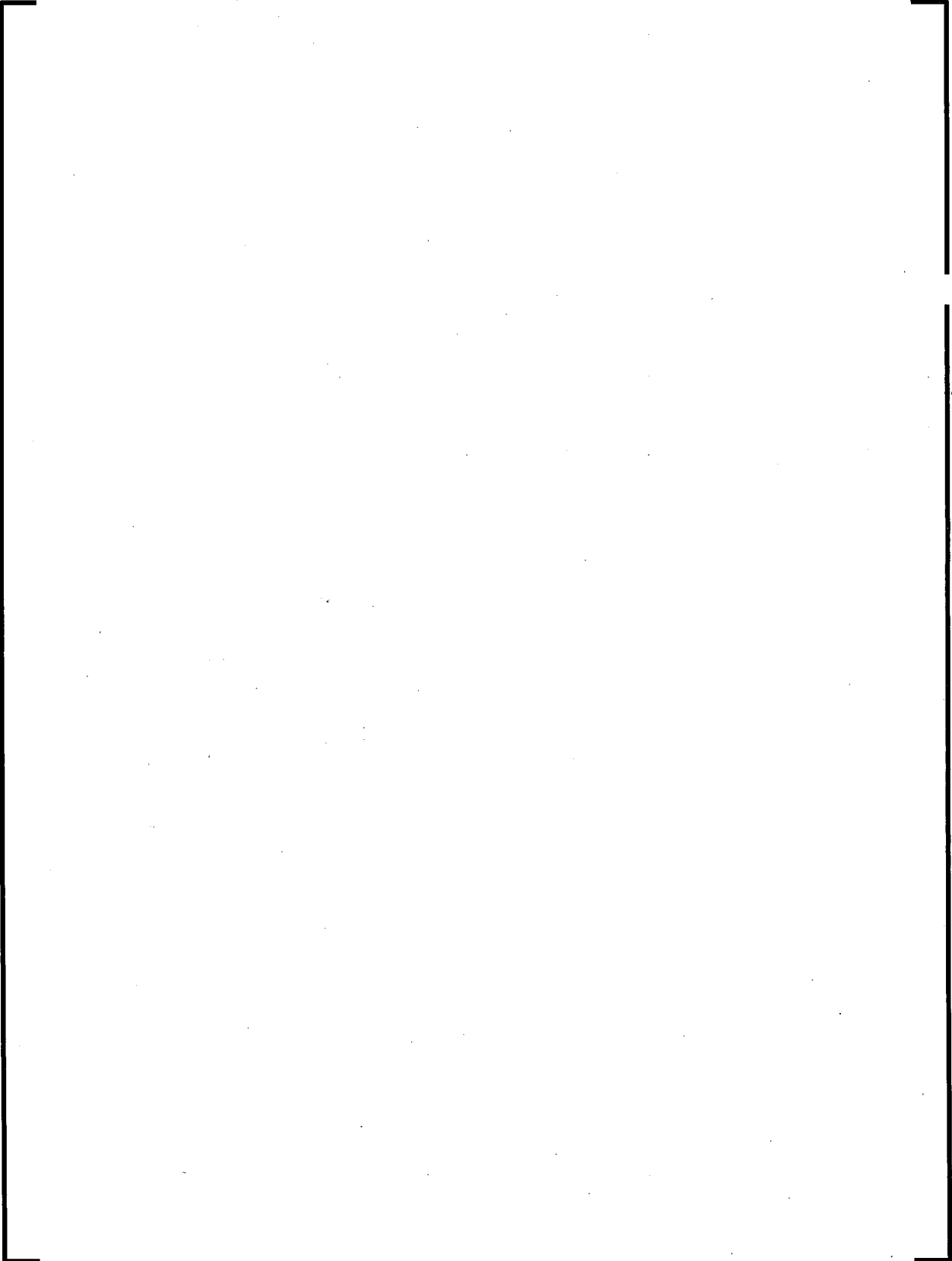


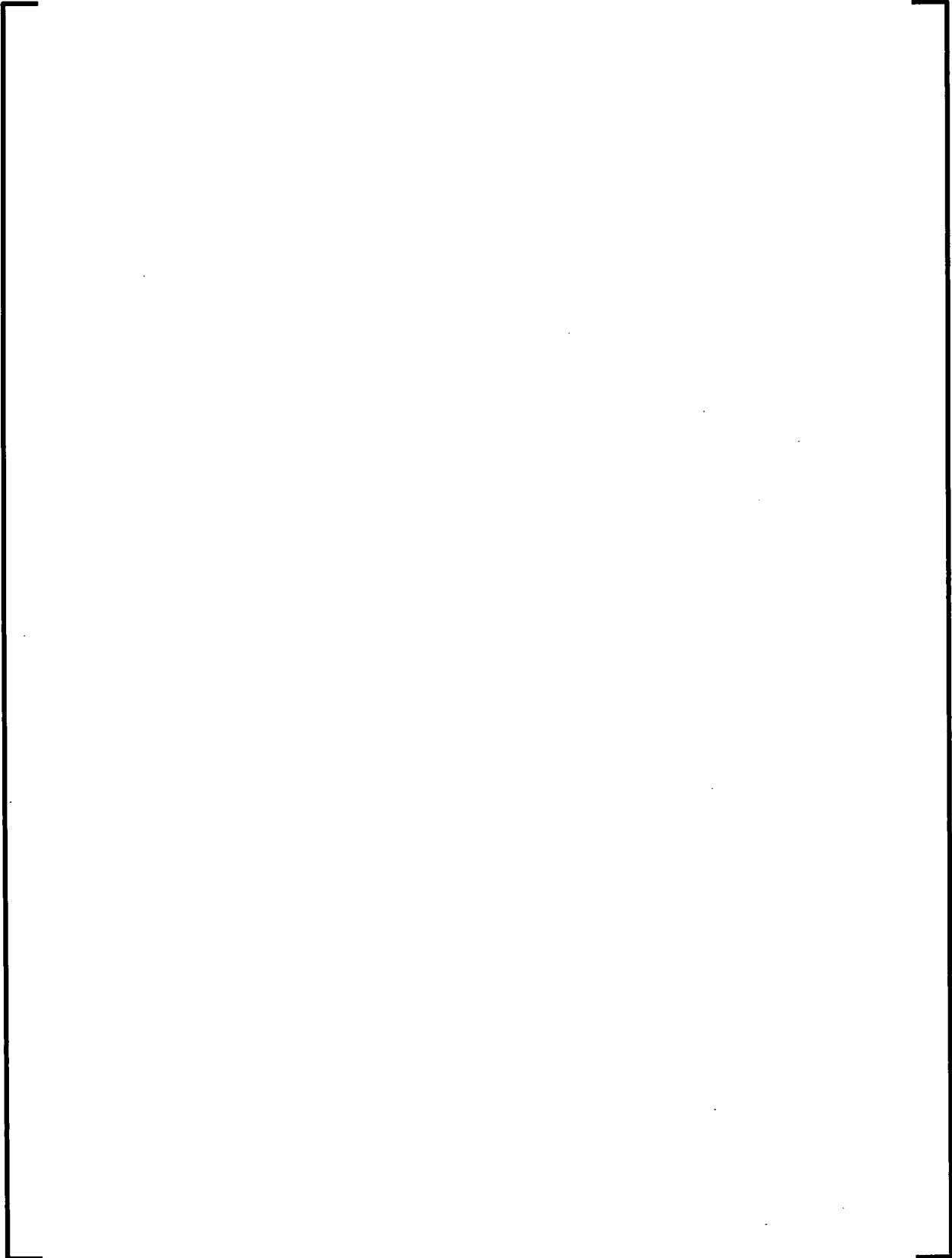


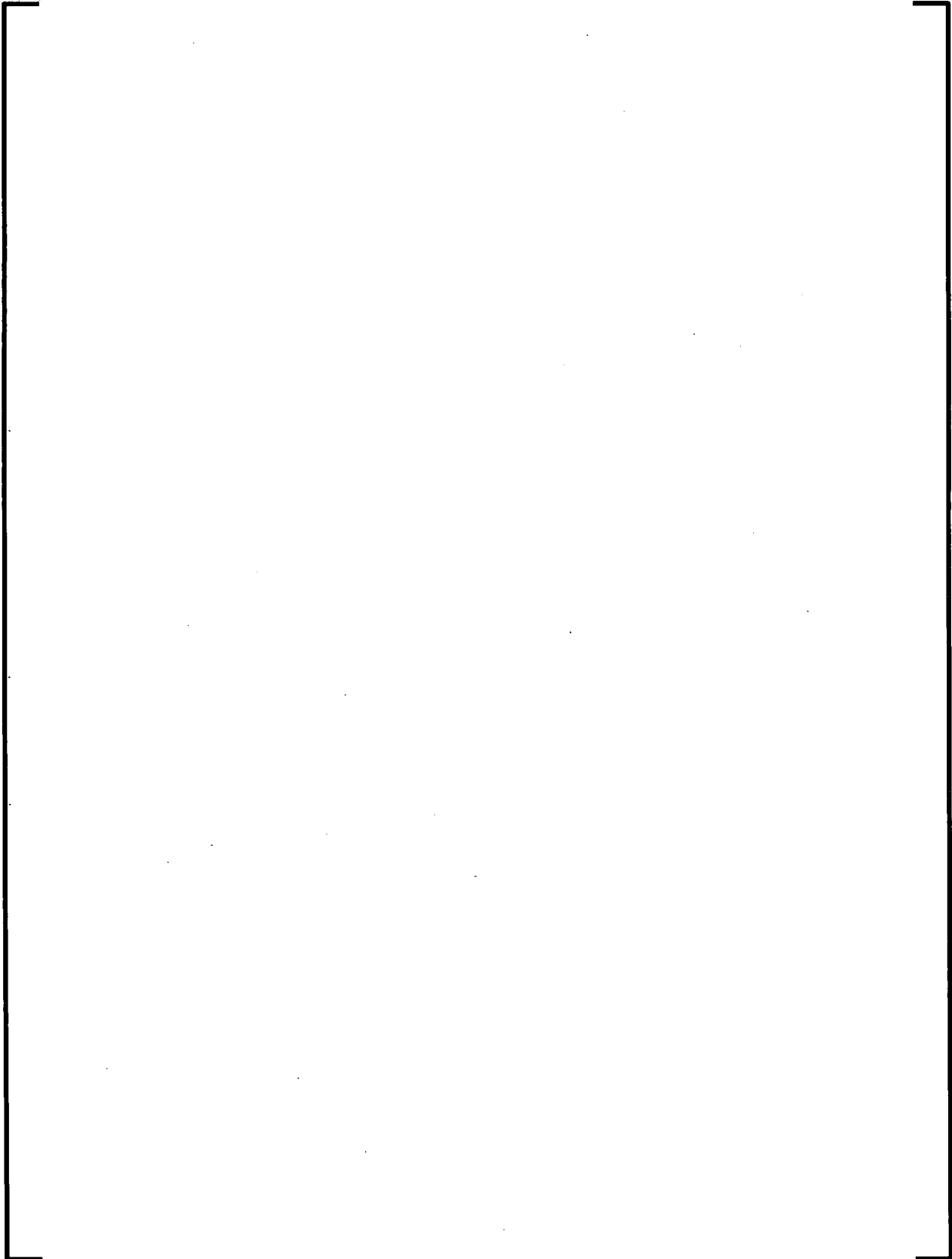












The guidance and recommendations for environmental factors such as lighting and acoustics are available for review by the NRC staff.

The subject matter addressed in this response contains representative information from the V&V IP.

The schedule for providing the revised U.S.EPR V&V Implementation Plan is provided below:

Document Number	Commitment Date
U.S.EPR Human Factors Verification and Validation Implementation Plan	4/16/2010

References for Question 18-62:

1. Abdolmonhammadi, M. J. & Usoff, C. A. (2001). The Assessment of Task Structure, Knowledge Base and Decision Aids for a Comprehensive Inventory of Audit Tasks Quorum: Westport, CT.
2. James R. Phimister, Vicki M. Bier, and Howard C. Kunreuther, "Flirting with Disaster" (Issues, Fall 2005).
3. Norman, D. A. (1988). The Psychology of Everyday Things. Basic Books: New York.

4. Perin, C., Marcus, A., Westrum, R. & Clarke, L. (2006) Can We Anticipate Disasters? Issues in Science and Technology, Vol. 22, winter 2006 Pages: 1-1
5. Broadbent, D.E. (1958). Perception and Communication. London: Pergamon.
6. Kahneman, D. (1973). Attention and effort. New Jersey, U.S.A.: Prentice Hall.
7. Posner, M.I. (1978). Chronometric explorations of mind. Hillsdale: Erlbaum.
8. Wickens, C.D. (1984). Processing resources in attention. In R. Parasuraman and D.R. Davies (Eds.). Varieties of attention. (pp. 63-102). London: Academic Press.
9. O'Donnell, R.D. & Eggemeier, F.T. (1986). Workload assessment methodology. In K.R. Boff, L. Kaufman & J.P. Thomas (Eds.), Handbook of perception and human performance. Volume II, cognitive processes and performance. (pp 42/1-42/49). New York: Wiley.
10. Wickens, C.D. (1992). Engineering psychology and human performance. New York: HarperCollins.
11. Norman, D.A. & Bobrow, D.G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.
12. Mulder, G. (1986). The concept and measurement of mental effort. In G.R.J. Hockey, A.W.K. Gaillard and M.G.H. Coles (Eds.), Energetics and human information processing (pp. 175-198). Dordrecht, The Netherlands: Martinus Nijhoff Publishers.
13. Sanders, A.F. (1983). Towards a model of stress and human performance. Acta Psychologica, 53, 61-97.
14. Meijman, T.F. & Mulder, G. (1992). Arbeidspsychologische aspecten van werkbelasting. (Workpsychological aspects of work-demand) In P.J.D. Drenth, H. Thierry & Ch.J. de Wolf (Red.), Nieuw handboek A&O psychologie, Hoofstuk 2.11. Deventer: Van Loghum Slaterus.
15. Brookhuis, K.A. (1989). Event related potentials and information processing. PhD Discussion. Groningen: University of Groningen.
16. Wijers, A.A. (1989). Selective visual attention: an electrophysiological approach. PhD discussion, University of Groningen.
17. Pribram, K.H. & McGuiness, D. (1975). Arousal, activation and effort in the control of attention. Psychological review, 82, 116-149.
18. Hockey, G.R.J. (1986). A state control theory of adaptation and individual differences in stress management. In G.R.J. Hockey, A.W.K. Gaillard and M.G.H. Coles (Eds.), Energetics and human information processing (pp. 285-298). Dordrecht, The Netherlands: Martinus Nijhoff Publishers.
19. Van Ouwkerk, R., Meijman, Th.F. & Mulder, G. (1994a). Mentale belasting (Mental Workload). In P.C. Buijs, A. van Oosterom & H. Wolvetang (Red.), Handboek Bedrijfsgezondheidszorg (Hoofstuk B3-1). Utrecht, The Netherlands: Bunge.
20. Cnossen, F. (1994). Mental effort from energetical and computational perspectives. Unpublished paper for the BCN course Cognitive Neuroscience. Haren, The Netherlands: Traffic Research Centre, University of Groningen.
21. Mulder, G. (1980). The heart of mental effort. PhD Discussion. Groningen: University of Groningen.

22. Rouse, W.B., Edwards, S.L. & Hammer, J.M. (1993). Modelling the dynamics of mental workload and human performance in complex systems. *IEEE transactions on systems, man, and cybernetics*, 23, 1662-1671.
23. Kantowitz, B.H. (1987). Mental workload. In P.A. Hancock (Ed.), *Human Factors Psychology*. (pp 81-121). Amsterdam: North-Holland.
24. Meijman, T.F. & O'Hanlon, J.F. (1984). Workload. An introduction to psychological theories and measurement methods. In P.J.D. Drenth, H. Thierry, P.J. Willems & C.J. de Wolff (Eds.), *Handbook of Work and Organizational Psychology*. (pp. 257-288). New York: Wiley.
25. Zijlstra, F. & Mulder, G. (1989). Mentale belasting: theoretische gezichtspunten en overzicht van meetmethoden (mental workload: theoretical points-of-view and an overview of measurement methods). In T. Meijman (Ed.), *Mentale belasting en werkstress. Een arbeidspsychologische benadering*. (pp. 21-41). Assen, The Netherlands: Van Gorcum.
26. Norman, D.A. & Bobrow, D.G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, 7, 44-64.
27. Aasman, J., Mulder, G. & Mulder, L.J.M. (1987). Operator effort and the measurement of heart-rate variability. *Human Factors*, 29, 161-170.
28. Vicente, K.J., Thornton, D.C. & Moray, N. (1987). Spectral analysis of sinus arrhythmia: a measure of mental effort. *Human Factors*, 29, 171-182.
29. Schneider, W. & Shiffrin, R.M. (1977). Controlled and automatic human information processing: I. Detection, search and attention. *Psychological Review*, 84, 1-66.
30. Shiffrin, R.M. & Schneider, W. (1977). Controlled and automatic information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological review*, 84, 127-190.
31. Gopher, D. & Sanders, A.F. (1984). S-Oh-R: Oh stages! Oh resources!. In W. Prinz & A.F. Sanders, *cognition and motor processes*. (pp 231-253). Berlin: Springer Verlag.
32. Kantowitz, B.H. & Knight, J.L. (1976). Testing tapping timesharing, II: auditory secondary task. *Acta Psychologica*, 40, 340-362.
33. Gopher, D. & Donchin, E. (1986). Workload -an examination of the concept. In K.R. Boff, L. Kaufman & J.P. Thomas (Eds.), *Handbook of perception and human performance. Volume II, cognitive processes and performance*. (pp 41/1-41/49). New York: Wiley.
34. Parkes, A.M. (1991). Data capture techniques for RTI usability evaluation. In Commission of the European Communities, *Advanced telematics in road transport, Proceedings of the DRIVE conference*. (pp. 1440-1456). Amsterdam: Elsevier.
35. Michon, J.A. (1971). *Psychonomie Onderweg*. Inaugural lecture, University of Groningen. Groningen, Wolters Noordhoff.
36. Michon, J.A. (1985). A critical view of driver behavior models: what do we know, what should we do? In L. Evans & R.C. Schwing (Eds.), *Human behavior & traffic safety* (pp. 485-524). New York: Plenum Press.
37. Janssen, W.H. (1979). *Routeplanning en -geleiding: een literatuurstudie (Route planning and route guidance: a review of the literature)*. (Report IZF 1979-C13). Soesterberg, The Netherlands: Instituut voor Zintuigfysiologie.

38. Verwey, W.B. (1990). Adaptable driver-car interfacing and mental workload: a review of the literature (Report V1041/GIDS/DIA/1). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
39. Michon, J.A. (Ed.) (1993). Generic Intelligent Driver Support System. London: Taylor & Francis.
40. Verwey, W.B. (1993a). How can we prevent overload of the driver? In A.M. Parkes & S. Franzén, *Driving future vehicles*. (pp 235-244). London: Taylor & Francis.
41. Kantowitz, B.H. (1992a). Heavy vehicle driver workload assessment: lessons from aviation. In *Proceedings of the Human Factors Society 36th annual meeting* (pp. 1113-1117). Santa Monica, CA: Human Factors Society.
42. Wiener, E.L. (1987). Application of vigilance research: rare, medium, or well done? *Human Factors*, 29, 725-736.
43. Hancock, P.A. & Parasuraman, R. (1992). Human Factors and safety in the design of Intelligent Vehicle-Highway Systems (IVHS). *Journal of Safety Research*, 23, 181-198.
44. Schneider, W., Dumais, S.T. & Shiffrin, R.M. (1984). Automatic and control processing and attention. In R. Parasuraman and D.R. Davies (Eds.), *Varieties of attention*. (pp. 1-27). London: Academic Press.
45. Wierwille, W.W. & Eggemeier, F.T. (1993). Recommendation for mental workload measurement in a test and evaluation environment. *Human Factors*, 35, 263-281.
46. Meister, D. (1976). *Behavioral foundations of system development*. New York: Wiley.
47. Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, 18, 459-482.
48. Hebb, D.O. (1955). Drives and the C.N.S. (Conceptual Nervous System). *Psychological Review*, 62, 243-254.
49. Teigen, K.H. (1994). Yerkes-Dodson: a law for all seasons. *Theory & Psychology*, 4, 525-547.
50. O'Hanlon, J.F. (1981). Boredom: practical consequences and a theory. *Acta Psychologica*, 49, 53-82.
51. Reid, G.B. & Colle, H.A. (1988). Critical SWAT values for predicting operator overload. In *Proceedings of the Human Factors Society 32nd annual meeting* (pp. 1414-1418). Santa Monica, CA: Human Factors Society.
52. Rueb, J., Vidulich, M., Hassoun, J. (1992). Establishing workload acceptability: an evaluation of a proposed KC-135 cockpit redesign. In *Proceedings of the Human Factors Society 36th annual meeting* (pp. 17-21). Santa Monica, CA: Human Factors Society.
53. Meijman, T.F. (1989). *Mentale belasting en werkstress. Een arbeidspychologische benadering (Mental workload and workstress. A workpsychological approach)*. Assen, The Netherlands: van Gorcum.
54. Van Ouwkerk, R.J., Meijman, T.F. & Mulder, G. (1994b). *Arbeidspychologische taakanalyse. Het onderzoek van cognitieve en emotionele aspecten van arbeidstaken. (Workpsychological task analysis. Research on cognitive and emotional aspects of tasks of labour)*. Utrecht, The Netherlands: Lemma.

55. Tsang, R S., & Wilson, G. E (1997). Mental workload. In G. Salvendy (Ed.), *Human factors handbook*(2nd ed., pp. 417–449). New York: Wiley.
56. Brabazon, P. and Conlin, H. (2001). Assessing the safety of staffing arrangements for process operations in the chemical and allied industries, Contract Research Report 345/2001, (Health and Safety Executive, Sudbury).
57. Borg, G. (1978). Subjective aspects of physical and mental load, *Ergonomics*, 21, (3), 215-220
58. Brookhuis, K.A. and De Waard, D. (2002). On the assessment of (mental) workload and other subjective qualifications, *Ergonomics*, 45, (14), 1026-1031
59. Hancock, P.A. and Caird, J.K. (1993). Experimental evaluation of a model of mental workload, *Human Factors*, 35, (3), 413-429
60. Hart, S.G. and Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. Hancock and N. Meshkati (eds). *Human Mental Workload*. (North Holland, Amsterdam), 139-183
61. Van Winsum, W; Brookhuis, K.A.; De Waard, D. (1999). Lane change manoeuvres and safety margins. *Transportation Research Part F: Traffic Psychology and Behaviour*, 139-149.
62. Van Winsum, W., Martens, M., Herland, L. (1999). The effects of speech versus tactile driver support messages on workload, driver behaviour and user acceptance, TNO-report, TM-99-C.
63. Card, S.K, Moran, T.P., & Newell, A. (1983). "The Psychology of Human-Computer Interaction", Hillsdale, NJ: Lawrence Erlbaum Associates.
64. Wever, R. A., (1979). *The circadian system of man*. Berlin: Springer-Verlag.
65. Moore-Ede, Sulzman M, F., and Fuller, C., (1982). *The Clocks That Time Us: Physiology of the Circadian Timing System*. Cambridge: Harvard Univ. Press.
66. Knauth, P., and Rutenfranz, J. (1976). Experimental studies of permanent night and rapidly rotating shift systems. *International Archives of Occupational and Environmental Health*, 37, 125-137.
67. Akerstedt, T. (1977). Inversion of the sleep wakefulness pattern: Effects on circadian variations in psychophysiological activation. *Ergonomics*. 20, 459-474.
68. Reinberg, A., Andlauer, P., De Prins, J., Malbecq, W., Vieux, N., and Bourdeleau, P. (1984). Desynchronization of the oral temperature circadian rhythm and intolerance to shift work. *Nature*, 308, 272-274.
69. Monk, T.H., and Embrey, D. E., (1981). A field study of circadian rhythms in actual and interpolated task performance. In A. Reinberg, N. Vieux, and P Andlauer, Eds., *Night and shift work: Biological and social aspects*. Oxford, Pergamon.
70. Folkard, S., & Monk, T. H. (1979). Shiftwork and performance. *Human Factors*, 21, 483-492.
71. Folkard S., Wever R. A., & Wildgruber C. M. (1983). "Multioscillatory control of circadian rhythms in human performance". *Nature*, 305, 223-226.
72. Tepas, D. I., (1982). Work/sleep, time schedules and performance. In W. B. Webb, Ed., *Biological rhythms, sleep and performance*. New York: Wiley.

73. Tepas, D. I., Walsh, J. K., Moss, P. D., & Armstrong, D. (1981). Polysomnographic correlates of shift worker performance in the laboratory. In A. Reinberg, N. Vieux, & P. Andlauer (Eds.), *Night and shift work: Biological and social aspects* (pp. 179–186). Oxford: Pergamon Press.
74. Tepas, D. I. (1990). Do eating and drinking habits interact with work schedule variables? *Work and Stress*, 4, 203–211.
75. Kelly, R. J. and Schneider, M. F., (1982). The twelve-hour shift revisited: Recent trends in the electric power industry. *Journal of Human Ecology*, 11 (suppl.), 369-384.
76. Bhatia N., & Murrell K. F. H. (1969) "An industrial experiment in organized rest pauses". *Human Factors*, 11, 167-174.
77. Costa, G., (1996). The impact of shift and night work on health, *Applied Ergonomics*, Vol. 27, No. 1, pp. 9-16.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Table 18-62-1—Scenarios with links to the PRA



Table 18-62-2—Categories of Task Complexity Models

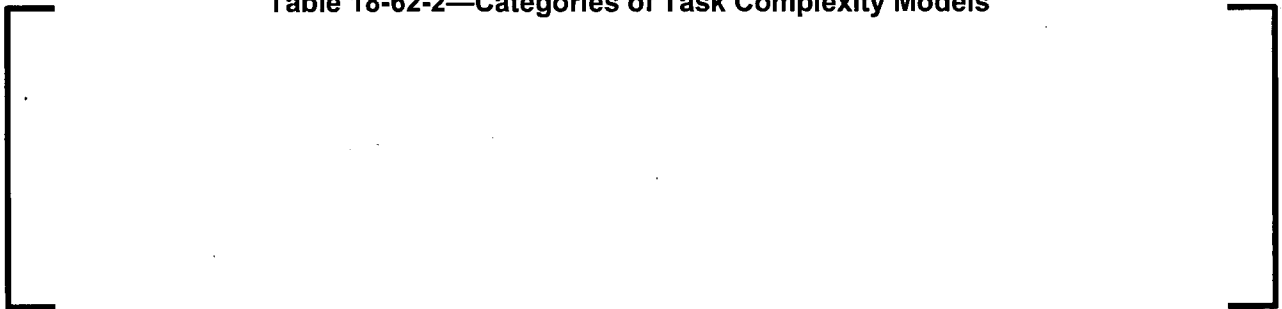


Table 18-62-4—Extended Human Information-Processing Model

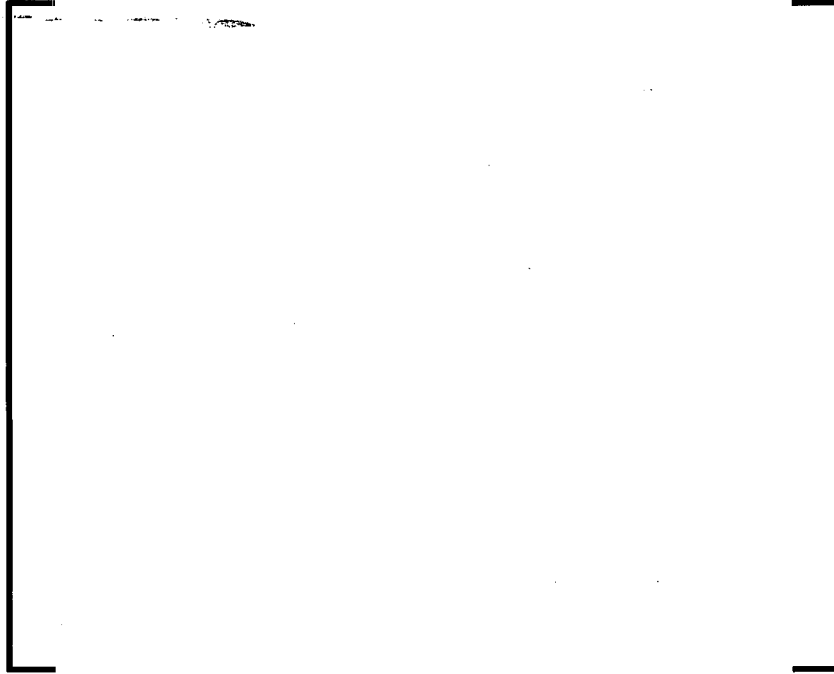


Table 18-62-5—Example of Cognitive Demand Workload Sheet



**Figure 18-62-1—Hypothetical Relationship between Demand and
Performance**



Figure 18-62-2—Workload and Performance in 6 Regions



Figure 18.62-3—Tools for Workload Assessment

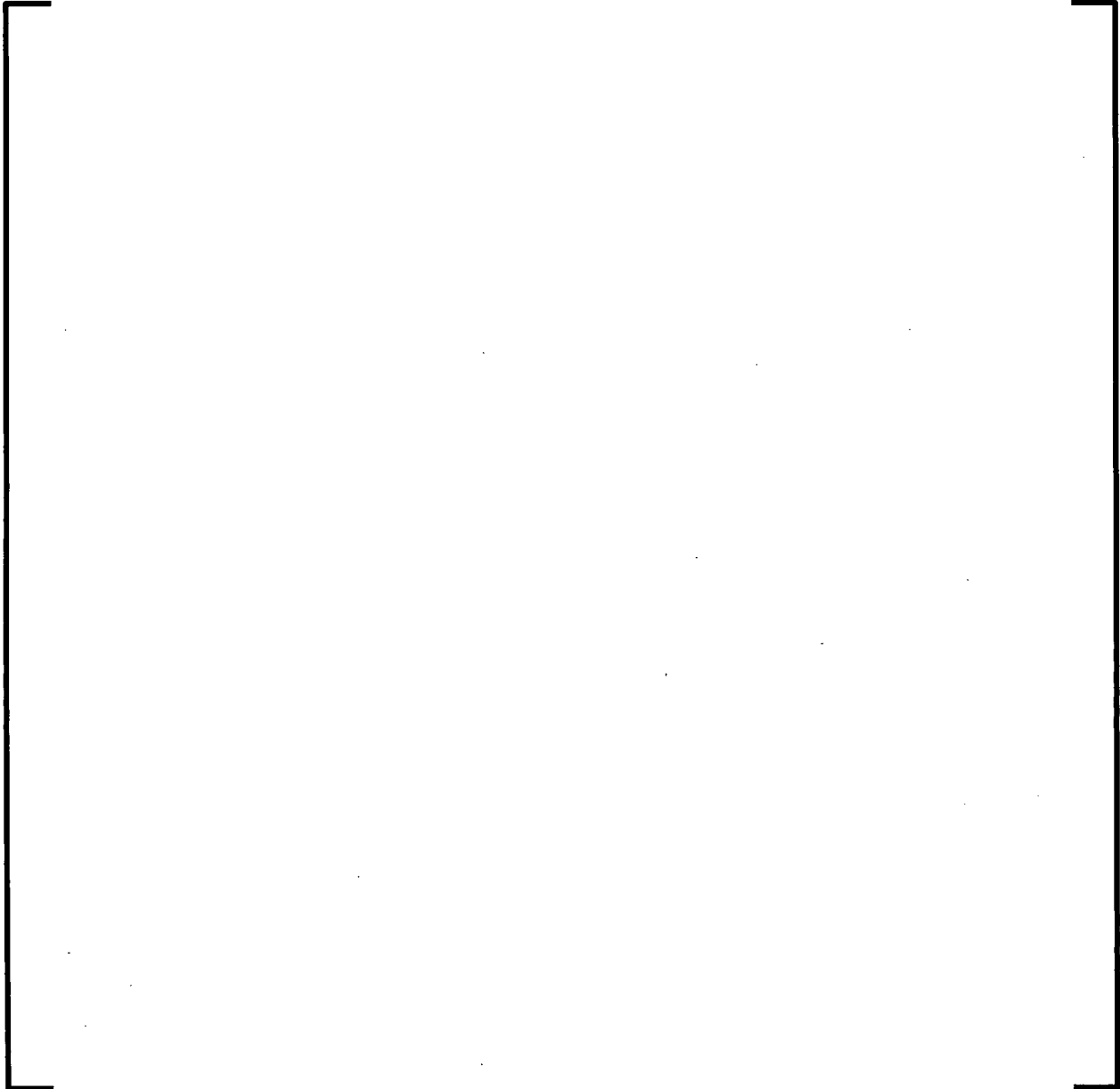


Figure 18-62-4—Model of Human Information Processing



Question 18-63:

This Question indicates insufficient information in the V&V Implementation Plan for the general principal derived from NUREG-0711. This is followed by specific examples that arose because the information provided was insufficient for the review. The examples provided do not comprise a complete set of issues for each category. Rather, they are used to illustrate the general issue caused by the missing information. It is the responsibility of the Applicant to apply the general principals illustrated by staff in the examples to determine the full-scope of issues affected by the missing information.

Typos and Errors. There are a number of typos and editorial errors apparent in the document which have the adverse effect of completely changing the intended meaning. In several cases, these errors cause the text to violate the various aspects of the guidance provided by NUREG-0711. Staff must review materials exactly as presented, not based on inference. The following is not a complete set of criteria that are not met due editing issues, nor is it intended to be a complete set. The material needs to be thoroughly reviewed to identify these errors and provide clarification. These errors include, but are not limited to:

1. Section 3.6.3, which discusses selection of test participants, combines inappropriately characteristics for the selection of test administrators. As written, this section contradicts the NUREG criteria that test participants will not be members of the design team. Staff request clarification of selection of test participants and test administrators (conductors).
2. Section 3.5.1.2 states that Appendix B has the list of procedure driven tasks that will be used during V&V. However, Appendix B contains the roles and responsibilities of the HF team. Investigation indicated that the information referenced may be that presented in Appendix C. Staff inquires whether to use Appendix C in place of B.
3. Section 3.6.11 is not relevant to ISV. Is this to be associated with a different component of V&V?
4. Section 3.9.3.3 is referenced multiple times in the plan. The first time it is referred to in HSI scenario design, it is used appropriately to develop one-dimensional scenarios to test HSI design. However, the 2nd and 3rd times Section 3.9.3.3 is referenced, it is used to develop multi-dimensional scenarios. Section 3.9.3.3 is not written to support development of multidimensional scenarios -- it states that only one dimension is to be sampled. A method to develop multidimensional scenarios must be provided if the Applicant will not be able to provide the complete set of scenarios that will be used during V&V.
5. Three potentially separate databases are referenced in this plan and other plans: the HED database, the HFE database, and a QA database. Staff inquires whether these databases are the same but given different names in editing. If they are a single database, one name should be used. If they are different databases, provide an explanation, differentiation, and definition of each.
6. Section 3.6.11.3 states that test data 'should' be analyzed using established analysis techniques. Use of 'should' is inappropriate.
7. In Section 3.9.3.5, the Applicant provides an overview of the process to prioritize HEDs for justification and resolution. The process will consist of justification of HED, determination of whether HEDs have safety consequences (Priority 1), if not then determination of whether the HED has performance consequences (Priority 2), and if none of the above, classification as other. In the HSI Design Implementation Plan, HED categories are referred to with

different designations, which has caused some confusion. Please clarify, either by use of one designation or explain the designation process and the categories.

Response to Question 18-63:

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The schedule for providing the revised U.S.EPR V&V Implementation Plan is provided below:

Document Number	Commitment Date
U.S.EPR Human Factors Verification and Validation Implementation Plan	3/30/2010

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-64:

This Question indicates insufficient information in the V&V Implementation Plan for the general principal derived from NUREG-0711. This is followed by specific examples that arose because the information provided was insufficient for the review. The examples provided do not comprise a complete set of issues for each category. Rather, they are used to illustrate the general issue caused by the missing information. It is the responsibility of the Applicant to apply the general principals illustrated by staff in the examples to determine the full-scope of issues affected by the missing information.

Performance Measurement and metrics. NUREG-0711 divides the review criteria for performance measurement into three sections. Section 11.4.3.2.5.1 addresses the measurement characteristics that effect the quality of the performance measures, Section 11.4.3.2.5.2 addresses the identification and selection of variables to represent measures of performance, and Section 11.4.3.2.5.3 addresses the development of performance criteria. Performance metrics must be directly linked to the scenarios tested, and the criterion for success for the scenario. Performance metrics should be linked to HRA, risk important human actions, results of Task Analysis, and/or Operator Experience. These items are not linked to performance metrics in the V&V plan. The V&V plan does not link metrics to scenarios, nor provide discussion of how performance metrics will be used. Discussion of the analysis of performance data and selection of performance metrics neglects discussion of data reliability, validity, or verification of the conclusions of the analyses. The issues below are representative of deficiencies in these areas, but are not limited to just these examples:

1. In section 3.6.12, the Applicant states that validation conclusions will be iteratively documented in the validation output reports during the design process. Staff did not find any discussion of independent verification of analyses in the HF V&V Implementation Plan. Methods to verify and validate conclusions and analyses independent of the process are needed. Reliability and validity of conclusions and data are also not addressed. AREVA is requested to address conclusion reliability and validity. How will metrics be defined for scenarios? Which metrics are linked to which scenarios? What are the success criteria?
2. In Section 3.6.12, the Applicant states that "analysis will determine if data are pass/fail." It is not clear to staff what is meant here. Performance measures should be designated as pass/fail criteria with defined thresholds before the data are collected or analyzed, and the threshold for pass/fail should be set before data collection or analysis. The relationship between the data collected and the performance criteria needs to be defined so that reason for the selection of analysis techniques is transparent. In the V&V plan the analysis providing validation of the performance measures is selected, and that analysis will determine which measures are used for pass/fail determination after the analysis is performed. Performance measures should be identified as pass/fail criteria and the level required for pass prior to the administration of the test. Otherwise it could allow criteria that support the goodness of the design to be picked and performance metrics that question the goodness of the design to be ignored. Provide a method to define or the defining measures that will be used as pass/fail criteria, the scenarios in which they will be used, the thresholds for each, and discuss how the thresholds were derived. Also discuss how the required data for these metrics will be obtained, and how bias will be avoided.
3. In Section 3.6.10.1 of the HF V&V Implementation plan, the Applicant states, "The approach to establishing criteria should be based on the comparisons between the measurement and criteria that are performed (e.g., requirements referenced, benchmarks referenced,

normative referenced, and expert-judgment referenced)." Staff does not understand what is meant here. Clarification is required. Which criteria will be performed? How will these be used to establish criteria? Which criteria will be established?

4. Section 3.6.10.1 states a criterion for performance measurement will be established and evaluated as part of test development; ANSI 58.8-1994 will be considered a source for response time criteria. Will reaction time be the only performance measure of interest? Please explain. What sources and metrics will be used to define performance limits beyond reaction time data? It further states that more accurate performance requirements will be defined as a function of the HRA and TA performed for this plant design; however, these data used from these techniques are not identified and the plans are not referenced. More information is therefore needed. Reference the HRA and TA plans. Identify what data from the HRA and TA will be used to define performance requirements.

Response to Question 18-64:

Independent verification will be discussed in the revised Verification and Validation (V&V) Implementation Plan (IP). The subject matter addressed in this response contains representative information from the revised V&V IP.

Evaluation Team

This section identifies the members of the human factor (HF) V&V team and their minimum qualifications (see Figure 18-64-1). It provides examples of their typical contributions to the evaluation.

Identification of the Evaluation (HF V&V) Team

The control room design team (CRDT) prepares the human system interface (HSI) program and IPs, guides and oversees the design implementation process through the remaining steps to the final validation of the implemented design, and verifies that the execution and documentation of each step in the process is carried out in accordance with the established program and procedures. The CRDT is comprised of a multi-disciplinary team with expertise in HFE and in other technical areas relevant to HSI design, evaluation, and operations.

The HF V&V team, independent of the CRDT, is comprised of individuals who were not involved in the design of the HSI being evaluated. The HF V&V activities must be performed in accordance with the AREVA NP engineering operation procedures for the performance of independent quality related verification. Individuals who were involved in the design must not be directly responsible for directing those portions of the evaluation process that require objectivity about the quality of that design. The design team must be independent of the evaluation team, but the design and evaluation teams must work in close cooperation. The evaluation team must have access to the original HSI designers as resource persons (for example, during the delineation of system functions, operator task analyses, or control room inventory efforts).

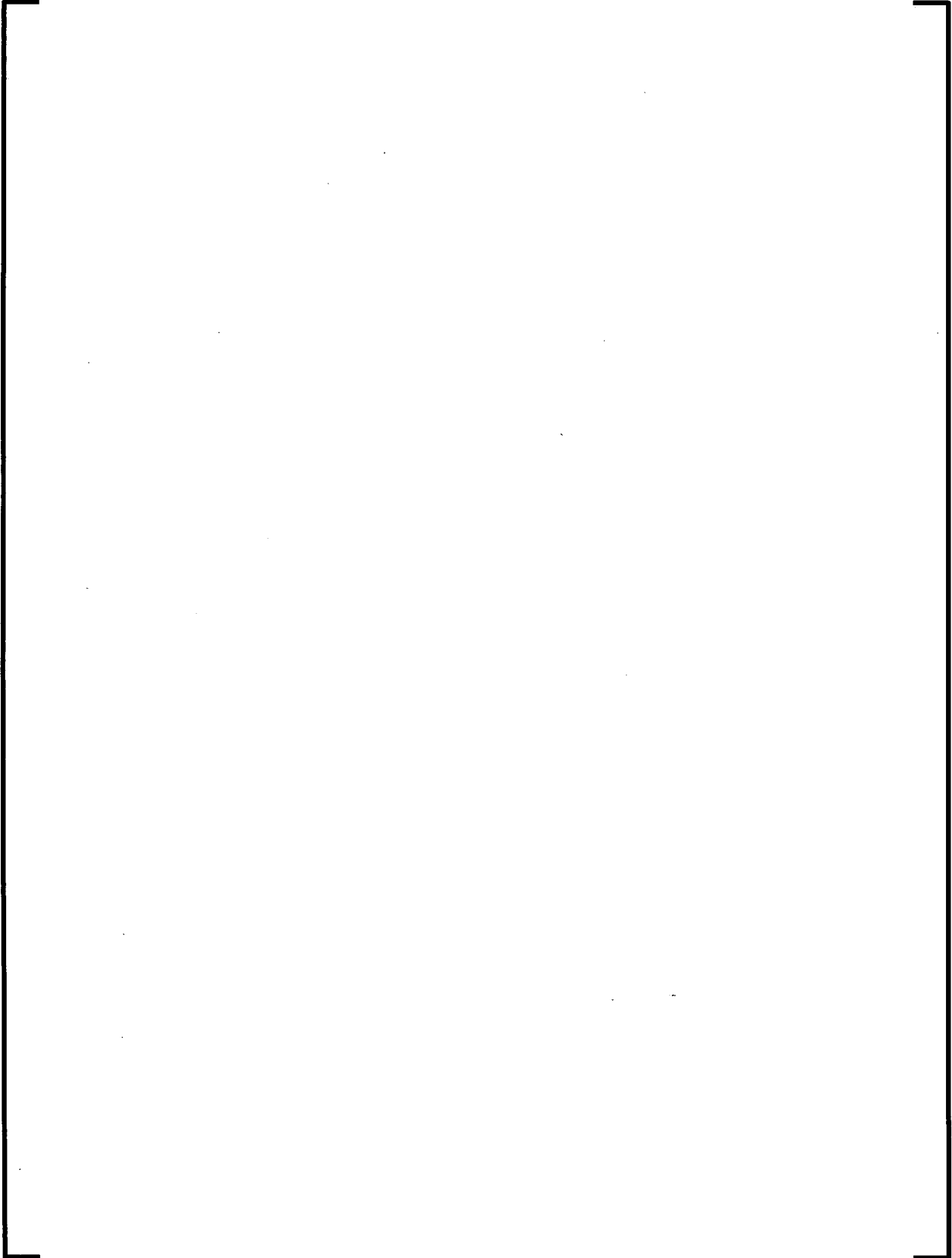
Due to the qualification requirements for the HF V&V team, the team is interdisciplinary or multi-disciplinary. As needed, the evaluation team must be composed of individuals with the following expertise: nuclear engineering, architectural design and civil engineering, system analysis, instrumentation and control systems, information and computer systems, human factors

engineering (HFE), operating experience, and personnel training. The required professional experience may be satisfied by the evaluation team as a collective whole. Satisfaction of the professional experience requirements associated with a particular skill may be realized through the combination of the professional experience of two or more members of the evaluation team who each satisfy the other defined credentials of the particular skill area but who do not possess all of the specified professional experience.

The number of members in the team must be kept low to verify efficient work, but the number must allow for varied discussions and opinions. One person may possess multiple skills. Expertise in areas not covered by the evaluation team must be provided consulting experts outside the team or AREVA NP.

The revised V&V IP will appropriately delineate the complexion of the evaluation team. Statements such as "pass/fail" will be removed because those were misnomers. The success of the evaluation is reflected through both objective and subjective methods, and the evaluation results are both quantitative and qualitative. Success is not measured through concepts of "pass/fail" but rather concepts like the goodness of design, availability of components and elements, and usability. Shortcomings do not indicate failure but rather a need for design modification, a revisit to function allocation, function requirements, or task analysis. Outcomes are documented, modifications are made as appropriate, and through the iterative process, the system process accommodates any aspect of design that may need bolstered. The human engineering discrepancy (HED) documentation and use of the HITS recognizes issues and verifies their resolution.

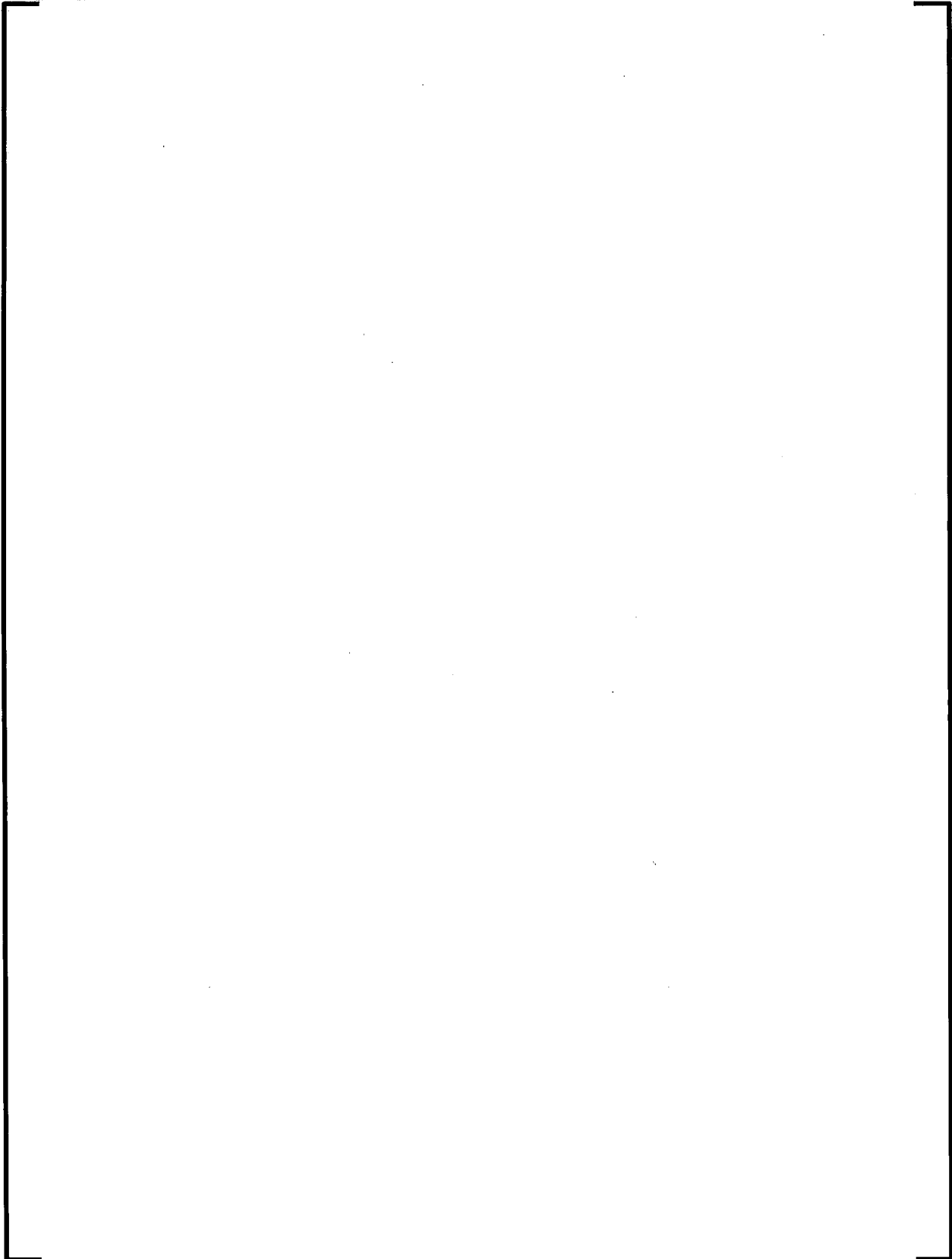


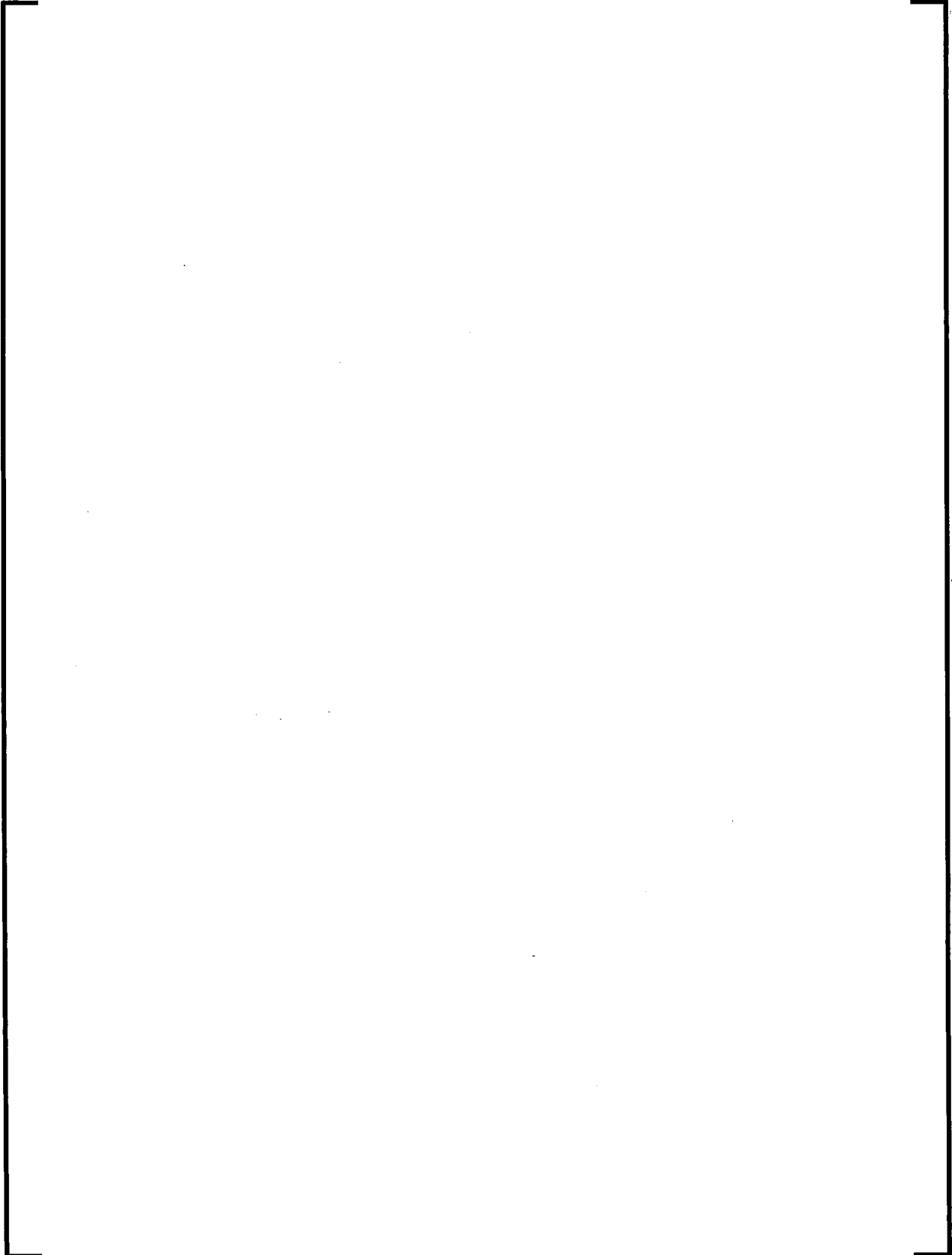


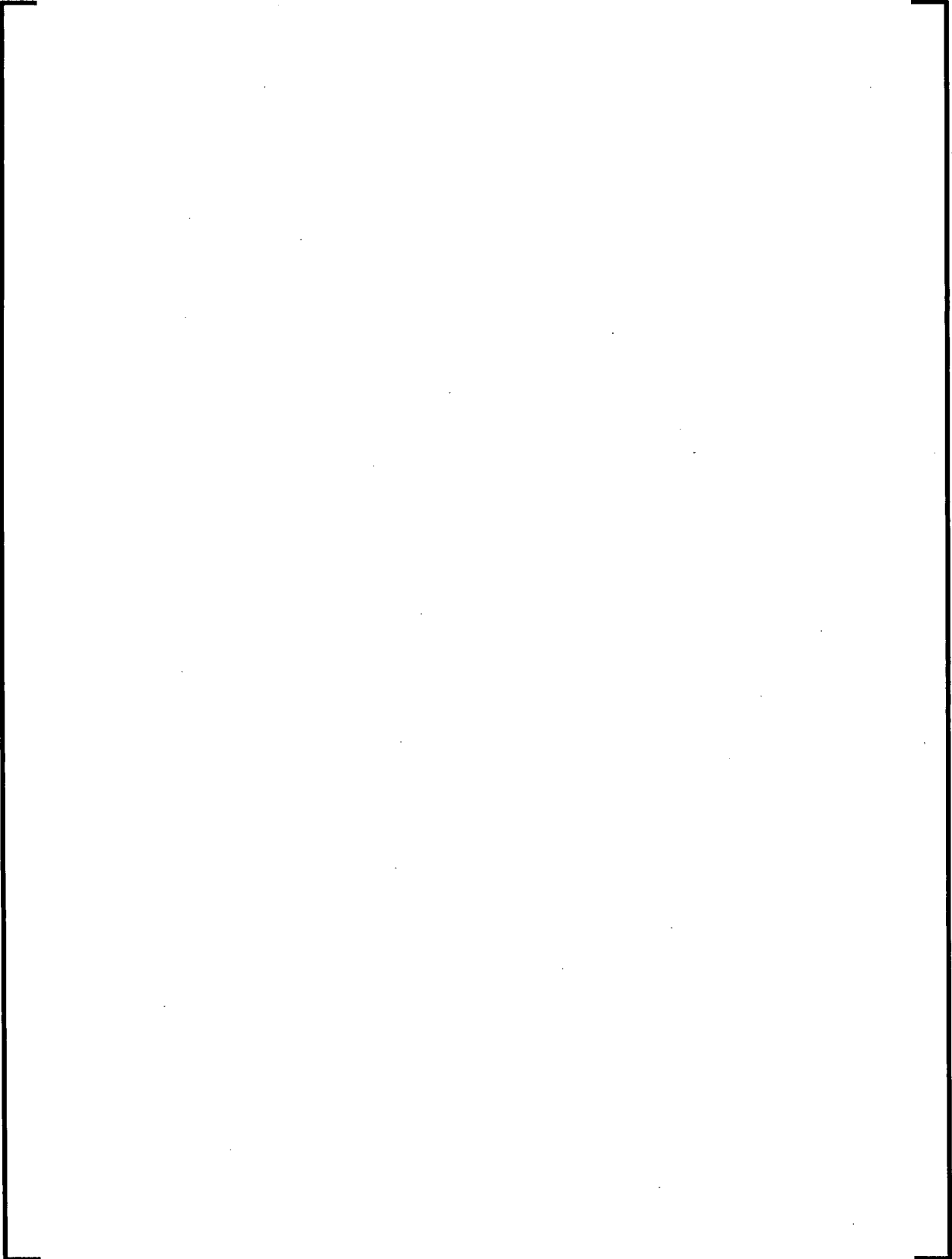
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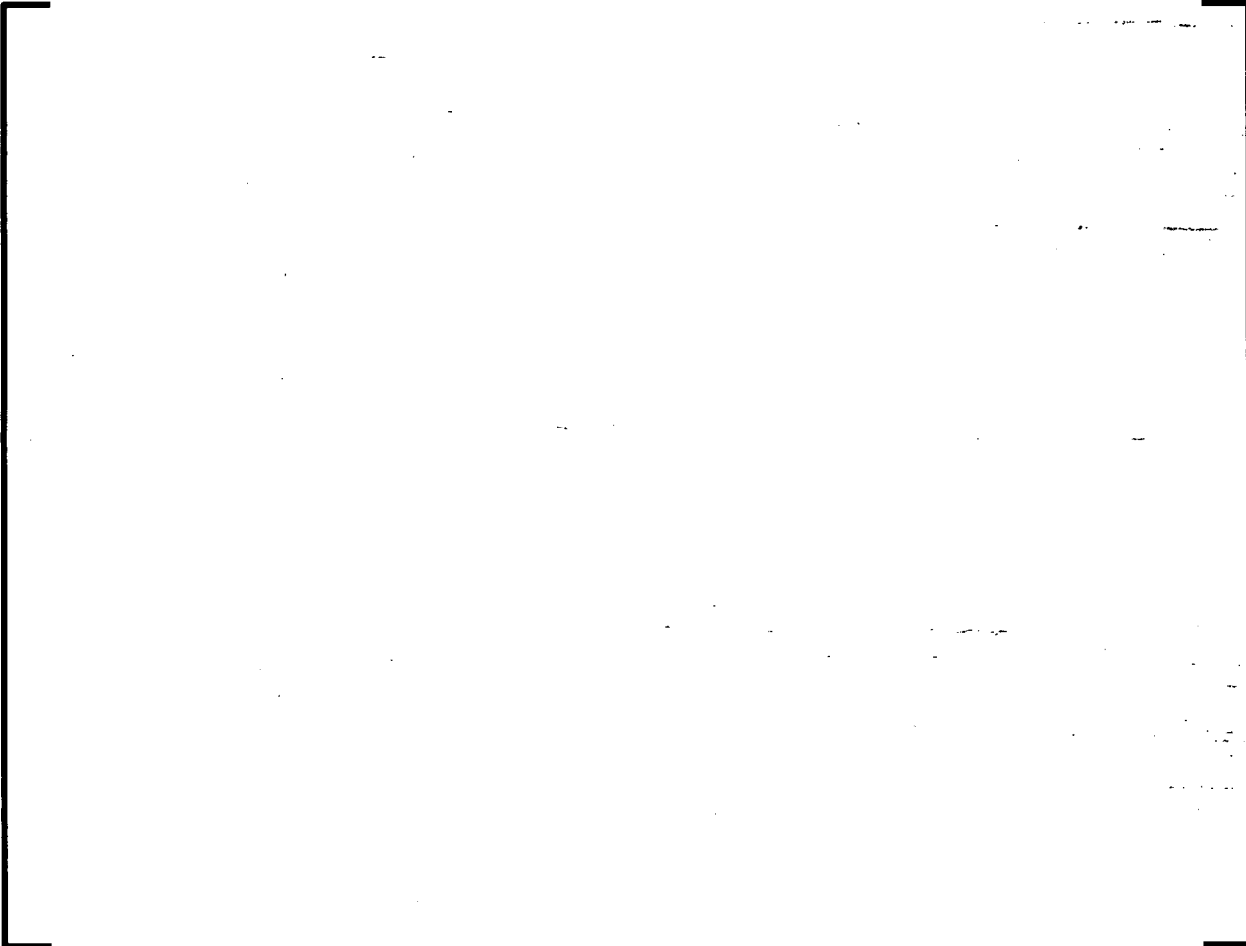
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FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Figure 18-64-1—Levels of Design and Evaluation



Figure 18-64-2—Example of a Functionality Matrix



Question 18-65:

This Question indicates insufficient information in the V&V Implementation Plan for the general principal derived from NUREG-0711. This is followed by specific examples that arose because the information provided was insufficient for the review. The examples provided do not comprise a complete set of issues for each category. Rather, they are used to illustrate the general issue caused by the missing information. It is the responsibility of the Applicant to apply the general principals illustrated by staff in the examples to determine the full-scope of issues affected by the missing information.

Task Analysis. Section 11.4.4.2 (5) and 11.4.2.2.2 (2) and (4) discuss the role of Task Analysis within the HF V&V design. NUREG-0711 states that the HSIs and their characteristics (as defined in the HSI inventory and characterization) should be compared to the personnel task requirements identified in the task analysis. As stated in NUREG-0711, design solutions to correct HEDs should be consistent with system and personnel requirements identified in the Preparatory Analysis (i.e., Operating Experience Review, Function and Task Analysis, and HSI Characterization). Use of the Limited Scope Task Analysis in the V&V is discussed multiple times in the V&V IP; however, its justification is unclear. Issues regarding the use of the Limited Scope Task Analysis in the HFE V&V IP include, but are not limited to:

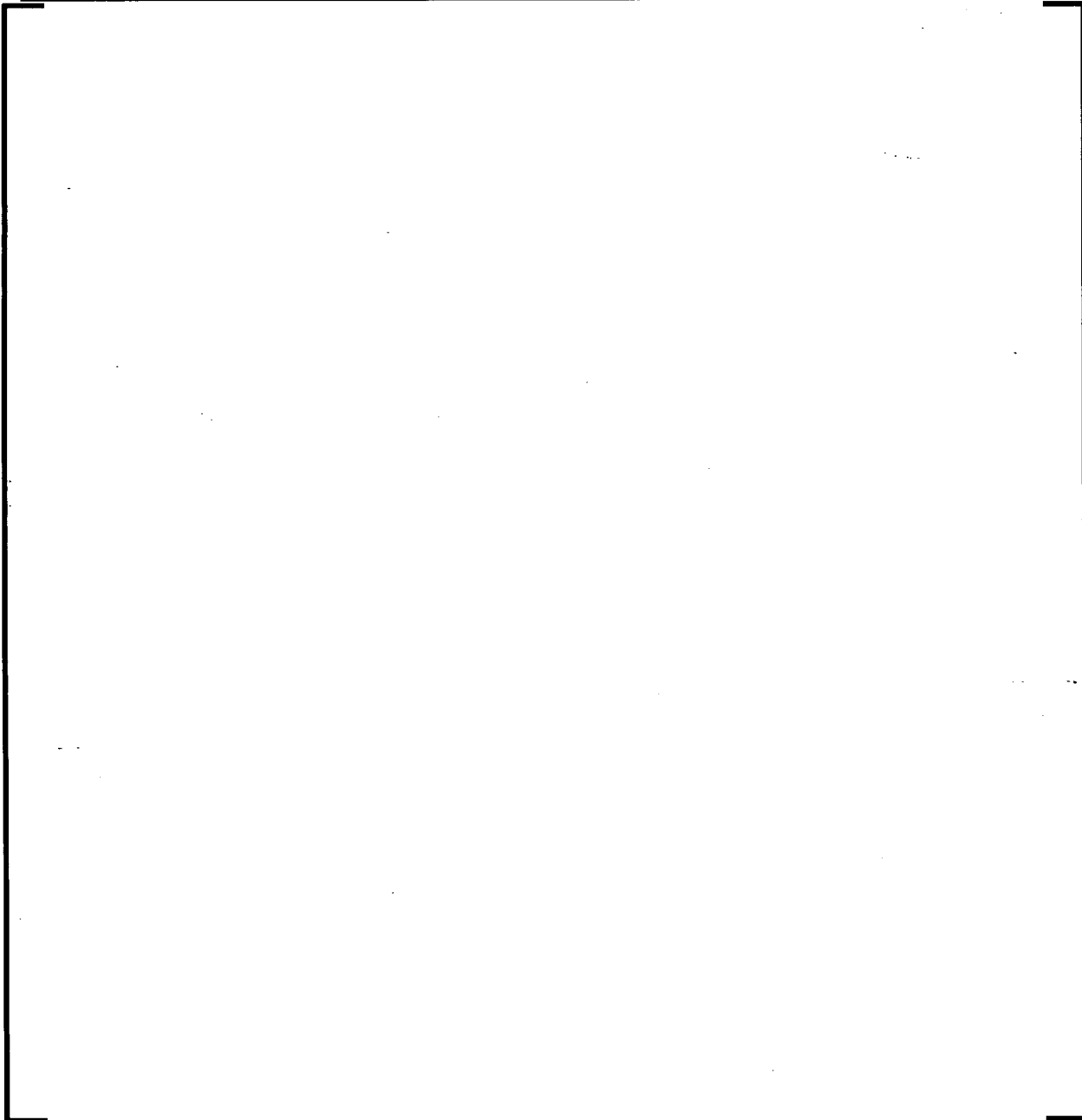
1. What are the bases for the limited scope task analysis? What is the scope? The methods to produce the limited scope task analysis is not documented in V&V or in the Task Analysis Implementation Plans. How will limited scope task analysis be performed? It is not clear that a limited scope task analysis will sufficiently review the entirety of the task to define the interactions occurring at multiple levels (global, situational, detailed) of the scenario. Please clarify how this will be used, and information to determine that the limited task analysis will be sufficient for the application. Staff inquires why limited scope task analysis will be used in place of the information derived from the full scope task analysis.
2. Section 3.9.3.2 of the V&V Implementation plan states it will use dynamic HSI Task Support Verification. What is meant by Dynamic Task Support Verification? Further clarification of its use is required. What is its scope? How is it performed? How does it differ from Task Analysis?

Response to Question 18-65:

The subject matter addressed in this response contains representative information from the V&V IP.

1. The term "limited scope task analysis" is discussed in the Response to Question 18-69.
2. The term "dynamic task support verification" is renamed dynamic human system interface (HSI) task support verification.





FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-66:

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ISV – Validation Testbeds. Section 11.4.3.3.2 of NUREG-0711 addresses the requirements to be met by the validation testbed. There are 2 sections of the HFE V&V IP that address the development of ISV testbeds. While the V&V plan clearly commits to developing at least one full scope simulator, several questions were raised. They include, but are not limited to:

1. The V&V Implementation plan states that the full-scope ISV simulator will be completed and certified via the ANSI/ANS-3.5-1998 process prior to the use of the simulator during V&V. However, the NRC does not inspect a simulator to certify it as a plant reference simulator at this time. Please clarify what is meant by certify and the status of the simulator to be used for ISV.
2. In Section 3.6.11 of the V&V Implementation Plan, development of a 'Mockup' is discussed. Section 3.81 discusses the development of a "full-scope simulator." The Applicant commits to incorporating accurate plant models into both the Mockup and the full-scope simulator as these models become available. How do these two simulators differ? How is the development of the high fidelity simulator related to the development of the mockup? These sections appear to indicate that multiple simulators will be developed at different times. Is this correct? For what tasks will the mockup be used? For what tasks will the simulator be used?
3. What are the relative schedules for the development of the mockup and the full-scope simulator with respect to the other portions of the V&V Implementation plan?

Response to Question 18-66:

The subject matter addressed in this RAI response contains representative information from the V&V IP.

1. AREVA NP does not expect the NRC to certify the full-scope simulator. AREVA NP will certify the simulator according to ANSI/ANS-3.5-2009.

ANSI/ANS-3.5-2009: Nuclear Power Plant Simulators for Use in Operator Training and Examination Current Standard, supersedes ANSI/ANS-3.5-1998

"This standard establishes the functional requirements for full-scope nuclear power plant control room simulators for use in operator training and examination. The standard also establishes criteria for the scope of simulation, performance, and functional capabilities of simulators. This standard does not address simulators for test, mobile, and research reactors, or for reactors not subject to U.S. Nuclear Regulatory Commission licensing. This standard does not establish criteria for the use of simulators in training programs."

The engineering simulator and workstation mockup is scheduled to be completed three years prior to the development of the full scope simulator. The full scope simulator is scheduled to be completed two years prior to fuel load.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-67:

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Scenario Assignment, and Crew/Participant Selection and Training. NUREG-0711 divides the review criteria for test design into five sections. Section 11.4.3.2.6.1 addresses coupling crews and scenarios, Section 11.4.3.2.6.2 addresses test procedures, Section 11.4.3.2.6.3 addresses the training of test conductors, Section 11.4.3.2.6.4 addresses the training of test participants, who are separate from test conductors, and Section 11.4.3.2.6.5 addresses the conduct of pilot studies. Section 11.4.3.2.6.1 of NUREG-0711 states that important characteristics of scenarios should be balanced cross crews. Random assignment of scenarios to crews is not recommended. The value of using random assignment to control bias is only effective when the number of crews is quite large. Instead, the validation team should attempt to provide each crew with a similar and representative range of scenarios. Several aspects of the HFE V&V IP are not clear and appear to violate the guidance above. Issues include, but are not limited to:

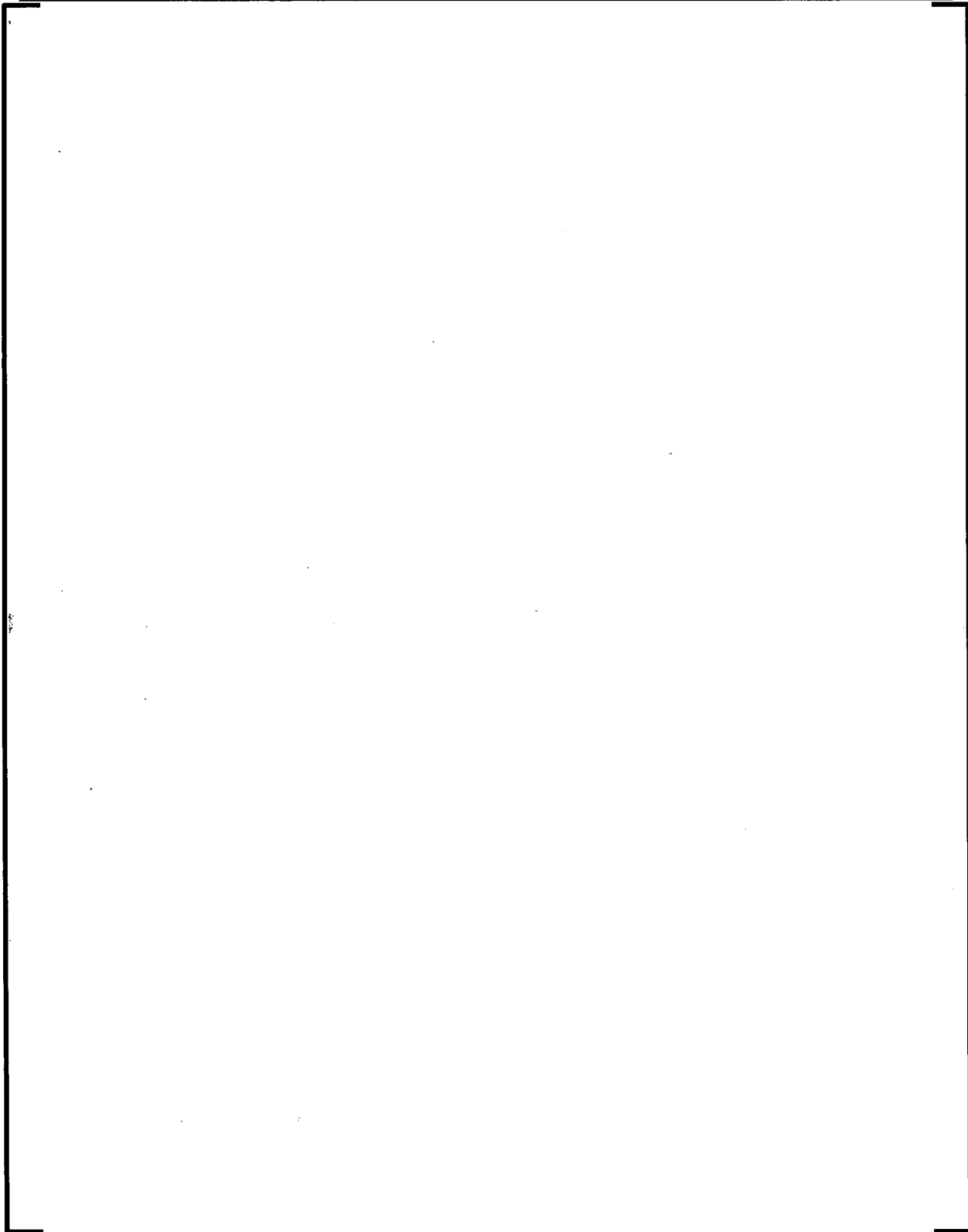
1. As stated in NUREG-0711, Section 11.4.3.2.6.1, random assignment of scenarios is not recommended because the number of crews typically run is not sufficient to automatically average out effects of order or experience. Section 3.5.4 of the V&V Implementation plan states that random assignment of scenarios to participants will be used. It is not clear from the V&V Implementation plan whether a high enough number of crews to balance testing effects will be used. If the number of crews is too small to allow for statistical power to ensure that order effects are not an issue in testing, scenarios order and assignment should be balanced across testing and crews. The validation team should attempt to provide each crew with a similar and representative range of scenarios, balanced across critical characteristics. Provide more information to determine how order effects will be avoided. Provide more information to determine how critical characteristics of scenarios will be balanced across crews.
2. In Section 3.5.4 of the HF V&V IP, staff is not clear whether random selection will be used to select the factors to be combined in a scenario or whether random selection will be used to select from a list of predetermined scenarios. If the first case, staff requests more information to determine how realism of scenarios will be ensured. If the latter case, staff requests more information to determine how multiple variants of the same scenario will be avoided. If an alternate method will be used, it should be described. Also clarify if the same set of scenarios will be presented across test crews or if new scenarios will be randomly generated for each.
3. Section 3.6.7 states that a procedure will be developed as part of the validation procedure, and that test procedures should minimize the opportunity for participant or administrator bias. The discussion in this section is primarily a restatement of some of the guidance provided in NUREG-0711. More detail is needed regarding the procedures to be followed during validation testing. What considerations should affect interaction between participants and administrators? What considerations will guide how and when will data be collected and stored? What procedures will be followed for documentation of

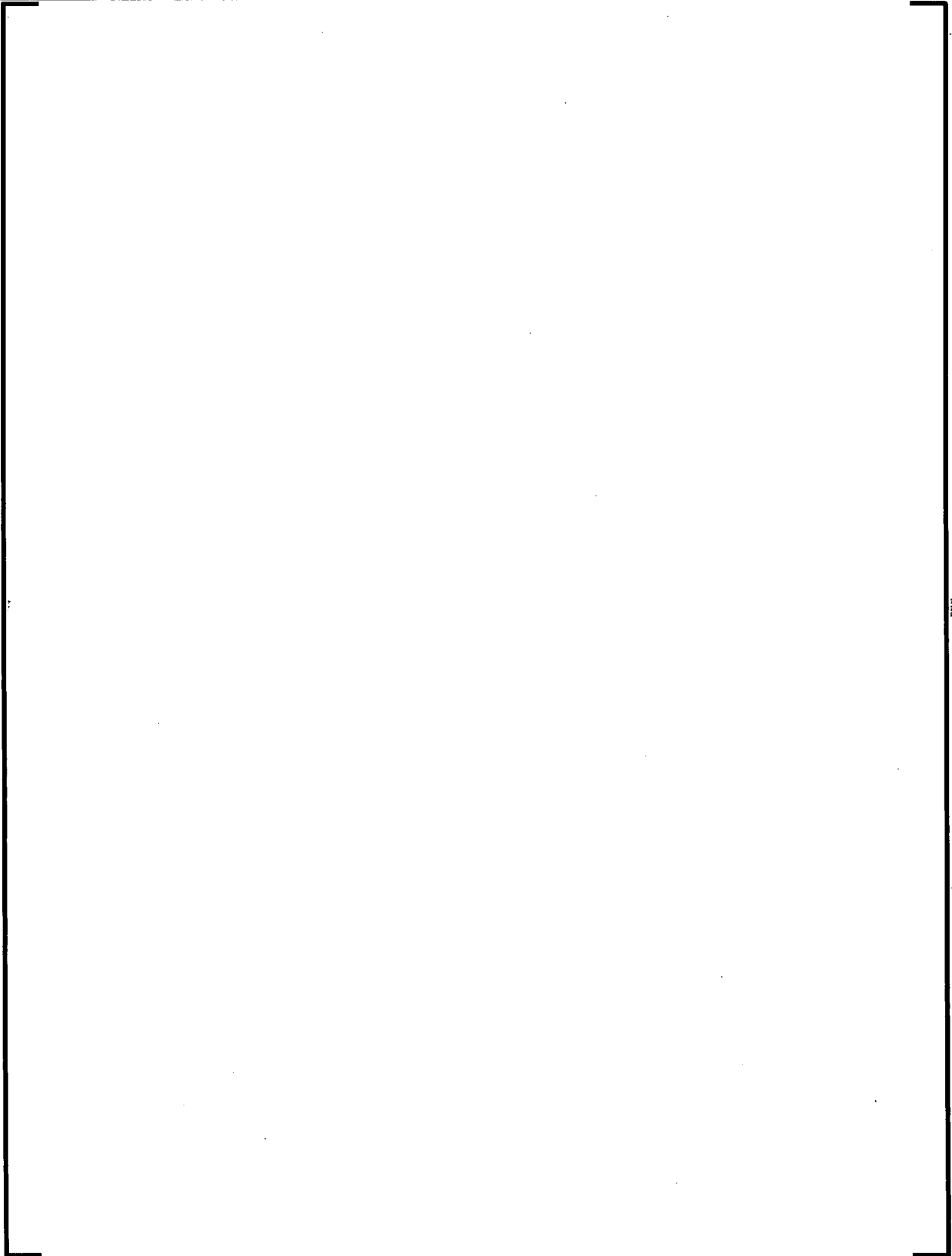
the testing scenarios? Procedures for the documentation of testing irregularities and training on the importance of documenting training irregularities should be presented.

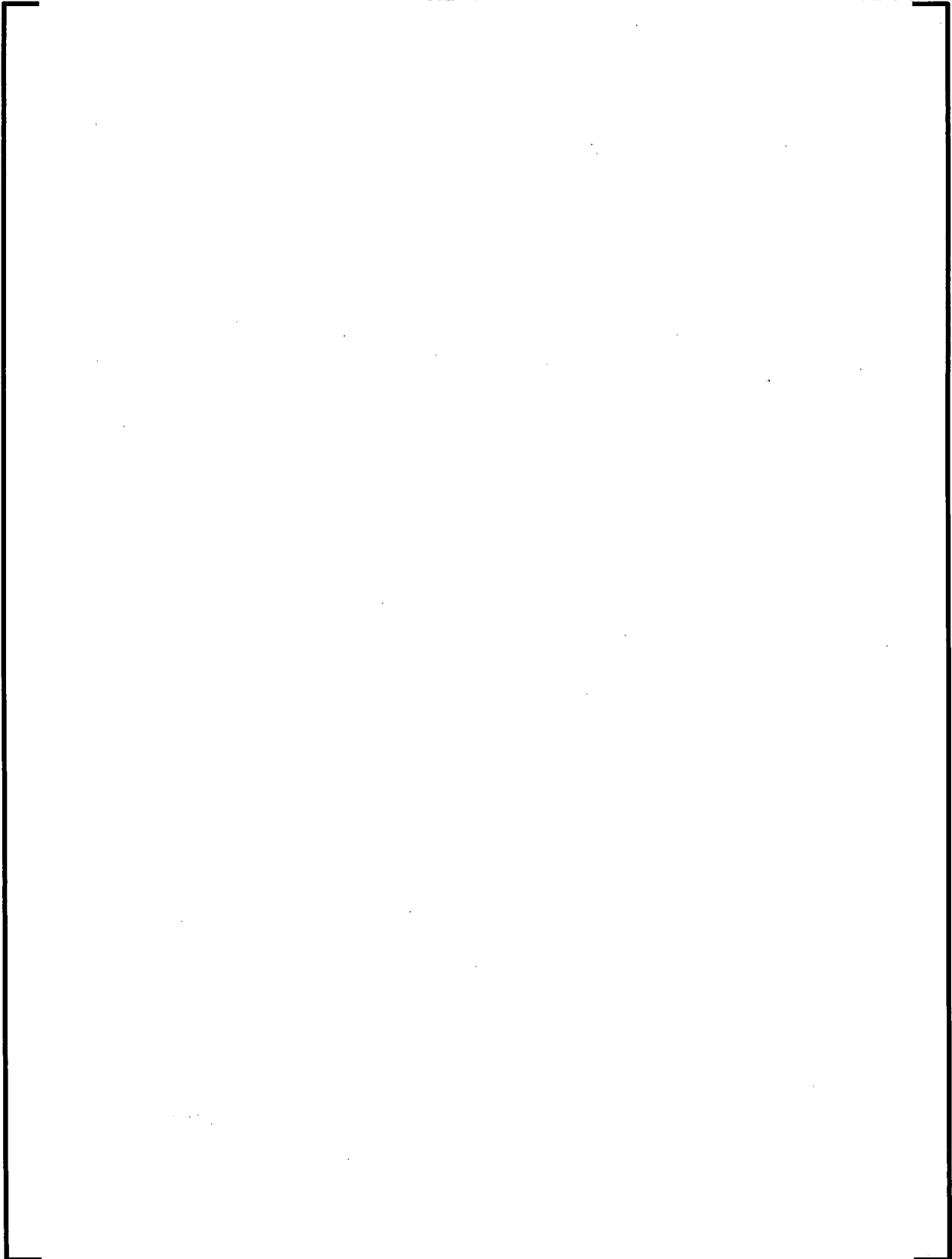
4. Section 3.6.9, Training of Test Participants, states: All test participants will be required to have basic US EPR™ operator training. All participants will have training on screen protocols and HMI interaction processes. They will also have training to help prevent potential human errors. Further information is requested to understand how performance bias will be avoided. At what point relative to performance in the validation test will test participants receive training (immediately before testing, a few weeks before)? On what topics will training be received? How will performance bias due to training be avoided?
5. Section 3.6.8 states an intention to train test administrators on the simulator using scenarios with predetermined malfunctions or by having test administrators perform the test scenarios. An information checklist will be developed from the protocols used to govern interaction with test participants. Plans to train test administrators do not address experimenter bias, importance of documenting problems that occur during testing or how test procedures should be used. Training of test administrators is focused entirely on familiarizing test administrators with the scenarios and workings of the plant and simulator and on how and what information may be communicated between test participants and administrators, which is one purpose of the Pilot Study. More information is requested for the development of procedures, what they should be used to prevent, what characteristics they should have, and how they should be used. More information is needed to determine how experimenter bias will be avoided and what training administrators will receive regarding bias.
6. Discuss how factors such as circadian rhythms, fatigue and environmental effects will be incorporated into scenario development with respect to their related sections.

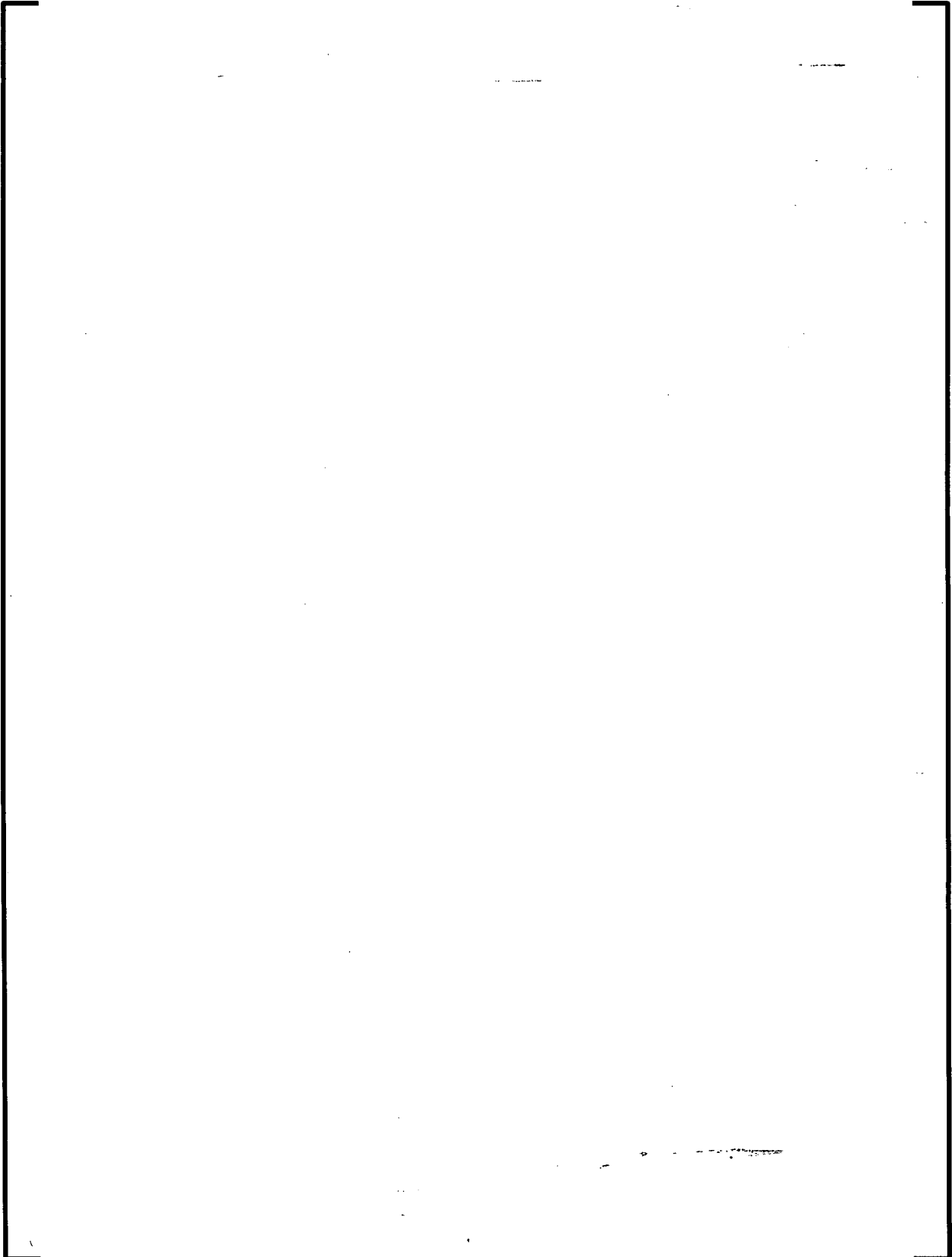
Response to Question 18-67:

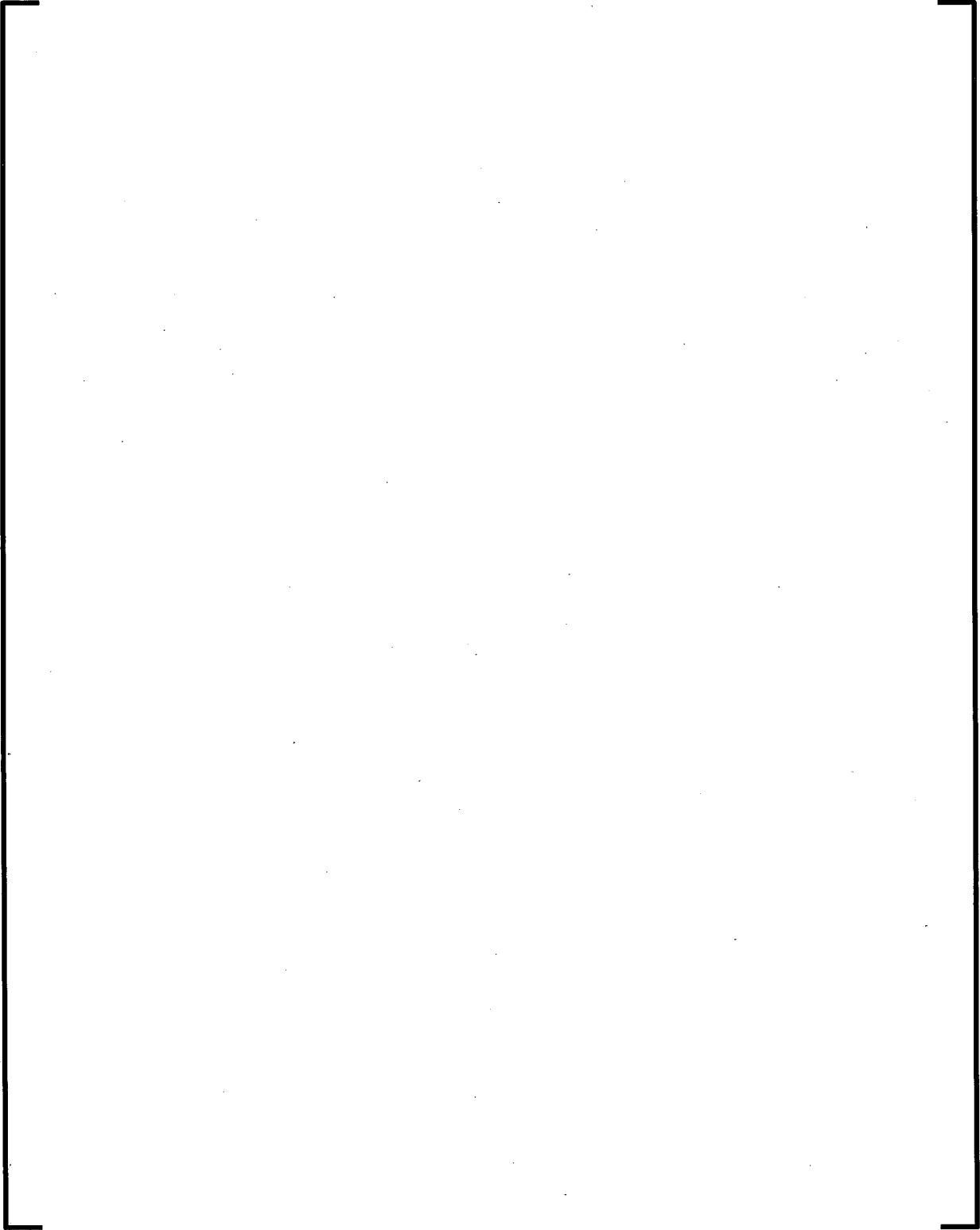
AREVA NP is not randomly assigning scenarios to the available crews. Neither the U.S. EPR FSAR nor the Validation and Verification (V&V) Implementation Plan (IP) indicate random assignment of scenarios. Random assignment of scenarios is unrelated to random assignment of participants to crews.











FSAR Impact:

U.S. EPR FSAR Tier 2, Section 18.10.3.4 will be revised as described in the response and indicated on the enclosed markup.

Question 18-68:

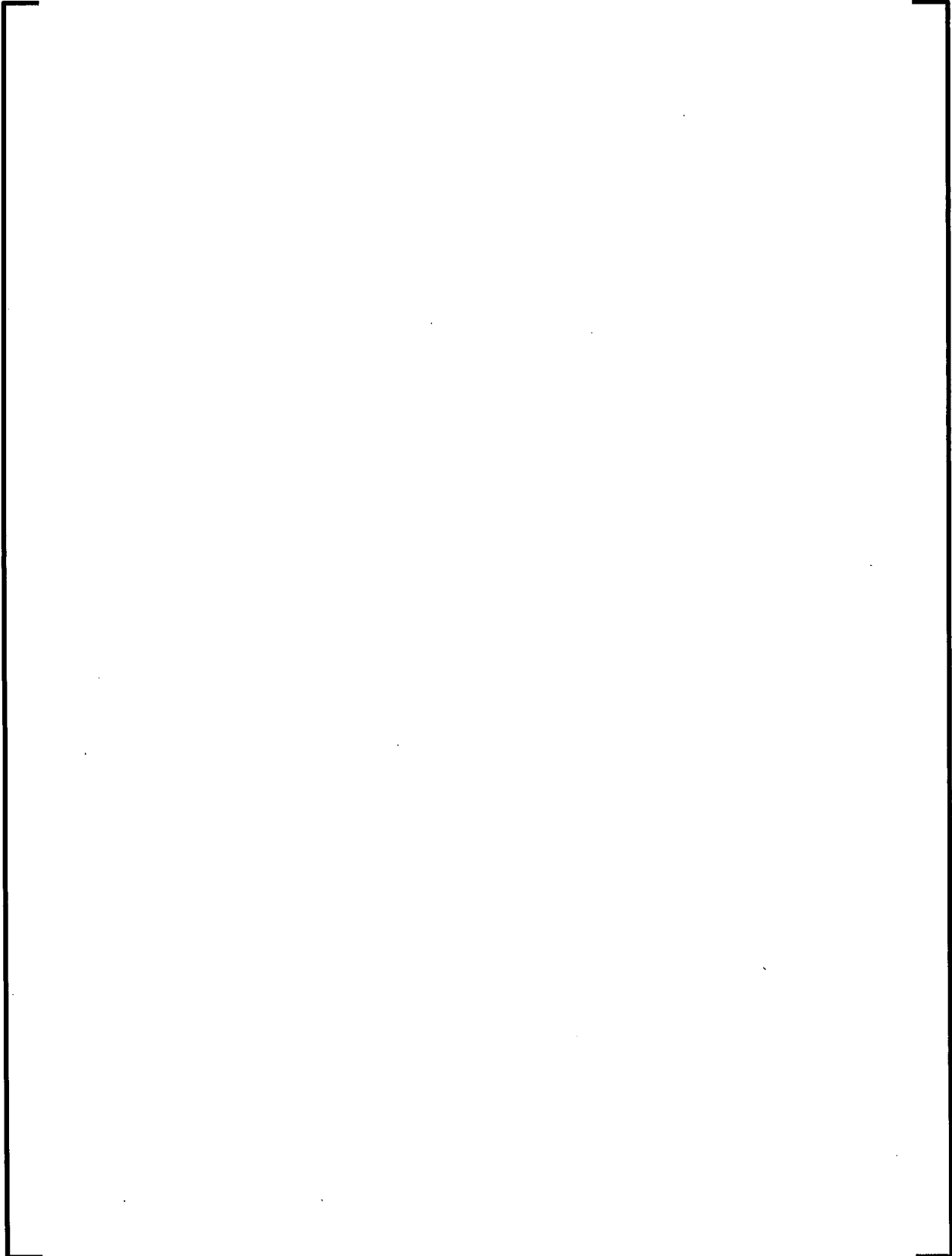
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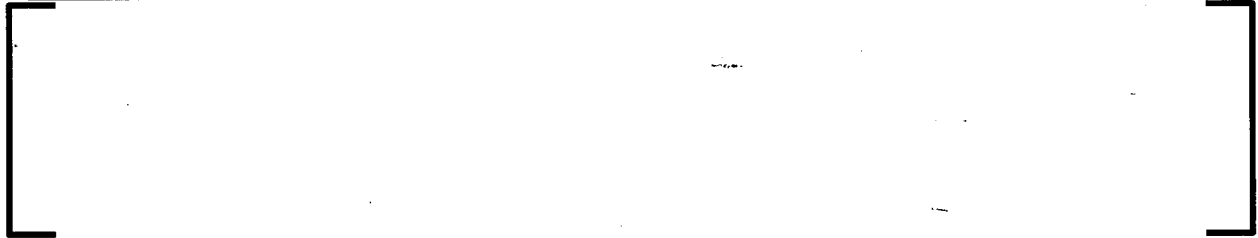
HED Resolution. Section 11.4.4. of NUREG-0711 states the purpose of the staff's review of the HED Resolution is to ensure that the applicant has adequately evaluated HEDs to determine the need for their correction, identified design solutions to address significant HEDs, and verified the implementation of the design solutions resolving HEDs. HEDs should not be considered in isolation and, to the extent possible, their potential interactions should be considered when developing and implementing solutions. Issues related to HED Resolutions that were identified include, *but are not limited to*:

1. After the initial comparison of the first HSI to HFE guidelines and determination of an HED, the remainder of the HSI in the set to be evaluated is classified as discrepant, according to the Applicant's procedure (Section 3.9.3.2 HFE Design Verification, Step 3). Staff request clarification regarding Steps 2 & 3.
2. Clarification is needed on whether the justification process for HEDs will include analysis of impact on plant safety and performance. This is presented in Figure 3.1, but not reflected in the text.

Response to Question 18-68:

1. The Verification and Validation (V&V) Implementation Plan (IP), "Human Factors Engineering (HFE) Design Verification," Rev. 0, Section 3.9.3.2, Steps 2 and 3 did state:





FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

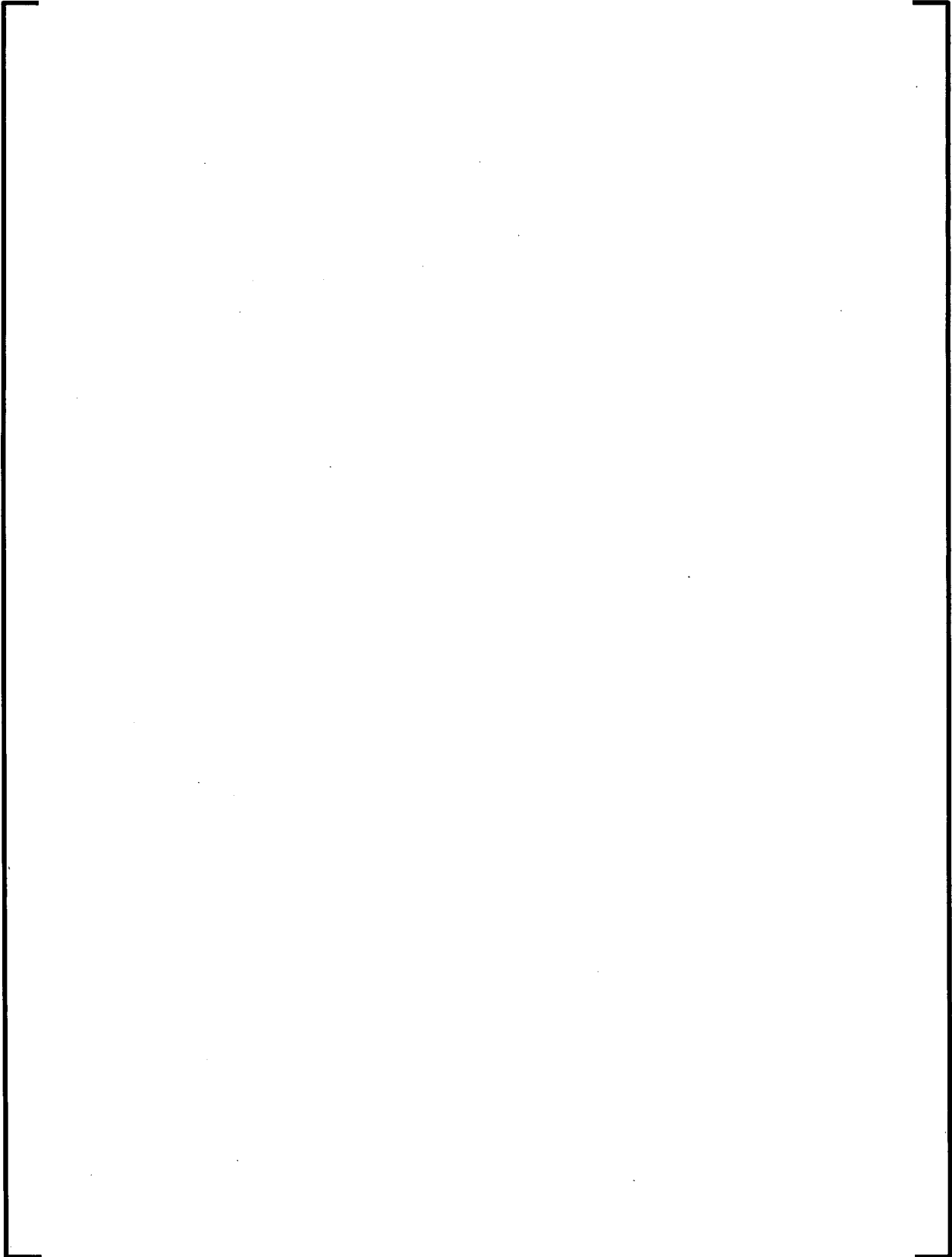
Question 18-69:

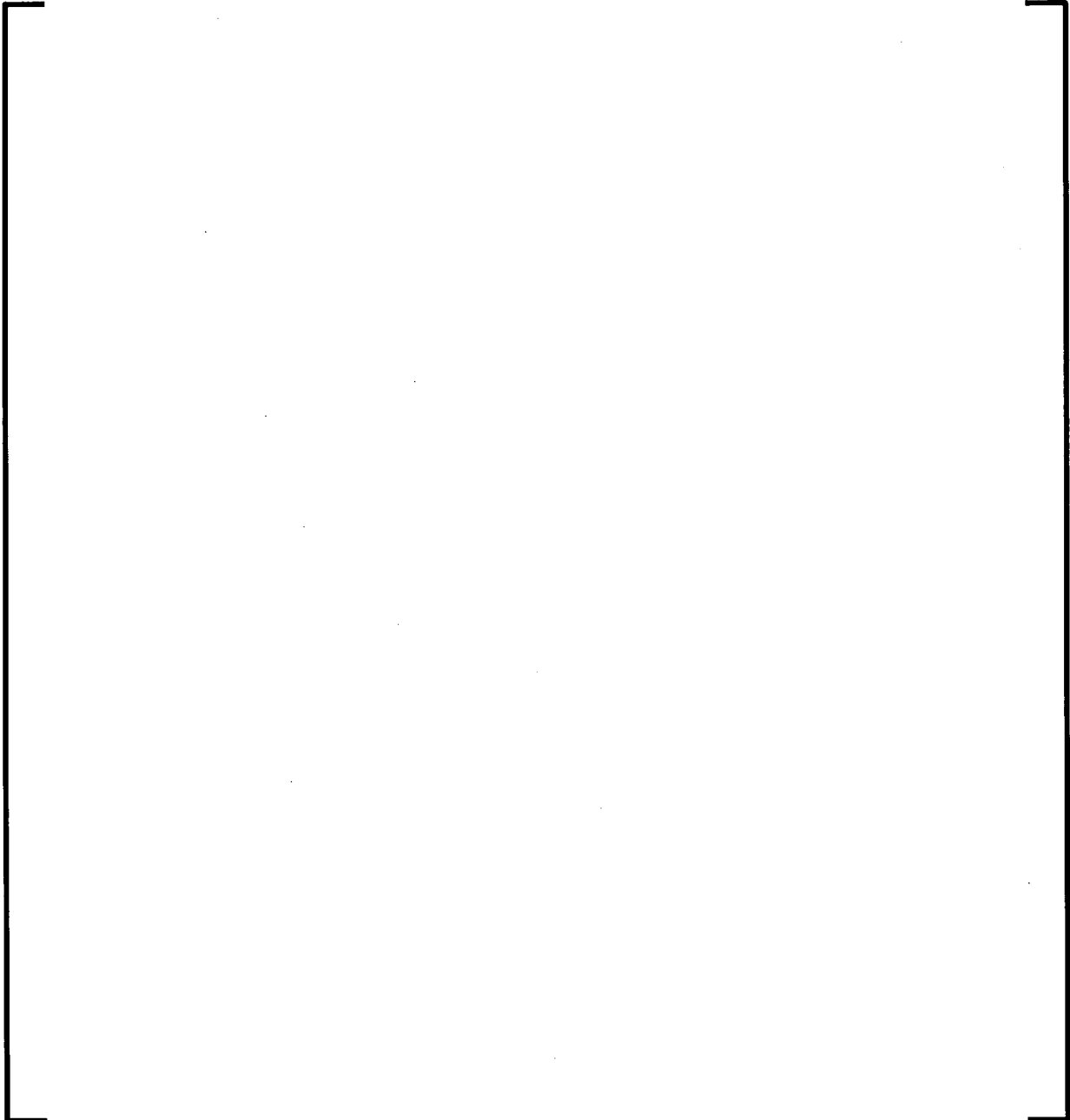
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HSI Task Support. Section 11.4.2.2.1 of NUREG-0711 states that the objective of this review is to ensure that the applicant verifies that the HSI provides all alarms, information, and control capabilities required for personnel tasks. Section 11.4.2.2.2 criterion 3 states that an HED should be identified when an HSI needed for task performance (e.g., a required control or display) is not available and/or when HSI characteristics do not match the personnel task requirements, e.g., a display shows the required plant parameter but not the range or precision needed for the task. Issues related to these criteria include, but are not limited to:

1. Section 3.4.2.2 of the HF V&V Implementation Plan, HSI Task Support Review Criteria, provides 4 questions to be used as criteria for determining the adequacy of HSI. Positive answers to the questions outlined would, in 2 cases, lead to the rejection of designs that meet desired criteria. The V&V Implementation plan indicates that a positive answer to any of these questions would indicate that an HSI deficiency is present, and should be documented in the design process. However, staff points out that positive answers to these questions (2 and 4 in the text) would not identify deficiencies in most properly designed HSI. The questions of interest ask:
 - Does the HSI or HFE feature have proper integration with the rest of the HSI?
 - Does the HSI or HFE feature meet the guidance in the U.S. EPR™ HSI Design Style Guide [9] and the HIS design implementation plan [16], which include the HSI Design Procedures
2. Section 3.9.3.3.2 of the HF V&V Implementation Plan outlines the method to be used by the V&V or HF engineer to perform dynamic HSI Task Support verification using the simulator. Step 2 requires that process monitoring indicators or task goals be developed to benchmark performance. It is not clear to staff how process monitoring indicators will be developed or task goals identified. It is not clear to staff how 'proper' allocation of functions will be determined or what is meant by 'proper'. Nor is it clear how 'proper' capture of functional requirements will be assessed. How will 'proper' be determined?
3. Section 18.10.3.2 of the FSAR discusses HSI Task Support Verification. The FSAR states that the HSI TSV shows that the HSI provides alarms, information, and control capabilities required for identified tasks that are performed by personnel and that the characteristics of the alarms, information, and controls conform to the requirements developed during the TA. In Section 3.4.2.1, of the V&V plan, the Applicant states that the HSI Task Support Verification will be performed using a limited scope task analysis conducted during the HSI design. Neither the FSAR nor the V&V Implementation plan indicates how or when the HSI requirements will be defined. This information is needed to determine how this criterion will be met.

Response to Question 18-69:

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FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 18-70:

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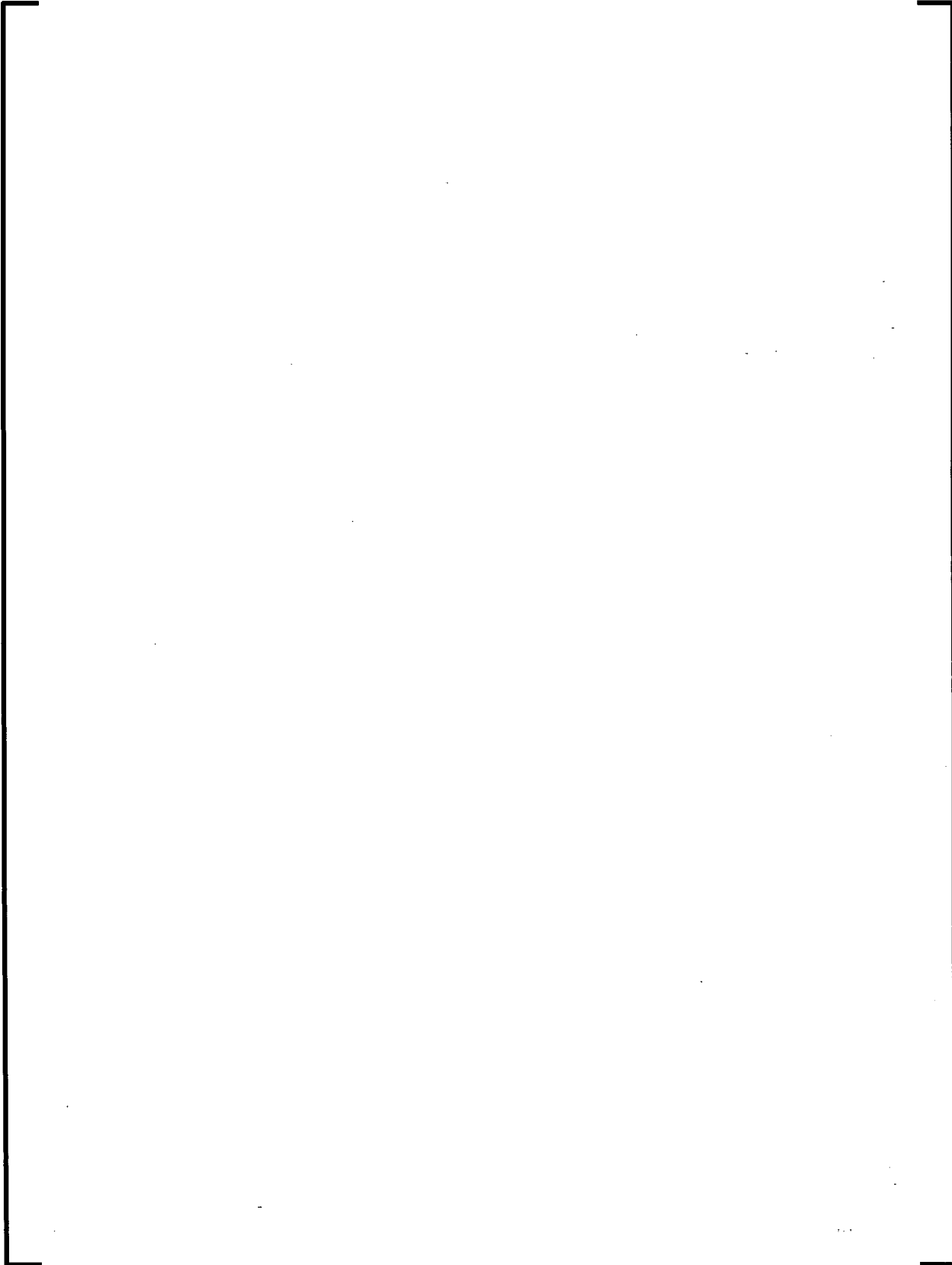
Operational Conditions Sampling. Section 11.4.1.1 states that the review should ensure that the applicant has identified a sample of operational conditions that (1) includes conditions that are representative of the range of events that could be encountered during operation of the plant, (2) reflects the characteristics that are expected to contribute to system performance variation, and (3) considers the safety significance of HSI components. These sample characteristics are best identified through the use of a multidimensional sampling strategy to ensure that variation along important dimensions is included in the V&V evaluations. The review criteria, therefore, address the sampling dimensions used and the identification of scenarios based on those dimensions. Issues identified include, but are not limited to:

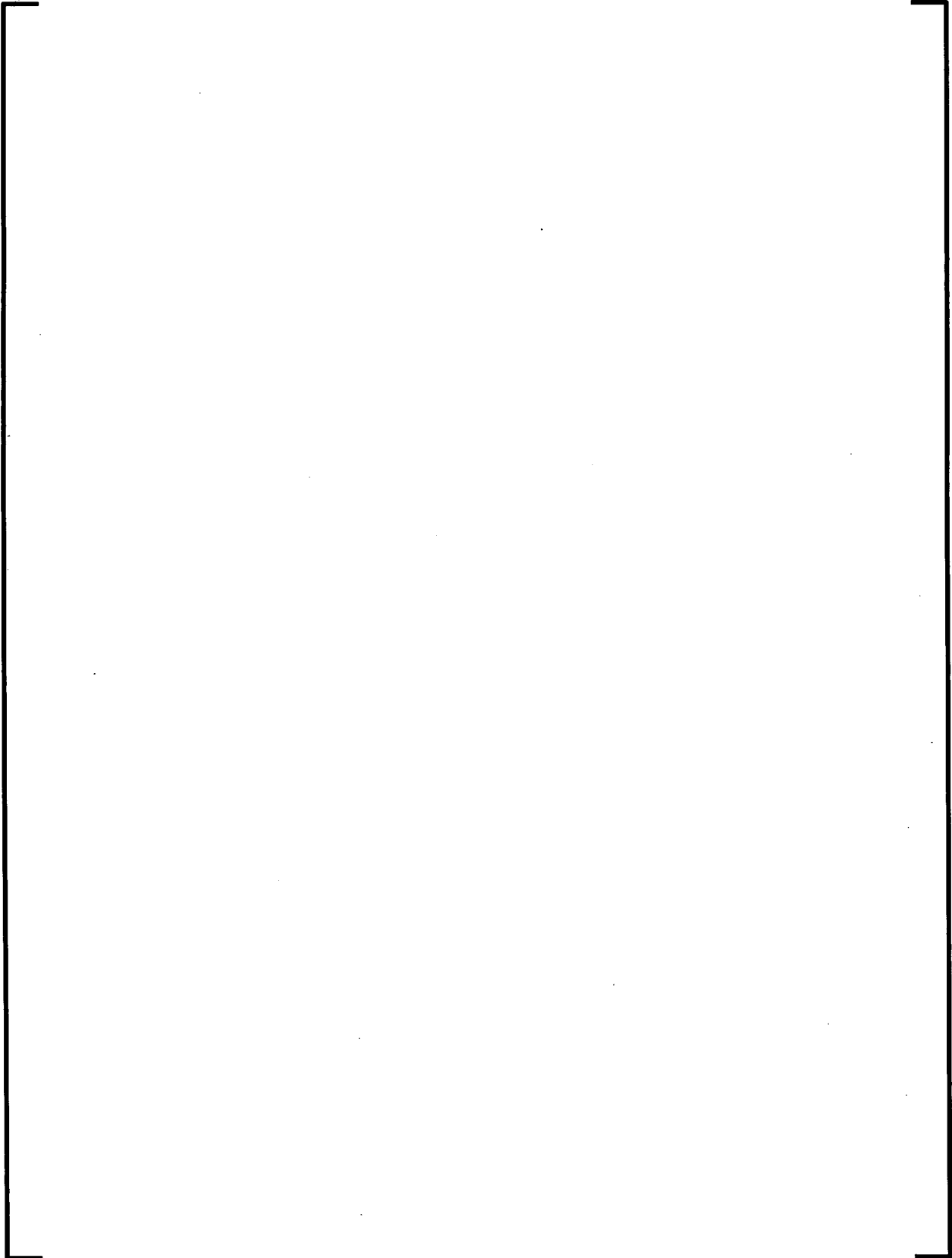
1. A set of tasks, representative of plant conditions as derived from the Preparatory Analysis (i.e., Operating Experience Review, and Function and Task Analysis) should be determined. These scenarios should reflect situational factors known to challenge performance, the full range of personnel tasks and interactions, and environmental conditions, and include tasks determined to be difficult via the Task analysis and HRA. Staff requires that the actual scenarios as selected using the OCS process and to be used in the V&V be provided for staff review. An alternative to full scenarios may be a smaller sample of complete scenarios together with an in-depth discussion of the derivation and sampling techniques for those scenarios be presented in the plan. Scenario development should include discussion of participant recruitment and assignment to scenarios.
2. Staff request that the methods be expanded to include inclusion of environmental effects, including how they may be simulated, what may be simulated, the limitations of simulation.

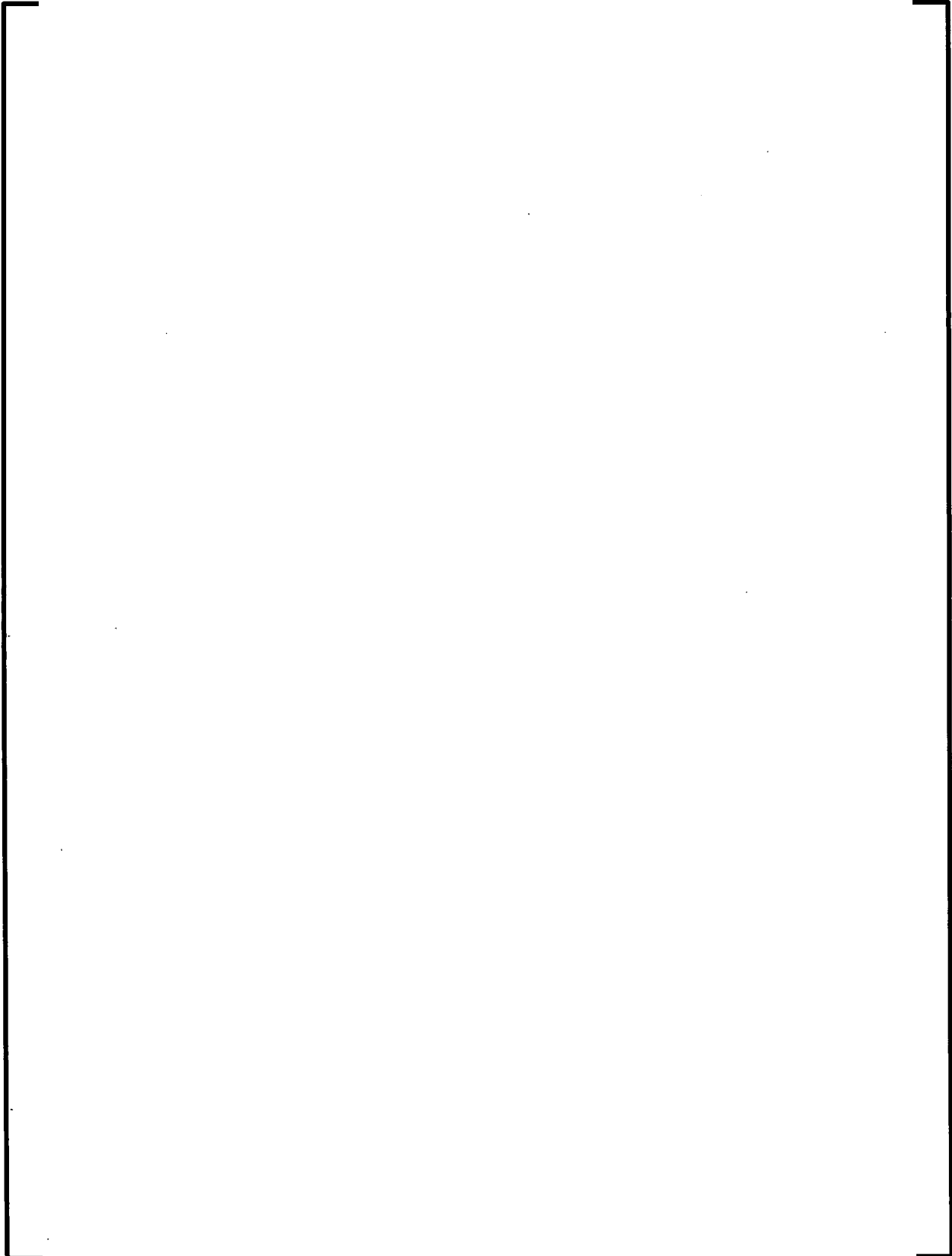
Response to Question 18-70:

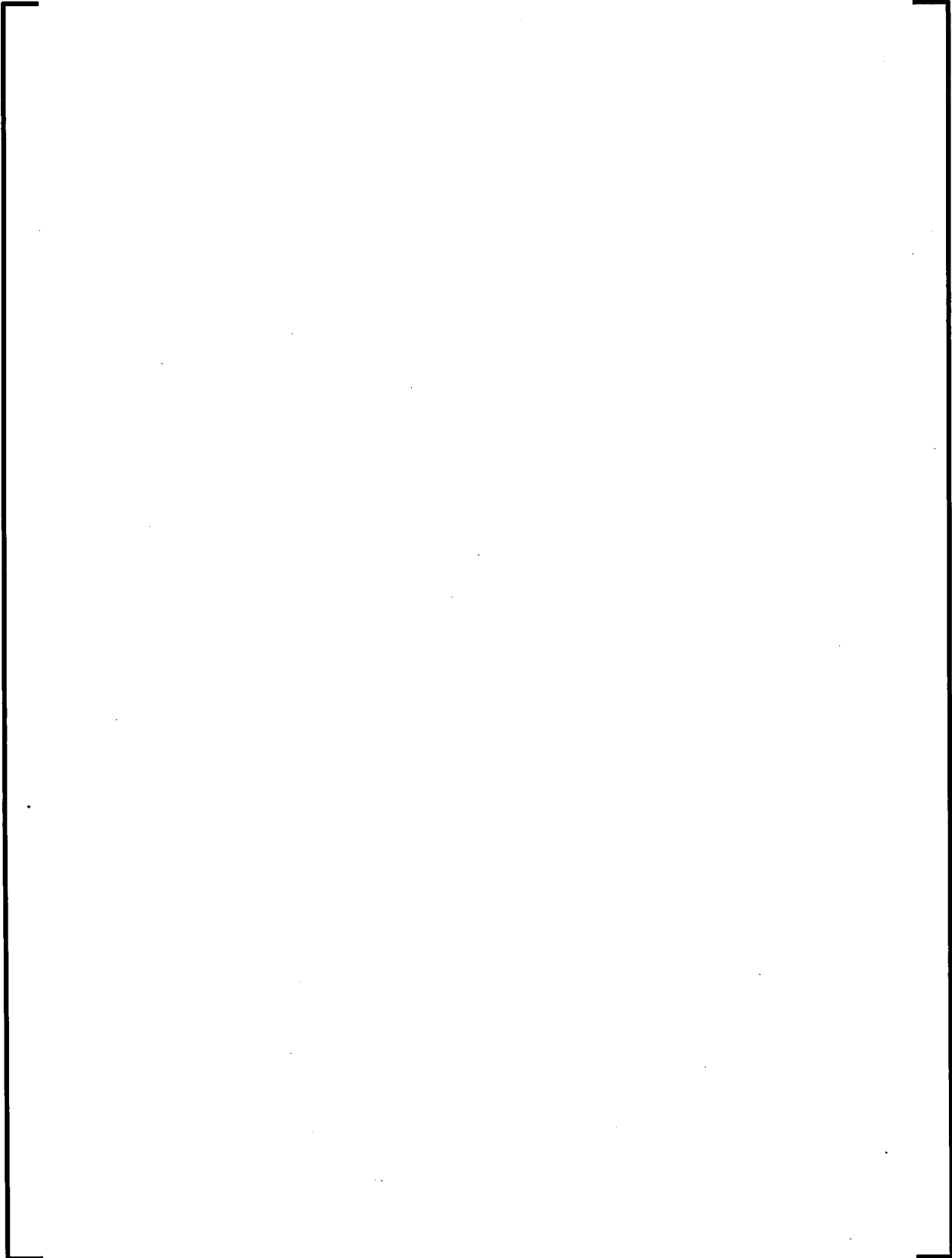
The subject matter addressed in this response contains representative information from the revised V&V IP.

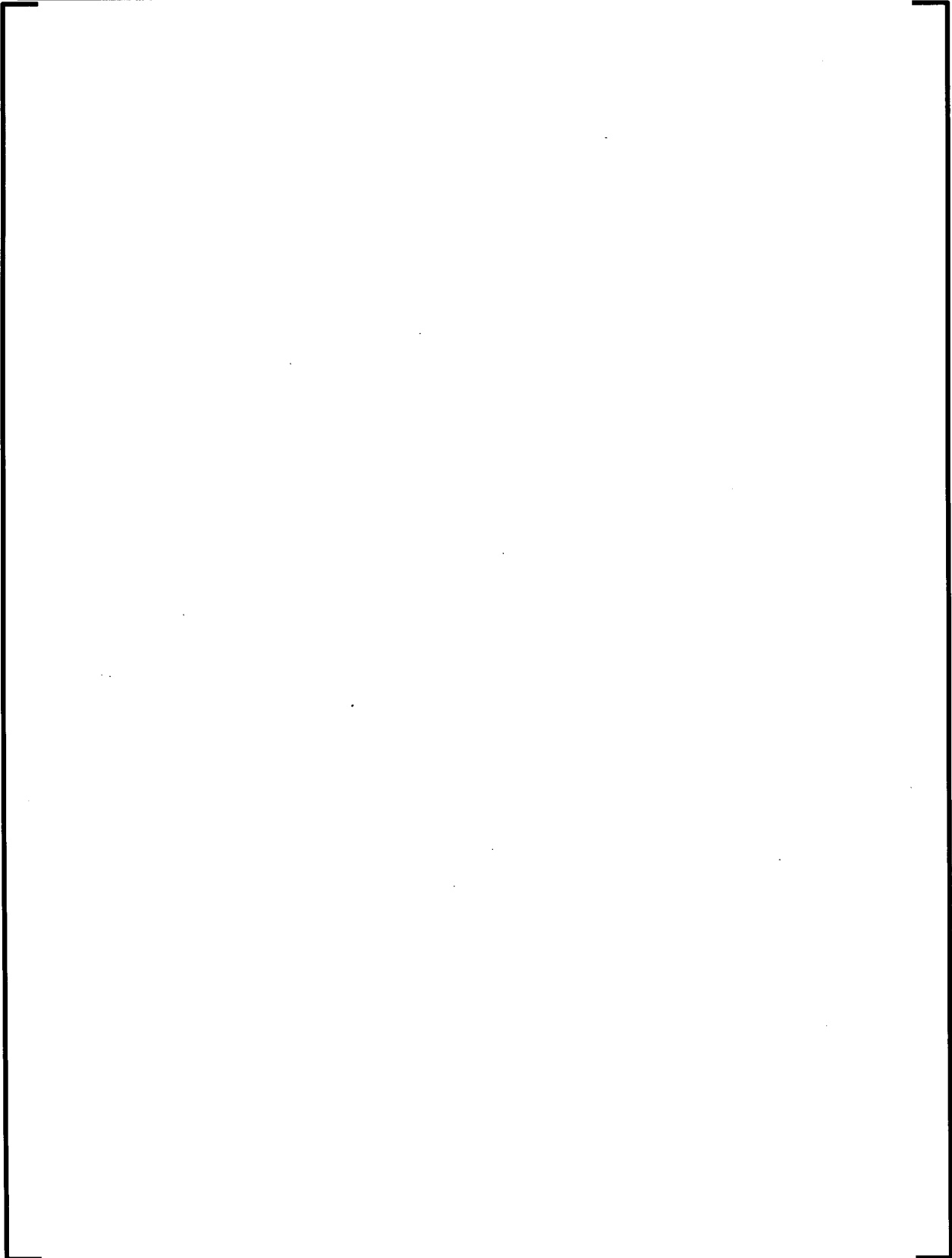












FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Appendix 1 References for Workload

1. Aasman, J., Mulder, G. & Mulder, L.J.M. (1987). Operator effort and the measurement of heart-rate variability. *Human Factors*, 29, 161-170.
2. Alm, H. & Nilsson, L. (1994). Changes in driver behaviour as a function of handsfree mobile phones-A simulator study. *Accident Analysis and Prevention*, 26, 441-451.
3. Backs, R.W. & Ryan, A.M. (1992). Multimodal measures of mental workload during dual-task performance: energetic demands of cognitive processes. In *Proceedings of the Human Factors Society 36th annual meeting* (pp. 1413-1417). Santa Monica, CA: Human Factors Society.
4. Backs, R.W. & Seljos, K.A. (1994). Metabolic and cardiorespiratory measures of mental effort: the effects of level of difficulty in a working memory task. *International Journal of Psychophysiology*, 16, 57-68.
5. Backs, R.W. & Walrath, L.C. (1992). Eye movement and pupillary response indices of mental workload during visual search of symbolic displays. *Applied Ergonomics*, 23, 243-254.
6. Bartenwerfer, H. (1969). Einige praktische Konsequenzen aus der Aktivierungstheorie. *Zeitschrift für experimentelle und angewandte Psychologie*, 16, 195-222.
7. Bauer, L.O., Goldstein, R. & Stern, J.A. (1987). Effects of information-processing demands on physiological response patterns. *Human Factors*, 29, 213-234.
8. Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin*, 91, 276-292.
9. Berntson, G.G., Cacioppo, J.T., Quigley, K.S. & Fabro, V.T. (1994). Autonomic space and psychophysiological response. *Psycho-physiology*, 31, 44-61.
10. Blaauw, G.J. (1984). Car driving as a supervisory control task. PhD Discussion. TNO-Institute for Perception, Soesterberg, The Netherlands.
11. Borg, G. (1978). Subjective aspects of physical and mental load, *Ergonomics*, 21, (3), 215-220.
12. Brabazon, P. and Conlin, H. (2001). Assessing the safety of staffing arrangements for process operations in the chemical and allied industries, Contract Research Report 345/2001, (Health and Safety Executive, Sudbury).
13. Brenner, M., Doherty, E.T. & Shipp, T. (1994). Speech measures indicating workload demand. *Aviation, Space, and Environmental Medicine*, 65, 21-26.
14. Broadbent, D.E. (1958). *Perception and Communication*. London: Pergamon.
15. Brookhuis, K.A. & De Waard, D. (1993). The use of psychophysiology to assess driver status. *Ergonomics*, 36, 1099-1110.
16. Brookhuis, K.A. (1989). Event related potentials and information processing. PhD Discussion. Groningen: University of Groningen.
17. Brookhuis, K.A. (1995a). DETER, Detection, Enforcement and Tutoring for Error Reduction. Final Report. (Report 2009/DETER/ Deliverable 20). Haren, The Netherlands: Traffic Research Centre, University of Groningen.

18. Brookhuis, K.A. (1995b). Driver Impairment Monitoring System. In M. Vallet & S. Khardi, *Vigilance et Transports. Aspects fondamentaux, dégradation et prévention*. Lyon, France: Presses Universitaires de Lyon.
19. Brookhuis, K.A. (1989). Event related potentials and information processing. PhD Discussion. Groningen: University of Groningen.
20. Brookhuis, K.A. and De Waard, D. (2002). On the assessment of (mental) workload and other subjective qualifications, *Ergonomics*, 45, (14), 1026-1031.
21. Brookhuis, K.A., De Vries, G. & De Waard, D. (1989). De effecten van het gebruik van de autotelefoon op het rijgedrag (The effects of mobile telephoning on driving performance). (Report VK 89-02). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
22. Brookhuis, K.A., De Vries, G. & De Waard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention*, 23, 309-316.
23. Brookhuis, K.A., De Vries, G. & De Waard, D. (1993). Acute and subchronic effects of the H1-histamine receptor antagonist ebastine in 10, 20 and 30 mg dose, and triprolidine 10 mg on car driving performance. *British Journal of Clinical Pharmacology*, 36, 67-70.
24. Brookhuis, K.A., De Vries, G., Prins van Wijngaarden, P., Veenstra, G., Hommes, M., Louwerens, J.W. & O'Hanlon, J.F. (1985a). The effects of increasing doses of Meptazinol (100, 200, 400 mg) and Glafenine (200 mg) on driving performance (Report VK 85-16). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
25. Brookhuis, K.A., De Waard, D. & Mulder, L.J.M. (1994). Measuring driving performance by car-following in traffic. *Ergonomics*, 37, 427-434.
26. Brookhuis, K.A., Louwerens, J.W. & O'Hanlon, J.F. (1985b). The effect of several antidepressants on EEG and performance in a prolonged car driving task. In W.P. Koella, E. Rüther & H. Schulz (Eds.) *Sleep '84*, (pp. 129-131). Stuttgart: Gustav Fischer Verlag.
27. Brookhuis, K.A., Louwerens, J.W. & O'Hanlon, J.F. (1986). EEG energy-density spectra and driving performance under the influence of some anti-depressant drugs. In J.F. O'Hanlon & J.J. de Gier (Eds.), *Drugs and Driving* (pp. 213-221). London: Taylor & Francis.
28. Brouwer, W.H. & Ponds, R.W.H.M. (1994). Driving competence in older persons. *Disability and Rehabilitation*, 16, 149-161.
29. Brouwer, W.H., Waterink, W., Van Wolfelaar, P.C. & Rothengatter, J.A. (1990). Divided attention in experienced young and older drivers: lane tracking and visual analysis in a dynamic driving simulator. *Human Factors*, 33, 573-582.
30. Brown, I.D. & Poulton, E.C. (1961). Measuring the spare 'mental' capacity of cardrivers by a subsidiary task. *Ergonomics*, 4, 35-40.
31. Brown, I.D., Thickner, A.H. & Simmonds, D.C.V. (1969). Interference between concurrent tasks of driving and telephoning. *Journal of Applied Psychology*, 53, 419-424.
32. Brown, J.D. & Huffman, W.J. (1972). Psychophysiological measures of drivers under actual driving conditions. *Journal of Safety Research*, 4, 172-178.

33. Byers, J.C., Bittner, A.C. & Hill, S.G. (1989). Traditional and raw task load index (TLX) correlations: are paired comparisons necessary? In A. Mital (Ed.), *Advances in industrial ergonomics and safety, I* (pp 481-485). London: Taylor & Francis.
34. Cnossen, F. (1994). Mental effort from energetical and computational perspectives. Unpublished paper for the BCN course Cognitive Neuroscience. Haren, The Netherlands: Traffic Research Centre, University of Groningen.
35. Cooper, R., Osselton, J.W. & Shaw, J.C. (1980). *EEG Technology*. London: Butterworths.
36. Dawson, M.E., Schell, A.M. & Filion, D.L. (1990). The electrodermal system. In J.T. Cacioppo & L.G. Tassinari (Eds.), *Principles of psychophysiology* (pp. 295-324). Cambridge: Cambridge University Press.
37. De Vries, G., De Waard, D. & Brookhuis, K.A. (1989). A double blind study to compare the acute and subchronic effects of Ebastine 10, 20 and 30 mg o.d., triprolidine 10 mg o.d. and placebo on car driving performance (Report VK 89-22). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
38. De Waard, D. & Brookhuis, K.A. (1991a). Assessing driver status: a demonstration experiment on the road. *Accident Analysis and Prevention*, 23, 297-307.
39. De Waard, D. & Brookhuis, K.A. (1991b). The feasibility of a device that monitors driver's status and abilities. In *Proceedings of the 24th ISATA International symposium on automotive technology and automation* (pp. 725-731). Croydon, England: Automotive Automation Limited.
40. De Waard, D. & Brookhuis, K.A. (in press,--1997). Behavioural adaptation of drivers to warning and tutoring messages. Results from an on-the-road and simulator test. Special Issue 'Driver Vehicle Interaction', *Heavy Vehicle Systems, International Journal of Vehicle Design*, 4, 222-234.
41. De Waard, D. & Brookhuis, K.A. (1991a). Assessing driver status: a demonstration experiment on the road. *Accident Analysis and Prevention*, 23, 297-307.
42. De Waard, D. & Brookhuis, K.A. (1991b). The feasibility of a device that monitors driver's status and abilities. In *Proceedings of the 24th ISATA International symposium on automotive technology and automation* (pp. 725-731). Croydon, England: Automotive Automation Limited.
43. De Waard, D. & Brookhuis, K.A. (in press,--1997). Behavioural adaptation of drivers to warning and tutoring messages. Results from an on-the-road and simulator test. Special Issue 'Driver Vehicle Interaction', *Heavy Vehicle Systems, International Journal of Vehicle Design*, 4, 222-234.
44. De Waard, D. & Steyvers, F.J.J.M. (1995). Wegbelijning in rurale verblijfgebieden: een experiment met kantbelijning (Road delineation in rural residential areas: an experiment with edgelines). (Report VK 95-07). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
45. De Waard, D. (1991). Driving behaviour on a high-accident-rate motorway in the Netherlands. In C. Weikert, K.A. Brookhuis and S. Ovinius (Eds.), *Man in complex systems, Proceedings of the Europe Chapter of the Human Factors Society Annual Meeting. Work Science Bulletin 7* (pp 113-123). Lund, Sweden: Work Science Division, Department of Psychology, Lund University.

46. De Waard, D. (1996). The measurement of drivers' mental workload. PhD discussion, University of Groningen. Haren, The Netherlands: University of Groningen, Traffic Research Centre.
47. De Waard, D., Brookhuis, K.A., Van der Hulst, M. & Van der Laan, J.D. (1994). Behaviour comparator prototype test in a driving simulator (Report 2009/DETER/Deliverable 10 (321B)). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
48. De Waard, D., Jessurun, M., Steyvers, F.J.J.M., Raggatt, P.T.F., Brookhuis, K.A. (1995). Effect of road layout and road environment on driving performance, drivers' physiology and road appreciation. *Ergonomics*, 38, 1395-1407.
49. De Waard, D., Van der Hulst, M. & Brookhuis, K.A. (submitted;--1999). Elderly and young driver's reaction to an in-car enforcement and tutoring system. *Applied Ergonomics*, 30, 147-157.
50. De Waard, D., Van der Linden, L.H.K. & Westra, E.J. (1990). Observaties van rijgedrag in een geïstrumenteerde auto op de A-28 tussen Assen en Groningen (Observations of driving behaviour in an instrumented vehicle on the A28 motorway between Assen and Groningen). (Report VK 90-16). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
51. Dimberg, U. & Thell, S. (1988). Facial electromyography, fear relevance and the experience of stimuli. *Journal of Psychophysiology*, 2, 213-219.
52. Dimberg, U. (1988). Facial electromyography and the experience of emotion. *Journal of Psychophysiology*, 2, 277-282.
53. Egelund, N (1982). Spectral analysis of heart rate variability as an indicator of driver fatigue. *Ergonomics*, 25, 663-672.
54. Eggemeier, F.T. & Wilson, G.F. (1991). Performance-based and subjective assessment of workload in multi-task environments. In D.L. Damos (Ed.), *Multiple-task performance*. (pp. 217-278). London: Taylor & Francis.
55. Eggemeier, F.T., Wilson, G.F., Kramer, A.F. & Damos, D.L. (1991). Workload assessment in multi-task environments. In D.L. Damos (Ed.), *Multiple-task performance*. (pp. 207-216). London: Taylor & Francis.
56. Fairclough, S. H. (1993). Psychophysiological measures of workload and stress. In A.M. Parkes & S. Franzén (Eds.), *Driving Future Vehicles*. (pp. 377-390). London: Taylor & Francis.
57. Fairclough, S.H. (1991). Adapting the TLX to measure driver mental workload (Report V1017/BERTIE/No. 71). Loughborough, Leics, UK: HUSAT Research Institute.
58. Fairclough, S.H. (Ed.) (1994). Driver State Monitor (Report V2009/DETER/Deliverable 5 (330A)). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
59. Fairclough, S.H. (1991). Adapting the TLX to measure driver mental workload (Report V1017/BERTIE/No. 71). Loughborough, Leics, UK: HUSAT Research Institute.
60. Fairclough, S.H., Ashby, M.C. & Parkes, A.M. (1993). In-vehicle displays, visual workload and usability evaluation. In A.G. Gale, I.D. Brown, C.M. Haslegrave, H.W. Kruysse & S.P. Taylor (Eds.), *Vision in vehicles -IV* (pp. 245-254). Amsterdam: North-Holland.

61. Fairclough, S.H., Ashby, M.C., Ross, T. & Parkes, A. (1991). Effects of handsfree telephone use on driving behaviour. In Proceedings of the 24th ISATA International symposium on automotive technology and automation (pp. 403-409). Croydon, England: Automotive Automation Limited.
62. Fibiger, W., Christensen, F., Singer, G. & Kaufmann, H. (1986). Mental and physical components of sawmill operatives' workload. *Ergonomics*, 29, 363-375.
63. Frankenhaeuser, M. (1989). A biopsychosocial approach to work life issues. *International Journal of Health Services*, 19, 747-758.
64. Fridlund, A.J. & Cacioppo, J.T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, 23, 567-589.
65. Godthelp, J. (1984). Studies on human vehicle control. PhD Discussion, Soesterberg, The Netherlands: Institute for Perception, TNO.
66. Godthelp, J. (1988). The limits of path error-neglecting in straight lane driving. *Ergonomics*, 31, 609-619.
67. Godthelp, J., Milgram, P. & Blaauw, G.J. (1984). The development of a time-related measure to describe driving strategy. *Human Factors*, 26, 257-268.
68. Gonzalez Gonzalez, J., Mendez Llorens, A., Mendez Novoa, A. & Cordero Valeriano, J.J. (1992). Effect of acute alcohol ingestion on short-term heart rate fluctuations. *Journal of Studies on Alcohol*, 53, 86-90.
69. Gopher, D. & Braune, R. (1984). On the psychophysics of workload: Why bother with subjective measures? *Human Factors*, 26, 519-532.
70. Gopher, D. & Donchin, E. (1986). Workload -an examination of the concept. In K.R. Boff, L. Kaufman & J.P. Thomas (Eds.), *Handbook of perception and human performance*. Volume II, cognitive processes and performance. (pp 41/1-41/49). New York: Wiley.
71. Gopher, D. & Sanders, A.F. (1984). S-Oh-R: Oh stages! Oh resources!. In W. Prinz & A.F. Sanders, *cognition and motor processes*. (pp 231-253). Berlin: Springer Verlag.
72. Green, P., Lin, B. & Bagian, T. (1993b). Driver Workload as a function of road geometry: a pilot experiment (Report UMTRI-93-39). Ann Arbor, MI, U.S.A.: The University of Michigan Transportation Research Institute.
73. Green, P., Williams, M., Hoekstra, E, George, K. & Wen, C. (1993a). Initial on-the-road tests of driver information system interfaces: route guidance, traffic information, IVSAWS, and vehicle monitoring (Report UMTRI-93-32). Ann Arbor, MI, U.S.A.: The University of Michigan Transportation Research Institute.
74. Gronwall, D.M.A. & Sampson, H. (1974). The psychological effects of concussion. Auckland, New Zealand: Auckland University Press.
75. Grossman, P. (1992). Respiratory and cardiac rhythms as windows to central and autonomic biobehavioral regulation: selection of window frames, keeping the panes clean and viewing the neural topography. *Biological Psychology*, 34, 131-161.
76. Hancock, P.A. & Parasuraman, R. (1992). Human Factors and safety in the design of Intelligent Vehicle-Highway Systems (IVHS). *Journal of Safety Research*, 23, 181-198.

77. Hancock, P.A. and Caird, J.K. (1993). Experimental evaluation of a model of mental workload, *Human Factors*, 35, (3), 413-429.
78. Hart, S.G. & Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In P.A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (139-183). Amsterdam: North-Holland.
79. Hebb, D.O. (1955). Drives and the C.N.S. (Conceptual Nervous System). *Psychological Review*, 62, 243-254.
80. Hedman, L.R. & Sirevaag, E.J. (1991). In C. Weikert, K.A. Brookhuis and S. Ovinus (Eds.), *Man in complex systems*, Proceedings of the Europe Chapter of the Human Factors Society Annual Meeting. *Work Science Bulletin* 7 (pp 12-18). Lund, Sweden: Work Science Division, Department of Psychology, Lund University.
81. Heino, A., Van der Molen, H.H. & Wilde, G.J.S. (1990). Risk-homeostatic processes in car following behaviour: Electrodermal responses and verbal risk estimates as indicators of the perceived level of risk during a car-driving task (Report VK 90-22). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
82. Heino, A., Van der Molen, H.H. & Wilde, G.J.S. (1996). Differences in risk experience between sensation avoiders and sensation seekers. *Personality and Individual Differences*, 20, 71-79.
83. Hendy, K.C., Hamilton, K.M. & Landry, L.N. (1993). Measuring subjective workload: when is one scale better than many? *Human Factors*, 35, 579-601.
84. Heslegrave, R.J., Ogilvie, J.C. & Furedy, J.J. (1979). Measuring baseline-treatment differences in heart rate variability: variance versus successive difference mean square and beats per minute versus interbeat intervals. *Psychophysiology*, 16, 151 -157.
85. Hicks, T.G. & Wierwille, W.W. (1979). Comparison of five mental workload assessment procedures in a moving-base driving simulator. *Human Factors*, 21, 129-143.
86. Hill, S.G., Iavecchia, H.P., Byers, J.C., Bittner, A.C., Zaklad, A.L. & Christ, R.E. (1992). Comparison of four subjective workload rating scales. *Human Factors*, 34, 429-439.
87. Hockey, G.R.J. (1986). A state control theory of adaptation and individual differences in stress management. In G.R.J. Hockey, A.W.K. Gaillard and M.G.H. Coles (Eds.), *Energetics and human information processing* (pp. 285-298). Dordrecht, The Netherlands: Martinus Nijhoff Publishers.
88. Hoeks, L.T.M. (1995). The pupillary response as a measure of mental processing load: with application to picture naming. PhD Discussion, Nijmegen, The Netherlands: University of Nijmegen.
89. Hughes, P.K. & Cole, B.L. (1988). The effect of attentional demand on eye movement behaviour when driving. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith & S.P. Taylor (Eds.), *Vision in vehicles-II* (pp. 221-230). Amsterdam: North-Holland.
90. Humphrey, D.G. & Kramer, A.F. (1994). Toward a psychophysiological assessment of dynamic changes in mental workload. *Human Factors*, 36, 3-26.
91. Hyndman, B.W. & Gregory, J.R. (1975). Spectral analysis of sinus arrhythmia during mental loading. *Ergonomics*, 18, 255-270.

92. Hyönä, J., Tammola, J. & Alaja, A.-M. (1995). Pupil dilation as a measure of processing load in simultaneous interpretation and other language tasks. *The Quarterly Journal of Experimental Psychology*, 48A, 598-612.
93. Itoh, Y, Hayashi, Y., Tsukui, I. & Saito, S. (1990). The ergonomic evaluation of eye movement and mental workload in aircraft pilots. *Ergonomics*, 33, 719-733.
94. Jäncke, L. (1994). An EMG investigation of the coactivation of facial muscles during the presentation of affect-laden stimuli. *Journal of Psychophysiology*, 8, 1-10.
95. Janssen, W.H. & Gaillard, A.W.K. (1985). EEG and heart rate correlates of task load in car driving. In A. Gundel (Ed.), *Proceedings of the workshop 'Electroencephalography in transport operations*. Köln, Germany: DFVLR-Institut für Flugmedizin.
96. Janssen, W.H. (1979). Routeplanning en -geleiding: een literatuurstudie (Route planning and route guidance: a review of the literature). (Report IZF 1979-C13). Soesterberg, The Netherlands: Instituut voor Zintuigfysiologie.
97. Janssen, W.H., Kuiken, M.J. & Verwey, W.B. (1994). Evaluation studies of a prototype intelligent vehicle. In ERTICO (Ed.) *Towards an intelligent transport system. Proceedings of the first world congress on applications of transport telematics and intelligent vehicle-highway systems* (pp. 2063-2070). Boston: Artech House.
98. Jennings, J.R., Stringfellow, J.C. & Graham, M. (1974). A comparison of the statistical distributions of beat-by-beat heart rate and heart period. *Psychophysiology*, 11, 207-210.
99. Jessurun, M., De Waard, D., Raggatt, P.T.F., Steyvers, F.J.J.M. & Brookhuis, K.A. (1993). Implementatie van snelheidsbeperkende maatregelen op 80 km/uur wegen: effecten op rijgedrag, activatie en beleving (Implementation of speed-reducing measures on A-class roads: effects on driving performance, activation and appreciation). (Report VK 93-01). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
100. Jessurun, M., Steyvers, F.J.J.M., De Waard, D., Dekker, K., Brookhuis, K.A. (1990). Beleving, waarneming en activatie tijdens het rijden over een deel van de A2 (Appreciation, perception and activation while driving over a section of the A2 motorway). (Report VK 90-18). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
101. Johnson, A.K. & Anderson, E.A. (1990). Stress and arousal. In J.T. Cacioppo & L.G. Tassinary. *Principles of psychophysiology* (pp. 216-252). Cambridge: Cambridge University Press.
102. Jordan, P.W. & Johnson, G.I. (1993). Exploring mental workload via TLX: the case of operating a car stereo whilst driving. In A.G. Gale, I.D. Brown, C.M. Haslegrave, H.W. Kruysse & S.P. Taylor (Eds.), *Vision in Vehicles-IV*. (pp. 255-262). Amsterdam: North-Holland.
103. Jorna, P.G.A.M. (1992). Spectral analysis of heart rate and psychological state: a review of its validity as a workload index. *Biological Psychology*, 34, 237-257.
104. Jorna, P.G.A.M. (1993). Heart rate and workload variations in actual and simulated flight. *Ergonomics*, 36, 1043-1054.
105. Kahneman, D. (1973). *Attention and effort*. New Jersey, U.S.A.: Prentice Hall.

106. Kalsbeek, J.W.H. & Ettema, J.H. (1963). Scored regularity of the heart rate and the measurement of perceptual load. *Ergonomics*, 6, 306.
107. Kantowitz, B.H. & Knight, J.L. (1976). Testing tapping timesharing, II: auditory secondary task. *Acta Psychologica*, 40, 340-362.
108. Kantowitz, B.H. (1987). Mental workload. In P.A. Hancock (Ed.), *Human Factors Psychology*. (pp 81-121). Amsterdam: North-Holland.
109. Kantowitz, B.H. (1992a). Heavy vehicle driver workload assessment: lessons from aviation. In *Proceedings of the Human Factors Society 36th annual meeting* (pp. 1113-1117). Santa Monica, CA: Human Factors Society.
110. Kantowitz, B.H. (1992b). Selecting measures for human factors research. *Human Factors*, 34, 387-398.
111. Kecklund, G. & Åkerstedt, T. (1993). Sleepiness in long distance truck driving: an ambulatory EEG study of night driving. *Ergonomics*, 36, 1007-1017.
112. Korteling, J.E. (1994a). Multiple-task performance and aging. PhD Discussion. Groningen: University of Groningen.
113. Korteling, J.E. (1994b). Effects of aging, skill modification, and demand alternation on multiple-task performance. *Human Factors*, 36, 27-43.
114. Kramer, A.F. (1991). Physiological metrics of mental workload: a review of recent progress. In D.L. Damos (Ed.), *Multiple-task performance*. (pp. 279-328). London: Taylor & Francis.
115. Lee, D.H. & Park, K.S. (1990). Multivariate analysis of mental and physical load components in sinus arrhythmia scores. *Ergonomics*, 33, 35-47.
116. Louwerens, J.W., Brookhuis, K.A. & O'Hanlon, J.F. (1983). The effects of the antidepressants Oxaprotiline, Mianserin, Amitryptiline and Doxepin upon actual driving performance (Report VK 83-05). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
117. Louwerens, J.W., Gloerich, A.B.M., De Vries, G., Brookhuis, K.A. & O'Hanlon, J.F. (1987). The relationship between drivers' blood alcohol concentration (BAC) and actual driving performance during high speed travel. In P.C. Noordzij & R. Roszbach (Eds.), *Alcohol, Drugs and Traffic Safety-T86* (pp. 183-186). Amsterdam: Excerpta Medica.
118. Macdonald, W.A. & Hoffmann, E.R. (1980). Review of relationship between steering wheel reversal rate and driving task demand. *Human Factors*, 22, 733-739.
119. Mascord, D.J. & Heath, R.A. (1992). Behavioral and physiological indices of fatigue in a visual tracking task. *Journal of Safety Research*, 23, 19-25.
120. Mascord, D.J., Walls, J. & Starmer, G.A. (1995). Fatigue and alcohol: interactive effects on human performance in driving-related tasks. In L. Hartley (Ed.), *Fatigue and Driving. Driver Impairment, Driver Fatigue and Driving Simulation* (pp.189-205). London: Taylor & Francis.
121. Matsumoto, R., Walker, B.B., Walker, J.M. & Hughes, H.C. (1990). Fundamentals of Neuroscience. In J.T. Cacioppo & L.G. Tassinari (Eds.), *Principles of psychophysiology* (pp. 58-112). Cambridge: Cambridge University Press.

122. May, J.G., Kennedy, R.S., Williams, M.C., Dunlap, W.P. & Brannan, J.R. (1990). Eye movement indices of mental workload. *Acta Psychologica*, 75, 75-89.
123. McLean, J.R. & Hoffmann, E.R. (1971). Analysis of drivers' control movements. *Human Factors*, 13, 407-418.
124. McLean, J.R. & Hoffmann, E.R. (1975). Steering reversals as a measure of driver performance and steering task difficulty. *Human Factors*, 17, 248-256.
125. Meijman, T.F. & Mulder, G. (1992). Arbeidspsychologische aspecten van werkbelasting. (Workpsychological aspects of work-demand) In P.J.D. Drenth, H. Thierry & Ch.J. de Wolf (Eds.), *Nieuw handboek A&O psychologie*, Hoofdstuk 2.11. Deventer: Van Loghum Slaterus.
126. Meijman, T.F. & O'Hanlon, J.F. (1984). Workload. An introduction to psychological theories and measurement methods. In P.J.D. Drenth, H. Thierry, P.J. Willems & C.J. de Wolff (Eds.), *Handbook of Work and Organizational Psychology*. (pp. 257-288). New York: Wiley.
127. Meijman, T.F. (1989). Mentale belasting en werkstress. Een arbeidspsychologische benadering (Mental workload and workstress. A workpsychological approach). Assen, The Netherlands: van Gorcum.
128. Meijman, T.F. (1991) Over vermoeidheid, arbeidspsychologische studies naar de beleving van belastingseffecten (About being tired, workpsychological studies into the perception of the effects of demand). PhD discussion, Rijksuniversiteit Groningen. Amsterdam: Studiecentrum Arbeid en Gezondheid, Universiteit van Amsterdam.
129. Meister, D. (1976). Behavioral foundations of system development. New York: Wiley.
130. Michaels, R.M. (1962). The effect of expressway design on driver tension responses. *Public Roads*, 32, 107-112.
131. Michon, J.A. (1971). Psychonomie Onderweg. Inaugural lecture, University of Groningen. Groningen, Wolters Noordhoff.
132. Michon, J.A. (1985). A critical view of driver behavior models: what do we know, what should we do? In L. Evans & R.C. Schwing (Eds.), *Human behavior & traffic safety* (pp. 485-524). New York: Plenum Press.
133. Michon, J.A. (Ed.) (1993). *Generic Intelligent Driver Support System*. London: Taylor & Francis.
134. Muckler, F.A. & Seven, S.A. (1992). Selecting performance measures: 'objective' versus 'subjective' measurement. *Human Factors*, 34, 441-455.
135. Mulder, G. & Mulder, L.J.M. (1980). Coping with mental workload. In S. Levine & H. Ursin (Eds.) *Coping and Health* (pp. 233-258). New York: Plenum Press.
136. Mulder, G. & Mulder, L.J.M. (1981). Information processing and cardiovascular control. *Psychophysiology*, 18, 392-402.
137. Mulder, G. (1980). The heart of mental effort. PhD Discussion. Groningen: University of Groningen.
138. Mulder, G. (1986). The concept and measurement of mental effort. In G.R.J. Hockey, A.W.K. Gaillard and M.G.H. Coles (Eds.), *Energetics and human information processing* (pp. 175-198). Dordrecht, The Netherlands: Martinus Nijhoff Publishers.

139. Mulder, G. (1995). The search for energetical indices of mental task load. Contribution to the EPOS workshop 'Psychophysiology of Mental Resources', September 5-8, Amsterdam.
140. Mulder, L.J.M. (1988). Assessment of cardiovascular reactivity by means of spectral analysis. PhD Discussion. Groningen: University of Groningen.
141. Mulder, L.J.M. (1992). Measurement and analysis methods of heart rate and respiration for use in applied environments. *Biological Psychology*, 34, 205-236.
142. Mulder, L.J.M., Schweizer, D. & Van Roon, A.M. (1990). An environment for data reduction, correction and analysis of cardiovascular signals. Abstract 4th 'Computers in Psychology' workshop, Tilburg, The Netherlands.
143. Mulders, H., Meijman, T., Mulder, B., Kompier, M., Broersen, S., Westerink, B. & O'Hanlon, J. (1988). Occupational stress in city bus drivers. In J.A. Rothengatter & R.A. de Bruin (Eds.), *Road user behaviour: theory and research* (pp. 348-358). Assen, The Netherlands: Van Gorcum.
144. Mulders, H.P.G., Meijman, T.F., O'Hanlon, J.F. & Mulder, G. (1982). Differential psychophysiological reactivity of city bus drivers. *Ergonomics*, 25, 1003-1011.
145. Müller, A., Schandry, R., Montoya, P. & Gsellhofer, B. (1992). Differential effects of two stressors on heart rate, respiratory sinus arrhythmia, and T-wave amplitude. *Journal of Psychophysiology*, 6, 252-259.
146. Myrtek, M., Deutschmann-Janicke, E., Strohmaier, H., Zimmermann, W., Lawerenz, S., Brügger, G. & Müller, W. (1994). Physical, mental, emotional, and subjective workload components in train drivers. *Ergonomics*, 37, 1195-1203.
147. Norman, D.A. & Bobrow, D.G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, 7, 44-64.
148. Nygren, T.E. (1991). Psychometric properties of subjective workload measurement techniques: implications for their use in the assessment of perceived mental workload, *Human Factors*, 33, 17-33.
149. O'Donnell, R.D. & Eggemeier, F.T. (1986). Workload assessment methodology. In K.R. Boff, L. Kaufman & J.P. Thomas (Eds.), *Handbook of perception and human performance*. Volume II, cognitive processes and performance. (pp 42/1-42/49). New York: Wiley.
150. O'Hanlon, J.F. (1981). Boredom: practical consequences and a theory. *Acta Psychologica*, 49, 53-82.
151. O'Hanlon, J.F. (1984). Driving performance under the influence of drugs: rationale for, and application of, a new test. *British Journal of Clinical Pharmacology*, 18, 121S-129S.
152. O'Hanlon, J.F., Haak, T.W., Blaauw, G.J. & Riemersma, J.B.J. (1982). Diazepam impairs lateral position control in highway driving. *Science*, 217, 79-80.
153. Paas, F.G.W.C., Van Merriënboer, J.G.J. & Adam, J.J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills*, 79, 419-430.
154. Papillo, J.F. & Shapiro, D. (1990). The cardiovascular system. In J.T. Cacioppo & L.G. Tassinary. *Principles of psychophysiology* (pp. 456-512). Cambridge: Cambridge University Press.

155. Parkes, A.M. (1991). Data capture techniques for RTI usability evaluation. In Commission of the European Communities, Advanced telematics in road transport, Proceedings of the DRIVE conference. (pp. 1440-1456). Amsterdam: Elsevier.
156. Pohlmann, S. & Traenkle, U. (1994). Orientation in road traffic. Age-related differences using an in-vehicle navigation system and a conventional map. *Accident Analysis and Prevention*, 26, 689-702.
157. Porges, S.W. & Byrne, E.A. (1992). Research methods for measurement of heart rate and respiration. *Biological Psychology*, 34, 93-130.
158. Porges, S.W. (1992). Vagal tone: a physiologic marker of stress vulnerability. *Pediatrics*, 90, 498-504.
159. Porges, S.W., Bohrer, R.E., Cheung, M.N., Drasgow, F., McCabe, P.H. & Keren, G. (1980). New time-series statistic for detecting rhythmic co-occurrence in the frequency domain: the weighted coherence and its application to psychophysiological research. *Psychological Bulletin*, 88, 580-587.
160. Posner, M.I. (1978). *Chronometric explorations of mind*. Hillsdale: Erlbaum.
161. Pribram, K.H. & McGuiness, D. (1975). Arousal, activation and effort in the control of attention. *Psychological review*, 82, 116-149.
162. Raggatt, P.T.F. & Morrissey, S.A. (submitted,--1997). A field study of stress and fatigue in long-distance bus drivers. *Behavioral Medicine*, 23, 122-129.
163. Reid, G.B. & Colle, H.A. (1988). Critical SWAT values for predicting operator overload. In Proceedings of the Human Factors Society 32nd annual meeting (pp. 1414-1418). Santa Monica, CA: Human Factors Society.
164. Reid, G.B., Shingledecker, C.A. & Eggemeier, F.T. (1981). Application of conjoint measurement to workload scale development. In Proceedings of the Human Factors Society 25th annual meeting (pp. 522-526). Santa Monica, CA: Human Factors Society.
165. Riedel, W.J. (1991). Eye-movements, expert ratings, weaving and time-to-line-crossing as measures of driving performance and driving performance impairment. In A.G. Gale, I.D. Brown, C.M. Haslegrave, I. Moorhead & S. Taylor (Eds.), *Vision in vehicles -III* (pp. 299-306). Amsterdam: North-Holland.
166. Rockwell, T.H. (1988). Spare visual capacity in driving-revisited. New empirical results for an old idea. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith & S.P. Taylor (Eds.), *Vision in vehicles-II* (pp. 317-324). Amsterdam: North-Holland.
167. Roscoe, A.H. (1992). Assessing pilot workload. Why measure heart rate, HRV and respiration? *Biological Psychology*, 34, 259-287.
168. Roscoe, A.H. (1993). Heart rate as psychophysiological measure for in-flight workload assessment. *Ergonomics*, 36, 1055-1062.
169. Rothengatter, J.A. (1991). Automatic policing and information systems for increasing traffic law compliance. *Journal of applied behavior analysis*, 24, 85-87.
170. Rouse, W.B., Edwards, S.L. & Hammer, J.M. (1993). Modelling the dynamics of mental workload and human performance in complex systems. *IEEE transactions on systems, man, and cybernetics*, 23, 1662-1671.

171. Rueb, J., Vidulich, M., Hassoun, J. (1992). Establishing workload acceptability: an evaluation of a proposed KC-135 cockpit redesign. In *Proceedings of the Human Factors Society 36th annual meeting* (pp. 17-21). Santa Monica, CA: Human Factors Society.
172. Sanders, A.F. (1970). Some aspects of the selective process in the functional visual field. *Ergonomics*, 13, 101-117.
173. Sanders, A.F. (1983). Towards a model of stress and human performance. *Acta Psychologica*, 53, 61-97.
174. Schneider, W. & Fisk, A.D. (1983). Attention theory and mechanisms for skilled performance. In R. Magill (Ed.), *Memory and control of action*. New York: North-Holland.
175. Schneider, W. & Shiffrin, R.M. (1977). Controlled and automatic human information processing: I. Detection, search and attention. *Psychological Review*, 84, 1-66.
176. Schneider, W., Dumais, S.T. & Shiffrin, R.M. (1984). Automatic and control processing and attention. In R. Parasuraman and D.R. Davies (Eds.), *Varieties of attention*. (pp. 1-27). London: Academic Press.
177. Settels, J.J. & Wesseling, K.H. (1985). FIN.A.PRES: non-invasive finger arterial pressure waveform registration. In J.F. Orlebeke, G. Mulder & L.P.J. van Doornen (Eds.), *The psychophysiology of cardiovascular control* (pp. 267-283). New York: Plenum Press.
178. Shiffrin, R.M. & Schneider, W. (1977). Controlled and automatic information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological review*, 84, 127-190.
179. Sirevaag, E., Kramer, A.F., De Jong, R. & Mecklinger, A. (1988). A psychophysiological analysis of multi-task processing demands. *Psychophysiology*, 25, 482.
180. Sirevaag, E.J., Kramer, A.F., Wickens, C.D., Reisweber, M., Strayer, D.L. & Grenell, J.F. (1993). Assessment of pilot performance and mental workload in rotary wing aircraft. *Ergonomics*, 36, 1121-1140.
181. Smiley, A. & Brookhuis, K.A. (1987). Alcohol, drugs and traffic safety. In J.A. Rothengatter & R.A. de Bruin (Eds.), *Road users and traffic safety*. (pp. 83-105). Assen, The Netherlands: Van Gorcum.
182. Snijders, T.A.B. (1995). personal communication.
183. Sokolov, E.N. (1963). *Perception and the conditioned reflex*. Oxford: Pergamon.
184. Stein, A.C., Parseghian, Z. & Allen, R.W. (1987). A simulator study of the safety implications of cellular mobile phone use. In *American Association for Automotive Medicine*. (pp. 181-200). *Proceedings of the 31st annual conference*. Desplaines, IL: AAAM.
185. Steptoe, A. & Sawada, Y. (1989). Assessment of baroreceptor reflex function during mental stress and relaxation. *Psychophysiology*, 26, 140-147.
186. Stern, J.A., Boyer, D. & Schroeder, D. (1994). Blink rate: a possible measure of fatigue. *Human Factors*, 36, 285-297.

187. Steyvers, F.J.J.M. (1993). The measurement of road environment appreciation with a multi-scale construct list. In A.G. Gale, I.D. Brown, C.M. Haslegrave, H.W. Kruysse & S.P. Taylor (Eds.), *Vision in Vehicles-IV*. (pp. 203-212). Amsterdam: North-Holland.
188. Steyvers, F.J.J.M., Dekker, K., Brookhuis, K.A. & Jackson, A.E. (1994). The experience of road environments under two lighting and traffic conditions: application of a Road Environment Construct List. *Applied Cognitive Psychology*, 8, 497-511.
189. Teigen, K.H. (1994). Yerkes-Dodson: a law for all seasons. *Theory & Psychology*, 4, 525-547.
190. Thomas, D.B., Herberg, K.-W., Brookhuis, K.A., Muzet, A.G., Poilvert, C., Tarriere, C., Norin, F., Wyon, D.P., Schievers, G. & Mutschler, H. (1989). Demonstration experiments concerning driver status monitoring (Report V1004/DREAM). Köln, FRG, Technische Überwachungs-Verein Rheinland e.V.
191. Thorsvall, L. & Åkerstedt, T. (1987). Sleepiness on the job: continuously measured EEG changes in train drivers. *Electroencephalography and Clinical Neurophysiology*, 66, 502-511.
192. Tsang, R S., & Wilson, G. E (1997). Mental workload. In G. Salvendy (Ed.), *Human factors handbook*(2nd ed., pp. 417-449). New York: Wiley.
193. Unema, P. (1995). Eye movements and mental effort. PhD Discussion, TU Berlin. Aachen, Germany: Verlag Schalter.
194. Van Boxtel, A. & Jessurun, M. (1993). Amplitude and bilateral coherency of facial and jaw-elevator EMG activity as an index of effort during a two-choice serial reaction task. *Psychophysiology*, 30, 589-604.
195. Van der Beek, A.J., Meijman, T.F., Frings-Dresen, M.H.W., Kuiper, J.I. & Kuiper, S. (1995). Lorry drivers' work stress evaluated by catecholamines excreted in urine. *Occupational and Environmental Medicine*, 52, 464-469.
196. Van Ouwelkerk, R., Meijman, Th.F. & Mulder, G. (1994a). Mentale belasting (Mental Workload). In P.C. Buijs, A. van Oosterom & H. Wolvetang (Red.), *Handboek Bedrijfsgezondheidszorg* (Hoofstuk B3-1). Utrecht, The Netherlands: Bunge.
197. Van Ouwelkerk, R.J., Meijman, T.F. & Mulder, G. (1994b). Arbeidspsychologische taakanalyse. Het onderzoek van cognitieve en emotionele aspecten van arbeidstaken. (Workpsychological task analysis. Research on cognitive and emotional aspects of tasks of labour). Utrecht, The Netherlands: Lemma.
198. Van Roon, A.M. (in preparation). Simulation of short-term cardiovascular effects of mental workload. PhD Discussion, University of Groningen.
199. Van Winsum, W., Martens, M., Herland, L. (1999). The effects of speech versus tactile driver support messages on workload, driver behaviour and user acceptance, TNO-report, TM-99-C.
200. Van Winsum, W., Van Knippenberg, C. & Brookhuis, K. (1989). Effect of navigation support on drivers' mental workload. In *Current issues in European transport, Vol I. Guided transport in 2040 in Europe* (pp. 69-84). London: PTRC Education and Research Services.

201. Van Winsum, W; Brookhuis, K.A.; De Waard, D. (1999). Lane change manoeuvres and safety margins. *Transportation Research Part F: Traffic Psychology and Behaviour*, 139-149.
202. Van Wolffelaar, P.C., Brouwer, W.B. & Rothengatter, J.A. (1990). Divided attention in RTI-tasks for elderly drivers (Report 1006/DRIVAGE/Deliverable TRC1). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
203. Vaughan, G., May, A., Ross, T. & Fenton, P. (1994). A human-factors investigation of an RDS-TMC system. In ERTICO (Ed.) *Towards an intelligent transport system. Proceedings of the first world congress on applications of transport telematics and intelligent vehicle-highway systems* (pp. 1685-1692). Boston: Artech House.
204. Veltman, J.A. & Gaillard, A.W.K. (1993). Indices of mental workload in a complex task environment. *Neuropsychobiology*, 28, 72-75.
205. Veltman, J.A. & Gaillard, A.W.K. (in press). Measurement of pilot workload with subjective and physiological techniques. Paper presented at the annual meeting of the Europe Chapter of the Human Factors and Ergonomics Society, November 1993, Soesterberg, The Netherlands.
206. Verwey, W.B. & Veltman, J.A. (1995). Measuring workload peaks while driving. A comparison of nine common workload assessment techniques (Report TNO-TM 1995 B-4). Soesterberg, The Netherlands: TNO Human Factors Research Institute.
207. Verwey, W.B. (1990). Adaptable driver-car interfacing and mental workload: a review of the literature (Report V1041/GIDS/DIA/1). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
208. Verwey, W.B. (1993a). How can we prevent overload of the driver? In A.M. Parkes & S. Franzén, *Driving future vehicles*. (pp 235-244). London: Taylor & Francis.
209. Verwey, W.B. (1993b). Driver workload as a function of road situation, age, traffic density, and route familiarity (Report IZF 1993 C-11). Soesterberg, The Netherlands: TNO Institute for Perception.
210. Vicente, K.J., Thornton, D.C. & Moray, N. (1987). Spectral analysis of sinus arrhythmia: a measure of mental effort. *Human Factors*, 29, 171-182.
211. Vidulich, M.A. & Tsang, P.S. (1986). Techniques of subjective workload assessment: a comparison of SWAT and the NASA-bipolar methods. *Ergonomics*, 29, 1385-1398.
212. Vidulich, M.A. & Wickens, C.D. (1986). Causes of dissociation between subjective workload measures and performance. Caveats for the use of subjective assessments. *Applied Ergonomics*, 17, 291-296.
213. Vivoli, G., Bergomi, M., Rovesti, S., Carrozzi, G. & Vezzosi, A. (1993). Biochemical and haemodynamic indicators of stress in truck drivers. *Ergonomics*, 36, 1089-1097.
214. Volkerts, E.R., Brookhuis, K.A. & O'Hanlon, J.F. (1987). Comparison of the effects of Buspirone 5 mg and 10 mg, Diazepam 5 mg and Lorazepam 1 mg (t.i.d.) upon actual driving performance (Report VK 87-02). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
215. Volkerts, E.R., Louwerens, J.W., Gloerich, A.B.M., Brookhuis, K.A. & O'Hanlon, J.F. (1984). Zopiclone's residual effect upon actual driving performance versus those of

- Nitrazepam and Flunitrazepam (Report VK 84-10). Haren, The Netherlands: Traffic Research Centre, University of Groningen.
216. Waterink, W. & Van Boxtel, A. (1994). Facial and jaw-elevator EMG activity in relation to changes in performance level during a sustained information processing task. *Biological Psychology*, 37, 183-198.
217. Wickens, C.D. (1984). Processing resources in attention. In R. Parasuraman and D.R. Davies (Eds.). *Varieties of attention*. (pp. 63-102). London: Academic Press.
218. Wickens, C.D. (1991). Processing resources and attention. In D.L. Damos (Ed.), *Multiple-task performance*. (pp. 3-34). London: Taylor & Francis.
219. Wickens, C.D. (1992). *Engineering psychology and human performance*. New York: HarperCollins.
220. Wiener, E.L. (1987). Application of vigilance research: rare, medium, or well done? *Human Factors*, 29, 725-736.
221. Wientjes, C.J.E. (1992). *Respiration in psychophysiology: methods and applications*. *Biological Psychology*, 34, 179-203.
222. Wientjes, C.J.E. (1993). *Psychological influences upon breathing: situational and dispositional aspects*. PhD discussion, Soesterberg, The Netherlands: TNO Institute for Perception.
223. Wierwille, W.W. & Casali, J.G. (1983). A validated rating scale for global mental workload measurement application. In *Proceedings of the Human Factors Society 27th Annual Meeting* (pp. 129-133). Santa Monica, CA: Human Factors Society.
224. Wierwille, W.W. & Eggemeier, F.T. (1993). Recommendation for mental workload measurement in a test and evaluation environment. *Human Factors*, 35, 263-281.
225. Wierwille, W.W., Rahimi, M. & Casali, J.G. (1985). Evaluation of 16 measures of mental workload using a simulated flight task emphasizing mediational activity. *Human Factors*, 27, 489-502.
226. Wijers, A.A. (1989). *Selective visual attention: an electrophysiological approach*. PhD discussion, University of Groningen.
227. Wildervanck, C., Mulder, G. & Michon, J.A. (1978). Mapping mental load in car driving. *Ergonomics*, 21, 225-229.
228. Wilhelm, B. & Wilhelm, H. (1995). Das Pupilverhalten verrät Übermüdung. *Zeitschrift für Verkehrssicherheit*, 41, 116-118.
229. Wilson, G.F. & Eggemeier, F.T. (1991). Psychophysiological assessment of workload in multi-task environments. In D.L. Damos (Ed.), *Multiple-task performance* (pp. 329-360). London: Taylor & Francis.
230. Wilson, G.F. (1992). Applied use of cardiac and respiration measures: practical considerations and precautions. *Biological Psychology*, 34, 163-178.
231. Yeh, Y.Y. & Wickens, C.D. (1988). Dissociation of performance and subjective measures of workload. *Human Factors*, 30, 111-120.
232. Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, 18, 459-482.

233. Zeier, H. (1979). Concurrent physiological activity of driver and passenger when driving with and without automatic transmission in heavy city traffic. *Ergonomics*, 22, 799-810.
234. Zijlstra, F. & Meijman, T. (1989). Het meten van mentale inspanning met behulp van een subjectieve methode (measurement of mental effort with a subjective method). In T. Meijman (Ed.), *Mentale belasting en werkstress. Een arbeidspsychologische benadering.* (pp. 42-61). Assen, The Netherlands: Van Gorcum.
235. Zijlstra, F. & Mulder, G. (1989). Mentale belasting: theoretische gezichtspunten en overzicht van meetmethoden (mental workload: theoretical points-of-view and an overview of measurement methods). In T. Meijman (Ed.), *Mentale belasting en werkstress. Een arbeidspsychologische benadering.* (pp. 21-41). Assen, The Netherlands: Van Gorcum.
236. Zijlstra, F.R.H. & Van Doorn, L. (1985). The construction of a scale to measure perceived effort. Delft, The Netherlands: Department of Philosophy and Social Sciences, Delft University of Technology.
237. Zijlstra, F.R.H. (1993). Efficiency in work behavior. A design approach for modern tools. PhD discussion, Delft University of Technology. Delft, The Netherlands: Delft University Press.

Appendix 2 References for Circadian Rhythms and Fatigue

1. Akerstedt, T. (1977). Inversion of the sleep wakefulness pattern: Effects on circadian variations in psychophysiological activation. *Ergonomics*, 20, 459-474.
2. Aschoff, J., (1994). Naps as Integral Parts of the Wake Time Within the Human Sleep-Wake Cycle. *Journal of Biological Rhythms*, 9: 145-155.
3. Binkley, Sue. *The Clockwork Sparrow: Time, Clocks, and Calendars in Biological Organisms*. New Jersey: Prentice-Hall, Inc., 1990, 262 pgs.
4. Campbell, S. S., (1995). Light Treatment for Sleep Disorders: Consensus Report; V. Age-Related Disturbances. *Journal of Biological Rhythms*, 10: 151-154.
5. Costa, G., (1996). The impact of shift and night work on health, *Applied Ergonomics*, Vol. 27, No. 1, pp. 9-16.
6. Dijk, Derk-Jan, (1995). Light Treatment for Sleep Disorders: Consensus Report; II. Basic Properties of Circadian Physiology and Sleep Regulation. *Journal of Biological Rhythms*, 10: 113- 125.
7. Dinges, D.F. (1989). Napping Patterns and Effects in Human Adults." In *Sleep and Alertness: Chronobiological, Behavioral, and Medical Aspects of Napping*, eds., D.F. Dinges and R.J. Broughton. New York: Raven Press, Ltd., pp. 171-204.
8. Douillard, J., (2001). *Body, Mind and Sport*. New York: Three Rivers Press.
9. Dust, M. (2001). Sleep patterns. Retrieved on January 20, 2010, 2003 from <http://www.mikedust.com/fascinatum/2001/fascinatum-121301.html>
10. Folkhard, S., and Monk, T. H., (1979). Shiftwork and performance. *Human Factors*, 21, 483-492.
11. Folkhard, S., Wever, R. A., and Wildgruber, C. M., (1983). Multi-oscillatory control of circadian rhythms in human performance. *Nature*, 305, 223-226.
12. Gordon, N., (1986). The prevalence and health impact of shift work. *American Journal of Public Health*, Vol. 76, No. 10, pp. 1225-1228.
13. Gwinner, E., (1981). Circannual Systems. In *Handbook of Behavioral Neurobiology*, Volume 4: Biological Rhythms, ed., Jürgen Aschoff. New York: Plenum Press, , pp. 391-410.
14. Haus, E. (1992). Chronobiology of Circulating Blood Cells and Platelets. In *Biological Rhythms in Clinical and Laboratory Medicine*, eds., Y. Touitou and E. Haus. Berlin: Springer-Verlag, pp. 504-526.
15. <http://www.hhmi.org/news/takahashi.html>
16. Immelmann, K. (1973). Role of the Environment in Reproduction as Source of Predictive Information." In *Breeding Biology of Birds*, ed., D.S. Farner. Washington, D.C.: National Academy of Sciences, pp. 121-147.
17. Jehue, Richard, (1993). Effect of Time Zone and Game Time Changes on Team Performance: National Football League. *Medicine and Science in Sports and Exercise*. 25(1): 127-31.

18. Kay, S.A., (1989). Rice Phytochrome is Biologically Active in Transgenic Tobacco. *Plant Cell*. 1: 775-782.
19. Kelly, R. J. and Schneider, M. F., (1982). The twelve-hour shift revisited: Recent trends in the electric power industry. *Journal of Human Ecology*, 11 (suppl.), 369-384.
20. Knauth, P., and Rutenfranz, J. (1976). Experimental studies of permanent night and rapidly rotating shift systems. *International Archives of Occupational and Environmental Health*, 37, 125-137.
21. Koukkari, W.L., (1987). Chronobiology Projects and Laboratory Exercises. *Chronobiologia*, 14.
22. Lamberg, L. (1991). Chronotherapeutics: Implications for Drug Therapy. *American Pharmacy*, 1991; N831(11): 20-23.
23. Ladou, J. (1982). Health effects of shift work, *Western Journal of Medicine*, December 1982, pp. 525-530.
24. Menaker, M. (1972). Nonvisual Light Reception. *Scientific American*, 22-29.
25. Millar, A.J., et al. Firefly Luciferase as a Reporter of Regulated Gene Expression. *Plant Molecular Biology Reporter*. 1992; 10(4): 324-337.
26. Mitler, M., (1988). Catastrophes, Sleep, and Public Policy: Consensus Report. *Sleep*. 11: 100-109.
27. Monk, T.H., and Embrey, D. E., (1981). A field study of circadian rhythms in actual and interpolated task performance. In A. Reinberg, N. Vieux, and P. Andlauer, Eds., *Night and shift work: Biological and social aspects*. Oxford, Pergamon.
28. Moore-Ede, Sulzman M, F., and Fuller, C., (1982). *The Clocks That Time Us: Physiology of the Circadian Timing System*. Cambridge: Harvard Univ. Press.
29. National Safety Council. *Accident Facts*. (1994). Itasca, IL., 120 pgs.
30. National Transportation Safety Board. *Fatigue, Alcohol, Other Drugs, and Medical Factors in Fatal-to-the-Driver Heavy Truck Crashes*. (1990). Vol.I. PB90-917002. NTSB/SS-90/01. Washington, D.C.: National Transportation Safety Board, 181 pgs.
31. National Transportation Safety Board. "Aircraft Accident Report: Uncontrolled Collision with Terrain, American International Airways Flight 808, Douglas DC-8-61, N814CK, U.S. Naval Air Station, Guantanamo Bay, Cuba. August 18, 1993." PB94-910406, NTSB/AAR94/04. Washington, D.C.: NTSB, 1994, 141 pages.
32. Page, E., (1992). Safety and the Trucking Industry. Lecture presented at Industrial Symposium at the Center for Innovative Technology, Herndon, Virginia. Feb. 9 and 10, 1992.
33. Palmer, J. D., (1974). *Biological Clocks in Marine Organisms: The Control of Physiological and Behavioral Tidal Rhythms*. New York: John Wiley and Sons.
34. Parkes (2003). Shiftwork and Environment as Interactive Predictors of Work Perceptions. *Journal of Occupational Health Psychology*. Vol. 8 (4) Pp 266-281.
35. Parkes K. (2002). Age, smoking, and negative affectivity as predictors of sleep patterns among shiftworkers in two environments. *Journal of Occupational Health Psychology*. Vol. 7 (2) Pp 156-173.

36. Reinberg, A., Andlauer, P., De Prins, J., Malbecq, W., Vieux, N., and Bourdeleau, P. (1984). Desynchronization of the oral temperature circadian rhythm and intolerance to shift work. *Nature*, 308, 272-274.
37. Rosekind, Mark R. (1994). Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long-Haul Operations." NASA Technical Memorandum No. 108839. Moffett Field, CA: Ames Research Center.
38. Rosenzweig, M. R., Breedlove, S.M., & Leiman, A.L. (2002). *Biological psychology: an introduction to behavioral, cognitive, and clinical neuroscience* (3rd ed.). Sunderland, MA: Sinauer Associates, Inc. Ralph, M. R., and Menake, M.. (1988). A Mutation of the Circadian System in Golden Hamsters." *Science*, Sept. 2, 1988; 241: 1225-1227.
39. Rutenfranz, J., (1982). Occupational health measure of night- and shift workers. *Journal of Human Ergology*. 11(suppl.)67-86.
40. Rutenfranz, J., Knauth, P., and Angersbach, D., (1981). Shift work research efforts, IN L. C. Johnson, D. I. Tepas, W.P. Colquhoun, and M. J. Colligan, Eds. *Biological rhythms, sleep, and shift work*. New York: Spectrum Publications.
41. Scott, A., Shiftwork: Effects on sleep and health with recommendations for medical surveillance and screening, *Occupational Medicine*, Vol. 5, No. 2, pp. 273-299.
42. Siffre, Michael. (1975). Six Months Alone in a Cave. *National Geographic*, 426-435.
43. Tepas, D. I., (1982). Work/sleep, time schedules and performance. In W. B. Webb, Ed., *Biological rhythms, sleep and performance*. New York: Wiley.
44. Touitou, Y. and E. Haus. (1992). Biological Rhythms and Aging. In *Biological Rhythms in Clinical and Laboratory Medicine*, eds., Y. Touitou and E. Haus. Berlin: Springer-Verlag, , pp. 188-207.
45. Thorner, M. (1992). Ultradian Rhythms and Growth Hormone Regulation. Lecture presented to students in the Summer Course in Biological Timing at the Univ. of Va., August 6, 1992.
46. Underwood, H., (1992). Endogenous Rhythms." In *Biology of the Reptilia: Hormones, Brain, and Behavior*, Vol. 18, Phys. E. eds., Carl Gans and David Crews. Chicago: Univ. of Chicago Press, pp. 229-297.
47. U.S. Congress, Office of Technology Assessment. (1988). *Gearing Up for Safety: Motor Carrier Safety in a Competitive Environment*. OTA-SET-382. Washington, D.C.: U.S. Government Printing Office.
48. U.S. Congress, Office of Technology Assessment. (1988). *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment*. OTA- SET-381. Washington, D.C.: U.S. Government Printing Office.
49. U.S. Congress, Office of Technology Assessment. (1991). *Biological Rhythms: Implications for the Worker*. OTA-BA-463. Washington, D.C.: U.S. Government Printing Office.
50. Ward, Ritchie R., (1971) *The Living Clocks*. New York: Alfred A. Knopf, Inc.
51. Wever, R. A., (1979). *The circadian system of man*. Berlin: Springer-Verlag.
52. *Working Nights Health & Safety Guide*. Circadian Information, Lexington, Mass.

U.S. EPR Final Safety Analysis Report Markups

- A description of the integration of HRA into the HFE program.

The HFE design gives special attention to those plant scenarios, risk-important HAs, and HSIs that have been identified by PRA and HRA as being important to plant safety and reliability.

The HRA evaluates and identifies specific HAs based on the impact of potential errors on plant safety. This evaluation is iterative. It begins early in the design process and continues throughout each all phases of the design. The initial HRA is defined by a set of scenarios and accident sequences that contribute to core damage frequency or large release frequency. The HRA also considers operating experience, staffing and training, and other engineering assumptions that affect plant operation and human performance. From these inputs, human error probabilities (HEP) are calculated. HEPs are influenced by performance shaping factors (PSF), which are used to adjust the base HEPs to account for conditions such as the complexity of the accident and the stress upon the operators (refer to Chapter 19).

As the EPR design develops, the HRA model is refined to incorporate other HFE elements that will affect human performance. These elements influence the HEP estimates through the PSF values and the PRA evaluates the impact of these errors on accident scenarios. The HRA supports the HFE by providing the HSI design team with feedback that assists in minimizing personnel errors, and improving operator recovery from human errors and plant system failures.

Risk-significant HAs and their associated tasks and scenarios are specifically addressed during function allocation analyses, task analyses, HSI design, procedure development, and training. This process helps verify that these tasks are well supported by the design and are within acceptable human performance capabilities (e.g., within time and workload requirements).

As described in Section 18.10, HRA assumptions such as decision making and diagnosis strategies for dominant sequences are validated by walkthrough analyses with operationally experienced personnel using a plant-specific control room mockup or simulator. Reviews are then incorporated into the final quantification stage of the PRA. subsequent iterations of HRA and PRA. Risk-significant humans actions are addressed during integrated system validations.

18-56

18.6.3

Results

An output report identifies the list of risk-important HAs and summarizes how those HAs and the associated tasks and scenarios were addressed during the various parts of the HFE design process. The output report addresses the results of the HRA assumption validation.

18-67

- Random scenario selection and sequencing is used to keep the testing unbiased. The easy scenarios are not always conducted first and testing participants get random assignments.

18.10.3.5 Integrated System Validation

ISV is a performance-based evaluation of integrated system design and human task performance to establish that the HSI is operable within performance requirements and supports safe operation of the plant. The ISV addresses the following:

- Adequacy of the entire HSI configuration for achievement of the HFE program goals.
- Confirmation of allocation of functions and the structure of tasks assigned to personnel and machine.
- Adequacy of staffing and HSI that support tasks.
- Adequacy of procedures and operating instructions.
- Validation of the dynamic aspect of HSI for task accomplishment.
- Identification of aspects of the integrated system that may negatively affect integrated system performance.

The goals of ISV are to:

- Test the integration of personnel and plant systems.
- Validate the integration of the design with:
 - Personnel actions.
 - Plant response.
 - HSIs.
 - Procedures.

ISV is performed using a high-fidelity simulator. ISV seeks to confirm the adequacy of the HSI and the human performance assumptions, so appropriate performance measures are selected to include both HSI and human performance issues. ISV performance measurement is complex and addresses the following areas:

- Operational safety and task performance (e.g., avoidance of errors, alarm conditions, technical specification violations, response time, task completion time, and procedure compliance).
- Human error.

18.12 Human Performance Monitoring

Monitoring human performance is performed throughout the life of the plant so that:

- The results of the integrated system validation are maintained.
- Operator performance does not degrade over time.
- Issues discovered by operating and maintenance personnel are noted, tracked, and corrected before plant safety is compromised.
- Changes made to the design do not result in a degradation of human performance.

The U.S. EPR human performance monitoring (HPM) strategy, as described in the HPM Implementation Plan (Reference 3), provides a method to accomplish this goal. A COL applicant that references the U.S. EPR design certification will implement an HPM program similar to that which is described in this section.

18.12.1 Objectives and Scope

18-57

The objectives for HPM are to provide a framework of programs, which when implemented, perform the following:

- To confirm that the design can be effectively used by personnel.
- To confirm that human actions (HA) are accomplished within an acceptable time and meet performance criteria.
- To confirm that design changes do not adversely affect personnel performance.
- To confirm that the acceptable level of performance established during the integrated system validation remains valid.
- To detect degrading human performance before plant safety is compromised.
- To confirm identified errors in the design are resolved in a timely manner.

18-56

- Monitoring is done for HAs commensurate with their safety significance.

To verify that the objectives are met, HPM is conducted in areas of the plant requiring HAs, including:

- Main control room (MCR).
- Remote shutdown station (RSS).
- Technical support center (TSC).
- Local control stations (LCS) important to plant safety.

Operation, testing, and maintenance actions during each plant mode are also monitored for human performance.

18.12.2 Methodology

HPM is performed by observing personnel activities (i.e., during training and operation), interviews, self-initiated feedback, and walkthroughs. The use of a corrective action program combined with some means of tracking issues allows design errors, design issues, operator workarounds, operator burdens, or inefficiencies identified to be captured and addressed. Programs such as the design change control process, ~~operator focus index~~, performance indicators, corrective action program, and maintenance rule are in place to prevent degradation of human performance. The combination of these tools creates a strategy that meets the intent of HPM as described in NUREG-0711 (Reference 1).

18-59



~~process, operator focus index,~~ performance indicators, corrective action program, and maintenance rule are in place to prevent degradation of human performance. The combination of these tools creates a strategy that meets the intent of HPM as described in NUREG-0711 (Reference 1).

18-57



HAs and the level of performance are monitored during simulator-training and during actual plant conditions, when feasible. The data from monitoring is evaluated and the results are entered into the corrective action program for analysis and trending. The results of the trends are used to monitor for any change, positive and negative, in human performance. If the trend shows that performance has degraded, corrective actions are performed.

Risk-significant HAs are monitored more frequently so that degradation of safety-related performance is corrected before the safety of the plant is compromised.

18.12.2.1 Corrective Action Program and Issue Tracking

A U.S. EPR operator corrective action program is used so that self-identified and industry performance related issues are documented, reviewed, addressed, and tracked. Addressing these issues prevents the recurrence of degraded performance or failures. Specific issues that should be tracked include:

- HSI design errors.
- HSI design inefficiencies.
- User workarounds.
- Discrepancies between the full-scope simulator and the actual control room.
- Changes to the HSI design that create an adverse affect on other aspects of the design.
- Operating experience reports.

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~~So that issues are captured, plant personnel are encouraged to report errors, deficiencies, workarounds, and design inefficiencies. When an issue is entered into~~

the database, a cognizant engineer performs an analysis to determine safety significance. Those issues with a high safety significance are analyzed and corrective actions are promptly generated to lessen the potential for impact to plant safety.

If an adverse trend is noticed, a root cause analysis is performed by a cognizant human factors engineer to determine the extent of cause, extent of condition, and if human performance was a contributor. This analysis generates a thorough understanding of the underlying problem so that appropriate corrective actions can be taken. The results of the root cause analysis are used to categorize the issue and enable trending.

Industry and self-identified operating experience results contribute to enhancing human performance and preventing potential reduction in human performance. The operating experience review program described in Section 18.2 tracks self-identified as well as industry issues. These issues are screened for human performance issues and analyzed for applicability to the U.S. EPR. Preventive measures are taken for those issues that could potentially adversely impact human performance.

18.12.2.2 Monitoring and Trending

HAs and the level of performance are monitored during simulator training and during actual plant conditions, when feasible. The data from monitoring is evaluated and the results are entered into the corrective action program for analysis and trending. The results of the trends are used to monitor for any change, positive and negative, in human performance. If the trend shows that performance has degraded, corrective actions are performed.

Risk significant HAs are monitored more frequently so that degradation of safety-related performance is corrected before the safety of the plant is compromised.

18.12.2.3 Plant Operation

User activities are observed during simulator training and periodically during actual plant operation. The licensed operator training program allows monitoring of human performance and trending. Operator actions during training provide insight to potential operator workarounds, operator errors, and design inefficiencies. HAs are monitored for agreement with established time and performance criteria. These established performance measures are used as the baseline to determine changes in efficiency of user actions or their ability to perform tasks in a timely manner. Changes, along with any discovered design errors and decline in performance, are entered into the corrective action program to be analyzed for possible areas of improvement and used as input into human performance trending.

Other activities, such as communication between the control room and other areas of the plant, are also included in HPM and trending. Any inefficiencies, design errors, or

18-57 → failures noted by personnel are entered into the corrective action program and analyzed for possible areas of improvement and input to human performance trending.

18.12.2.4 Design Change Process

Before a design change that has a significant impact on FRA, FA, TA, HSIs, procedures, or training is implemented in the plant, the change is typically modeled on the engineering simulator. Human performance is monitored using applicable scenarios developed during operational condition sampling and used during the integrated system validation (see Section 18.10). These scenarios are limited to only those that use tasks affected by the design change to allow analysis of performance efficiency, degradation, or improvement. During simulation, user actions are observed for their efficiency and ability to perform tasks with the new design. The results are verified against the existing trend of human performance to determine if the performance was degraded by the design change.

18-58 → Any degradation in performance resulting from the design change is entered into the corrective action program to be analyzed for possible areas of improvement and used as input to human performance trending. Significant impacts to human performance require that the design change be modified. If no degradation in performance is observed, the design is implemented and results of the HPM are entered into the current trend.

When an approved design change has been implemented into the plant, performance is observed and users are interviewed. Interviews with users are performed to determine any operator workarounds, HSI inefficiencies, or design errors that resulted from the design change. Interview questions are centered on tasks that have been affected by the design change. Particular attention is given to user actions during their initial use of the new design to note any adverse affect on performance, confirm the design change is performing its intended function, and to view any operator workarounds. The significance of the design change impact determines the amount of

18-57 → monitoring effort required. A design control process described in Section 4.5.1 of the U.S. EPR HFE Program Management Plan (Reference 2) controls the design, design changes, design verification, and analysis activities. A similar process is used by the U.S. EPR operator to control design changes. The process confirms that changes made to the design are adequate and accomplish the goal of the design change. The process also confirms that the design change does not result in adverse effects on personnel performance.

A substantial HSI design change is simulated on the simulator. Evaluation of human performance determines the anticipated impact of the design change, verifies that the performance level has been maintained, and verifies that the design change can be effectively used by personnel. If the design change demonstrates performance

18-57 → enhancements and does not show an adverse impact, it may be implemented into the plant.

18.12.2.5 **Operational Focus Index Performance Indicators** ← 18-59

18-59 → An operational focus index is Performance indicators are used to trend performance of operator's day to day activities. Indicators are used to exhibit the level of performance and risk associated with different operational activities. The level of the indicator is based on operator performance for that activity (e.g., Red = Bad, Yellow = Caution, Normal = White, and Green = Good).

Operational activities include:

- Operator workarounds.
- Operator burdens.
- Control room correctives.
- Control room annunciations.
- Worker and maintenance tagouts greater than 90 days.
- Caution tagout greater than 90 days.
- Active fire protection impairment due to problem component.
- Corrective maintenance inventory.
- Plant elective maintenance inventory.
- Temporary modifications.

18-57 → Indicators are updated from this database periodically with a rolling average used to show trend. Adverse trends are entered into the corrective action program. Further analysis (e.g., root cause or operator interviews) may be required to understand the adverse trend and identify effective corrective actions.

18.12.2.6 **Probabilistic Risk Assessment**

Probabilistic risk assessment (PRA) models are used when plant or personnel performance can not be simulated, monitored, or measured. Performance data from modeled risk-significant HAs are used to evaluate the risk of the proposed design change on human performance during different operation modes. The U.S. EPR operator maintains the PRA model. After a design change, the PRA model is updated to reflect the new design. Risk-significant human actions are addressed through this monitoring program.

18.12.2.7 Overall Design Control Process

A design control process described in Section 4.5.1 of the U.S. EPR HFE Program Management Plan (Reference 2) controls the design, design changes, design verification, and analysis activities. A similar process is used by the U.S. EPR operator to control design changes. The process confirms that changes made to the design are adequate and accomplish the goal of the design change. The process also confirms that the design change does not result in adverse effects on personnel performance.

A substantial HSI design change is simulated on the simulator. Evaluation of human performance determines the anticipated impact of the design change, verifies that the performance level has been maintained, and verifies that the design change can be effectively used by personnel. If the design change demonstrates performance enhancements and does not show an adverse impact, it may be implemented into the plant.

18.12.2.8 Existing Plant Maintenance and Inspection Programs

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Additional plant programs are used to support human performance. Barriers, including the inservice inspection and inservice testing program and the maintenance rule, are used to prevent a negative impact on human performance. To maintain acceptable human performance, structures, systems, and components (SSC) must be maintained in proper working order. Routine testing and inspection of SSC is performed so that deficiencies are corrected before the SSC become ineffective or inoperable.

Operators require proper notification when an SSC is out of commission for maintenance or repair in order to maintain sufficient human performance. Use of an inoperable SSC could potentially be tracked as an error in human performance and indicate a false trend.

18.12.3 Results Summary

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HPM is continued throughout the life of the plant. It is expected that monitoring programs remain in place for the life of the plant. Reports summarizing human performance-related issues, resolution of those issues, implementation status, and operating experience results are maintained for trending purposes. Operating conditions determine the necessary frequency of these summary reports.

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A U.S. EPR operator shall maintain an HPM program which meets the intent given in this section. Documentation of HPM summarizes the following:

- Baseline human performance criteria established during V&V.
- HPM implementation strategy.