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(NUREG/CR-5705)

ORGANIZATIONAL FACTORS INFLUENCING IMPROVEMENTS IN NUCLEAR POWER PLANTS

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ABSTRACT

Nuclear power plants are complex organizational systems with a very demanding array of performance expectations. Among the most important expectations are that they be operated safely. Research reported here focuses on several safety-related performance indicators and seeks to identify the key organizational factors that influence those performance indicators over time. The present research builds upon organizational factors identified in NUREG/CR-5437, and begins to develop a theory of performance based on preliminary results in the earlier report that pointed toward the importance of learning and improvement.

A theory of safety-related performance and performance improvement in nuclear power plants is developed from economic and behavioral theories of the firm. Central to the theory are concepts of past performance, problem recognition, resource availability, resource allocation, and strategies that focus attention. Variables which reflect those concepts are combined in statistical models and tested for their ability to explain the Nuclear Regulatory Commission's performance indicators--scrams, safety system actuations, significant events, safety system failures, radiation exposure, and critical hours. Variables used in this research were restricted to those for which corresponding data for the population of commercial plants and their utility are publicly available. Results show that the past performance indicators differ with respect to the sets of variables which serve as the best predictors of future performance on any given indicator. However, across the performance indicators and across the various statistical models tested, past performance is the most consistent predictor of future performance on most indicators. In short, different performance indicators seem to have different profiles of predictor variables. A number of techniques and measures are used for the purpose of cross-validating the findings.

In addition, historic profit growth and commitment to nuclear power were separately studied as predictors of violations and reliability. Results show a curvilinear relationship over a five-year period.

Qualitative studies were undertaken in order to more fully understand the dynamics by which change in performance occurs over time, especially through processes of problem solving and learning. Based on reviews of NRC's plant diagnostic evaluations and seven site visits, suggestions are made regarding the need for the NRC to assess the level and quality of technical resources available, the abilities of the organization to deliver those resources where they are needed in the organization, effectively establish priorities among competing demands for resources, communicate and facilitate the flow of information, and involve a broad range of people throughout all phases of the learning process.

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ACKNOWLEDGEMENTS

The members of the team which performed this research wish to acknowledge the support and assistance of a number of colleagues and professionals who have made our work immeasurably better.

Our deepest debt of gratitude is to Joel Kramer and Erasmia Lois, who were NRC Program Managers for the project, and whose advice, technical feedback, and encouragement we always found rewarding to follow. Franklin Coffman of the U.S. NRC and Tom Ryan, previously with the NRC, were of great assistance throughout the project, providing critical reviews, offering suggestions that could expand the usefulness of the work, and linking us with other related projects and resource people, such as Carl Johnson, Steve Stern, Pat Baranowski, and Don Hickman of the NRC, and Jack Benson, of Niagara Mohawk Power. Other contractors of the NRC have also been very helpful with their comments and questions, especially personnel from Brookhaven National Laboratories, Scientific Applications International Corporation. UCLA, and .

We are also grateful for the absolutely terrific research assistance we received from graduate students, who served as colleagues in every way. May Nah Ho, Greg McAvoy, and Gordon Rands assisted us at the University of Minnesota. Mark Harris assisted at Wayne State University and Kathryn Baker assisted at Battelle. Specialized methodological consultation was contributed by Dr. Luke Tierney, University of Minnesota, and Dr. Kelly Price, Wayne State University. Some financial data were generously provided by COMPUSTAT. Sharon Genzler of the Strategic Management Research Center at the University of Minnesota provided all the administrative support for the entire project. That part, at least, could not have gone more smoothly, thanks to her.

Five nuclear power plants allowed us access to interview numerous personnel on site for research purposes. We are grateful to the executives who gave us the "go," and to each of the plant managers and personnel who gave us their time and their insights.

Despite all the contributions we gathered from others, shortcomings remain, and are solely our responsibility.

1.0 INTRODUCTION AND EXECUTIVE SUMMARY

1.1 Purpose of the Report

This report responds to a need of the U.S. Nuclear Regulatory Commission (NRC) to attempt to identify leading indicators of safety-related performance in nuclear power plants. The research reported in this technical report has focused on organizational factors as prospective sources of leading indicators. A broad-based and systematic approach to the research has been undertaken in order to respond to the stated NRC need.

The outcomes of this research are of three kinds. One, new knowledge has been discovered concerning organizational factors which influence safety-related performance over time, as well as knowledge that factors thought to have an influence apparently do not, at least in the models tested. Two, better understanding has been gained concerning how certain organizational factors combine in a dynamic way to influence improvement or degradation in performance. Three, practical tools which may be adapted for regulatory diagnostic purposes have been developed and tested through the project.

The NRC effort to develop leading indicators requires use of longitudinal data and the analysis of relationships over time. In support of that need, this project has developed theory, well-supported in the literature, concerning expected effects of organizational factors on safety-related performance over time, and has employed longitudinal data to test the theoretical ideas.

The fact that conditions in an industry are continually changing causes some to view historical data and longitudinal analyses with skepticism. However, if leading indicators or historical trends are to provide valid regulatory tools, they must be interpreted within the context of an explanatory theory of relationships that is robust over time. This explanatory theory and not the specific relationships discovered in a single time period are what is important. Longitudinal analyses are required to test the adequacy of the explanatory theory. Thus, this project has sought to develop and test a robust theory to meet the NRC needs. It is this theory that can be most useful to the NRC in pinpointing factors that have to be examined in more detail for their impact on the performance of nuclear power plants.

1.2 Description of Technology Employed and Its Applicability to the Problem

In this section the approach to the research need is described, and the way in which the outcomes might be used in the regulatory process is discussed. The approach consists of the development of an explanatory theory concerning expected relationships among organizational factors and safety-related performance outcomes in nuclear power plants. The theory is then used to guide a comprehensive set of empirical studies based on extensive data bases the research team has assembled, and qualitative studies designed to augment the data with information gathered from NRC diagnostic evaluations and structured interviews at plants.

The objective is to identify a set of concepts and measures (derived from the theory) which taken in combination will be useful guideposts or profiles for evaluating the safety performance of nuclear power plants. The statistical analysis undertaken in this report identifies important characteristics exhibited by the population of nuclear power plants. Individual power plants are not likely to conform to the population characteristics and thus these characteristics cannot be used to predict when individual plants will experience performance problems. However, the characteristics are useful for developing a set of diagnostic measures for use in evaluating and monitoring plant performance and anticipating problems that might arise in their safety performance. Such diagnostic techniques and strategies are further developed through the qualitative analysis of this research project.

1.2.1 Studies of Predictors of Selected NRC Performance Indicators

In NUREG/CR-5437 conceptualizations of safety from the perspectives of industry, academe, and the NRC are reviewed, and the use of NRC performance indicators for research purposes is supported as follows (NUREG/CR-5437, p.86):

> "In NRC's charter, safety is defined as the requirement to protect the public health, prevent accidents, and in case of accidents to minimize the consequences. Ultimate and final indications of lack of safety would be serious accidents, significant overexposure, and massive releases of radioactivity. So-called penultimate safety measures are concerned with conditions that would dramatically increase the likelihood of direct safety effects--substantial degradation of plant safety systems or excessive challenges to these systems, and exposures or releases that approach or exceed regulatory limits....In October 1986, based on the work done by the Interoffice Task Group (1986), NRC selected a group of safety indicators that had such desirable features as nonsusceptibility to manipulation and comparability between licensees...The logic model NRC used in developing these indicators...is concerned with low frequency of transients, high availability of safety systems, inherent design features, and low potential for cognitive errors."

The indicators the NRC selected for tracking include scrams, safety system actuations, significant events, safety system failures, and radiation exposure. As shown in NUREG/CR-5437, these indicators are the same or consistent with safety-related indicators suggested by INPO and previous academic research. Because of the properties they possess, the extent to which they are supported by theory and practice, and the availability of consistent, longitudinal data, these NRC performance indicators are used in large part in the empirical studies reported in this document.

In Chapter 3.0, empirical studies of predictors of five NRC performance indicators, along with a measure of efficiency (critical hours) are reported. Variables derived from the theory presented in Chapter 2.0 are combined into predictive models which are then tested for their ability to explain the six dependent variables. Each of the dependent variables is presumed to have a different profile of predictor variables, and indeed this is demonstrated by the results. The predictor variables (independent variables) represent the theory, which argues that future performance on any given performance indicator is explained by past performance on the indicator, NRC problem identification, resource availability, resource allocation, and utility-level strategy, (after controlling for production experience and type of reactor). The theory posits that performance in the past is likely to persist and thereby determine performance in the future. Improvement only occurs if the organization focuses its attention on its problems. To do so requires that problems are recognized, resources are available for problem solving, those resources are appropriately applied, and the utility's attention is focussed on nuclear power and not distracted by other strategic thrusts or initiatives.

The results of the studies of scrams, safety system actuations, significant events, safety system failures, radiation exposure and critical hours consist of the best explanatory models this theory and the available data can provide. The models provide statistically significant explanations of each of the dependent variables and overall provide support for the adequacy of the theory (see Figure 2.1). The models are subjected to further tests to evaluate their stability in a later period. These results are reported in Chapter 5.0. Except for significant events, the models remain statistically significant, though the significance of coefficients of parameters in the models vary. This suggests that the theory as a whole is robust, but individual variables will not be able to be used as reliable predictors.

The theory should suggest to the NRC that by systematically following measures that represent the concepts in the theory and being on the alert for additional more in-depth investigation when changes take place in the measures, it should be able to contribute to nuclear power plant safety performance. The concepts and some of the measures used to represent the concepts used in this study are found in Figure 1.1. In Appendix E, an interview guide is provided that can be used for following up on sudden changes in these measures.

1.2.2 Studies of Predictors of Reliability and Violations

In addition to the NRC performance indicators and critical hours, studies were also undertaken which use longitudinal data to determine if patterns of reliability and violations by nuclear power plants could be predicted using organizational factors measures.

In Chapter 4.0 a strategic variable (the parent utility's commitment to nuclear power) and a resource availability variable (prior profit growth) are used to predict reliability and violation rates for commercial nuclear power plants and their utilities. Reliability is considered important because a plant operating as designed is expected to evidence few safety shutdowns and operate without challenges to safety systems. In a continuous process operation, reliability also reflects the efficient use of resources (NUREG/CR 3215). Violations are issued when, in the judgment of the NRC, the utility has failed to maintain aspects of its planned defense-in-depth. As such it reflects the degree to which the utility conforms to regulatory requirements.

Figure 1.1
Concepts from the Theory and Associated
Measures Used in the Empirical Study

PLANT PERFORMANCE
NRC PIs

SCRAMS
Safety System Actuations
Significant Events
Safety System Failure
Collective Radiation Exposure

OTHER INDICATORS

Critical Hours
Reliability
Weighted Violations

UTILITY FINANCIAL PERFORMANCE

Return on Assets (ROA)
Debt to Equity (DEBT)
Return on Investors Capital (ROI)
Operating Efficiency (earnings before taxes as a percentage of total assets)

NUCLEAR POWER PLANT
PRODUCTION EXPERIENCE

Historic Megawatts Generation
(Age X Reactor Size X Historic Capacity Factor)

UTILITY BUSINESS STRATEGIES

Power Production (Sales For Resale/ Revenues From Net Generation)
Diversification (Equity in Earnings of Subsidiary Companies/Revenues from Net Generation)
Transmission & Distribution (Transmission & Distribution Plant Costs/Nuclear Power Plant Costs)
Grow and Build (Electric Construction Work in Progress)
Other Power Generation (Extent of Generation from Biomass, Fuel Cells, Geothermal, Solar, Waste, Wind and Wood)

NRC PROBLEM IDENTIFICATION

Minor Violations
Major Violations
Systematic Assessment of Licensee Performance (SALP)

UTILITY APPLICATION OF RESOURCES

Fixed Costs

- Plant Costs Per Megawatt Capacity
- Structure and Improvement Costs Per Megawatt Capacity

Variable Costs

- Production Expenses Per Megawatt Capacity
- Operations Supervision and Engineering Expenses Per Megawatt Capacity
- Maintenance Supervision and Engineering Expenses Per Megawatt Capacity

Staffing

- Total Number of Plant Personnel
- Plant Personnel in Operations and Maintenance

While important, neither of these estimates is considered to be an ultimate measure of safeness. For instance, plant reliability might be maintained at the expense of other aspects of safeness or low reliability might well reflect the fact that safety concerns were considered more important than continuous operation. While violations reflect aspects of defense-in-depth, the absence of violations should not be equated with safeness. Beyond their use as reflections of safeness, estimates of reliability and violations are also important on their own. Greater reliability may yield high economic returns to the utility while the number and types of violations also has economic consequences to the utility.

Results of the analyses show the importance of curvilinear relationships between profit growth by heavily committed and not heavily committed utilities in explaining violation and reliability rates at both a plant and utility level of analysis over a five-year period. These results provide further evidence of the role of financial performance, and provide a new finding regarding the potential importance of the strategic decision frame of executives. Both these and the earlier studies are potentially useful to regulators in compiling an advance profile of characteristics of plants and utilities that may require closer scrutiny.

In Chapter 5.0, the same method and independent variables are used to predict the NRC performance indicators. Interestingly, the indicators that were not predicted with as much significance and stability (significant events and safety system actuations) are better explained within the framework of Chapter 4.0.

1.2.3 Qualitative Studies of Learning and Improvement

A companion set of studies has been conducted for the purpose of augmenting the cross-sectional data for the population of commercial nuclear plants with detailed qualitative data gathered from NRC's diagnostic evaluations and our plant interviews at a selected group of plants. These data are useful for more deeply exploring some of the phenomena suggested by the pattern of quantitative results. In particular, these studies focus on processes of problem solving and learning as mechanisms for improvement in safety-related performance of the plants over time. These crucial processes have been suggested by results obtained in the present quantitative studies as well as preliminary results reported in NUREG/CR-5437.

The approach to understanding problem solving and learning has been to examine in detail seven Diagnostic Evaluations conducted by NRC's Office for the Analysis and Evaluation of Operational Data (AEOD) and our seven case studies using interviews and site visits at plants.

The qualitative studies help answer four questions related to NRC needs:

(1) the relationship between organizational learning and safety performance in nuclear power plants;
(2) the process of learning (what are its essential elements?);
(3) the factors that promote or inhibit organizational learning; and
(4) the factors NRC should look for in evaluating the ability of a plant to improve its level of safety performance through learning.

1.2.4 Sources of Data

As indicated previously, an extensive array of data have been assembled for the quantitative portions of the project. These data come from the entire population of privately owned US nuclear power plants for which financial data on the parent utility is available.

For the studies described in Section 1.2.1, complete data for the measured variables are available for 58 plants. Data on NRC performance indicators for 1985-1988 have been obtained from AEOD. The source of data on utility financial performance for 1985-1986 and resource allocation is the Department of Energy EIA (Energy Information Administration--DOE/EIA:Financial Statistics of Selected Electric Utilities).

For the studies described in Section 1.2.2, data to support profit growth calculations for 1975-1987 have been obtained from the COMPUSTAT Annual Utility data base through the cooperation of COMPUSTAT, which assisted for purposes of basic research. Reliability calculations on the total hours of operation of plants, have been provided by the NRC in NUREG-0020 (U.S.N.R.C., 1984, 1985, 1986, 1987, 1988). Commitment to nuclear power has been calculated based on data available in Department of Energy documents (D.O.E./E.I.A. 0095, 1984, 1985, 1986, 1987, 1988).

As previously indicated, sources of data for the qualitative studies are AEOD Diagnostic Evaluations for seven plants (Zion, Dresden, Palo Verde, Brunswick, Perry, McGuire, and Arkansas Nuclear One), and site visits to six commercial nuclear power plants and one Department of Energy research reactor. In the site visits a total of eighty-nine interviews were completed using a formal interview protocol.

1.3 Research Methods

1.3.1 Research Method for Studies of Predictors of NRC Performance Indicators

These studies are guided by theory developed for the project and reported in Chapter 2.0 of this Technical Report. The theory of safety-related performance in nuclear power plants is grounded in more general economic theory and in prominent behavioral theories of organizations. The theory is presented in propositional form, and the propositions are carefully grounded in the literature referenced in the chapter.

In explaining performance and improvement in performance on five NRC performance indicators and critical hours, the theory incorporates concepts of past performance, problem recognition, resource availability, resource application, and utility business strategy. The empirical studies are designed to test these concepts in a systematic analysis of performance and change in performance over time. Alternative variables representing the concepts in the theory are used in the analyses at different times for the purposes of testing the robustness of and validating the overall theory rather than testing specific measures of the concepts. The view held by the researchers is that adherence to particular measures is not as important as gaining a general understanding of the effects of the concepts which the measures represent.

Poisson regression models are used to develop predictive models of scrams, safety system actuations, significant events, and safety system failures. Poisson regression models are chosen because these performance indicators are event count data and they do not appear to conform to normality assumptions required for ordinary least squares models. Ordinary least squares regression models are used to construct predictive models of radiation exposure and critical hours.

Dependent variables in the models are the sums for 1987-1988 of each of the following performance measures - scrams, safety system actuations, significant events, safety system failures, radiation exposure, and critical hours. The independent variables are measures of past performance on the particular performance indicator for 1985-1986, problem identification (number of major violations and SALP scores in 1985), resource availability in 1985 and 1986, utility application of resources in terms of fixed costs and variable costs in 1985-1986, and utility business strategies (inferred from measures derived from financial data for 1984-1986). For all of the independent variables, lagged values are used. Correlation analyses using the same years for both the independent and dependent variables as opposed to lagged years, show only weak contemporaneous effects and are therefore not reported. In all of the models, controls are used for production experience and reactor type (boiling water reactor or pressurized water reactor).

1.3.2 Research Method for Studies of Reliability and Violations

Hierarchical multiple regression models have been built through sequential addition of control variables, main effects, curvilinear terms, linear interactions, and curvilinear interactions in order to explain the dependent variables of violations and reliability. Controls consist of region, reactor type, whether a utility has single or multiple plants, and plant age. The predictor variables in these analyses are the utility commitment to nuclear power, as measured by the ratio of utility nuclear power generating capacity to the total generating capacity of the utility, and utility profit growth over the previous five years. A logarithm is used to assess the multi-year profit growth rate, and it is subjected to a bootstrap methodology which is explained in detail, to obtain unbiased estimates of the mean and standard error of the distribution.

Hierarchical multiple regressions are reported for both the plant and utility levels of analyses, and for each of the years 1983-1987 and the averages across the five years on the dependent variables. For the violations dependent variable, a weighted violations measure has been constructed which represents a composite of levels one through five violations.

1.3.3 Research Methods for Qualitative Studies of Processes of Problem Solving and Learning

Sources of information for the qualitative studies are the seven AEOD Diagnostic Evaluations and a total of 89 interviews at six nuclear power plants and one DOE research reactor. The method employed for the review of Diagnostic Evaluations is abstracting from each of them any information associated with plant improvement programs, operating experience review programs, equipment performance and trending programs, root cause analysis, plant safety analysis review programs, and quality assurance programs directed at plant performance, including corrective action programs. Any additional information on any organizational factors specifically cited as contributing to the level of performance of the various learning-oriented programs also has been abstracted for later interpretation.

The method for case studies of the seven plants includes in-depth, on site interviews with corporate level and plant personnel. A formal interview protocol has been followed. At each site, 12 to 20 individuals have been interviewed, including plant management, the heads of major plant functions (e.g. operations, maintenance, engineering, QA), and individuals charged with responsibility for the major plant improvement programs (e.g. HPES, operating experience review, equipment history programs). All respondents have been guaranteed anonymity. The methodology includes review of plant documentation of improvement and operating experience assessment programs. The case studies are designed to get directly at the process of learning and the management strategies and organizational factors that either promoted or inhibited learning at the sites. Unlike diagnostic evaluations, the case studies tended to focus on average or better than average performing plants.

The information gathered is interpreted in light of a model of the learning process. The process consists of the subprocesses of problem recognition, problem diagnosis, solution formulation, solution implementation, resource allocation, assessment, and feedback. The information gathered is used to provide case study documentation of ways in which management and organizational factors influence the context of organizational learning.

1.4 Organization of the Report

The Technical Report proceeds from this Introduction to present in Chapter 2.0 a theory of nuclear power plant safety. The theory is rooted in economic and behavioral theories of organizations, both of which are thoroughly documented. The theoretical concepts set forth as predictors of safety-related performance are then tested in Chapter 3.0. In Chapter 3.0 models are built which provide statistically significant explanation of each of six performance measures--scrams, safety system actuations, significant events, safety system failures, radiation exposure, and critical hours. Chapter 4.0 reports tests of statistical models for violations and reliability, employing a different methodology--hierarchical multiple regression. Additional statistical analyses of the model in a later time period and evaluation of their stability are presented in Chapter 5.0. In Chapter 6.0 results are reported from qualitative studies undertaken to augment the quantitative data and expand the understanding of how management and organization factors influence the context and processes of learning. Conclusions from the entire research effort are presented in Chapter 7.0.

1.5 Summary of Conclusions

1. Central concepts in the theory of safety in nuclear power plants (Chapter 2.0), which have roots in economic and behavioral theories of organizations, are effective in predicting safety-related performance in plants. Furthermore, the patterns of results can be logically interpreted in light of the proposed theory. The central concepts of the theory combine in different ways across indicators such that:

*Past performance on a given performance indicator other things being equal, will persist and thus predict future performance.

*Improvement is more likely to occur when NRC problem identification plays a role, resources are available, the resources are allocated to a set of problem solving activities, and utility attention is not diverted by the pursuit of business strategies unrelated to nuclear production.

2. Different performance indicators have different sets of explanatory concepts which predict them. In these models, some are only predicted by their past performance, while others have fuller sets of predictors which explain improvements in operations. It is the sets of concepts (or "profiles") which are predictive and explanatory, and not the individual variables. The individual variables are merely representative of the broader concepts. The statistical analyses validate the broader theoretical model, not the individual measures.

3. The theory shows that plant performance is influenced by utility-level factors in addition to plant-level factors. Valid plant profiles must include such utility-level variables as financial condition, allocation of resources, and business-level strategies.

The sets of concepts, or profiles, taken together are robust and could serve as the basis for a set of diagnostic measures for evaluating nuclear power plant safety and alerting regulators to potential problems. The promise is in using the theory as a whole as a framework for tracking measures that represent the concepts.

If striking oscillations take place in the pattern of measures then the theory suggests that further investigation by NRC may be called for. For instance, aberrations in utility profitability, debt, and operating efficiency might call for additional NRC investigations about their impact on nuclear performance. So too, changes in resource allocation to classifications of expenses identified as supervision and engineering for operations and maintenance might require NRC assessment of impacts. If a utility decides to deemphasize nuclear operations by focussing on other business or power generation strategies, this should alert NRC. A combination of many changes at once mean a likely impact on nuclear power plant performance. NRC should question utility and plant staff about the ramifications of these changes for nuclear. How is the nuclear organization going to absorb utility-wide change? How is it going to adjust to it? What will be the likely impact on its performance? (A series of good questions to ask is found in Appendix E).

5. In the portion of this study which focused on explaining patterns of plant and utility violations and reliability rates, a curvilinear relationship was discovered with the predictors being degree of commitment to nuclear power generation and utility profit growth. These findings suggest that commitment to nuclear power generation coupled with utility profit growth combine to influence how executives frame their decisions about factors that influence plant performance. Certain combinations of commitment and profitability conditions produce what appear to be more risk-oriented decisions by utility executives. This finding, discussed fully in Chapter 4.0, warrants further investigation.

6. Organizational factors exert a clear and consistent influence over time on safety-related performance. The factors require a lag time to show influence, but once they do, inertial forces cause the influence to persist over time. Thus, plants get drawn into beneficent or vicious cycles from which they do not readily depart. When they do depart, for better or worse, it is due to changes in organizational factors described in the derived models in Chapter 3.0. Past performance on a given performance indicator is the most consistent predictor of future performance on that indicator.

→ is not useful as a leading [illegible] [illegible].

7. Improvement in safety-related performance can be obtained through management attention to processes of organizational learning and the context in which such learning processes occur. The findings correspond to the theory and models tested in Chapters 2.0 and 3.0, and allow considerable insight into how the organizational factors work together to produce improved performance. Specific contextual factors which seem most promising for management and the NRC to attend to, as reported in Chapter 6.0 are:

- The level and quality of technical resources available relative to the need for these resources
- The ability of the organization to deliver those resources to the other line organizations (e.g. operations and maintenance)
- The ability of the organization to allocate the technical resources to where they are most needed through a sound process of establishing priorities among competing demands
- The ability to communicate and facilitate the flow of appropriate information among and within departments, groups, and ranks in the organization
- The ability to involve all affected personnel in the definition of the problem and the development and implementation of solutions

Appendix E provides an example protocol for how the NRC can begin to assess plant capabilities in these areas.

2.0 ECONOMIC AND BEHAVIORAL PERSPECTIVES ON NUCLEAR POWER PLANT PERFORMANCE

In NUREG/CR-5437, a framework was proposed which links organization factors and nuclear power plant performance. The framework was developed by surveying and merging perspectives from industry, academe, and the NRC. Preliminary and limited tests of the model showed that it is a promising foundation for studying the role of organization factors in nuclear power plant performance.

The framework (NUREG/CR-5437) portrays, and the limited empirical testing confirmed, that nuclear power plants are complex entities affected by forces both inside and outside plant management's control that develop and exert an influence over time. The organizational factors presented in the framework point toward factors to look at, but they do not in themselves reveal how they may combine to create forces that influence nuclear power plant performance, nor do they tell how the forces work to influence performance. That is the task of theory development that is undertaken in this chapter.

The goal of developing theory is to provide understanding of how the forces that influence performance work, and through that understanding to gain useful knowledge which can be applied by regulators, corporate-level utility executives, and plant management personnel. Since nuclear power plants are complex systems, insights into how to manipulate single organizational factors may only be partially useful, in the long term, to regulators or managers. Therefore, the aim of this chapter is to develop a well-grounded theory of how known organizational factors may combine to influence safety performance in nuclear power plants.

Two well-established bodies of theory about firm behavior – economic and behavioral theories of the firm – are drawn upon to create a theory of how organizational factors combine to influence safety-related performance in nuclear power plants. Both economic and behavioral theory of the firm are general theories of organizations. Both have proved extraordinarily useful. However, they were not developed with nuclear power plants in mind. In this chapter the general theories are drawn upon and applied to nuclear power plants and in some instances to the utility level of analysis.

In economic theory (Panzar and Savage, 1989), safety is determined by:

*the ability of a producer <u>to afford</u> safety since safety is both desirable and costly;

*government <u>regulation</u> to account for a lack of safety incentives because of market defects such as imperfect information and limited liability; and

*firm <u>production decisions</u> such as allocating resources to different categories of fixed and variable costs (e.g. plant investment versus supervision and engineering costs).

The type of technology and the producer's cumulative experience with that technology also have an impact.

The body of theory known as "the behavioral theory of the firm," suggests that additional factors may affect safety including:

*the organization's past routines which reflect its accumulated skills and standard operating procedures; and
*its strategic choices.

Routines have a central place in the behavioral theory of the firm. The largest portion of organizational activity is determined by them (March and Simon, 1958; Cyert and March, 1963; and Nelson and Winter, 1982). Organizations respond habitually to common circumstances according to routines which unfold automatically at an inert level based on well-learned "scripts" (Weick, 1979; Leibenstein, 1976; Langer, 1978). The routines focus the organization's attention and allow it to operate in ways which have been learned from the past to be successful, given the goals. Limits on the ability to process information and solve problems afresh for each problem that arises make it impossible for organizations to function without them. On the other hand, the routines maintain current behavior, whether it is functional or not, and make change difficult to accomplish (Bromiley and Marcus, 1987). Thus, the organization's strategy choices are important since they channel attention to certain categories of activities within a constellation of competing claims for attention and may divest attention from other activities.

This chapter explores questions such as the following:

*To what extent is improvement likely to occur as a result of normal operating processes at nuclear power plants?

*To what extent are nuclear utilities able to overcome inertia and do better?

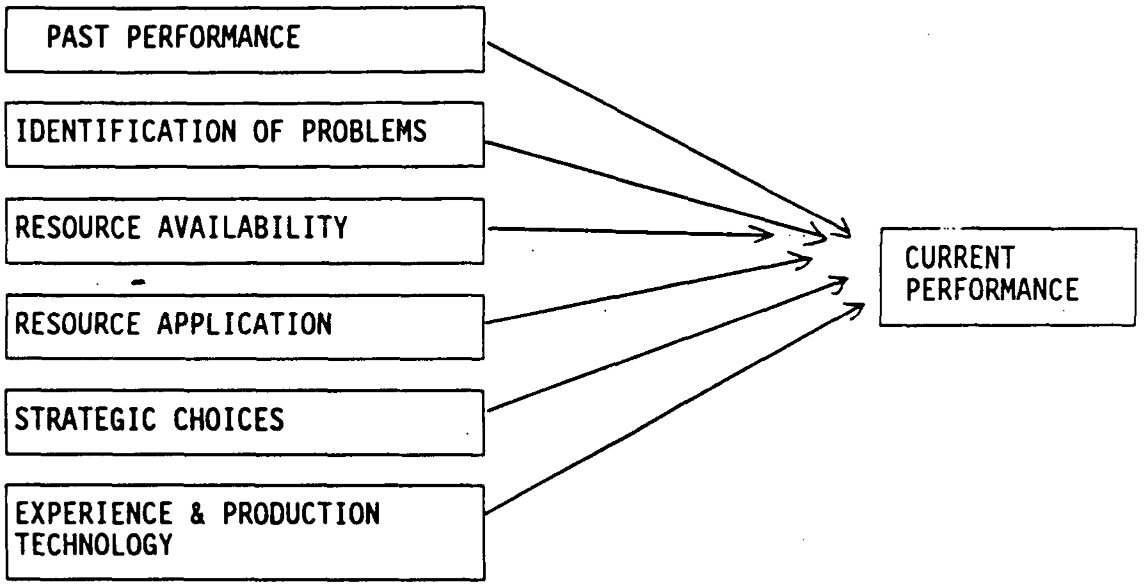
*What are the factors that stimulate this improvement?

In addressing these questions, elements from the economic and behavioral perspectives are combined in an integrated framework created to examine safety-related performance and change in performance at nuclear power plants. The integrated approach is tested using data from the industry.

This framework is illustrated in Figure 2.1. The basic premise is that inertia prevails (past performance determines future performance) unless the organization focuses its attention on its problems. The problems must be identified (here the role of the regulatory agency can be important). The organization must have the resources to address its problems (here the concept of being able to afford safety is important); and it must appropriately apply these resources toward resolving its problems (here the resource allocation and the strategic decisions it makes are important). Its experience and the production technology it uses set limits on the improvements it can make.

Figure 2.1

A Model of Improvement
Combining Economic and Behavioral Elements



Section 2.1 develops the economic perspective on safety and Section 2.2 the behavioral perspective. The combined model is presented in Section 2.3 along with an overview of the approach to testing and validating the combined model which is fully reported in Chapter 3.0.

2.1 The Economic Perspective

The economic perspective employs a utilitarian calculus. In the general theory it is assumed that safety is desirable but costly to achieve (Moses and Savage, 1990). The level of safety that is attained, therefore, is not the highest that is technically and humanly possible, but depends on the resources a utility has available to spend on safety.

PROPOSITION 1: The level of safety is related to the producer's ability to afford it.

Utilities choose a level of safety by balancing the benefits of accident reduction against the costs of safety improvements. In this utilitarian calculus, the costs of accident avoidance include more expensive maintenance, higher wages, additional training, and the acquisition of newer and more advanced equipment. The benefits of accident reduction include an enhanced public reputation, less onerous regulation, lower insurance costs, fewer liability suits, and less serious injury awards.

Utilities are subject to growing pressure from consumers to keep rates down (see Anderson, 1981; Gormley, 1983) as well as increased competition, since there has been substantial deregulation of many aspects of their operations (Moorhouse, 1986). Public utility commissions have given them incentives to maximize nuclear power production (NUREG/CR-4911). An example is Diablo Canyon's agreement with the California Public Utilities Commission. This agreement permits Pacific Gas and Electric (PG&E) to set rates at a level so that operation at 58 percent generating capacity allows it to break even. Above 58 percent generating capacity the utility makes money, but operating below this level yields losses. If the goals set by a PUC are not met, the profit margins of a utility go down, which may result in the utility having difficulty raising funds in debt and equity markets.

Financial pressures change the way utilities allocate resources to different categories of activities. For instance, when faced with financial pressures, utilities may decide to lower wages; or they may reduce training, either the initial training they give their employees or the career-long training they provide. Either way, lower wages and less training may translate into less experienced managers and a lower quality staff than previously. As talented employees try to leave the utility and find employment elsewhere, the rate of turnover increases. Morale suffers and commitment to the job among remaining staff goes down.

Another cycle leading to degradation when the utility is under financial pressure occurs when investments in maintenance are deferred, or not made at all. Also the utility may be less inclined to replace older, perhaps less safe equipment, with modern, improved equipment. It may decide to use the old equipment even if it has not been properly maintained, or it may fail to update the procedures that relate to the use of the equipment. These decisions may be made because of the pressures that come about because of limited resources.

Thus with fewer resources available, performance in vital-safety areas may degrade.

PROPOSITION 2: The level of safety is affected by the allocation of resources to different categories of activities.

2.1.1 The Need for Regulation

The economic assumption is that utilities select a level of safety which minimizes their costs. If they bear full responsibility for accidents, then markets would be efficient in choosing an appropriate level of safety to protect the public. However, because of a variety of defects with the operation of markets, the private incentives provided by the market are not sufficient to provide an adequate level of safety. Because of a divergence between the public and private incentives, government regulation is necessary.

PROPOSITION 3: The level of safety is affected by government regulation.

Under a system in which the producer was entirely liable for the costs of an accident, there would be strong incentives to operate plants safely. The incentives include avoiding the financial loss of the plant, the lost revenue from the plant's output, the impairment of the utility's ability to provide electrical service, and deterioration of its financial condition including the possibility of default. However, the utilities that operate nuclear power plants do not bear full financial responsibility for the failure of their plants.

A main source of the market defects that make regulation necessary (e.g. see Akerloff, 1970; Klein and Leffler, 1981; Shapiro, 1982; and Allen, 1984) is both imperfect information and the fact that utilities do not bear full responsibility for the costs of an accident.

- The utility knows more about the safety of its operations than the public which is at risk and consumes the power that is made. The public experiences differential risk and therefore is under different incentives to be informed and to demand adequate protection from the utility.

- Those providing insurance do not have proper incentives to become fully cognizant of the risks. Thus, there are facts known to the producer which are not known to the insurer. The producer has no incentive to provide these facts, and the insurer has no incentive to discover them.

Economists refer to these problems as adverse selection and moral hazard. Along with issues of limited liability these matters make markets less perfect than they should be in allocating risk.

Adverse Selection. With regard to the public, a small segment bears a disproportionate amount of the risk. Those most likely to be impacted by an accident are the people who live in the immediate vicinity of the plant. For these people (and for those who work at the plant) the incentive to become fully informed about the risks and to demand a high level of safety is great. However, other people enjoy the benefits of electricity without the same direct exposure to the risks. For these people, there may be less of an incentive to be fully informed and to demand a high level of safety.

Given that the provision of electricity is not carried out in fully competitive markets, the public in any event has no choice; even if it had better information it could not switch to a utility that offered more safety. In this respect, utilities are unlike businesses in other industries, which have incentives to maintain high levels of safety to avoid reputational consequences and losses of business in case of safety failures. Reputational and competitive gains from achieving lower risk are not as great as they would be in more competitive industries.

Moral Hazard. Since utilities are covered by insurance, they do not fully bear the costs of running unsafe plants. The holding of insurance reduces the desirable effects of a system of producer liability. The incentive to the insurers to be fully informed also is limited because of publicly guaranteed protection under the Price-Anderson Act. The government assures that the liabilities of nuclear utilities do not exceed a ceiling, and it provides part of the insurance to cover remaining damage claims at token fees:

> The nuclear industry is unique in the degree to which it is sheltered from damage claims in the event of a serious accident. Airlines and aircraft manufacturers face potentially great liability in the event of a crash; nuclear utilities...face a much smaller liability in relation to the size of potential damage claims (Wood, 1983; p. 15).

Should an accident take place beyond the insured limits, the government is likely to bailout the nuclear power company by providing the remaining compensation (McCracken, 1982). Ultimately, taxpayers, who have little capacity for evaluating the risks of nuclear power, and not private insurance companies, have to bear the responsibility for failure.

Limited Liability. There is another factor which limits utility liability. Under existing legal definitions shareholders can be held liable for no more than a company is worth. However, the costs of a serious nuclear accident easily could exceed the net worth of a nuclear utility (Wood, 1983).

The downside risks to shareholders in the event of the accident are limited, but they have the right to unlimited positive returns. Managers acting in behalf of shareholders therefore may have an incentive to increase risk taking, perhaps by reducing safety expenditures, in anticipation of the profits which are not affected by potential losses. Thus, the way that bankruptcy rules have been constructed (see Bulow and Shoven, 1978; and Golbe 1981) are another market defect which justify regulation. Since in the event of a serious accident the shareholders of a nuclear utility cannot lose as much as the public, the incentive of managers to guard against such an accident is not as great as the public's incentive to prevent it.

These reasons - adverse selection, moral hazard, and limited liability - are used to justify regulation. They are the rationale for the government's extensive safety and surveillance activities, for the safety rules and regulations in place, and the inspection and penalty policies created to assure compliance with these rules. However, the government, too, is restricted by the costs of carrying out these activities and by deficiencies in its capabilities. Its programs in the area of nuclear safety regulation, however extensive, are not perfect. They are not completely comprehensive. Gaps exist in what the government can do both because of resource and competency limitations.

2.1.2 Technological Experience

Another element in the economic theory is the relationship between experience and safety. Classic studies in manufacturing show that as production experience grows, learning increases and organizational performance improves. Producer skills rise with the accumulated knowledge about the physical equipment and the materials used in production. Productivity grows continuously with experience because of increasing organizational knowledge about the technology (Dutton et. al., 1984).

Many of the initial studies of learning in manufacturing were carried out in the American aviation industry where unit costs declined rapidly with cumulative output. Greenberg (1969) extended this type of analysis to safety contending that as organizations matured they would have fewer accidents. Prolonged experience with the hardware reveals information about performance and operating characteristics (See Rosenberg, 1982) that in turn should lead to new practices that increase safety.

PROPOSITION 4: The level of safety is affected by production experience with a technology.

However, why production experience is associated with better performance is not certain. Each basic process in manufacturing is supposed to have its own production function (Yelle, 1979), and no stable progress rate or universal progress function has been found. Learning may be a function of investment in a series of successively better capital goods, or it may come about simply because of increased technical know-how without changes in plants and facilities. Knowledge can penetrate the organization via improved capital goods, labor skills, materials, engineering, and managerial expertise. Separating the influence of these different factors is not easy.

2.1.3 Previous Tests of the Economic Model

According to economic theory, safety is a function of resource availability, resource allocation, government regulation, and production experience. Some of the efforts that have been made to test the economic model are traced and shown in Figure 2.2. Rose (1989) in her work on the airline industry emphasizes the importance of the resource availability variables (financial indicators), while Feinstein (1989) in his work on the nuclear power industry emphasizes the importance of regulatory enforcement. Both use cumulative production experience as a control variable. Marcus et. al. (NUREG/CR-5437) combine resource availability, regulatory enforcement, and production experience in models they test. However, none of these studies uses resource allocation. If the characteristic management activity is resource allocation, then all of these studies are deficient. Subsequent sections report on an approach that starts to include the missing resource allocation variables.

Financial Variables. Rose (1989) reviews previous efforts to study airline industry safety. Graham and Bowes (1979) examined maintenance expenditures and service complaints in addition to financial conditions, while Golbe (1986), assessed firm profitability. These studies failed to establish a strong link between financial conditions and accident rates.

To measure profitability, Rose uses operating margin – pretax returns to equity and interest payments over revenues. In some of her models she relies upon leverage (interest coverage) and liquidity (interest coverage ratio and working capital). In her examination of the relationship between financial performance and accident rates she controls for operating characteristics that describe variations in technology and the learning curve. A dummy variable has been created to take into account exposure to risky flying and weather conditions in international operations (differences in operating conditions); and a variable representing cumulative flight experience has been included to capture the idea that safety levels may rise with airline experience.

Rose uses lagged values of the independent variables to reduce potential simultaneity problems. The lagged values are appropriate since the impact of reduced profits and the other variables on accidents is unlikely to be immediate. Since safety cannot be observed directly, she relies on proxies for safety, including the number of accidents with actual injury and loss of human life and the number of incidents such as near mid-air collisions and runway incursions.

Poisson models are used in the analysis to determine the probability that a flight selected at random from a pool of available flights will be involved in an accident. The Poisson models establish the risk distribution that characterize the probability that a flight will be involved in a hazardous event. They recognize the infrequent and discrete nature of accidents and have been widely used in accident probability studies (Barnett et. al., 1979; Barnett and Higgins, 1987; and Golbe, 1986). The Poisson distribution treats the accident rate as an exponential function of the airline's financial and operating characteristics.

Figure 2.2

Past Tests of the Economic Theory

Industry	Resource Availability Variables	Resource Allocation Variables	Regulation Variables	Experience Variables	Sample Size	Analysis Method
Rose (1989) AIRLINES	YES	NO	NO	YES	all	POISSON
Feinstein (1989) NUCLEAR	YES	NO	YES	YES	17	POISSON
Marcus et. al. (1990) NUCLEAR	YES	NO	YES	YES	all	POLYNOMIAL DISTRIBUTED LAGS

Rose finds that lower profitability is related to higher accident and incident rates, particularly for small carriers. She admits that her models are deficient because she only accounts for resource availability, i.e. airline profitability, and not for the allocation of resources to such activities as maintenance, training, and operating procedures. Such important variables as safety investments in maintenance, equipment, and personnel are missing from her models. Variables that account for more frequent maintenance, newer equipment that embodies more advanced technology, and more experienced and better trained personnel should be in the models but are not. Rose simply assumes that more profitable airlines choose to spend more on maintenance and other safety enhancing activities, while less profitable carriers "cut corners" and do not make these expenditures.

Rose also fails to use regulatory variables – FAA inspection results and the number of citations and fines. These depend on the intensity of FAA enforcement activity which cannot detect all violations. Rose refers to resource allocation and regulation as safety inputs which are transformed into safety outcomes by the airlines, but the safety inputs are not in her analyses.

<u>Regulation</u>. Feinstein (1989), in a very interesting study, but one which only involves 17 nuclear power plants, notes that safety has the characteristics of a public good in that the utility incentive to ensure safety "may be less than is socially desirable" (p. 115). <u>Regulation</u> therefore is necessary to control the risks. Rather than looking at the relationship between regulation and safety, however, he first models the relationship between a series of independent variables and regulation (NRC violations). The number of violations is viewed as being a function of <u>financial status</u> (the level of resources which can be devoted to achieving compliance as measured by the power plant principal owner's bond rating); <u>past NRC sanctions</u> against a particular plant or the industry at large; <u>technology</u> (whether the plant is a pressurized or boiling water reactor); and <u>age</u> to control for "learning curve" effects.

Feinstein's hypothesis is that fewer resources lead to more violations. He tests this hypothesis using the Poisson model and finds that neither financial distress nor past NRC sanctions influence current noncompliance, however technology does He interprets this finding to mean that the heterogeneity among U.S. power plants, especially in comparison with other countries, may be an important factor in determining the level of safety of the industry.

<u>Financial and Regulatory Variables</u>. Marcus et. al. (NUREG/CR-5437) test a model that includes both <u>financial</u> (resource availability) and <u>regulatory</u> variables, but also does not have resource allocation variables. The financial variables are debt equity ratios and return on assets (ROA), and the regulatory variables, which are proxies for problem identification, are major violations and licensee event reports (LERs). A theory of learning is suggested, in which a utility: first, experiences critical events (violations and LERs) which enable it to identify problems; and second, must have the resources available (reflected by the debt to equity ratio and ROA) to correct these problems. Thus, Marcus et. al. hypothesize that more past safety

violations and LERs and higher past debt/equity ratios and ROA are related to fewer future safety incidents.

In each of these studies, safety incidents are measured by scrams, significant events, forced outages, safety system actuations, and safety system failures. Later, some of the reasons these indicators have been used as well as some of their limitations are discussed.

Notice, that unlike Feinstein (1989), Marcus et. al. (NUREG/CR-5437) maintain that intense regulatory enforcement, coupled with adequate utility resources, should result in fewer safety incidents and not more as in Feinstein's models. Enforcement leads to problem correction, not simply problem identification. Another difference between Marcus et. al. and Feinstein is that Marcus et. al. use available data from all nuclear power plants, not a restricted sample of plants from two NRC regions. Moreover, Marcus et. al. control for more variables than Feinstein. There are controls for utility experience with the technology by including in the models the age of the plants and number of plants a utility has; for production technology by comparing Babcock and Wilcox, Combustion Engineering, and Westinghouse plants, which are PWRs, with GE plants which are BWRs;[1] for NRC region, and for plant size (net megawatt capacity).

Unfortunately, Marcus et. al. do not rely on the Poisson models that Rose and Feinstein use, although these are likely to be more accurate when dealing with infrequent events. (The means of the annual occurrence of scrams, safety system actuations, significant events, and safety system failures range from 1.84 to 3.76 in the 1985-87 period that is examined.) While not using the Poisson distribution, Marcus et. al. try to capture the lagged structure of these occurrences. Their analyses use the polynomial distributed lag function to test for the effects of five previous years (1981 through 1985) of major violations, LERs, debt to equity ratio, and return on assets (ROA) on 1985-87 performance of nuclear power plants on NRC's performance indicators.

As reported in NUREG/CR-5437, the polynomial distributed lag function provides explanation for a large amount of the variance for scrams (adjusted R squared of .79) and fairly good results for significant events (adjusted R squared of .29), but not for safety system actuations (adjusted R squared of .12) or safety system failures (adjusted R squared of .13). Fewer scrams in 1985-87 are associated with more major violations in 1984 and 1985, more LERs in 1982, higher debt to equity ratios in 1982, 1983, and 1984, and more profitability (ROA) in 1982, 1983, and 1984. Fewer significant events (1985-87) are associated with more LERs in 1982 and 1983, higher debt to equity ratios in 1982 and 1983, and more profitability (ROA) in 1982, 1983, and 1984. These results conform to the learning theory proposed. They suggest that problem identification variables (violations and LERs) and financial variables (debt/equity and ROA) have a lagged effect on some safety measures. Nuclear power plants need to have problems identified (via regulation) and need to

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[1] Samantha et. al. (1988) discovered that different reactor designs had different sensitivities to operator error. Babcock and Wilcox reactors were more sensitive to this type of error than the reactors of other suppliers.

have the resources available to do something about these problems (measured here by debt/equity ratios and profitability) to have fewer scrams and significant events.[2]

However, polynomial distributed lag functions with such a large number of independent variables and so few total observations (only 48 for scrams and 67 for significant events) are highly unstable. They are sensitive to the fine-tuning of the polynomial (should it be a first, second, or third order polynomial?), and to changes in the time period and to the variables in the model.[3] Given these characteristics, it would not be surprising that if one changed the years examined the results would be different. The results in Marcus et. al. (NUREG/CR-5437), though they suggest that a combination of financial and regulatory variables play a role in determining safety performance, have to be viewed with caution and are preliminary in nature.

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[2] A number of the control variables are significantly related to the dependent variables in the studies reported in NUREG/CR-5437. Control variables that are significantly related to scrams are region (fewer scrams in the South and Midwest), age (fewer scrams as plants age), and number of plants (more scrams with more plants in a given utility). Region is significantly related to significant events (fewer significant events in the South and Midwest).

[3] A first order polynomial is a straight line relationship like that which is found in ordinary regressions. A second order polynomial traces a parabola that opens either upward (positive intercept) or downward (negative intercept). It has a single squared item. Third order and higher polynomials model simultaneously more than one reversal in curvature and have more than one squared item. They appear as waves (i.e. a series of parabolas) with troughs and peaks depending upon the investigator's assumptions.

Pindyck and Rubinfeld in their econometrics text (1981; p. 238) state: "The choice of length of lag depends more on the nature of the problem being specified so that useful rules of thumb are not available. In practice it is common for researchers to vary the degree of the polynomial, the length of the lag, and the endpoint restrictions." Ramanathan (1989) in his econometrics text gives an example of a controversy in economics about the lagged effects of monetary (money supply) and fiscal policy (government receipts and expenditures) on GNP. The investigators used different forms of polynomial distributed lags and the results vary suggesting that polynomial distributed lags are very sensitive to small changes in investigators' assumptions. Cassidy (1981; p. 51) in his book on econometrics cautions about the use of polynomials: "the interpretation of the individual regression coefficients become difficult...For example, the slope of the third degree polynomial may be positive...then negative, and then positive again." Later (p. 68), he writes, "the resulting PDL (polynomial distributed lag) estimates have an element of arbitrariness to them." He (p.1) advises taking "great care" in the development of "one's priors to insure that the functional form will achieve exactly what is intended and no more."

2.1.4 Graphical Evidence for Factors Drawn from Economic Theory

Rose (1984) emphasizes resource availability variables, Feinstein (1989) problem identification variables, and Marcus et. al. (NUREG/CR-5437) both types, but missing from these analyses are the resource allocation variables. To be more complete, the theory should incorporate the concept of resource allocation, which could be represented by a number of different variables. Incorporating the concept brings recognition to the fact that it is not simply a matter of problems being identified and resources being available but it is how these resources are allocated that influences safety. After all, if resources are available managers can allocate them to many things, including more managerial perks, which should have no influence on safety. An important missing element from the existing economic studies is the allocation of resources. These variables are found in none of the studies.

Exploratory graphical analyses, therefore, have been carried out as part of the present research to examine this potential deficiency in previous work. The graphs permit a reassessment of the role of the resource availability and problem identification variables in light of the instability of the polynomial distributed lag model, and the inclusion of specific resource allocation variables. They serve as a preliminary test of the organizational factors derived from economic theory.

The graphical analyses proceeded by comparing the performance of a set of "best" plants on NRC's performance indicators with the performance of "average" and "weak" plants (see Dervis and Petri, 1986 for a similar use of graphical analyses to compare the economic performance of developing countries). The purpose of the exploratory graphical analyses was to observe whether the best and poorest plants on various performance indicators also showed systematic differences in resource availability, resource allocation, and problem identification measures. Details of the analyses and the graphs themselves are shown in Appendix A.

2.1.5 A Summary: Vicious and Beneficent Cycles

A summary of the graphical analyses is found in Table 2.1. The summary suggests the existence of vicious and beneficent cycles. Poor performers have less profit and more debt and are cited for more major and minor violations in the prior period. In the next period they have to spend more to operate and maintain their nuclear power plants - which in turn may mean less profitability and more debt in the following period. Good performers, on the other hand, have more profit and less debt and are cited less for major and minor violations in the prior period. In the next period they have to spend less to operate and maintain their nuclear power plants - which in turn may mean more profit and less debt in the following period.

The cycles of poor and good performance suggest that nuclear power plants are inertial systems which are hard to change. In inertial systems what brings about change? How can the poor performers be extracted from the cycle of poor performance, and what would indicate that the performance of plants with good records was degrading? These are the types of questions taken up next in this chapter.

Table 2.1
The Graphical Evidence: A Summary

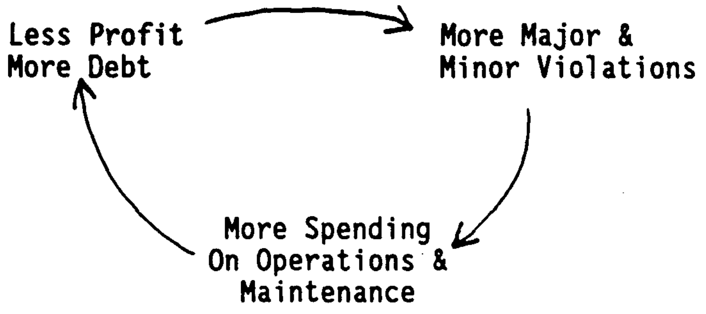
	1980-85				1985-89		
	Resource Availability		Problem Identification		Resource Application		
1985-89	ROA	Debt	Major	Minor	O&M	Op.	Main.
SCRAMS	+*	+	-	-	+	+	+
SSA	-	+*	-*	+*	+	+	+
SIG.EVTS	-	+	+*	+	+	+	+
SSF	-	0	+	+	+	+	+
RAD	-	+	+	+	+	+	+
CRIT HRS.	+	-	-	-	-	-	-

+ indicates a positive pattern of relationship between the performance indicator and the predictor variables;

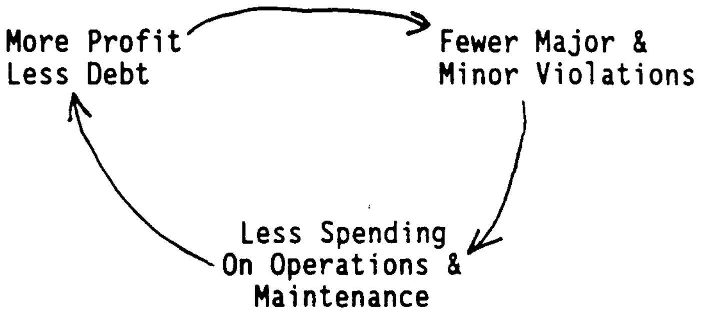
- indicates a negative pattern of relationship

*qualified by the observation that one or two years show exceptions to the pattern

The Vicious Cycle of the Poor Performing Plants



The Beneficent Cycle of the Good Performing Plants



In ending this section, it is necessary to reiterate that the type of graphical analyses reported here have many limitations. First, they involve no statistical tests of whether the differences between the high, medium, and low performing plants are significant. Second, they do not include all the relevant variables in a single model which tests for the combined significance of the variables; thus, they do not control for the presence of other variables that may have a significant effect on the outcomes. Third, the complete set of items that can be used to represent the variable categories – resource availability, regulation, and resource application has not been exhausted. All relevant variables which represent the categories have not been used. Thus, while suggestive, the graphical analysis reported here only provides circumstantial evidence about the relationships between resource availability, regulation, expenditures, and performance. The conclusions are tentative.

This section has developed several propositions and referred to data examined graphically (see Appendix A) in a manner consistent with an economic view of the utility and plant. In the next section, the behavioral theory of the firm is explored and the emerging theory of safety in nuclear power plants is elaborated more fully.

2.2 The Behavioral Perspective

So far economic theory has been used to explain performance in a given time period, but has not dealt with change and improvement across time periods. The analyses have not consistently considered the effects of past performance (an exception is Feinstein). Therefore, they have not addressed more dynamic factors associated with change and improvement. How do some plants, given an existing level of performance, either improve or degrade? Why does performance get better or worse? To move to a more dynamic concept of performance, it is necessary to incorporate insights from behavioral theory. Behavioral theory in general and more specifically the behavioral theory of the firm emphasizes the inertia of organizational systems and the difficulties of overcoming this inertia in making improvements.

Although it has been difficult to reduce economic theory to a few simple hypotheses, the effort to do so has been made to simplify the analysis and to use the available data in a productive manner. It is probably more difficult to reduce behavioral theories to a few simple ideas.[4] There are different

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[4] A complete review of behavioral theories of firm's is beyond the bounds of what can be attempted here. Some important references are Cyert and March (1963), Thompson (1967), Miles and Snow (1978), Pfeffer and Salancik (1978), Nelson and Winter (1982), and Andrews (1987). Cyert and March (1963) were the original formulators of the behavioral theory of firms. Their focus mainly was on what happened inside a firm. Thompson (1967) had a more open system's perspective in which a firm was vulnerable to outside influences and in which it tried to protect ("buffer") its core technology. Pfeffer and Salancik (1978) discuss exchanges between a firm and its environment in their work on resource dependency theory. Andrews (1987) and Miles and Snow (1978) were among the initiators of the business strategy perspective which may be viewed

versions of the behavioral theory and not everything in the different versions can be covered. What is offered here is a partial rendering based mainly on Cyert and March (1963) and Nelson and Winter (1982) that emphasizes: sequential attention to goals; the importance of an organization's past performance in limiting the improvements it can make; the focusing of attention on particular areas by the organization as a result of the strategic choices it makes (whether by intention and volition or inadvertently and unconsciously through a progression of small organizational choices); and the role of problem recognition, resource availability, and resource application in a theory of organizational learning. The behavioral view does not abandon concepts that are part of the economic perspective, rather it refashions the economist's use of these concepts, adds new elements, and address change over time.

2.2.1 Sequential Attention to Goals

According to the behavioral perspective, an organization is faced with a number of goals, not just a single profit-making goal as in the economic perspective. Further, decision makers in the organization pay attention to goals sequentially, seeking only to "satisfice" (achieve an acceptable level) on a goal before moving on to another (March and Simon, 1963). Decision makers do not deal with inconsistencies between goals by making explicit trade-offs. For the economist, these explicit trade-offs are necessary, but for the behavioral theorist they are not. The behavioral perspective assumes that organizations operate with a large set of unrationalized goals. The disparate demands facing the organization form a set of "independent constraints." The organization's goals are not highly correlated.

PROPOSITION 5: Performance indicators do not form a single, highly correlated dimension.

There are a number of reasons why goals form a set of independent constraints and are not highly correlated. The first is the division of labor in organizational decision making. The organization is a coalition of subgroups where different problems are addressed and decisions made by different sub-units. The degree of overall coordination may be small. A kind of "local rationality" exists in which problems are factored into subproblems that are parceled out to separate units, each of which sees the problem primarily in terms of its own goal. For instance, for the safety engineers in a typical manufacturing facility, safety is an important goal, but for the marketing or sales divisions, it is a matter of peripheral concern, competing with other matters such as price and design.

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as an extension and revision of the behavioral theory. Clearly, what is being attempted here is in no sense a comprehensive development of either the economic or behavioral approaches. For a good comparison of the use of such alternative paradigms in the examination of organizational decision making, see Allison (1971).

The second reason that goals form a set of independent constraints is that organizations resolve potential conflict by attending to goals one at a time, only seeking to "satisfice" on the goal before attending to others. They do not confront conflicting objectives simultaneously. The time buffer allows them to resolve each problem separately. It reduces the need to deal with apparent inconsistencies between goals. Through the mechanisms of sequential attention and satisficing, conflicts need be only partially resolved and the organization can exist with considerable latent goal conflict. Therefore, different sets of antecedents are likely to influence different performance indicators differently.

2.2.1.1 An Empirical Test: Factor Analysis of the Performance Indicators

As the behavioral theory of firms suggests, performance indicators would not be expected to form a single safety dimension. To test this implication of the behavioral theory, factor analysis has been conducted on the performance indicators. It also should be noted that independence was an NRC requirement when the PIs first were selected. The PIs were intentionally selected to measure different aspects of safety. Does the analysis show that they indeed are independent?

Five of the performance indicators listed below have been analyzed:

1) Scrams = SCRM
2) Safety System Actuations = SSA
3) Significant Events = SE
4) Safety System Failure = SSF
5) Collective Radiation Exposure = RAD

A summary of the results in shown in Table 2.2

At first glance there seem to be two factors. The "A" factor, that is the occurrence of scrams and the actuation of safety systems, may be interpreted as frequency of plant challenges; these are accident initiating circumstances. In the "B" factor, safety system failures may be interpreted as representing the ability of the plant to respond to these challenges. Radiation exposure, on the other hand, also in the "B" factor, measures occupational exposure under normal operating conditions. The close relationship between safety system failures and radiation exposure suggests that occupational safety and public health may be related.

Since both safety system failures (the "B" factor) and scrams (the "A" factor) are considered when the NRC designates an incident significant, it makes sense that significant events should shift between categories. This performance indicator indeed floats between factor "A" and factor "B." Safety system actuations load on factors "A" in individual years, but on factors "B" in the span 1985-89.

However, the factors are not stable from year to year, as a comparison of the columns shows. By 1989, safety system actuations no longer aligns with scrams. In the totals for the five year data, scrams stand alone.

Table 2.2
Factor Analysis and Correlation Matrix: Five Performance Indicators

1985

	FACTOR A	FACTOR B	Communality[1]
SCRAM	.76	-.17	.61
SSA	.67	.28	.52
SE	.71	.45	.71
SSF	-.23	.77	.64
RAD	-.28	.68	.54

N= 76

1986

	FACTOR A	FACTOR B	Communality
SCRAM	.88	-.07	.78
SSA	.40	.32	.26
SE	.41	.65	.60
SSF	-.25	.79	.69
RAD	.16	.67	.48

N= 83

1987

	FACTOR A	FACTOR B	Communality
SCRAM	.78	-.13	.62
SSA	.72	.09	.52
SE	.21	.56	.36
SSF	-.03	.73	.54
RAD	-.25	.66	.49

N= 93

1988

	FACTOR A	FACTOR B	Communality
SCRAM	.84	-.07	.72
SSA	.74	.06	.56
SE	.03	.77	.58
SSF	.19	.79	.66
RAD	-.24	.68	.53

N= 97

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[1] The communality is the amount of variance in the performance indicators explained by the two factors.

Table 2.2 (continued)
Factor Analysis and Correlation Matrix:
Five Performance Indicators

1989

	FACTOR A	FACTOR B	Communality
SCRAM	.75	-.17	.60
SSA	.75	.22	.62
SE	.28	.76	.66
SSF	-.09	.81	.67
RAD	.39	.10	.16

N= 104

1985-1989

	FACTOR A	FACTOR B	Communality
SCRAM	.92	.02	.85
SSA	.25	.57	.39
SE	.33	.62	.50
SSF	-.22	.76	.64
RAD	.01	.76	.58

N= 72

Correlation 1985-1989

	SCRM	SSA	SE	SSF	RAD
SCRM	1.0				
SSA	.09	1.0			
SE	.15	.18	1.0		
SSF	.00	.22	.26	1.0	
RAD	.10	.26	.31	.44	1.0

n=72

The correlation matrix of the variables for the five year period is also presented in the table. None of the variables is very highly correlated (>.5) with any of the other variables. Thus, as the NRC intended, the five indicators seem to represent distinct safety dimensions. Pursuit of one safety goal does not appear to be highly related to the pursuit of other safety goal. Each performance indicator, therefore, should have a different set of predictors, a different profile of factors that are associated with its improvement or degradation. The testing of this implication, that the indicators have different determinants, is carried out in the next chapter. An additional factor analysis was attempted on six enforcement measures with substantially the same result. The factor analysis is reported in Appendix B.

2.2.1.2 Conclusions

The attempt to factor analyze the NRC performance indicators goes to the heart of the debate about what is safety in nuclear power plants. Multiple indicators are used by the NRC, the industry, and INPO, and it is further argued in NUREG/CR-5437 that multiple "intermediate conditions" lead to penultimate safety. These findings from the factor analyses, showing that the performance indicators do not collapse into stable factors, and lack of correlations among performance indicators are further evidence of the wisdom of using a multi-indicator approach to managing and regulating.

For purposes of the present study, the results of the factor analyses have several immediate implications:

1. The performance indicators must be analyzed separately, that is, treated as separate dependent variables;

2. It is likely that organizational factors will show different relationships with different performance indicators;

3. Different "profiles," or combinations of organizational factors will be associated with different performance indicators;

4. Relationships of specific organizational factors and performance indicators may be somewhat unstable over time, thus arguing for focusing attention on broad concepts that may be measured in different ways so that the robustness of the concepts may be tested.

The empirical studies reported in Chapters 3.0 and 4.0 are conducted with these implications in mind.

2.2.2 The Past As Determinant of Current Behavior

The behavioral theory predicts that organizational performance in a particular time period is likely to be influenced by performance in the past time period. As Nelson and Winter (1982; p. 10) state, "the regularities observable in present reality are...the result (of) understandable dynamic processes..produced from known...conditions in the past." Since the conditions of an industry in a prior period bear the seeds of what it is going to do in the next period (p.19), by considering what an organization has done in the past it is possible to sharpen predictions about what it is to do in the future (p. 89).

PROPOSITION 6: The current level of safety is influenced by the organization's past safety performance.

Behavioral theorists view human rationality as being constrained by information processing limitations. The problems that managers confront are too complex for them to comprehend in their entirety. Thus, managers cannot optimize in a way that economists define optimization – based on a universal consideration of alternatives, complete knowledge, and freedom from organizational constraints to make decisions; rather, relatively simple and straightforward rules based on the past guide most managerial actions (Simon, 1959, 1965). Since rationality is bounded and choices driven by past rules and since multiple conflicting goals are usually present, managers "satisfice" rather than maximize. Aspiration levels set by the past substantially determine the goals of current activities.

The rules which establish an organization's predictable behavior cover a vast array of activity. There are rules for task performance, for regular record-keeping and reporting, and for the handling of information generated inside and outside the organization ("routing" and "filtering" rules; see March and Simon, 1963). The predictable behavior patterns and routines that guide behavior range from the well specified technical routines that enable production to take place, to the procedures in place in the organization for hiring and firing workers and for stepping up production in the case of increased demand (Nelson and Winter, 1982). The rules extend to the organization's schedules, plans, and precedents. They include tacit programs, scripts, rules of thumb, and appropriate sequences of actions for a wide variety of contingencies. They also involve the policies the organization has regarding investment, research and development, and marketing.

In any contingency the organization faces there is likely to be a stereotypical way of behaving that is based on the organization's past rules and precedents. A particular individual in the organization may not be conscious of following these rules (Nelson and Winter, 1982). That person may be unable to clearly articulate them or may not even completely understand the rules employed; nonetheless, the rules have a powerful influence on what the person does. In this sense, the rules are tacit rather than explicit. They are the persistent features of the organization that make predictable behavior patterns possible.[5]

Tomorrow's behavior, according to this view, is largely generated from past activities which are regular, predictable, and constant. A reliance on rules, which are designed to control behavior and limit discretion, is especially noticeable in the nuclear industry, where it is necessary to prevent severe accidents by imposing uniform behavior patterns. In an industry

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[5] Nelson and Winter compare them to genes.

where mistakes can be catastrophic, the place for unpredictable, novel actions has to be limited. The industry and NRC have created a vast number of rules and procedures for which every effort is expended to obtain compliance. Employees learn to conform through formal sanctions and informal means instituted via the processes of recruitment, socialization, and training. Thus, as nuclear power plants have been designed intentionally to enhance predictability via rules and their scrupulous observance, the expectation is that the influence of these rules would carry forward from one period to the next.

2.2.3 Focusing Attention

The behavioral approach emphasizes that well-defined routines structure a large part of the organization's behavior. These routines go further than ordinary production techniques which are affected by the machinery in use and extend to: such "low order" decision rules or procedures as to how to handle a request made by an operations unit to fix a component or system; and such "high order" decision rules or policies about what type of additional increments of power (coal, nuclear, or other alternatives) should be added to the organization.

Nelson and Winter (1982) place in the category of an organization's rules the strategies it adopts. These strategies focus its attention. They structure both consciously and unconsciously its actions by (March and Olsen, 1976):

*having it pay attention to certain problems and diverting its attention from others;

*providing guidance on how to allocate scarce time;

*giving instructions about what to do (a sense of priorities about what is immediate, specific, operational, and required, and what can be ignored because it is distant, general, and not very important);

*regulating the flow of problems and solutions;

*establishing explicit measurable criteria to evaluate behavior.

Since many demands are made on the organization and it cannot pay attention to them all, the organization's strategies transfer demands among possible sets of active, inactive, and unconsidered activities (Cyert and March, 1963).

PROPOSITION 7: The level of safety is affected by the organization's attention focusing strategies.

An empirical study of this relationship is Osborn and Jackson's (1988) study which examines the effects of utility power generation strategies on the performance of nuclear power plants. They assess the impact of utility investment in nuclear technology on plant safety and reliability, hypothesizing that utilities that have chosen to be highly committed to nuclear power should be more willing, and able, to safely manage their plants. The commitment to nuclear power should be linked to a willingness to initiate new safety programs, to study safety issues, and to develop new employee training programs. Their results, however, do not bear this out. In fact, the opposite is true. In Chapter 4.0, their analysis is updated and expanded with a larger data set from a later point in time.

However, many changes have taken place in the nuclear industry which put into question this commitment to nuclear power (See Fenn, 1983; Russo, 1989; McCormick, 1986; Navarro, 1985; Anderson, 1981; Hyman and Habicht, 1986; and Joskow 1988). The pressures and uncertainties to which this industry has been subject have forced it to reexamine numerous assumptions which previously governed its behavior. The main strategy the electric power industry followed in the post World War Two period was to "grow and build" (Fenn, 1983). During this period, demand increased rapidly and new construction was needed to meet growing demand. New construction yielded economies of scale, greater efficiencies, and declining marginal costs. Public utility commissions lowered prices which stimulated additional demand. The utilities were required by law to meet customer demand. As a regulated natural monopoly, they had an obligation to serve. As long as prices were falling, demand continued to rise and additional construction was necessary. If the industry was earning its allowed rate of return, the only way to increase profits was to expand the rate base by building new plants and equipment (the so-called Averch-Johnson effect).

The period of industry growth came to an end in the 1970s. Numerous forces came together to force a re-evaluation of the prior strategy. In briefest form the effect of these forces can be seen in the industry's deteriorating financial condition.[6] Conditions in the industry's external

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[6] The deterioration can be summarized with reference to the following observations:
1) Fuel prices escalated including the weighted average costs of all fossil fuels (oil, coal, and natural gas) and the spot market price of uranium oxide.
2) Economic growth rates slowed.
3) Operating and maintenance costs, including the costs of labor, supplies and material, and administrative expenses went up, leading to higher costs per unit of capacity (higher costs per kwh).
4) The price of electricity went up.
5) Sales growth rates declined.
6) Interest rates escalated, and inflation rates accelerated.
7) The cost of capital and the yield on bonds grew.
8) Construction costs rose.
9) Nuclear power plant and coal power plant capital costs increased.
10) The average cost of new generating capacity and installed capacity per kwh went up.
11) Net earnings, earnings per share, and revenues per kwh were down, and long term debt escalated.
12) New long term bonds and stock had to be issued and short term bank loans made.
13) Interest coverage ratios and credit ratings declined.

environment exacerbated the financial stress. Many people came to believe that coal and nuclear power plants were a threat to the environment, that new options had to be developed, and that conservation was important. Perhaps the greatest change took place in the electric power companies' relationship to the public utility commissions. This once friendly relationship deteriorated under the onslaught of the other changes that were taking place. The main issue that the commissions had to confront was how to hold rate increases to a minimum in a period of generally rising prices when utility costs were growing and utility abilities to keep up with these escalating costs were shrinking.[7]

In response to these changes, the grow and build strategy no longer was tenable. Different segments in the industry followed different courses based on divergent perceptions of where these trends would lead and what the future would bring:

> Alternative Power Generation. In areas of rapidly growing energy demand where the regulatory climate discouraged nuclear and coal plant construction, utilities might have no option but to explore alternative energy options. In these utilities there was a movement toward the use of renewable energy. They positioned themselves as contracting agents and energy brokers shifting the risk for developing new capacity to third parties. They increasingly used outside entrepreneurs for the addition of small modular units of capacity. Small increments in capacity were added as needed. These increments might be in the form of wind, geothermal, fuel cells, hydro, biomass, cogeneration, conservation, and different forms of load management. The addition of small increments provided the flexibility of short lead times and greater responsiveness to changes in demand compared to nuclear and coal construction.
>
> Modified Grow and Build. A number of utilities pursued a modified grow and build strategy based on the perception that economic growth would continue and that conservation and renewable energy would not be able to handle the increased demand. They had little faith in conservation or alternative energy sources. Instead, they maintained a strong emphasis on constructing new electrical generating facilities and on maintaining intact their existing production capabilities. Their intent was not only to supply their own users, but to sell power to other utilities in deregulated

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14) Surplus generating capacity increased.
15) Major generating units were canceled and capital appropriations cut back.

[7] The industry argued that short run rate suppression would only lead to higher costs in the long run as the utilities would be unprepared to meet rising energy demand when economic recovery arrived. Many commissions gave the utilities allowances for funds used during construction (AFUDC). AFUDC created paper earnings in that these non-cash accounting entries credit net income with imputed returns on funds tied up in new construction. AFUDC became a component of utility earnings when actual internal cash flow per construction outlay was declining.

markets where the profits would be very high, as they believed they could amass excess production capacity.

Diversification. The main attraction of diversification for utilities was that it freed them from the profit limitations imposed by public utility commissions. This freedom should have reduced business risks and made them more attractive to investors. Another attraction might be the synergistic side-benefits that diversification would have on their main line of business. Return on equity from the regulated portions of their business was stuck, which made it very attractive to invest in fast growing, more profitable ventures. But which ventures should these electric power companies choose? The options were many, from oil and gas exploration to coal mining, energy engineering, engineering services, real estate, computer services, telecommunications, and fish hatcheries.[8]

Transmission and Distribution. Some utilities reasoned that risk was high in both the construction end of the business (since demand was uncertain and environmental and safety constraints were high) and in the marketing of power (since PUCs, representing consumer pressure, put a limit on how much profit they could earn). Alternative power generation methods and conservation did not have much appeal for these utilities. Trying for additional profit from diversified businesses seemed too risky. These utilities were uncertain about where such ventures would lead and if they would have the managerial competence to benefit from them. Moreover, they often had cumbersome legal or regulatory issues that they had to contend with before they could diversify. Mostly located in the middle of the country between major producers and consumers of power, these utilities therefore chose to emphasize their transmission and distribution capabilities. Their strategic emphasis would be on the wheeling of power from one region to another. Power wheeling was unregulated and had fewer limits on its profit making potential.

The implication to be derived from this discussion is that turbulence in the external environment of the utilities and the strategic re-orientations that they made may have affected the performance of their nuclear power plants.

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[8] The electric power companies could invest in areas related to their business such as fuel exploration for resources such as coal, oil, gas, and uranium. They could invest in coal mining operations, appliance sales, steam production, electrical and energy management equipment, solar hot water heater sales, heat pumps, and cogeneration. They could market energy auditing services to customers interested in conservation. However, they might find ventures unrelated to their main line of business more attractive. These ventures include real estate, transportation, financial services, food production, telecommunications, oil and gas pipelines, water sales, or cable television.

2.3 A Combined Model

Now that the important behavioral elements of sequential attention to goals, past performance, and strategy as a means of focusing attention have been considered, it is possible to return to the original concepts in the economic model and reformulate them. Out of this reformulation will come a combined economic and behavioral theory of safety improvement on performance indicators that will be tested. The combined theory contains behavioral concepts of past performance and utility-level strategy, and economic concepts of problem recognition, resource availability, resource application, and controls for production experience and technological differences (see Figure 2.1). The theory which links the concepts in the combined model to improvement in performance is a theory of organizational learning in which problems are recognized via such means as comparisons with past performance, internal surveillance, SALP score evaluations, and violations. The utility has to have the resources to formulate solutions to the problems, and these resources have to be applied to implement the solutions. The problems are diagnosed based on the utility's capacity to focus attention on its nuclear power operations. If its attention is distracted by other priorities dictated by its business strategies, it is likely to be less successful in its problem-solving abilities.

2.3.1 Problem Recognition

The behavioral theory suggests that innovations and deviations from routines that upset an organization's equilibrium are relatively rare. Organizations resist change, and yet improvements depend upon a continual process of organizational change and learning (Carroll and Cebon, 1990). Therefore, it is necessary to understand the change process better, including the barriers to change and ways to overcome these barriers.

The starting point for change is problem recognition. Bhopal, Challenger, TMI, and the Valdez oil spill all were preceded by warnings that something was wrong, but adequate steps were not taken to change the situation. In almost all disasters prior warning signals were present, but are not heeded: the problems that lead to catastrophes were not appropriately recognized. Why?

One reason is that in organizations it is difficult to distinguish true signals from the noise. Problems go unnoticed because of detection errors (Kiesler and Sproul, 1982): information that is available is misinterpreted as to its gravity and meaning.

PROPOSITION 8: The level of safety is affected by the organization's ability to detect problems.

Detection errors arise because the noise to signal ratio is too high. Irrelevant information exists that obscures from attention what may be relevant to safety. Correctly noticing, interpreting, and incorporating stimuli are necessary for effective problem identification. Managers, however, may ignore or overlook undesirable events that have taken place; or they may assume that appropriate events have happened, even if they did not occur. Managers ignore overly discrepant information and fail to recognize information that is highly surprising (Kiesler and Sproull, 1982). Problem solving requires an awareness of problems that have to be solved, but key problems may go unnoticed while managers pay attention to peripheral and unimportant ones.

Managers routinely evaluate a broad variety of stimuli against performance and aspiration level criteria. Only if the comparison shows results less than the aspiration level expectations are problems perceived to exist. Only then does problem solving activity begin; otherwise no problem is perceived and therefore no steps taken to resolve it. According to Cyert and March (1963), the standard operating procedures of the organization can facilitate or inhibit the process. The organization only examines what its decision rules suggest that it should examine, and it will abandon a feasible set of decision rules only under duress.

In most organizations, there are periods of equilibrium and "revolution" (Gersick, 1991). During the periods of equilibrium, the basic organizational activity pattern remains the same. The inertia is strong. Cognitive barriers to change exist along side of emotional ones; there is the emotional pain of loss and uncertainty and the fear of failure lest new routines and modes of operation be introduced. Obligations to people inside and outside the system prevent change from taking place. People are bound by stable expectations of long term, enduring relationships.

Organizations respond to short run feedback resolving small problems as they arise, then wait for additional small problems to appear (Cyert and March, 1963). Even long term change is programmed, a response to long run feedback according to general rules. To move out of this stable condition of equilibrium, some external source of disturbance or shock to the system is needed: continuous decay that leads to a major problem, a major mishap or traumatic experience which focuses corporate attention on a problem. Search for new routines to replace the old is then stimulated by the problem and directed toward finding a solution.

Failures are extremely important in setting the stage for the process of improvement. Crises are needed. The organization has to experience serious performance pressures and troubles before it will abandon its routines. It needs to notice that it is not performing up to its aspirations and expectations. Large performance gaps (Downs, 1966 p. 191) in which the discrepancy between how it is performing and how decision makers believe it should be performing are needed. There have to be substantial mismatches between performance and expectations before there will be search for alternative courses of action to reduce the gap, before there will be an awareness that the existing knowledge base is deficient and there is a need to make corrections (Duncan and Weiss, 1979).

Some organizations are likely to view problem recognition as first steps to improvement, others as an impediment to normal business operations. The more openness there is to problems, the more likely it is that improvement can take place in an even, continuous, and progressive rather than in sudden, traumatic, and destabilizing fashion.

The NRC role in the nuclear industry is to make sure that this process of regular problem recognition occurs. It holds the plants to a philosophy of defense-in-depth, compelling them to adhere to a host of primary, secondary, and tertiary systems to control the reactor and prevent radiation (Osborn and Jackson, 1988). The philosophy of defense-in-depth commits the plants to multiple backups for important technical systems. To minimize the consequences of human error, it means that safety systems are automatically triggered if key equipment malfunctions. The NRC inspects plants to assure that they are complying with this philosophy and it does periodic on-site assessment. For failure to comply, plants can be cited for major and minor violations and deviations which are recorded and become part of their permanent record. The major violations, which occur at infrequent rates, can be major jolts to the system.

In assuring that the process of problem recognition works, the NRC is not perfect. It has only a small number of on-site inspectors (2 to 3 per site). It cannot be certain about what is going on at the plant. Regulatory failure is possible (Vaughan, 1990). Regulators depend on information provided by the plants. They can examine only a limited part of a plant's activities. Personnel at the plant may resist visits and even view them as counter productive to the safety, or try to persuade NRC to be lenient in applying the rules, since it is in the utility's interest to minimize the cost of complying. NRC faces numerous barriers to discovery, monitoring, and investigation.

2.3.2 Resource Availability

The organization notices discrepant events signaling danger through internal efforts and those of outside regulators. When it becomes aware that problems exist, it requires resources to do something about them. To solve problems, the utility must have adequate resources to apply to the problem and implement solutions. Both the behavioral and economic perspectives stress the financial costs of safety. Neither accepts the idea that safety can be guaranteed by the intervention of outside regulators alone. The utility has to do something to enhance safety.

PROPOSITION 9: The level of safety is affected by the resources available for safety enhancing activities.

Internally, there must be built up within the system a complex, highly differentiated administrative structure where responsibilities are widely dispersed among overlapping units that may be carrying out roughly the same tasks (Schulman, 1990). The redundancy increases reliability and lowers risk. Differentiation and overlap of administrative authority assures that there is an extra layer of thoughtfulness and caution in the organization's actions. To maintain this system of redundancy requires higher levels of staffing and substantial cross-training of personnel. Considerable discretionary resources have to be invested in problem diagnosis and prevention activities. Systems have to be in place for classifying problems, tracking them, and doing causal analysis as to what prior conditions and actions produced the problems. Analysis of consequences is needed to ascertain the importance the problem. These processes are not possible if there is inadequately trained or inexperienced engineering support on-site or at corporate headquarters, if there is a lack of training in root cause or human error analysis, and if there is a lack of data on equipment history.

Discretionary resources may be needed so that engineers have the possibility of becoming senior reactor operators, and so managers and supervisors can gain on-site experience by involvement in job rotation (Olson and Thurber, 1991). These programs are costly. There has to be a high level of support for them. Training with simulators is needed for reacting to and understanding unexpected sequences of events. To support these and other types of problem diagnosis and prevention activities, the utility must have a strong record of prior earnings growth (Osborn and Jackson, 1988). The plant needs resources to comply with NRC requirements, to acquire new and more sophisticated equipment, to carry out new and sophisticated training, to finance additional engineering support and safety review groups, and to achieve the defense-in-depth safety philosophy NRC requires.

The type of "gold plating" that is necessary is very expensive, and therefore only utilities with high earnings growth should be able to afford it. If they run safe plants then there will be a positive feedback on their earnings: they will not have to purchase power from other utilities if there are fewer safety mishaps and they are not shutdown as much.

2.3.3 Resource Application

Having the resources is not enough. The resources have to be applied so that specific groups in the utility are aware that there are problems. They have to discover the sources of error and create strategies to correct them (detect the mismatches between outcomes and expectations which disconfirm prevailing paradigms; see Argyris and Schon, 1978 as cited by Duncan and Weiss, 1979). To the extent that utilities commit resources to groups capable of identifying problems and devising solutions, they are likely to be safer.

PROPOSITION 10: The level of safety is affected by resources that have been committed to groups with strong problem solving capabilities.

The effectiveness of the organization over time reflects the commitments it has made to people capable of identifying and solving problems. A high level of know-how is needed to be aware that conditions have deteriorated and that changes are needed. There is only so much the regulators can do. Internal to the plant there must be a corp of people dedicated to reducing performance discrepancies.

When the anomalies occur, it is not always obvious what has happened. The causality of events is difficult to disentangle. The events that nuclear power plant personnel observe are difficult to interpret, the process of discovery and problem solving not simple. They have to make inferences and draw lessons from a relatively small number of observations. Forming interpretations, understanding and classifying what has happened, and devising solutions requires the specialist's understanding of an advanced technology and the generalist's abilities for a high degree of interdependence and interaction with others. It requires searching in the past history of the plant and in operating experience of other plants to understand what has happened.

Personnel need the capacity to carry out "root cause analysis," to discover why things have happened. This process is likely to involve representatives from all sectors in the plant. Plant personnel need a valid mental model of how the system in its entirety functions, but complete knowledge of all situations is impossible. Not everything can be known. Interactions among groups alerts people to the possibility of unexpected sequences. It provides them with a sense for scenarios that otherwise might not be considered. The nuclear utility needs groups and formalized processes designed to search endlessly for obvious and subtle error producing situations in an atmosphere of continual discovery and codification of the discoveries in procedures (see Schulman, 1990).[9]

Osborn and Jackson (1988) refer to nuclear power as a "competence destroying technology." It requires constant upgrading of peoples' skills, abilities, and knowledge. There is always the possibility of unexpected interactions in a complex, highly coupled system where complete knowledge of all that might take place is impossible to achieve (Perrow, 1984). Dangerous technologies, where there are complex, tightly coupled relations involving unanticipated interactions among multiple failures, demand intense, urgent attention to problems and to potential problems before they manifest themselves.

The two key groups at the power plant are operations and maintenance. Operations units are often heavily staffed with people with nuclear Navy backgrounds, maintenance units with people with craft and trade union (machinists and electricians) backgrounds. A third group is the engineers. Among these three groups there are likely to be differences in education, status, skills, modes of work, and motivation. Resource allocation plays an important role in nuclear power plant safety by distributing resources across these key problem solving groups. Resource allocation influences the distribution of power and the practical reality of how many people of what type are available to problem solve.

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[9] Olson et. at., 1984 found that plants with more elaborate and sophisticated administrations and many coordinative mechanisms between functional departments have fewer potential safety problems. More levels of administration, greater centralization, and more employees were associated with more potential problems.

2.3.4 Summary of the Combined Model

Thus the combined economic and behavioral models have concepts which represent (1) past performance; (2) problem recognition, (3) resource availability, (4) resource allocation, and (5) strategies that focus attention, and controls for (6) production experience, and (7) production technology. The combined model examines the dynamic process of improvement. It looks beyond performance and the role of routines in maintaining past behavior and considers the series of factors needed to overcome the inertia of the past. It views performance as a multi-dimensional concept with a diverse set of predictors for different attributes.

2.3.5 Overview of the Approach to Testing and Validation

The approach to testing and validating the theory has involved extensive systematic quantitative analyses, augmented by qualitative studies. The quantitative analyses reported in Chapter 3.0 focus on building predictive models of scrams, safety system actuations, significant events, safety system failures, radiation exposure, and critical hours. The predictive models incorporate independent variables representing the key concepts in the theory developed in this chapter. Different variables are sometimes used to test for the consistency of the findings when other means of measuring the key concepts are tried. The predictive models focus on explaining improvement or degradation in the performance measures. Time lags are built into most of the variables to reflect the fact that the effect of a change in the variable may not occur immediately.

In Chapter 4.0, additional quantitative analyses are reported, in which profit growth and commitment to nuclear power are used to predict violations and plant reliability. These analyses, while they focus on different dependent variables, demonstrate additional support for two of the key concepts in the theory.

Qualitative studies were undertaken to augment the quantitative studies, especially for the purpose of gaining insight into processes by which problem solving and learning occur. These processes are assumed to be important means by which improvement occurs. The qualitative studies and their results are documented in Chapter 6.0.

3.0 EMPIRICAL STUDIES OF PERFORMANCE INDICATORS (INCLUDES CRITICAL HOURS)

3.1 Research Method

The theory developed in the previous chapter integrates economic and behavioral perspectives of nuclear plant management into a model that identifies a set of important concepts for understanding the performance of nuclear power plants with regard to safety. The economic model assumes plants operate in an environment with scarce resources where tradeoffs must be made. Therefore, economic theories emphasize the importance of a utility's financial position and spending of resources as key to their performance. Those who have the resources to spend on safety improvements are likely to perform better than those facing financial difficulty. How they spend these resources and the regulation of the power plants should have an impact on safety performance.

The behavioral model emphasizes organizational inertia and attention as key elements to understanding nuclear power plant performance. Organizations like nuclear power plants must struggle to overcome existing patterns of operation and performance. Therefore, past performance should be an important predictor of future performance. In addition, behavioral theories recognize that organizations typically have multiple goals that they are simultaneously trying to meet. These multiple goals shift with changing organizational strategies. The shifts in organizational strategy may distract managers' attention from some goals while they end up emphasizing others.

Drawing on these two perspectives, the combined model stresses the following concepts: past performance, problem recognition, resource availability, resource application, and business strategy. The objective of this chapter is to test these concepts with a systematic analysis of the safety and reliability-related performance of nuclear power plants including the improvement and degradation in their performance over time. In this chapter, five performance indicators as well as critical hours are examined to assess their relationship to the explanatory concepts in the model. Since most of these safety indicators are event count data, a Poisson regression model has been used when appropriate.

Alternative variables are entered into the analyses to represent the concepts in the combined model in different ways. This serves as a means to seek the best variables to represent the concepts and to test the robustness of the concept itself. For example, in some sets of analyses return on assets is used to represent the concept of resource availability, and in other sets of analyses return on investment is used. The purpose of the empirical work is to validate the overall combined model and not the specific measures. Rigid adherence to particular measures is not as important as a general understanding of the effects of the concepts which the measures represent. Confidence in the general framework should increase to the extent that findings remain alike or nearly alike no matter how concepts are measured, models are constructed, and samples and time periods change.

3.1.1 Poisson Regression Model and Maximum Likelihood Estimation

Although social science theorizing is not constrained to think of phenomena as randomly generated from a normal distribution, quantitative analysis in the social sciences typically begins with this assumption. Relying on the Gauss Markov Theorem, least squares regression assumes that variables are related in a linear fashion and that the dependent variable is normally distributed. Theories and data which do not appear to conform to normality assumptions are altered in a variety of ways so that they more closely meet normality assumptions.

Unfortunately, both social science theories and real world phenomena do not always conform to these normality assumptions. In response, a variety of techniques have been developed which break with the linear tradition and do not impose normality assumptions. For example, non-linear least squares have been used to address a variety of social science problems which violate normality assumptions. They provide the means to test theories that are implicitly non-linear.

In this regard, event count models are of relevance for understanding some of the NRC performance indicators. They have been used to investigate the number of cars sold in a month, the number of home runs hit by a baseball team in a game, and the number of safety violations by nuclear power plants.

The Poisson distribution (named after the 18th century physicist and mathematician Simeon Poisson) is useful in describing the number of events that will occur in a specific time period. The Poisson shows the probability of an event occurring in a given unit of time or the mean or expected number of events per unit. Other examples for which the Poisson provides a good model (McClave and Benson, 1984) are: the number of industrial accidents in a given period of time observed by a plant supervisor; the number of noticeable defects found by quality inspectors; the number of errors per time period that employees make in an industrial plant; and the number of breakdowns of equipment or machinery per period in the plant.

Typically, event count models like these are not normally distributed, and the values of the variables are quite low (as is the case with NRC performance indicators). Research involving event count models suggests that these models typically follow a Poisson distribution. The assumptions in a Poisson model are (i) that the rate of occurrence of an event remains constant over the count period and (ii) that the likelihood of two events happening at the same time is close to zero. The second assumption is merely technical, while the first is theoretical. A simple Poisson model is not appropriate if the occurrence of an event changes the likelihood of another event occurring (i.e., the events are not independent).[1]

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[1] It should be noted that there are techniques of estimating models with contagion effects, but the standard Poisson model is not appropriate under these conditions.

Poisson models have the advantage of providing a better fit for event count data because a Poisson distribution is constrained to only positive values, unlike a linear model in which variables may take on positive or negative values. And unlike logit models, Poisson models do not limit the positive values to be between zero and one. The NRC performance indicators that have been used are always positive, therefore, using least squares estimation would lead to biased estimates of parameters. Least squares analyses of event counts are inappropriate because they can produce these biased and inconsistent estimates (King, 1988). The method of least squares with its assumption of linearity does not constrain the expected value of the dependent variable to be non-negative and thus can produce implausible predicted values.[2]

Because event count models and Poisson estimation provide a more plausible representation of event data, they are increasingly being used in social science research. In particular, they have been incorporated into the analysis of models of airplane accidents (Rose, 1990) and analysis of safety violations in nuclear power plants (Feinstein, 1989). In light of these analyses and the more plausible assumptions they provide about the nuclear power data, they have been used to investigate the performance of nuclear power plants for four performance indicators: Scrams, Safety System Actuations, Safety System Failures, and Significant Events.[3]

Because these performance measures are counts of events per year, the event count model seems appropriate. Normality tests performed on these safety indicators show that they are not normally distributed and support our use of Poisson regression, which does not assume a normal distribution.[4] Since it is difficult to know a priori if the occurrence of an event, like a scram, is independent from subsequent scrams, both the standard Poisson

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[2] Estimation techniques like least squares which do not account for the actual range of the variables can lead to biased estimates of parameters. Rather than estimating unbiased coefficients with the method of least squares, maximum likelihood is used to solve a log-linear function which uses numerical methods to find the parameter values which are most likely to have generated the given data. There are other techniques to deal with variables which are truncated at an upper or lower bound (i.e., censored data). One of the most common is Tobit analysis which is appropriate with interval data which take only positive values. For example, a model of the amount of money contributed by a corporation to charity could be estimated using Tobit analysis.

[3] Because radiation exposure and critical hours are measured by the amount per year, an event count model is not appropriate. Therefore, analy is of these dependent variables was conducted with ordinary least squares.

[4] The normality test for all four safety indicators used in the Poisson regression were performed using SAS. This normality analysis involves examining histograms and normality plots to see whether the data conform with a normal distribution. The results of the test show that the data are not normally distributed. See Appendix C for details.

regression, which assumes independence of scrams, and the over-dispersion Poisson model, which assumes scrams are dependent, were estimated (King, 1989). In the analysis of the over-dispersion model, the over-dispersion parameter has been estimated and found not to be statistically significant which suggests that dispersion is not apparent in the data. Therefore, the estimates reported are the results of the standard Poisson model.

This report shows how to develop appropriate statistical models for the four safety-related performance indicators which use discrete non-negative integers that measure the number of times an event occurs in a fixed time. In this case, data from a period of two years, 1987 through 1988, have been used as the dependent variable.

3.1.2 Description of Concepts and Variables

Based on organization and management theory, and following from NUREG/CR-5437, a theory has been developed, consisting of key concepts that are expected to affect plant safety-related performance - past performance, NRC problem identification (regulatory violations), nuclear utility application of resources, availability of resources reflected by nuclear utility financial performance, and nuclear utility business strategies. Controls are introduced for nuclear power plant production experience and type of technology (PWR or BWR). Improvement or degradation in safety-related performance is posited to be influenced by these factors.

3.1.2.1 Dependent Variables

The dependent variables in these analyses consist of the five NRC performance indicators and critical hours. A detailed definition of each performance indicator as described in NUREG/CR-5437 is as follows:

Unplanned Automatic Scram
An unplanned automatic scram (scram) occurs as an actuation of the reactor protection system that results in a scram signal at any time when the unit is critical. The scram signal may result from exceeding a set point or may be spurious. Scrams planned as a part of special evolutions or tests and manual scrams are not counted by this indicator. The number of scrams while critical is closely related to unit safety. Since unplanned automatic scrams are initiated to prevent the reactor from exceeding the safety limits and system safety settings, scrams usually indicate that something is wrong that could place the plant in a less safe condition. In addition, due to the fact that every scram challenges the safety systems and accumulates transient age on plant equipment, the absence of scrams is an indicator of good performance.

Safety System Actuation
Safety system actuation (SSA) occurs when a set point for the system is reached or when a spurious/inadvertent signal is generated and major equipment is actuated. The equipment that is considered in the actuation is the emergency core cooling system and AC emergency power. Any unplanned actuation of a safety system indicates a set point or limit established for safety has been reached. The systems have been selected

because their actuation is considered to be a direct indication of a significant off-normal plant condition.

Safety System Failure
A safety system failure (SSF) occurs when the system is unable to perform its intended function during the time that the reactor is in an operating mode that would normally require the availability of the safety system. Unavailability is caused by component failure or removal of components from service for corrective or preventive maintenance when the safety system is required to be available. System unavailability is calculated from component unavailable hours, using a model of the selected system. Therefore, it reflects not only the time the complete system is actually unavailable, but also includes a contribution due to partial system unavailability. In PWRs, emergency AC power, the high pressure safety injection system, and the auxiliary feedwater system are monitored. In BWRs, the systems monitored are emergency AC power, high pressure coolant injection or high pressure core spray system, and the reactor core isolation cooling or isolation condenser system.

Significant Events
As defined in NRC's AEOD annual report, 1988, "Significant events are those operational events reported to the NRC that the NRC staff identifies through detailed screening and evaluation as meeting certain selection criteria enumerated in this paragraph. The screening process includes a daily review and discussion of selected operating reactor events. Significant events normally involve one or more of the following selection criteria: (1) the degradation of important safety equipment; (2) an unexpected plant response to a transient or a major transient itself; (3) a degradation of fuel integrity, primary coolant pressure boundary, or important associated structures; (4) a reactor trip with complications; (5) an unplanned release of radioactivity exceeding plant Technical Specifications (TS) or other regulations; (6) operation outside the limits of TS; and (7) other events that are considered significant."

Collective Radiation Exposure

This is a measure of the average collective radiation exposure to utility employees, contractors and visitors by unit. This indicator is an indirect measure of plant safety since plants with low collective radiation exposure are generally regarded as being well-managed in the control of plant contamination and efficient in the administration of the ALARA (maintaining radiation exposures as low as reasonably achievable) program.

All performance indicators are totals for 1987 and 1988, thus they are represented, respectively, as TSM78, TSA78, TSF78, TSE78, and RAD78.

In addition, a measure of plant efficiency, critical hours, was included in the analysis to compare the results from the safety variables with efficiency. Critical hours (CRT) is the number of hours operating during a given year. In this analysis, the total critical hours for 1987 and 1988 were used.

3.1.2.2 Independent Variables

The independent variables used in these analyses are specified below:

Past Performance: For each model where past performance is used in an equation to explain improvement or degradation, it is represented as follows:

in models in which TSM78 is the dependent variable, one of the independent variables is TSM56 (scrams in 1985-86);

in models in which TSA78 is the dependent variable, one of the independent variables is TSA56 (safety system actuations in 1985-86);

in models in which TSE78 is the dependent variable, one of the independent variables is TSE56 (significant events in 1985-86);

in models in which TSF78 is the dependent variable, one of the independent variables is TSF56 (safety system failures in 1985-86);

in models in which RAD78 is the dependent variable, one of the independent variables is RAD56 (radiation in 1985-86);

in models in which CRT78 is the dependent variable, one of the independent variables is CRT56 (critical hours in 1985-86).

Problem Identification: For all models, NRC problem identification is represented by:

number of major violations in 1985 (NOMAJV85); and

1985 SALP scores (SALP).

The SALP scores (Systematic Assessment of Licensee Performance) are NRC evaluations of licensee performance in 1985, which are the sum of the total of operations, maintenance, surveillance and quality program scores, (each with a value of from 1 to 3, where 1 is excellent, and 3 is poor).

Resource Availability: Utility financial performance is represented in different models by:

return on assets in 1985 (ROA85)

debt to equity ratio in 1985 (DE85);

return on investors capital in 1985 and 1986 (ROI);

and operating efficiency in 1985 and 1986 (OPEFF), which is the earnings before taxes as a percentage of total assets

Resource Application: Utility application of resources is represented by:

a fixed cost component, 1985-86 plant costs per megawatt capacity (PLANT2); and

two variable cost components --

1985-86 operations supervision and engineering expenses per megawatt capacity (SEOP) and

1985-86 maintenance supervision and engineering expenses per megawatt capacity (SEMT); or

RSEOP, the ratio of operations supervision and engineering spending over total supervision and engineering (including maintenance) in 1985 and 1986 (RSEOP).

The final variable measures the amount of total supervision and engineering spending dedicated to operations. The higher the ratio for RSEOP, the greater emphasis management is placing on operations supervision and engineering as opposed to maintenance. This variable simplifies the analysis as it captures in a single dimension both SEOP and SEMT. It therefore permits a more careful assessment of the trade-off between spending on these two items.

Plant Experience: For all the models, plant experience is represented by:

historic production as of 1985 (E2X).

Historic production is defined as reactor age x its size in megawatts x its historic capacity factor as of 1985.

Technology: For all models, a control variable is introduced for:

type of reactor (TYPE).

A dummy variable is used with 0 representing pressurized water reactor and 1 representing boiling water reactor.

Business Strategies: Utility business strategies are represented in different models as follows:

Focus Diversification = Equity in Earnings of Subsidiary Companies/Net Generation Revenues 1984-86 (DIVER);

Focus Transmission & Distribution = Transmission and Distribution Plant Costs/Nuclear Power Plant Costs 1984-86 (TD);

Focus Alternative Power Generation = Other Generation/Total Generation 1984-86 (OTHER); and

Focus Power Production = Dollars from sales for Resale/Net Generation Revenues 1984-86 (PROD).

In some models a focus on the continued construction of generating capacity replaces the focus on production.

Focus On Continued Construction = Electric Construction Work in Progress 1984-86 (ecwp).

For all of the independent variables, lagged values have been used. A correlation analysis of concurrent years of the independent and dependent variables reveals weak contemporaneous effects. Moreover, explanatory models assume a time-lag. For an independent variable to affect a dependent variable, it must occur prior to the occurrence of the dependent variable. If independent and dependent variables are concurrent, it is not possible to know which set of variables causes the other. Lagged values therefore are presented here.

3.1.3 Plant Population

The analysis was conducted on 58 of the 100 privately-owned U.S. nuclear power plants. Due to the theory being tested, only privately owned plants where financial data on the parent utility is available can be used. The number of plants was reduced due to missing data. If a plant was missing data for any of the dependent or independent variables in the model, standard convention was followed and the plant was dropped from the analysis. Closer study of the distribution of the plants shows that it is quite representative with most plants coming from the northeast, southeast and the midwest, where most plants actually are located (see Appendix D for the actual distribution of nuclear power plants in the United States). There are fewer plants from the west and south as would be expected. There are 38 plants with pressurized water reactors and 20 plants with boiling water reactors, which is also similar to the actual distribution.

Nuclear Power Plants included in the study

NRC Region	Reactor type	Plant Name
North East 1	1 BWR	OYSTER CREEK
North East 1	1 BWR	NINE MILE PT. 1
North East 1	0 PWR	INDIAN POINT 2

North East	1	0	PWR	SALEM 1
North East	1	1	BWR	PEACH BOTTOM 2
North East	1	1	BWR	PEACH BOTTOM 3
North East	1	0	PWR	THREE MILE IS. 1
North East	1	1	BWR	PILGRIM
North East	1	0	PWR	SALEM 2
North East	1	1	BWR	SUSQUEHANNA 1
North East	1	1	BWR	SUSQUEHANNA 2
South East	2	0	PWR	TURKEY POINT 3
South East	2	0	PWR	TURKEY POINT 4
South East	2	0	PWR	ROBINSON 2
South East	2	0	PWR	OCONEE 1
South East	2	0	PWR	OCONEE 2
South East	2	0	PWR	SURRY 1
South East	2	0	PWR	SURRY 2
South East	2	0	PWR	OCONEE 3
South East	2	1	BWR	HATCH 1
South East	2	1	BWR	BRUNSWICK 2
South East	2	1	BWR	BRUNSWICK 1
South East	2	0	PWR	ST. LUCIE 1
South East	2	0	PWR	NORTH ANNA 1
South East	2	0	PWR	NORTH ANNA 2
South East	2	0	PWR	FARLEY 1
South East	2	0	PWR	FARLEY 2
South East	2	1	BWR	HATCH 2
South East	2	0	PWR	MCGUIRE 1
South East	2	0	PWR	MCGUIRE 2
South East	2	0	PWR	ST. LUCIE 2
South East	2	0	PWR	SUMMER
Midwest	3	1	BWR	BIG ROCK POINT
Midwest	3	1	BWR	DRESDEN 2
Midwest	3	1	BWR	DRESDEN 3
Midwest	3	1	BWR	QUAD CITIES 1
Midwest	3	0	PWR	PALISADES
Midwest	3	1	BWR	MONTICELLO
Midwest	3	1	BWR	QUAD CITIES 2
Midwest	3	0	PWR	PRAIRIE ISLAND 1
Midwest	3	0	PWR	ZION 1
Midwest	3	0	PWR	ZION 2
Midwest	3	0	PWR	KEWAUNEE
Midwest	3	0	PWR	PRAIRIE ISLAND 2
Midwest	3	0	PWR	COOK 1
Midwest	3	0	PWR	COOK 2
Midwest	3	1	BWR	DUANE ARNOLD
Midwest	3	1	BWR	LASALLE 1
Midwest	3	1	BWR	LASALLE 2
Midwest	3	0	PWR	CALLAWAY
South	4	0	PWR	ARKANSAS 1
South	4	0	PWR	ARKANSAS 2
South	4	0	PWR	BYRON 1
South	4	0	PWR	WOLF CREEK
West	5	0	PWR	SAN ONOFRE 1

West	5	0	PWR	DIABLO CANYON 1
West	5	0	PWR	TROJAN
West	5	0	PWR	SAN ONOFRE 2

Region total		Reactor type total
North East = 11	South = 4	PWR = 38
South East = 21	West = 4	BWR = 20
Midwest = 18		

3.2 Results

The results of the analyses are presented in this section. The purpose of the analyses is to test the concepts set forth in the combined theory described in Section 2.3. Five points should be made at the outset so that the results are somewhat easier to understand:

(1) What is being tested are full statistical models, that is, statistical models containing variables representing each of the different concepts thought to influence the performance indicators and critical hours. The theory states that variables work together to influence performance, and thus they are tested in combination rather than individually. In testing a full model, the assumption is that an independent variable influences a dependent variable in the presence of, or controlling for, the other independent variables.

(2) The empirical work is an attempt to test the theory and the concepts and not the specific variables. In fact, the analyses are sometimes deliberately run with different variables representing the various concepts in an effort to cross-validate the model and explore the robustness of it.

(3) The models are tested with regard to their ability to explain performance in a given time period, as well as their ability to explain improvement or decline (change) in performance. In tests where explanation of change in performance is sought, this is accomplished by controlling for past performance, so the actual dependent variable becomes the change in performance from one time period to the next.

(4) These are statistical models and therefore, the results when significant indicate that the greater the amount of an independent variable in a time period, the greater the amount of the dependent variable. With the theory, they have explanatory power, but they are not deterministic models in the sense that every time the independent variable exceeds a certain threshold, the dependent variable has to occur. Rather, in aggregate in the entire population, there is a strong tendency for the independent and dependent variables to be related. The best analogy is epidemiology, where the presence of a disease is found to a greater extent in a population, not microbiology, where the presence of a virus, holding everything else constant, <u>always</u> causes the disease.

(5) For the Poisson regressions the overall fit is evaluated using a chi-square test of the significance of the log-likelihood ratio. In all the

results presented, the p-values are approximately zero. This implies that the full models (Ha: not all β=0) are significantly better than the null models (Ho: all β=0) for all four safety indicators tested using Poisson regression. This test is similar to a test of the overall fit conducted in linear regression. In ordinary least squares regression, an F-test of the null hypothesis is conducted.

In Section 3.2.1, results of initial tests of the effects of the combined model on change in performance are presented. One or more variables representing each concept in the theory are included. In Section 3.2.2, the same variables are used as an initial test of the effects of the combined model on performance, irrespective of the past. In this test, past performance is not controlled for, thus the model predicts performance, not change in performance over time. In Section 3.2.3, conclusions from the initial tests of models predicting performance and change in performance are discussed and compared. Then Section 3.2.4 goes forward from those conclusions and tries to build a more refined model of change in the performance indicators and critical hours. The refined model represents some of the key concepts in a different way to determine if the initial findings are stable when slight variations are made in the representation of concepts. If the findings are stable with variant representations of the concepts, then the model is cross-validated. More confidence can be placed in it since regardless of how the concepts are measured, the results are roughly the same.

3.2.1 Initial Tests of the Effects of the Combined Model on Change in Performance Indicators

Results of the initial tests of the combined model and its ability to explain change in performance are presented in Tables 3.1-3.4. In these analyses, past performance is entered as a control variable. What is being explained by the model is change on the particular performance indicator under study over and above performance on the indicator in the previous time period. Type of reactor (TYPE) and production experience (E2X) are controlled for in the test of each model.

Definitions of the variables used in the analyses have been provided in Section 3.1.2. Analyses of models predicting scrams, safety system actuations, safety system failures, and significant events are based on Poisson models, as described in Section 3.1.1. Analyses of models for radiation exposure and critical hours are based on standard regression models using ordinary least squares.

Two different measures of utility business strategy are used in these initial analyses. In the models reported in Tables 3.1 and 3.2, the extent to which the utility focuses on power production (PROD, measured by sales for resale/revenues from net generation in 1984-86) is used. In the models reported in Tables 3.3 and 3.4, electric construction work in progress in 1984-86 (ECWP) replaces the production focus. The sample size reduces in Tables 3.3 and 3.4, because of missing data.

In interpreting the findings, a strong test for significance is applied. Significance levels of p<.05 or better are required before the finding is

Table 3.1 Poisson Regression Estimation:
Controlling for Past Performance
(Sale for Resale)

	tsm 78			tsa 78			tse 78			tsf 78		
	est	s.e.	t	est	s.e.	t	est	s.e.	t	est	s.e.	t
past 56	.05	1.41	3.34***	.09	.03	3.15***	.03	.04	.75	.03	.01	2.42**
nomaj 85	.04	.05	.10	-.12	.08	-1.61	-.01	.08	-.18	-.09	.03	-2.77***
t salp	-.00	.04	-.71	-.05	.06	-.97	.05	.07	.68	.17	.04	4.85***
roa 85	-.47	5.40	-.09	-4.11	7.79	-.53	-15.01	7.69	-1.95**	.52	3.91	.13
de 85	-.37	.21	-1.74*	.02	.23	.08	.20	.21	.92	-.01	.15	-.09
plant	-1.36	.82	-1.67*	.27	1.06	.25	1.92	1.44	1.34	1.75	.66	2.64***
semt	-.25	1.00	-.25	-2.06	1.40	-1.47	3.68	1.53	2.40	3.42	.67	5.07***
seop	.68	1.38	.49	1.05	2.12	.49	-6.96	2.35	-2.97	-6.39	1.05	-6.09***
other	1.41	1.75	.81	-.66	2.55	-.26	7.11	2.75	2.58***	4.64	1.33	3.49***
diver	-10.60	14.82	-.72	-8.2	18.6	-.44	-7.44	26.25	-.28	-2.17	12.03	-.18
td	.01	.05	.29	.05	.07	.74	.12	.07	1.66*	.06	.04	1.43
prod	.65	.77	.84	1.29	1.12	1.15	.71	1.28	.56	-.80	.63	-1.27
e2x	-.46	.34	-1.35	-.63	.45	-1.39	.59	.48	1.23	.31	.24	1.28
type	-.10	.15	-.63	.22	.19	1.18	-.09	.23	-.04	.45	.11	3.95***
constant	2.41	.65	3.43	1.07	.87	1.23	-.31	.98	-.31	.28	.55	.50
N	58			58			58			58		
Log likelihood Ratio:	394.4***			140.2***			180***			1194***		

est = estimated coefficient
s.e. = standard error
t = t statistic

*p< .10
**p< .05
***p< .01

Table 3.2 Ordinary Least Squares Estimation:
Controlling for Past Performance
(Sale for Resale)

	rad 78			crit 78		
	est	s.e.	t	est	s.e.	t
past 56	.40	.11	3.65***	.46	.24	1.95*
nomaj 85	.01	29.65	4.17***	-.05	.03	-1.76*
tsalp	-22.82	27.55	-.83	89.10	.03	.35
roa 85	-.06	.00	-1.77*	.00	.00	1.42
de 85	-9.49	87.79	-.11	.05	.09	.52
plant	-.07	.06	-1.09	-.01	.04	-1.48
semt	.00	.07	2.07**	-.00	.01	-.33
seop	-.00	.09	-1.59	.01	.01	.97
other	-.00	.00	.65	.00	.00	.18
diver	-.00	.01	-1.37	.00	.00	1.38
td	11.24	29.29	.38	-.02	.03	-.53
prod	-.03	.04	-.72	.00	.01	.38
e2x	.04	.02	1.63	-.01	.00	-3.32***
type	.02	.01	1.89*	-.00	.09	-1.71*
constant	.07	.04	1.81	.00	.00	2.04
N		51			56	
adj R squared		.71			.29	

est = estimated coefficient *p< .10
s.e. = standard error **p< .05
t = t-statistic ***p< .01

Table 3.3 Poisson Regression Estimation:
Controlling for Past Performance
(Electric Construction Work in Progress)

	tsm 78			tsa 78			tse 78			tsf 78		
	est	s.e.	t	est	s.e.	t	est	s.e.	t	est	s.e.	t
past 56	.05	.02	2.69***	.16	.05	3.16***	.04	.05	.80	.08	.02	3.50
nomaj 85	-.06	.08	-.74	-.05	.10	-.47	.03	.10	.25	-.04	.05	-.94
t salp	-.05	.05	-.95	-.11	.08	-1.35	.08	.10	.88	.12	.05	2.39**
roa 85	-5.39	6.04	-.89	-7.27	9.75	-.75	-4.30	9.43	-.46	10.79	5.09	2.11
de 85	-.28	.21	-1.37	.08	.25	.32	.14	.23	.61	-.19	.17	-1.07
plant	-2.80	1.34	-2.09**	-1.79	1.85	-.97	2.07	2.24	.92	.89	1.07	.83
semt	.25	1.27	.20	-3.26	2.16	-1.51	3.87	2.03	1.91*	4.86	.87	5.59***
seop	1.23	1.57	.78	3.76	2.62	1.44	-7.88	3.17	-2.49***	-7.51	1.55	-4.84***
other	-7.82	13.16	-.59	-25.59	22.61	-1.13	22.99	18.90	1.22	15.38	10.21	1.51
diver	-28.66	18.06	-1.59	-33.70	24.58	-1.37	4.47	33.71	.13	10.65	15.33	.69
td	-.02	.06	-.30	.05	.07	.66	.12	.10	1.24	.06	.05	1.14
ecwp	-.00	.00	-.64	-.00	.00	-.45	.00	.00	1.20	.00	.00	2.27**
e2x	.01	.40	.02	-.15	.57	-.27	.16	.57	.28	.23	.30	.78
type	.13	.19	.67	.31	.24	1.30	-.05	.27	-.18	.24	.13	1.86*
constant	2.56	.71	3.59	1.32	1.09	1.21	-.77	1.17	-.66	.28	.66	.42

N	46	46	46	46
Log Liklihood Ratio:	290***	120***	140***	934***

est = estimated coefficient *p< .10
s.e. = standard error **p< .05
t = t statistic ***p< .01

Table 3.4 Ordinary Least Squares Estimation:
Controlling for Past Performance
(Electric Construction Work in Progress)

	rad 78			crit 78		
	est	s.e.	t	est	s.e.	t
past 56	.44	.11	4.06***	.19	.27	.68
nomaj 85	.01	55.16	2.27**	-.05	.03	-1.45
t salp	-13.90	26.13	-.53	-.03	2.98	-1.14
roa 85	-.01	.00	-2.65***	.00	.00	1.17
de 85	24.82	72.47	-.34	-.02	.09	-.24
plant	-.04	.06	-.74	-.01	.01	-1.24
semt	.00	.01	1.72*	.00	.01	.36
seop	-.00	.01	-1.54	.00	.01	.25
other	.01	.01	1.56	-.00	.00	-2.34**
diver	-.01	.01	-.79	.00	.00	1.08
td	31.40	27.55	1.13	59.27	.03	.18
ecwp	-.00	.00	-.13	.00	.00	.28
e2x	.04	.02	1.73*	-.01	.00	-2.89***
type	.02	.01	1.62	-.00	.09	-1.52
constant	.06	.04	1.63	.00	.01	3.01
N		41			45	
adjusted R squared		.77			.35	

est = estimated coefficient *p< .10
s.e. = standard error **p< .051
t = t-statistic ***p<.01

deemed important for drawing conclusions. In many cases that cut-off is approached but not quite reached. In some of those cases, where the findings are significant at p<.10, they are mentioned, though they should be considered with caution.

As the model in Chapter 2 (Figure 2.1) suggests and the behavioral theory predicts, the past has a very strong influence on performance. Past performance has a significant effect (p< .05) on four of the six performance indicators (Tables 3.1 and 3.2):

*The fewer scrams in 1985-86, the fewer scrams in 1987-88.

*The fewer safety system actuations in 1985-86, the fewer safety system actuations in 1987-88.

*The fewer safety system failures in 1985-86, the fewer safety system failures in 1987-88.

*The less radiation in 1985-86, the less radiation in 1987-88.

While the above relationships can be interpreted in terms of their effect on improvement, the reverse is also true and can be interpreted as predicting decline in performance. That is, more scrams in 1985-86 is related to more scrams in 1987-88, etc. What is perhaps surprising is not the strength of the results (they are very strong), but the fact that significant results do not appear in the models run for significant events. The occurrence of a significant event is not predicted by the past occurrence of such an event in these models. Past critical hours is a relatively weak, but significant (p<.10) predictor of future critical hours.

<u>Problem Recognition</u>. Problem recognition via regulatory activity (major violations and SALP ratings) is a significant predictor of improvement in two performance indicators, safety system failures and radiation exposure (Tables 3.1 and 3.2):

*The more 1985 major violations, the fewer 1987-88 safety system failures; the fewer 1985 major violations the less 1987-88 radiation.

*The lower (the better) the 1985 SALP score, the fewer 1987-88 safety system failures.

It is interesting that regulatory impact is confined to these two performance indicators in the improvement models. Could it be that they are areas of particular concern to regulators as they have high public safety and occupational health impact without necessarily having production consequences? Utilities might therefore ignore them if it were not for NRC intervention. In contrast, utilities take care of scrams without regulatory intervention because when the reactor shuts down the utility faces the prospect of having to buy expensive replacement power.

The impact of the regulatory variables is complex. For safety system failures, major violations appear to correct problems and lead to improvement (since the more major violations, the fewer the failures). In contrast, high SALP scores in the past do not relate to improvement in safety system failures in the future; in fact, high past SALP scores predict more safety system failures. Similarly, for radiation, major violations may identify problems but the problems appear to persist (since the more major violations, the more radiation).

Resource Availability. Resource availability only affects improvement (p< .05) for one performance indicator - significant events, after controlling for past performance (Table 3.1):

*The more 1985 ROA, the fewer the number of 1987-88 significant events.

This relationship is not that stable. When the model with electric construction work in progress as a measure of business strategy is run, its effect on significant events disappears, but a relationship to low levels of radiation materializes (Table 3.4). Also, more ROA approaches significance in this model with radiation (Table 3.2), with p< .10. Debt equity ratios do not have strong impact on the performance indicators or on critical hours, though higher debt ratio approaches significance (p< .10) in predicting improvement in scrams (Table 3.1).

Resource Application. There are numerous findings for the resource application variables. Tables 3.1 and 3.2 show significant effects of resource allocation variables (< .05) on three of the performance indicators -- significant events, safety system failures, and radiation -- after controlling for past performance:

*The less plant spending per megawatt capacity, the fewer 1987-88 safety system failures.

*The lower supervision and engineering maintenance spending per megawatt capacity (SEOP), the more 1987-88 significant events, safety system failures, and radiation.

*The more supervision and engineering operations spending, the fewer 1987-88 significant events and safety system failures.

It should be pointed out that plant spending per megawatt capacity (PLANT) also approaches significance (p< .10) in its relationship to scrams. There appears to be a trade-off. When utilities spend more on operations supervision and engineering, as opposed to maintenance, they do better on important performance indicators such as significant events, safety system failures, and radiation. In Section 3.2.4, a different way of measuring the concept (RSEOP) will be reported and the results remain consistent with these, suggesting that resource application is important.

The reasons for the importance of the resource application findings, as suggested earlier, are complex. It is possible that vicious cycles are at work. Poor performance breeds high spending on maintenance supervision and engineering as opposed to operations supervision and engineering. The poor performing plants never catch up. Maintenance supervision and engineering spending may reflect expenditures to fix problems in a reactive way, siphoning off resources that could be applied in a more proactive manner. Funds spent on operations supervision and engineering may reflect investment in personnel who have broader training, who may be more likely to spot problems and solve them before they get out of hand, thereby functioning in a preventive manner. This interpretation of the statistical results is very speculative, but the pattern of results is very distinctive and should be more fully explored.

<u>Business Strategy</u>. The strategy variables also have impact on change in the performance variables. The initial model whose results are shown in Tables 3.1 and 3.2 shows:

> *The lower ~~the~~ percentage of alternative power consumed by the utility (OTHER), the fewer the 1987-88 significant events and 1987-88 safety system failures.

When electric construction work in progress is substituted for the sale for resale variable ~~in~~ the model (Table 3.3 and 3.4), alternative power consumption (OTHER) has a negative effect (p< .05) on critical hours, and electric construction work in progress has a positive effect (p< .05) on safety system failures. Additional findings emerge when past performance is removed (see Tables 3.5 and 3.6). These are discussed in Section 3.2.2. In general, the results suggest that strategies that tend to divert utility attention from nuclear power generation may have a negative effect on performance. This preliminary conclusion will be examined more fully in Sections 3.2.2 - 3.2.4.

<u>Production Experience.</u> Production experience has no effect on change in the performance indicators, though it has a very consistent negative impact (p< .05) on improvement in critical hours (Tables 3.2 and 3.4):

> *The more production experience, the fewer the 1987-88 critical hours.

This finding is contrary to the learning curve literature. Perhaps the effects of aging of the equipment exceeds the learning and efficiency that is normally expected to come with increased production experience.

<u>Technology</u>. Type of technology has a major impact (p< .05) only on safety system failures after controlling for past performance (Table 3.1):

> *BWRs have more safety system failures than PWRs.

The type of reactor also approaches significance (P< .10) for radiation exposure and critical hours (Table 3.2). It shows BWRs associated with more radiation exposure and fewer critical hours, after controlling for past performance.

3.2.2 Initial Tests of the Effects of the Combined Model on Performance Indicators (Not Controlling for Past Performance)

In this section results are reported from initial tests of the model, but where past performance is not entered as a control variable. Consequently, these models are constructed to predict performance and not change in performance on the indicators. Results in Section 3.2.1 consistently show that past performance on a particular performance indicator is the strongest predictor of future performance. Therefore, by not controlling for past performance, which is the way the models are run in this section, there is an accumulation effect for past performance and it may be very difficult for other variables to overcome past performance and show their own significance. Nevertheless, the tests are important to run for contrast purposes.

The findings are reported in Tables 3.5 and 3.6. Models using the same variables as those reported in Tables 3.1 and 3.2 have been run, with the same controls (except for past performance). Sale for Resale is entered as the production strategy variable instead of electric construction work in progress. Therefore, the appropriate comparisons between models run with and without controls for past performance are to compare Table 3.5 with 3.1, and Table 3.6 with 3.2. Electric construction work in progress does not appear to be as good a measure of production as sale for resale, and may have effects on other variables (e.g. major violations) that result in multicollinearity problems in the models.

<u>Problem Recognition</u>. Not taking into account past performance on the performance indicators, problem recognition variables predict ($p < .05$) four performance indicators:

*The more 1985 major violations, the fewer safety system failures, the more radiation exposure, and the fewer critical hours in 1987-88.

*The lower (better) the 1985 SALP score, the more safety system failures in 1987-88.

<u>Resource Availability</u>. Not taking into account past performance on the performance indicators, resource availability variables predict ($p < .05$) two performance indicators--significant events and radiation. Only ROA (not debt ratio) is significant:

*The more 1985 ROA, the fewer significant events and the less the radiation exposure.

<u>Resource Application</u>. Not taking into account past performance, resource application variables predict ($p < .05$) significant events, safety system failures, and radiation exposure:

*The lower plant spending, the fewer 1987-88 safety system failures.

Table 3.5 Poisson Regression Estimation:
Not Controlling for Past Performance
(Sale for Resale)

	tsm 78			tsa 78			tse 78			tsf 78		
	est	s.e.	t	est	s.e.	t	est	s.e.	t	est	s.e.	t
nomaj 85	-.02	.04	-.44	-.10	.07	-1.52	-.08	.08	-.10	-.09	.03	-2.96***
tsalp	.01	.04	.20	-.09	.06	-.16	.07	.07	.97	.20	.03	5.95***
roa 85	.67	5.33	-.13	-2.63	7.67	-.34	-16.97	7.11	-2.39**	-1.37	3.74	-.37
de 85	-.33	.20	-1.63	-.04	.22	-.19	.19	.21	.92	-.03	.15	-.17
plant	.45	.78	-.58	1.34	1.00	1.34	2.24	1.38	1.63	1.64	.66	2.46***
semt	-.40	1.05	-.38	-.83	1.34	-.62	3.65	1.52	2.41**	3.31	.67	4.93***
seop	-.49	1.35	-.36	-2.45	1.87	-1.31	-7.40	2.28	-3.24***	-6.19	1.03	-6.40***
other	1.82	1.74	1.05	.92	2.57	.36	7.59	2.67	2.84***	5.03	1.33	3.79***
diver	-9.71	13.66	-.71	-8.56	19.93	-.43	-.08	25.94	-.29	-.29	11.65	-.03
td	.05	.05	1.27	.16	.06	2.85***	.15	.07	2.24**	.05	.04	1.17
prod	.55	.77	.72	1.04	1.13	.93	.67	1.28	.52	-1.05	.62	-1.70
e2x	-.90	.32	-2.80***	-.86	.44	-1.95*	.62	.48	1.29	.35	.24	1.48
type	-.23	.15	-1.57	.28	.19	1.54	-.03	.23	-.14	.57	.10	5.69***
constant	2.56	.64	3.97	1.21	.85	1.42	-.30	.99	-.31	.29	.55	.52
N	58			58			58			58		
Log Liklihood Ratio	339.5***			140.8***			180***			1190***		

est = estimated coefficient *p< .10
s.e. = standard error **p< .05
t = t statistic ***p< .01

Table 3.6 Ordinary Least Squares Estimation:
Not Controlling for Past Performance
(Sale for Resale)

	rad 78			crit 78		
	est	s.e.	t	est	s.e.	t
nomaj 85	96.74	27.13	3.57***	-.06	.03	-2.28**
t salp	34.06	26.34	1.29	24.76	.02	.10
roa 85	-.01	.00	-2.09**	.00	.00	1.88*
de 85	38.82	.01	.38	-.05	.09	-.53
plant	.02	.05	.45	-.01	.00	-1.89*
semt	.00	.06	2.24**	-.00	.01	-.70
seop	-.00	.08	-3.15***	.00	.01	1.73*
other	.00	.00	2.82***	.00	.00	-1.05
diver	-1.71	.01	-1.95*	.00	.00	1.72*
td	36.88	32.54	1.13	-.02	.03	-.56
prod	-.05	.04	-1.05	-.00	.01	.31
e2x	.07	.02	3.27***	-.01	.00	-3.33***
type	.05	90.66	5.93***	-.00	.08	-2.29***
constant	.04	.04	1.00	.00	.00	4.21
N		58			58	
adj R square		.61			.24	

est = estimated coefficient *p< .10
s.e. = standard error **p< .05
t = t-statistic ***p< .01

*The lower supervision and engineering maintenance spending per megawatt capacity (SEMT), the fewer significant events, safety system failures, and radiation exposure.

*The more supervision and engineering operations spending per megawatt capacity (SEOP), the fewer significant events, safety system failures, and radiation exposure.

Business Strategy. Not taking into account past performance, business strategy variables predict ($p < .05$) four performance indicators:

*The lower the percentage of alternative power consumed by the utility (OTHER), the fewer the 1987-88 significant events, safety system failures, and less radiation exposure.

*The less involvement in transmission and distribution (TD) the fewer 1987-88 safety system actuations and significant events.

Involvement in diversification (DIVER) comes close ($P < .10$) to having a significant negative effect on radiation exposure, such that the more diversified the less the 1987-88 radiation exposure.

Production Experience. In these models, not controlling for past performance, production experience has a much stronger effect than when past performance is controlled. Production experience (E2X) predicts ($p < .05$) four performance indicators:

*The more production experience, the fewer the 1987-88 scrams, safety system actuations ($t=-1.95$, where -1.96 is significant at $p<.05$), the more 1987-88 radiation exposure and the fewer 1987-88 critical hours.

Technology. When past performance is not controlled for, type of technology predicts ($p < .05$) three performance indicators:

*BWRs have more safety system failures, radiation exposure, and fewer critical hours than PWRs.

Comparisons of Tables 3.5 with 3.1, and 3.6 with 3.2 shows these findings do not differ dramatically from those obtained when the models were run without controlling for past performance on the performance indicators. In the comparison, Table 3.1 and 3.5 show that significant predictors of scrams change from a model which includes past performance, and weak significance ($< .10$) of resource availability and resource allocation variables, to a model which excludes past performance and includes experience. In this case, since experience is cumulative, the reason this may become significant it that is may reflect past performance on scrams. For safety system actuations, the only predictor is past performance, whereas when that is not controlled for, a strategy measure (transmission and distribution) and experience become significant. The experience variable may be significant for the same reason as argued in the scram model. The signs of the relationships between past performance and both scrams and safety system actuations (positive signs) are different from the signs of the relationships between experience and scrams and safety system actuations. Apparently the length of the time frame is an important factor in these models. If plants are caught in beneficent and vicious cycles, as we have argued, the cycles appear to be at least as long as the two year (average) lag built into the models. For significant events and safety system failures, the factors which explain performance are stable, regardless of whether the past is used as a control or not for significant events. The reason may be that past performance is not a significant predictor of significant events, as Table 3.1 shows. However it is a predictor of safety system failures.

Tables 3.2 and 3.6 show that the models for radiation exposure and critical hours change more noticeably when past performance is not controlled. When controlling for the past, radiation is explained by factors which include the past, problem identification, and resource allocation ($p < .05$), and weakly ($p < .10$) by measures of resource availability and type of reactor. When not controlling for the past, radiation exposure is explained by measures representing all components of the theory - problem identification, resource availability, resource allocation, business strategy, experience, and reactor type. Critical hours (Table 3.1) goes from being explained (weakly, $p < .10$) by the past, problem identification, type of reactor, and experience ($p < .01$), when the past is controlled for, to being explained by problem identification, experience and type ($p < .05$), and weakly ($p < .10$) by resource availability, resource allocation, and business strategy.

Overall, when the past is not controlled for a few more significant relationships emerge, but their interpretation is muddied by the very strong impact of past performance. The same direction of results emerge with respect to the elements of the theory and the theory as a whole appears to be reasonably useful in providing variables which predict performance and improvement in performance. When the statistical models are further refined and tested (Section 3.2.4), the analyses will focus exclusively on models explaining improvement, where past performance is controlled, due to the almost uniform importance of the past in predicting the future given the time lags used here.

3.2.3 Summary and Conclusions from the Initial Studies

A summary of the significant effects of the different independent variables in the models so far run can be found in Table 3.7. As can be seen, for two of the performance indicators, scrams and safety system actuations, the only good predictor that can be derived from the models tested in this chapter is past performance. Inertia seems to be the only factor influencing the system. NRC regulatory enforcement, resource availability, resource application, utility business strategies, production experience, and production technology – as measured in the models tested in this chapter – have no discernible impact on scrams or safety system actuations. All that governs is prior performance. Poor past performance is reproduced in the present as is good past performance.

The effect of the past validates a basic premise of the behavioral theory. The best way to know the likely tendencies of a nuclear power plant's future behavior is to analyze its past behavior. In the studies conducted

Table 3.7 Summary of Significant* Findings

	Model 1	Model 2	Model 3	Significant
	Controlling for the Past	Not Controlling for the Past	Electrical Construction Work	Predictor in 2 or more models
past 56	tsm 78 (+)	0	tsm 78 (+)	tsm 78 (t)
	tsa 78 (+)	0	tsa 78 (+)	tsa 78 (t)
	tsf 78 (+)	0	tsf 78 (+)	tsf 78 (t)
	rad 78 (+)	0	rad 78 (+)	rad 78 (t)
	crit 78 (+)	0		
nomaj 85	tsf 78 (-)	tsf 78 (-)		tsf 78 (-)
	rad 78 (+)	rad 78 (+)	rad 78 (+)	rad 78 (+)
tsalp	tsf 78 (+)	tsf 78 (+)	tsf 78 (+)	tsf 78 (+)
roa	tse 78 (-)	tse 78 (-)	rad 78 (-)	tse 78 (-)
plant	tsf 78 (+)	tsf 78 (+)	tsm 78 (-)	tsf 78 (+)
semt	tse 78 (+)	tse 78 (+)		tsf 78 (+)
	tsf 78 (+)	tsf 78 (+)	tsf 78 (+)	tsf 78 (+)
	rad 78 (+)	rad 78 (+)		rad 78 (+)
seop	tse 78 (-)	tse 78 (-)	tse 78 (-)	tse 78 (-)
	tsf 78 (-)	tsf 78 (-)	tsf 78 (-)	tsf 78 (-)
		rad 78 (-)		
other	tse 78 (+)	tse 78 (+)	crit 78 (-)	tse 78 (+)
	tsf 78 (+)	tsf 78 (+)		tsf 78 (+)
		rad 78 (+)		
td		tsa 78 (+)		
		tse 78 (+)		
diver		rad 78 (-)		
ecwp	0	0	tsf 78 (+)	
e2x		tsm 78 (-)		
		rad 78 (+)		
	crit 78 (-)	crit 78 (-)	crit 78 (-)	crit 78 (-)
type	tsf 78 (+)	tsf 78 (+)		tsf 78 (+)
N	51-58	58	41-46	

* >.05

0 not in model

here, the lag time averages approximately 2.5 years. That is not a long time to turn a plant around, but for regulators is reasonable time for closely monitoring, seeking action, and following up. In an empirical sense, the finding is comforting in that it is simple and direct and seems to exclude surprises, but in a sense it is very disconcerting in that it is only a statistical relationship that has been true in the aggregate (i.e. for nuclear power plants as a whole) in the past (i.e. 1985-89). Whether it will be true in the future for a <u>specific</u> plant and whether favorable or unfavorable surprises are not likely to take place (e.g. an unfavorable surprise relating to a major mishap at an apparently well-functioning individual plant), cannot be determined with precision based on these statistical tests. Therefore the finding that the past generally reproduces itself in the present should not lead to regulatory laxity based on the assumption that problem plants are known and that otherwise the situation is well under control. The statistical findings simply suggest that plants that have had problems in the past may be more likely to have problems in the future and should continue to be watched closely by NRC inspectors and utility managers.

The past, moreover, is not the only factor governing some of the performance variables. The profile for significant events and safety system failures suggests that more than the past has to be addressed. With respect to these two performance indicators, the allocation of resources to the category of expenditures called operations supervision and engineering as opposed to the category called maintenance supervision and engineering is of considerable importance. Managerial decisions about how to spend utility money have an effect on nuclear power plant performance. Allocating money to different classes of activities improves or degrades performance.

So too, the managerial decisions about which strategy the utility is to pursue have an impact. Emphasizing alternative power consumption appears to send the wrong message to the nuclear personnel in a utility. It states that nuclear is not important. Perhaps this results in demoralization and lack of commitment to the nuclear program since it is associated with a situation wherein more significant events and safety system failures are likely to occur. Of course, here too untangling the web of causation in what is only a snapshot picture of nuclear performance at one point in time (1985-89) is difficult. Perhaps it is poor performance in the past that leads to a de-emphasis of nuclear and not the other way around. Again, this possibility suggests that vicious and beneficent cycles may be at work and that it is very difficult to make improvements at nuclear plants. The implication is that NRC inspectors and utility managers have to watch for changes both in utility spending patterns and utility business strategies, and assess their impact on nuclear programs. When these changes take place, further investigation of the nuclear utility may be called for (see the interview protocol in Appendix E as an example of the kinds of questions that might be asked).

But it is not only management in its resource allocation and strategic decisions that have an impact. The results clearly suggest that NRC regulatory programs have an influence on some indicators. Responsibility for safe operation of nuclear power plants, as the economic theory establishes and Congress has mandated, is shared between private utilities and government regulatory agencies, though ultimate responsibility for making the changes consistent with safety rests on the plants and utilities. The public's interest in the safe operation of nuclear power plants is guaranteed by public officials. The findings are interesting in that they show which indicators -- safety system failures and radiation -- the government's regulatory programs seem to be influencing. These may be indicators in which the utilities have less of an interest because they are not as closely tied to production, as for instance an indicator like scrams.

Thus, the theory combining economic and behavioral elements developed in Chapter 2 fits for all the performance indicators. However, various elements in the theory have different impacts on different indicators. In the 1985-89 period, safety system failures are a function of their own past values and variables representing regulation (NOMAJV and TSALP), resource allocation (PLANT, SEMT, and SEOP), and utility business strategies (OTHER). Significant events are a function of variables representing resource availability (ROA), resource allocation (SEMT and SEOP), and utility business strategies (OTHER). Radiation is a function of its own past values and variables representing regulation (NOMAJV) and resource allocation (SEMT). Scrams and safety system actuation are a function of their past values. Critical hours is a function of production experience.

The theory's basic premise is confirmed in that different performance indicators have different predictors. This is what the behavioral theory suggests about different performance dimensions. The different performance indicators are not highly related nor do they have the same predictors. The theoretical framework therefore has proven to be useful for examining variations in performance. As a theoretical framework, it appears to have great promise as a diagnostic tool for regulators and others interested in analyzing the industry's performance.

3.2.4 Building Refined Models of Change in Performance Indicators

The purpose of the analyses in this section is to construct more refined statistical models of the performance indicators and critical hours for purposes of prediction. Such a model represents some of the concepts differently to see if the results are stable. The analyses build from the findings of the initial analyses, reported in the preceding section (3.2.3). What is presented represents an attempt to construct the best statistical models possible for each performance indicator using variables derived from the theory. Determination of what appear to be the "best" models to date, given the theory, is based on these criteria: (1) they provide the best fit to the data (or explain the most variance in the data); (2) where alternative variables are available, they employ variables with the most face validity, making them more interpretable; and (3) where possible they employ variables that are less prone to accounting manipulation in financial reports than comparable variables may be.

While it may appear merely that tests of the same ideas are being run in different ways, the reader should note that the progression of tests is quite deliberate. The progression of tests with slight variations in variables allows the researchers to build better models, but perhaps more importantly from a prospective user's point of view, the consistency in the patterns of findings suggests that the theory underlying these analyses is really quite robust. As will be argued later, for prospective users, there is greater value in a validated theory, comprised of a set of specific explanatory concepts, than in a single variable.

In this section the results are presented and discussed by performance indicator. To further demonstrate the validity of the models, graphs are presented which predict the values of the dependent variables from the models constructed. This allows the reader to judge the extent to which the values predicted by the models conform to a reasonable range of what would be expected in the dependent variables.

3.2.4.1 Method of Estimation of the Statistical Models

In order to build refined models that predict change in the performance indicators, statistical models have been estimated using each of the performance indicators and critical hours as dependent variables and independent variables representing all of the concepts set forth in the theory. As in the tests described in Section 3.2.1, event count models are estimated for scrams, safety system actuations, safety system failures, and significant events. Ordinary least squares is used to estimate the models for radiation exposure and critical hours. Each of the models control for past performance of the safety indicators and therefore the independent variables in the model help identify the factors that led to change in performance by the plants.[5]

In order to aid in the interpretation of the results from the Poisson estimates of the safety models, graphs have been constructed.[6] The graphs help explain the magnitude of the relationship between the dependent and independent variables. The graphs are plotted by using the estimated coefficients from the Poisson models to predict the values of the safety measures. A different graph is constructed for each independent variable that is found to have a significant impact on the dependent variable. In order to control for the impact of the other variables in the equation, the values of the dependent variable are predicted by multiplying the mean of each independent variable in the equation by the corresponding value of the estimated coefficient for each independent variable. The variable of interest is then varied across the range of values that it took to provide predicted values for the dependent variables.

3.2.4.2 Definition of Predictor Variables

The predictor variables have been previously explained (see 3.1.2.2). When additional predictor variables are used to cross-validate the results, they are defined as they are introduced.

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[5] The Poisson models are estimated using the 'poisson' procedure in the SST software program as in the prior model estimations.

[6] The graphs have been constructed using the plotting function in the Mathematica software program installed on a SUN workstation.

3.2.4.3 Refined Statistical Models for Performance Indicators

The results of the analyses are in Tables 3.8-3.9. The goal of this section is to develop the best models possible for each of the variables, in light of the current theory and available data. Therefore the results will be presented and discussed by focussing on the best model for each of the performance indicators. In the discussion, the interpretation will focus on what explains improvement in performance (i.e. positive change instead of negative change). The interpretation can be readily reversed to explain degradation.

Scram Model:

The fewer scrams a plant has in the past, the fewer it is likely to have in the future; the more production experience it has, the fewer likely scrams it will have. Each of these predictors are significant at $p< .05$. Another theoretical concept which is also related to scrams ($p< .10$) is resource application, represented by plant costs. As the cost of the plant increases, the number of scrams decreases. This indicates that as the nuclear utilities spend more money on building, improving and re-structuring plants, they also lower the number of scrams. The model suggests that a well-built and well-maintained plant has fewer incidents of scrams.

Figure 3.1 shows that plants with middle range costs experience three to four scrams for 1987-1988, on average. Those plants with the highest plant costs had approximately two scrams per year. Figure 3.2 demonstrates that operating experience helps reduce scrams by three on average. Figure 3.3 suggests that having a low number of scrams in the 1985-86 period led to approximately three scrams in the 1987-1988 period. Those plants experiencing a high number of scrams, 20 to 25, had a relatively high number in 1987-88, seven to eight. In the statistical models, scrams are not predicted by other variables drawn from the theoretical framework.

Significant Event Model:

Significant events are negatively associated ($p< .05$) with ROI, return on investors' capital. Therefore, the more profitable the utility is the less likely its plants will experience significant events. Resource availability in the past leads to fewer significant events in the future. Figure 3.4 suggests that unprofitable utilities had two to five significant events between 1987-88, while profitable utilities had less than two.

The results also indicate resource application can help reduce the number of significant events a plant experiences. The more that supervision and engineering expenses are dedicated to operations (as opposed to maintenance) as measured by the ratio of SEOP and SEMT, the fewer significant events a plant ~~will~~ have ($p< .05$). Figure 3.5 shows that utilities spending the most on RSEOP reduce significant events by two.

In addition, past performance has an important influence ($p< .05$) on current performance. This is different than in the prior analyses of significant events. Figure 3.6 indicates that plants having a low number of

Table 3.8 Poisson Regression Estimation: Alternative Measures of Resource Availability (ROI & OPEFF) and Resource Allocation (RSEOP)

	Scram		SE		SSA		SSF	
Independent Variable	Est. Coef.	t-Stat	Est. Coef.	t-Stat.	Est. Coef.	t-Stat.	Est. Coef.	t-Stat.
Nomajv85	-0.020	-0.418	-0.059	-0.626	-0.136	-1.672	-0.084	-2.444***
Salp	-0.016	-0.390	5.916	0.856	-0.076	-1.226	0.185	5.043***
ROI	4.988	0.601	-28.069	-2.180**	-6.044	-0.504	-11.992	-1.924*
Opeff	4.627	0.656	15.802	1.436	10.228	1.030	12.765	2.280**
Plant	-0.833	-1.778*	0.131	0.179	0.123	0.199	-0.088	0.225
Rseop	-0.058	-0.152	-1.313	-2.062**	0.868	1.455	-1.720	-5.791***
Prod	0.839	0.986	1.357	1.021	1.557	1.271	-0.468	-0.687
Td	0.033	0.802	-0.026	-0.409	0.005	0.086	-0.019	-0.504
Diver	10.012	-0.637	5.360	0.209	-6.316	-0.326	-0.505	-0.040
Other	1.970	1.095	3.486	1.281	-1.734	-0.638	2.928	2.144**
E2x	-0.731	-2.071**	0.522	0.971	-0.661	-1.239	0.289	1.101
Type	0.002	0.009	0.180	0.640	0.435	1.968**	0.571	4.490***
Past	0.037	2.604***	0.083	2.172**	0.118	3.070***	0.025	1.792*
Constant	0.723	1.064	1.577	1.478	0.180	0.190	1.367	2.593
N	58		58		58		58	
Log Liklihood & Ratio	174***		50***		80***		1156***	

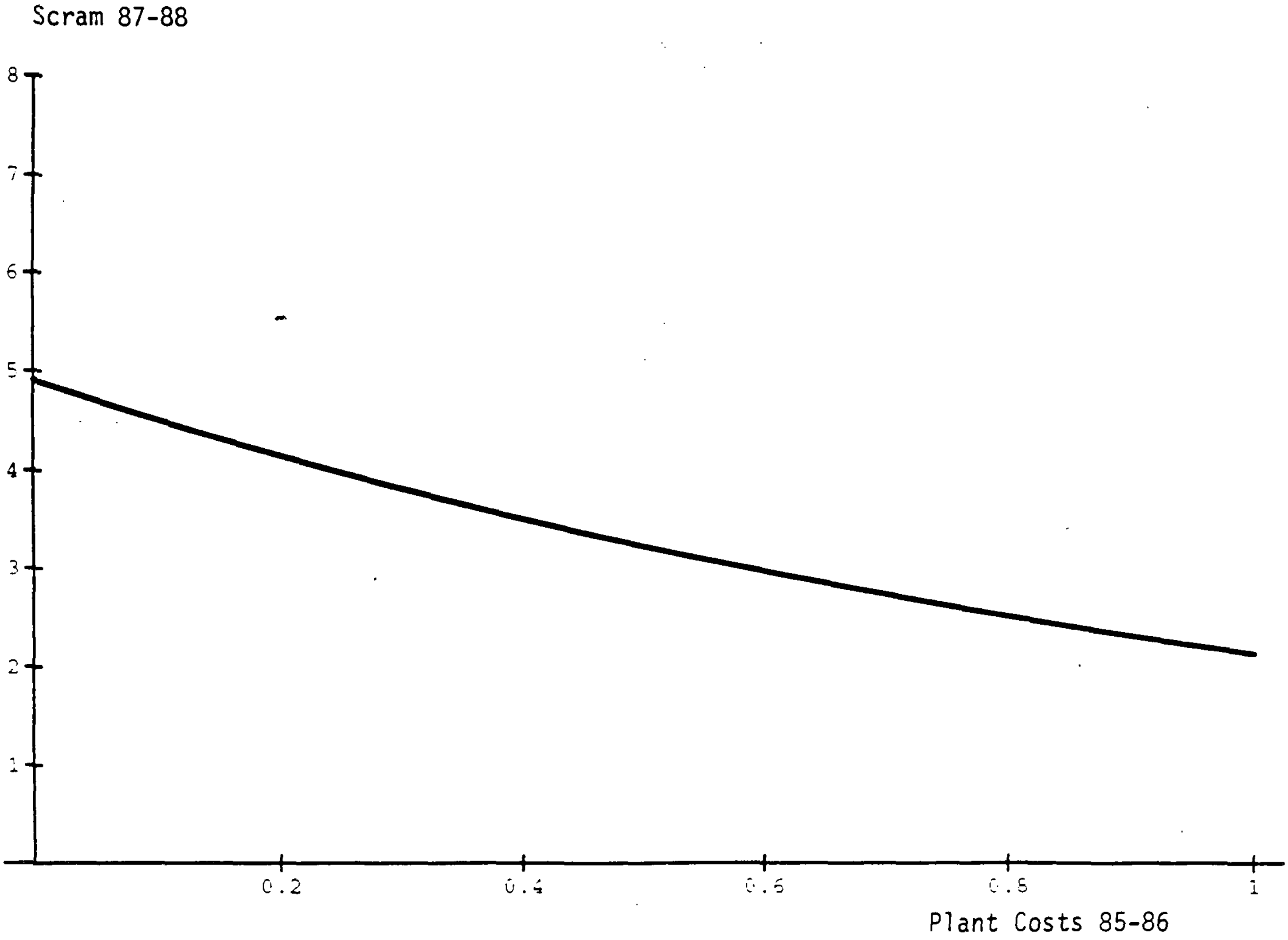
*p< .10
**p< .05
***p< .01

Table 3.9 Ordinary Least Squares Estimation: Alternative Measures of Resource Availability (ROI & OPEFF) and Resource Allocation (RSEOP)

Dependent Variable:	Radiation Exp. (1987-88)		Critical Hours. (1987-88)	
Independent Variable	Est. Coeff.	t-Stat	Est. Coeff.	t-Stat
Nomajv85	123.520	4.046***	-335.741	-1.135
Salp	-34.586	-1.312	15.731	0.061
ROI	3267.160	0.713	11334.100	0.216
Opeff	-3176.760	-0.801	-1654.090	-0.037
Plant	-490.506	-1.855*	-2841.200	-1.147
Rseop	-328.318	-1.361	2149.870	0.868
Prod	-276.245	-0.626	2748.420	0.550
Td	21.403	0.803	153.954	0.502
Diver	-12087.000	-1.633	107273.000	1.269
Other	125.087	0.084	3831.940	0.255
E2x	229.919	1.030	-5836.910	-2.705***
Type	160.054	1.301	-1150.540	-1.102
Past	0.510	5.190***	0.626	2.700***
Constant	651.306	1.438	6194.730	1.200
N	49		53	
Adjusted R-squared	0.74		0.25	

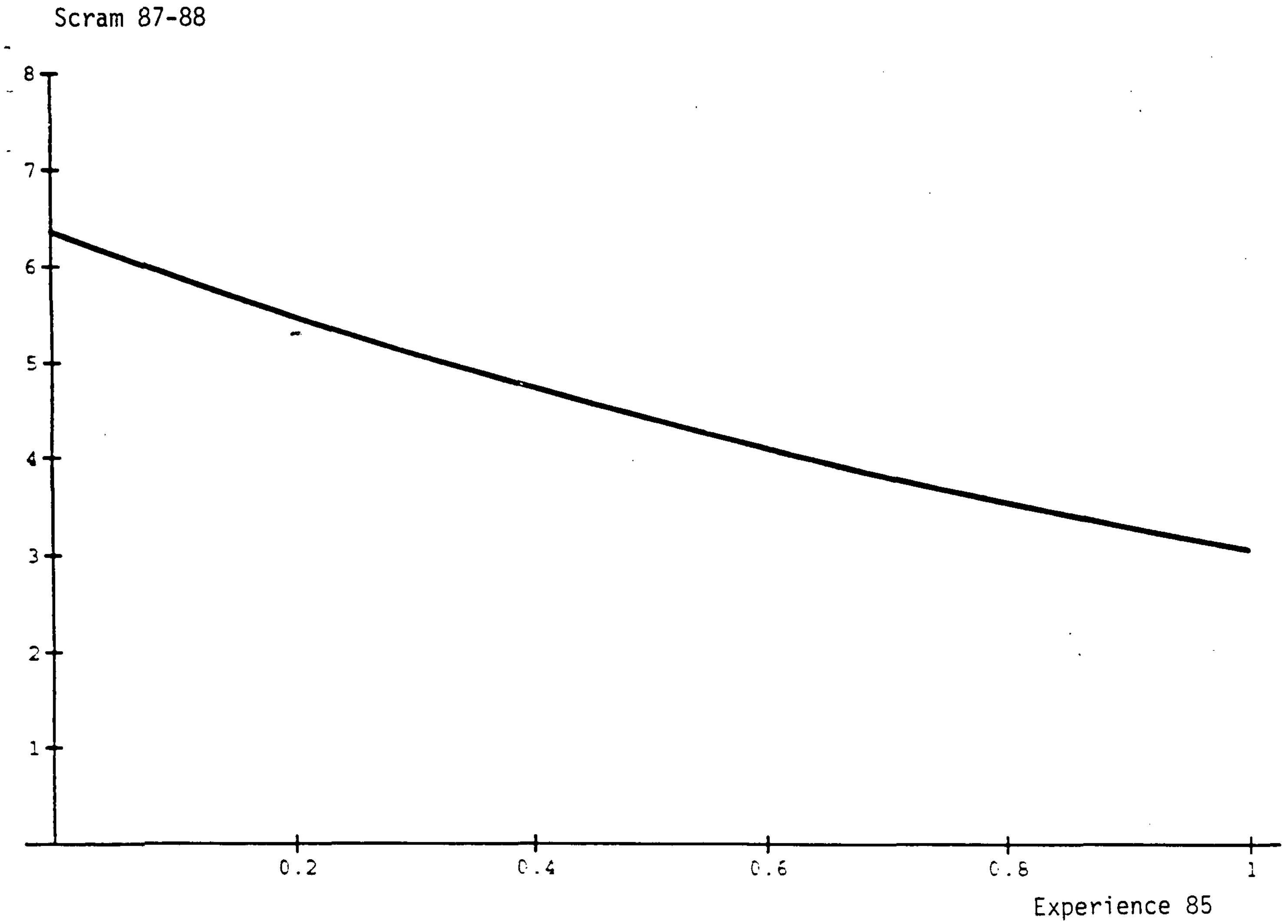
*p< .10
**p< .05
***p< .01

Figure 3.1



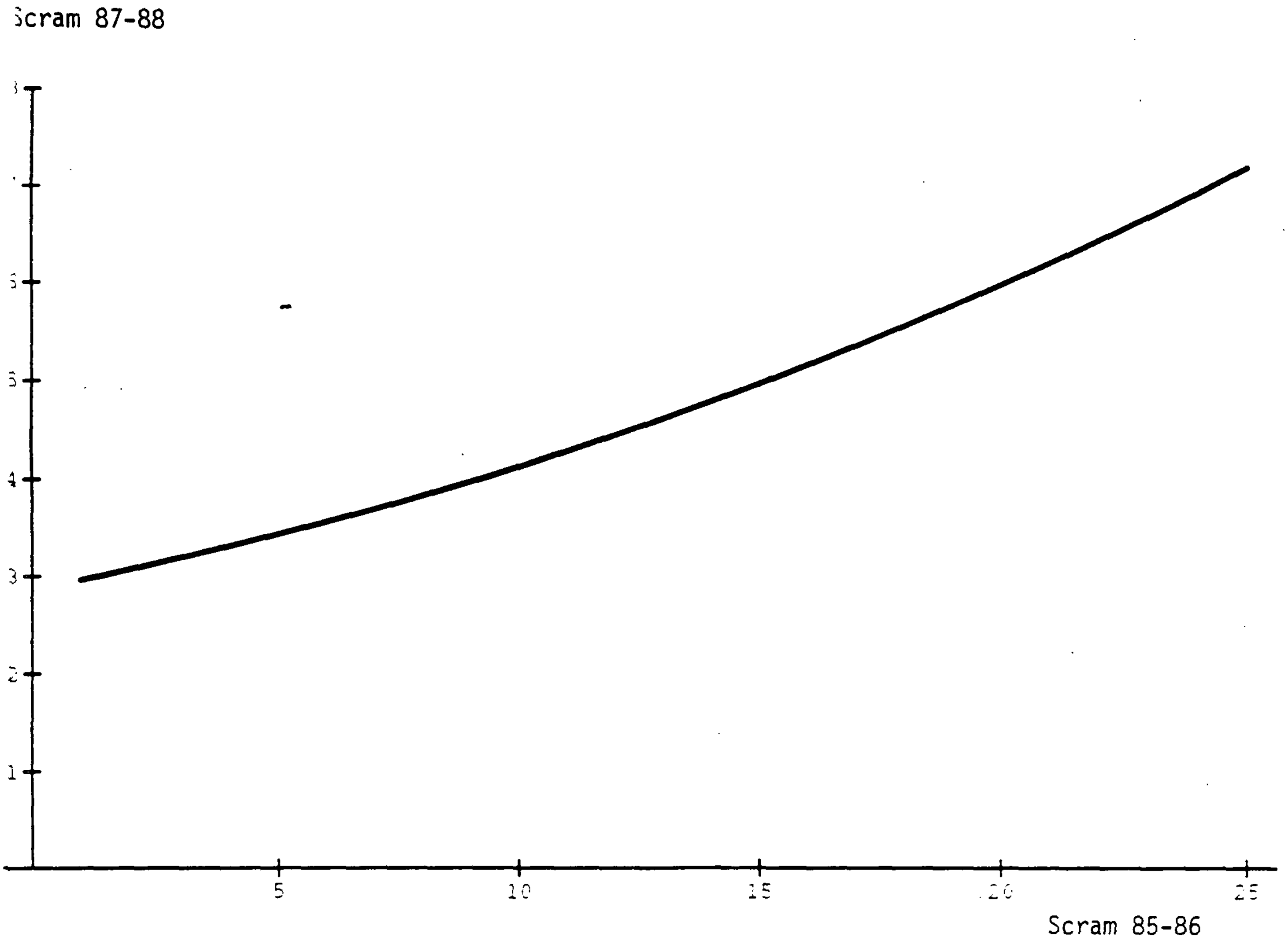
Predicted Values of Scrams 1987-88, varying Plant Costs, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.2



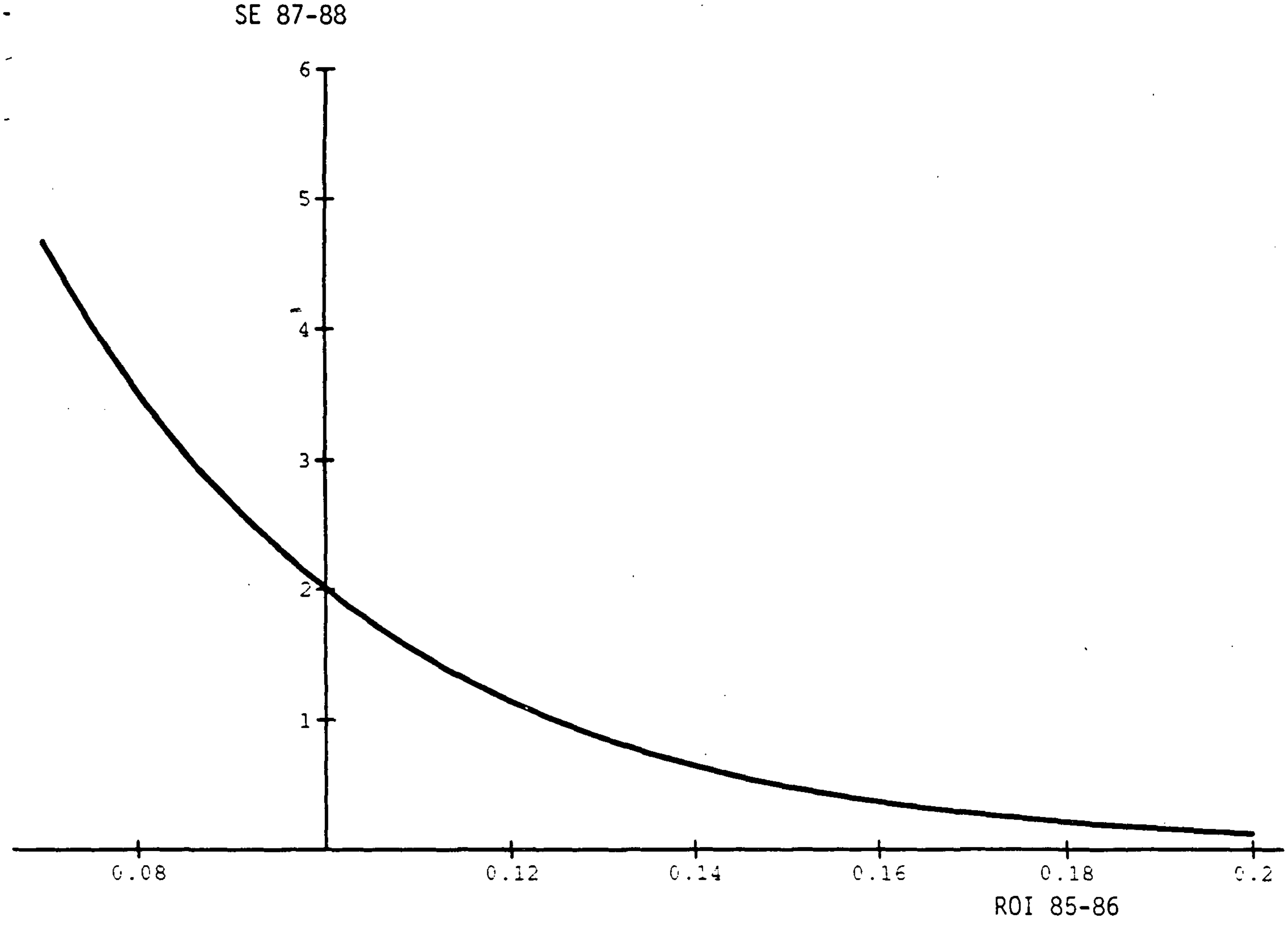
Predicted Values of Scrams 1987-88, varying Experience, 1985. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.3



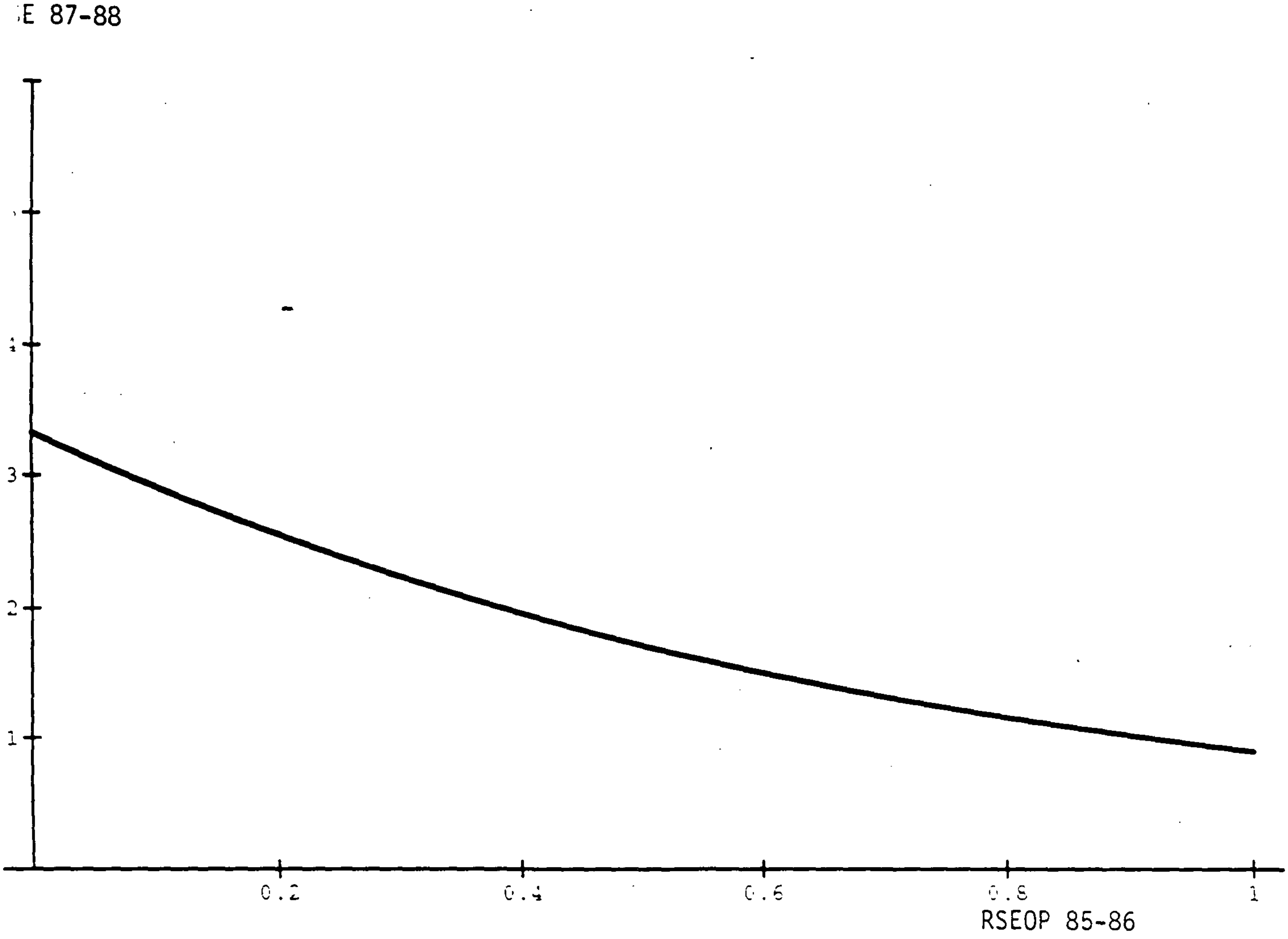
Predicted Values of Scrams 1987-88, varying Scrams, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.4



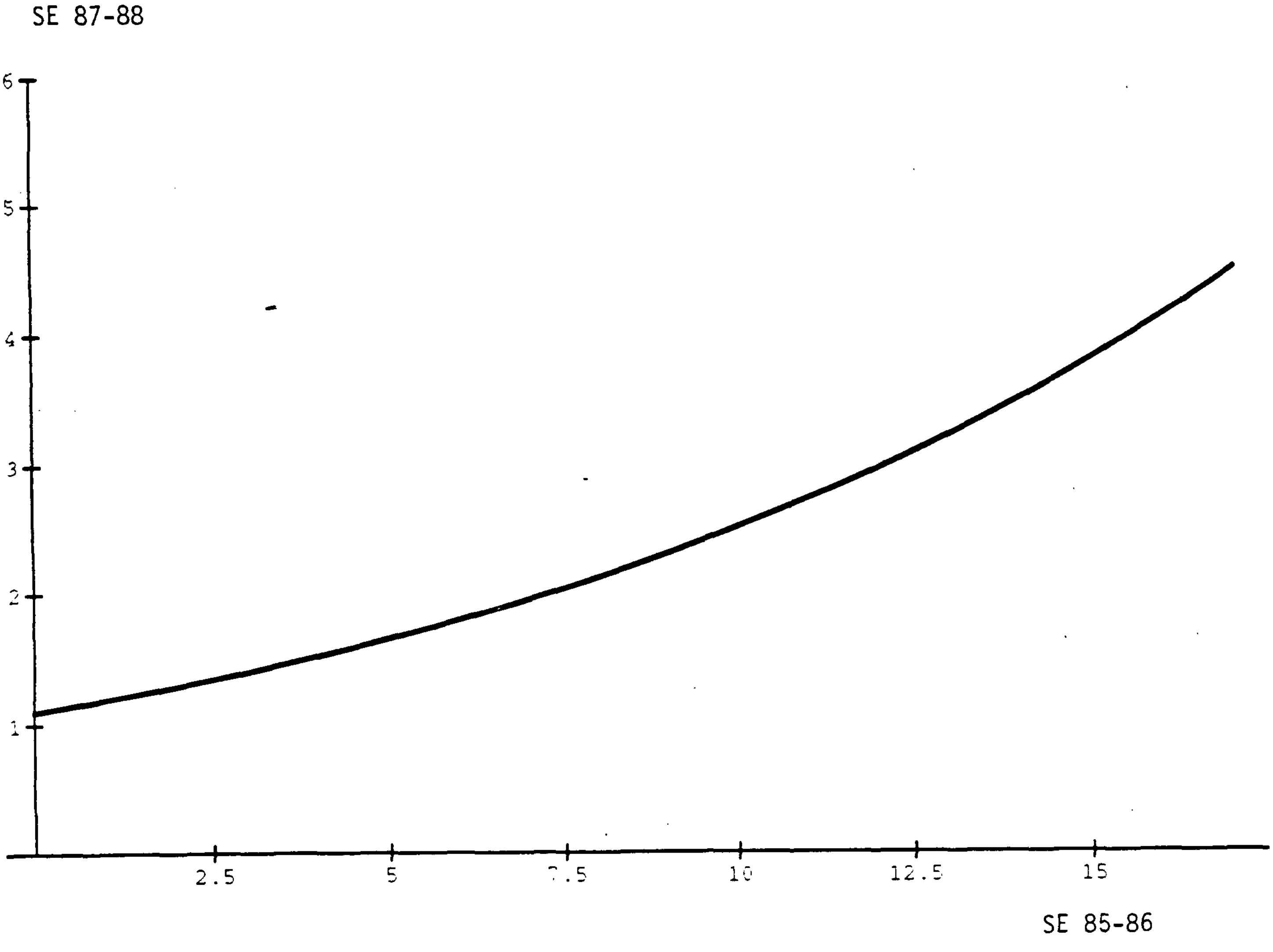
Predicted Values of Significant Events 1987-88, varying ROI, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.5



Predicted Values of Significant Events 1987-88, varying RSEOP, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.6



Predicted Values of Significant Events 1987-88, varying Significant Events, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

significant events in the 1985-86 period had only one to two significant events in the 1987-1988 period. Plants that experienced a high number of significant events, 12 to 15, had a relatively high number in 1987-88, four to five. However, significant events are not influenced by other factors such as the NRC problem identification and utility business strategies. The lack of effect of the business strategies is different than in prior models.

Safety System Actuation Model:

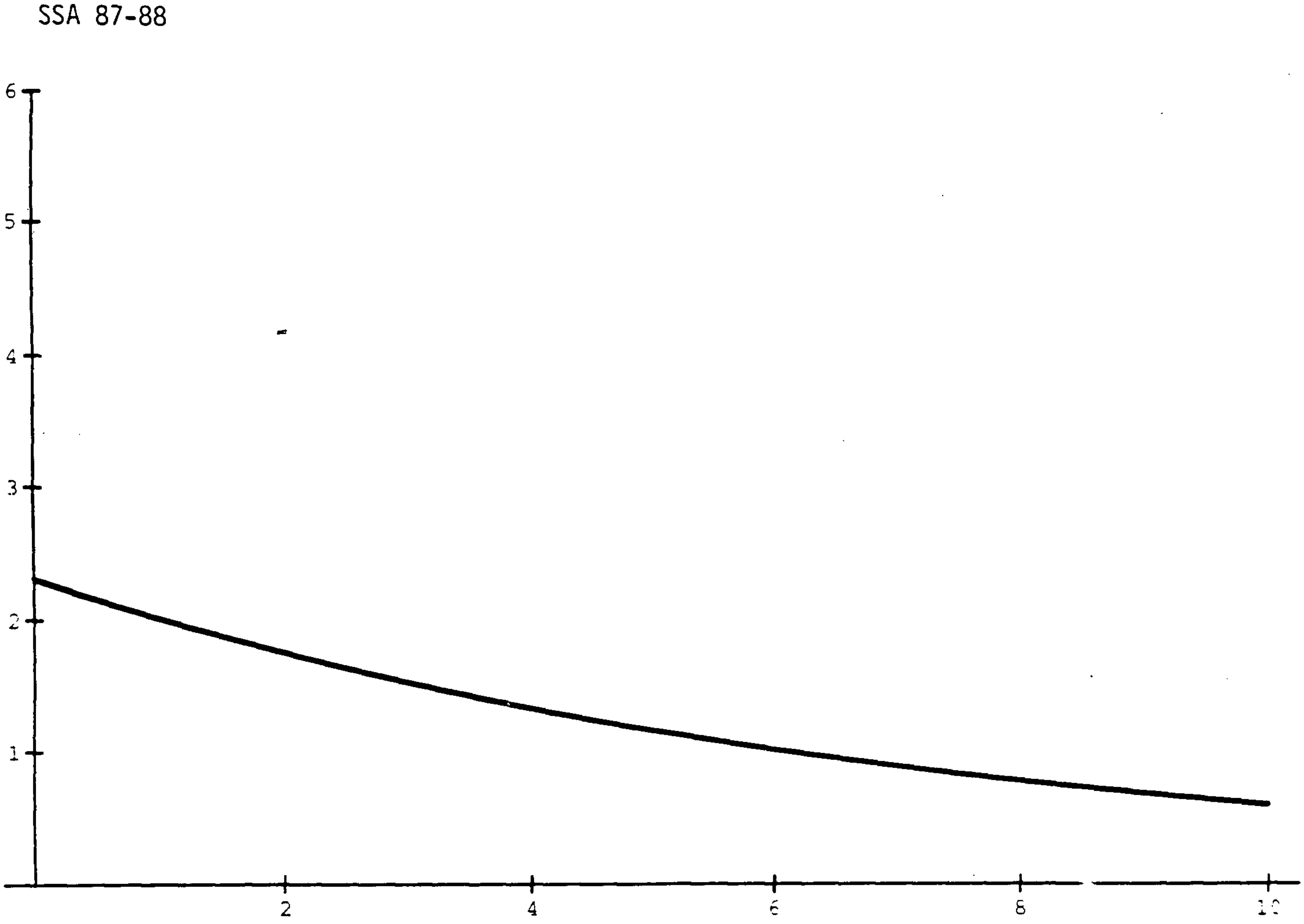
For safety system actuations, problem identification has some impact on future performance. Table 3.8 shows that the number of major violations was negatively related to safety system actuations ($p< .10$), suggesting that violations in the past lead to better performance in the future. It could be interpreted that by issuing citations, the NRC sends a message to the violating plants and, on average, plants address the problem and experience fewer safety system actuations in the future. However, Figure 3.7 shows that the amount of improvement is small, since those plants with a lot of violations only experience one fewer actuation on average than plants with a small number of violations. For this model, past performance on safety system actuations had a significant impact on future performance ($p< .05$). As indicated in Figure 3.8, plants with few safety system actuations (0-2) in 1985-86, had slightly more than 1 in 1987-88, while plants with a high number of safety system actuations (10-12) in 1985-86 experienced four to five actuations in 1987-88. In this model, the type of reactor also had a significant impact on safety system actuations ($p< .05$). PWR's experience fewer actuations than BWR's.

Safety System Failure Model:

Safety system failures are influenced by a variety of the concepts in the theoretical model. Both of the NRC problem identification variables are significant here ($p< .05$). This model suggests that as the lagged SALP score improves, the number of safety system failures decreases (Figure 3.9). Further as the number of past major violations increases the number of safety system failures decreases for the range found in the data (Figure 3.10).

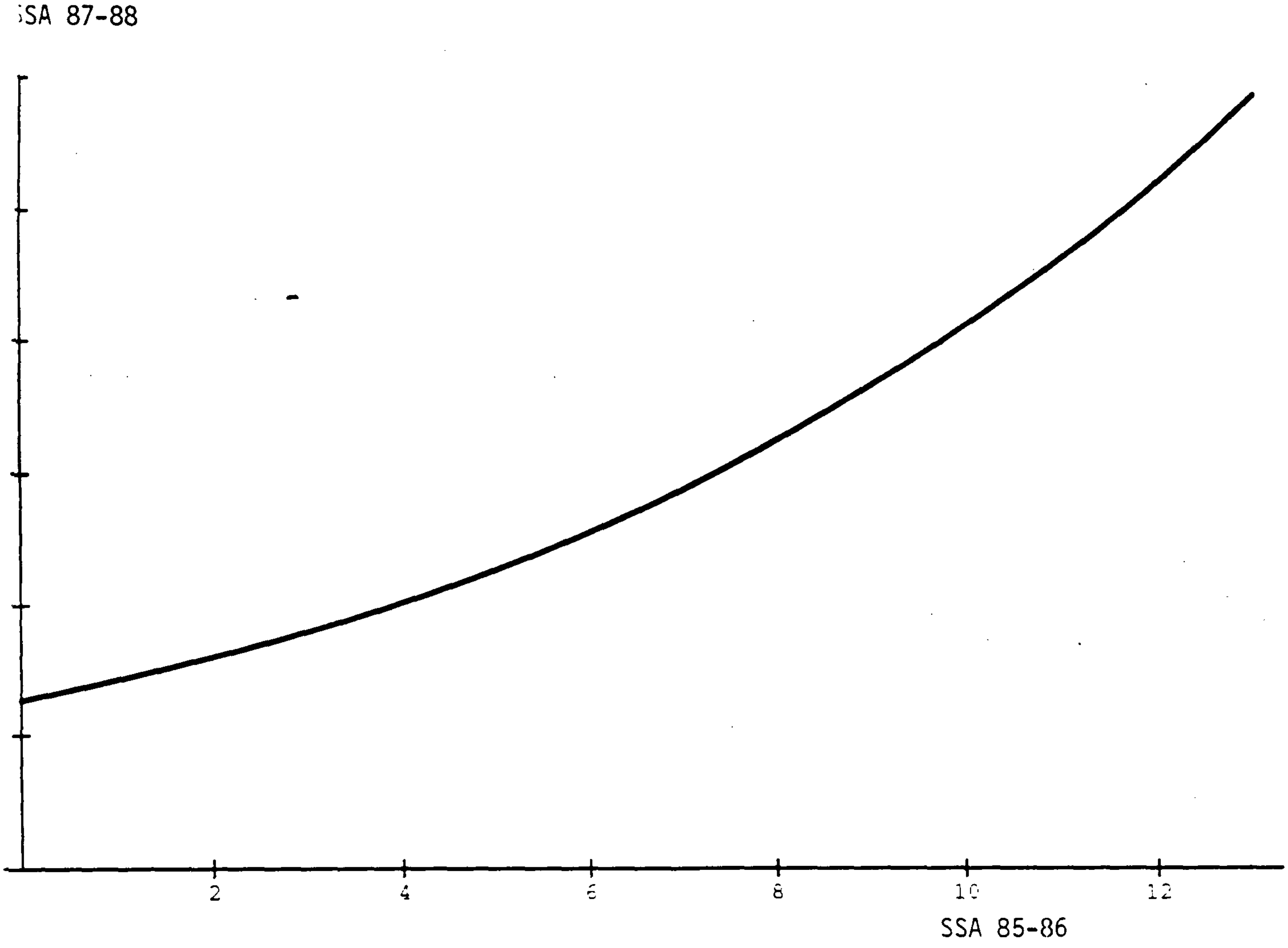
There is an influence of the resource availability variables on safety system failures. Both ROI ($p< .10$) and operating efficiency ($p< .05$) were significantly related to safety system failures. For ROI, the more profitable the utility was the fewer safety system failures it had (see Figure 3.11). On the other hand, operating efficiency was positively related to failures. Operating efficiency (Opeff) is the ratio of earnings before taxes to total assets employed. If earnings are high relative to total assets, it may suggest that expenses are being minimized and the benefits of running the assets are being harvested, with less concern for maintaining safety systems in an effective and efficient state. Another interpretation is that some slack in the resources and a willingness to spend them is necessary to be able to improve the plant's performance (see Figure 3.12). When resource availability is measured as ROA and debt no significant relationship with safety system failures are found.

Figure 3.7



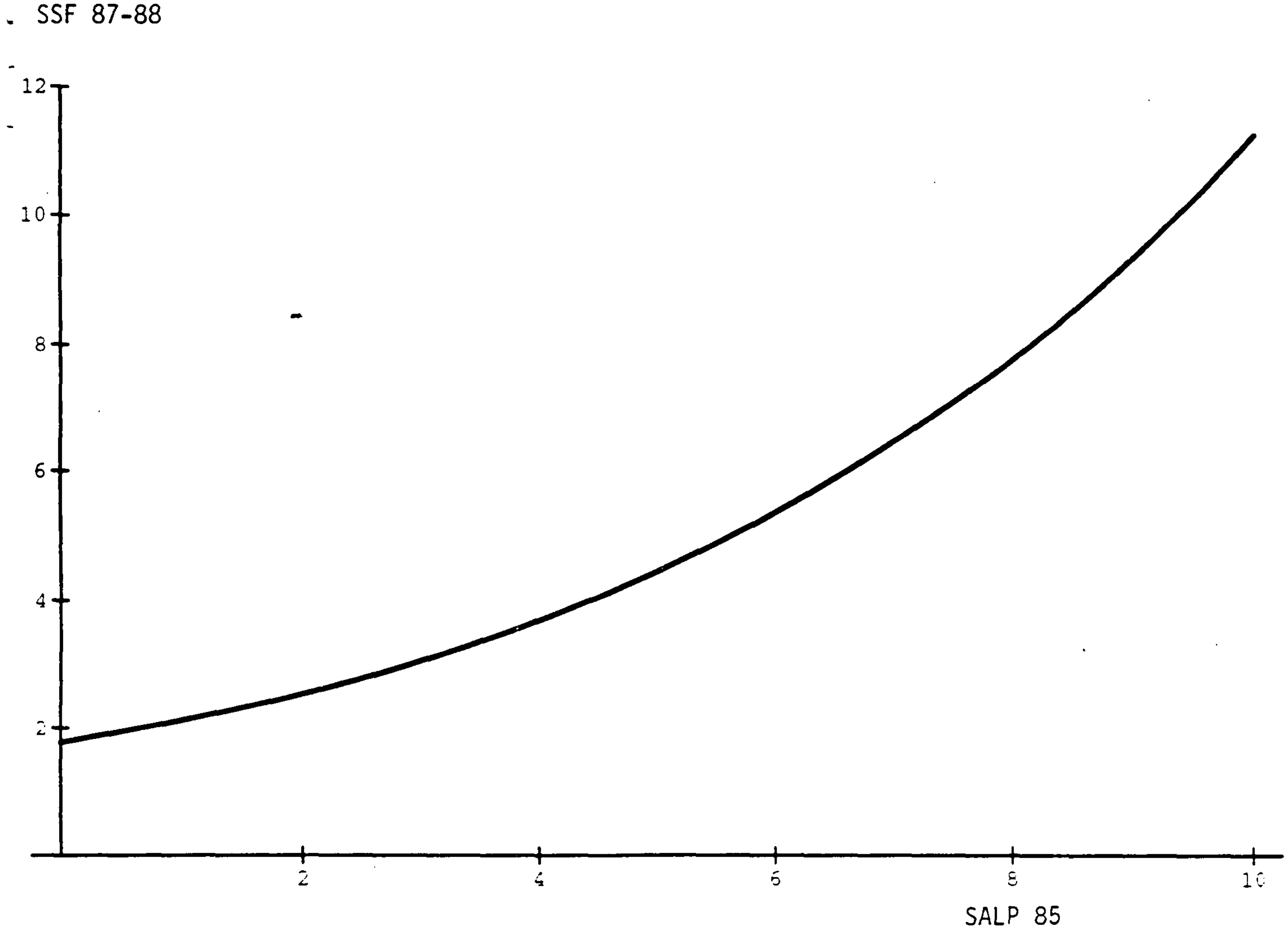
Predicted Values of Safety System Actuations, 1987-88, varying Number of Major Violations, 1985. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.8



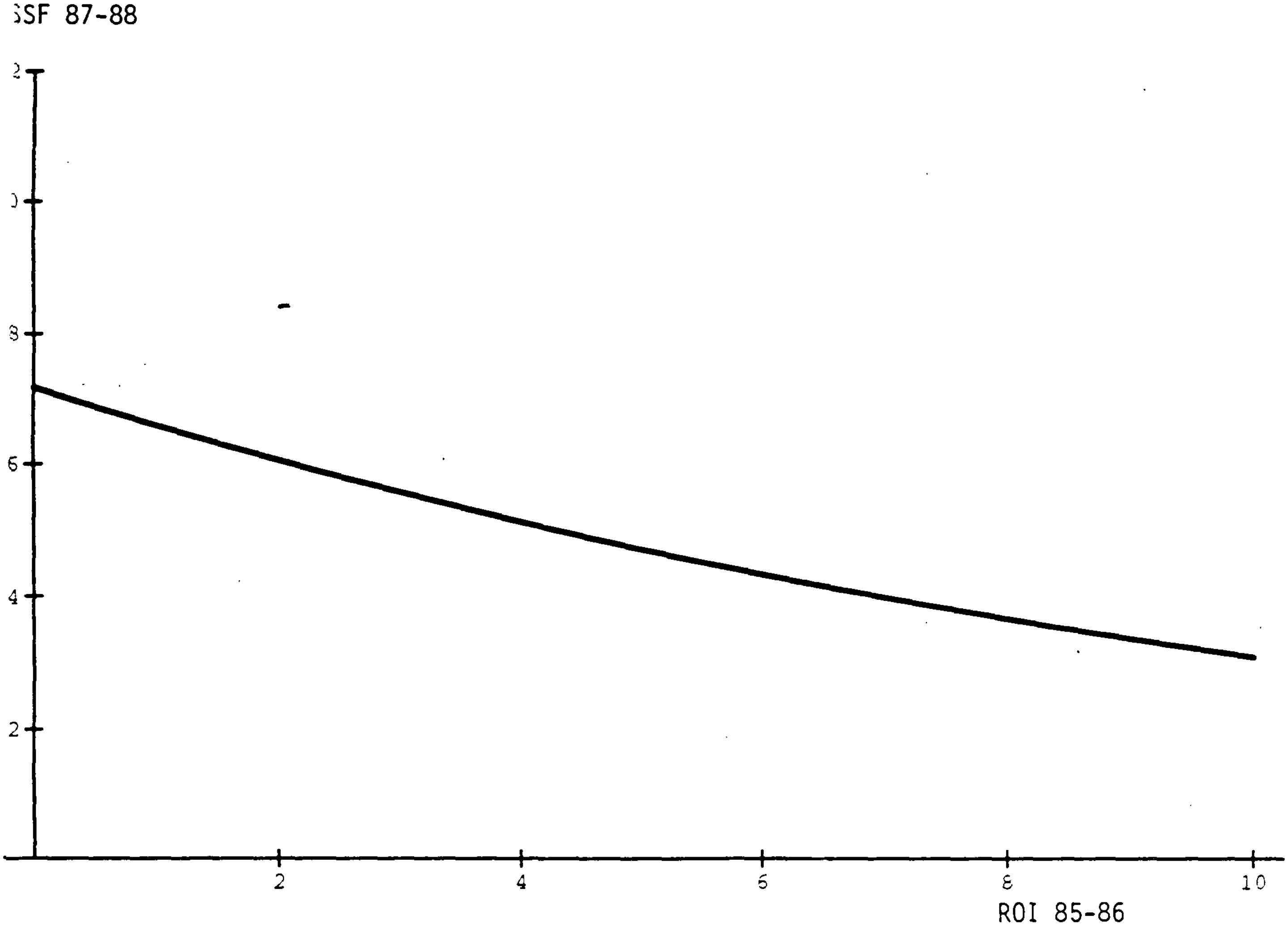
Predicted Values of Safety System Actuations, 1987-88, varying Safety System Actuations, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.9



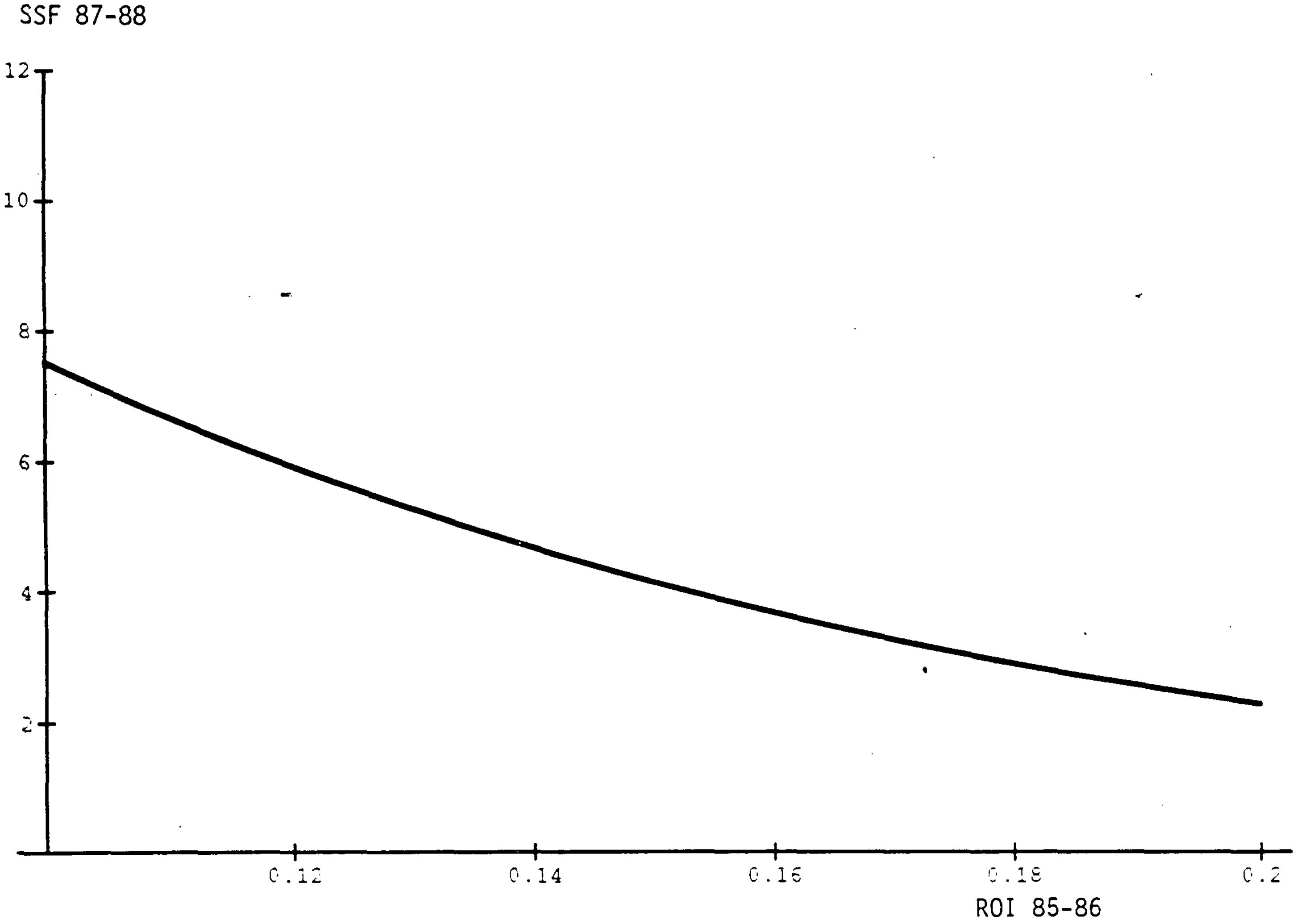
Predicted Values of Safety System Failures, 1987-88, varying SALP Scores, 1985. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.10



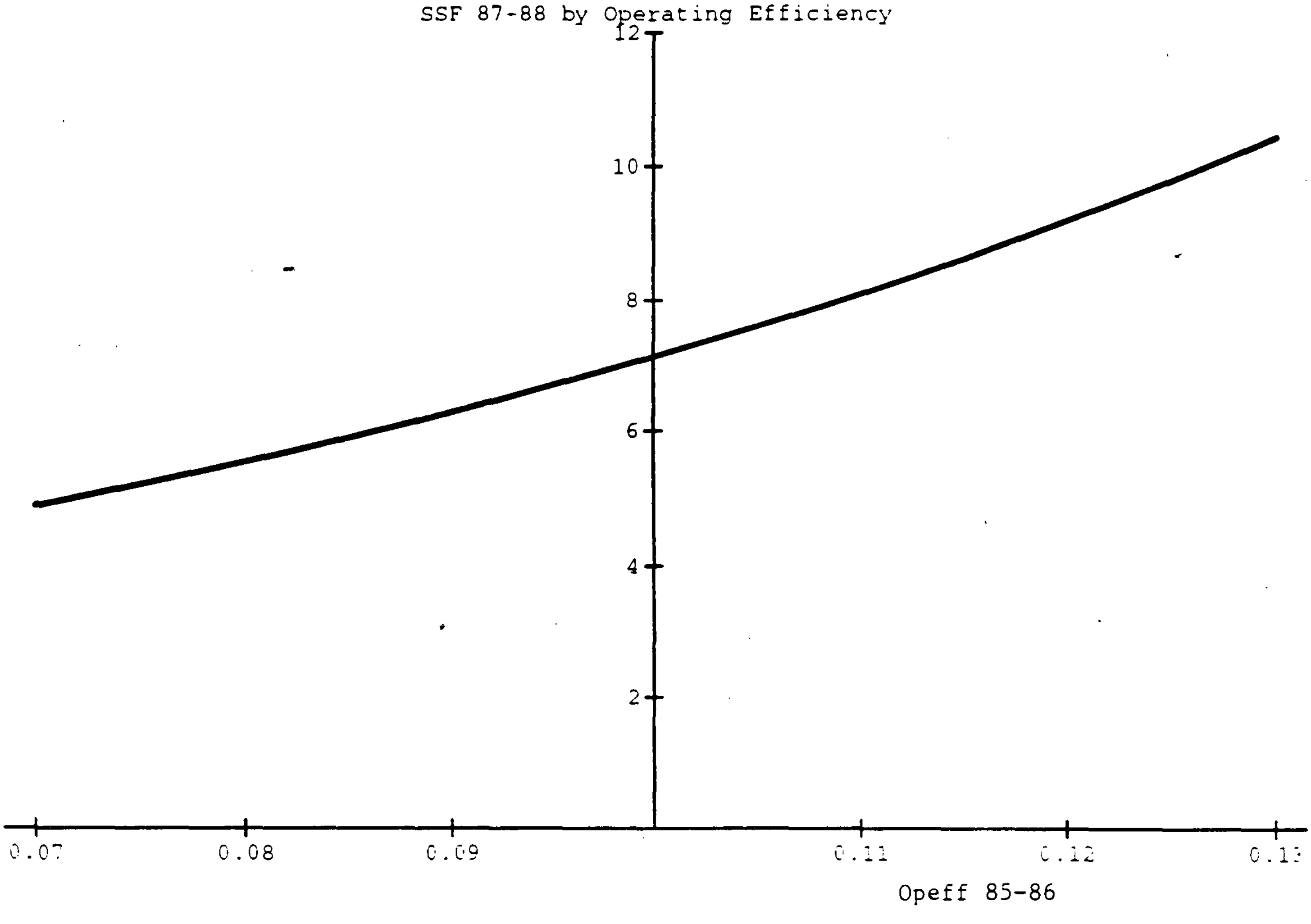
Predicted Values of Safety System Failures, 1987-88, varying Number of Major Violations, 1985. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.11



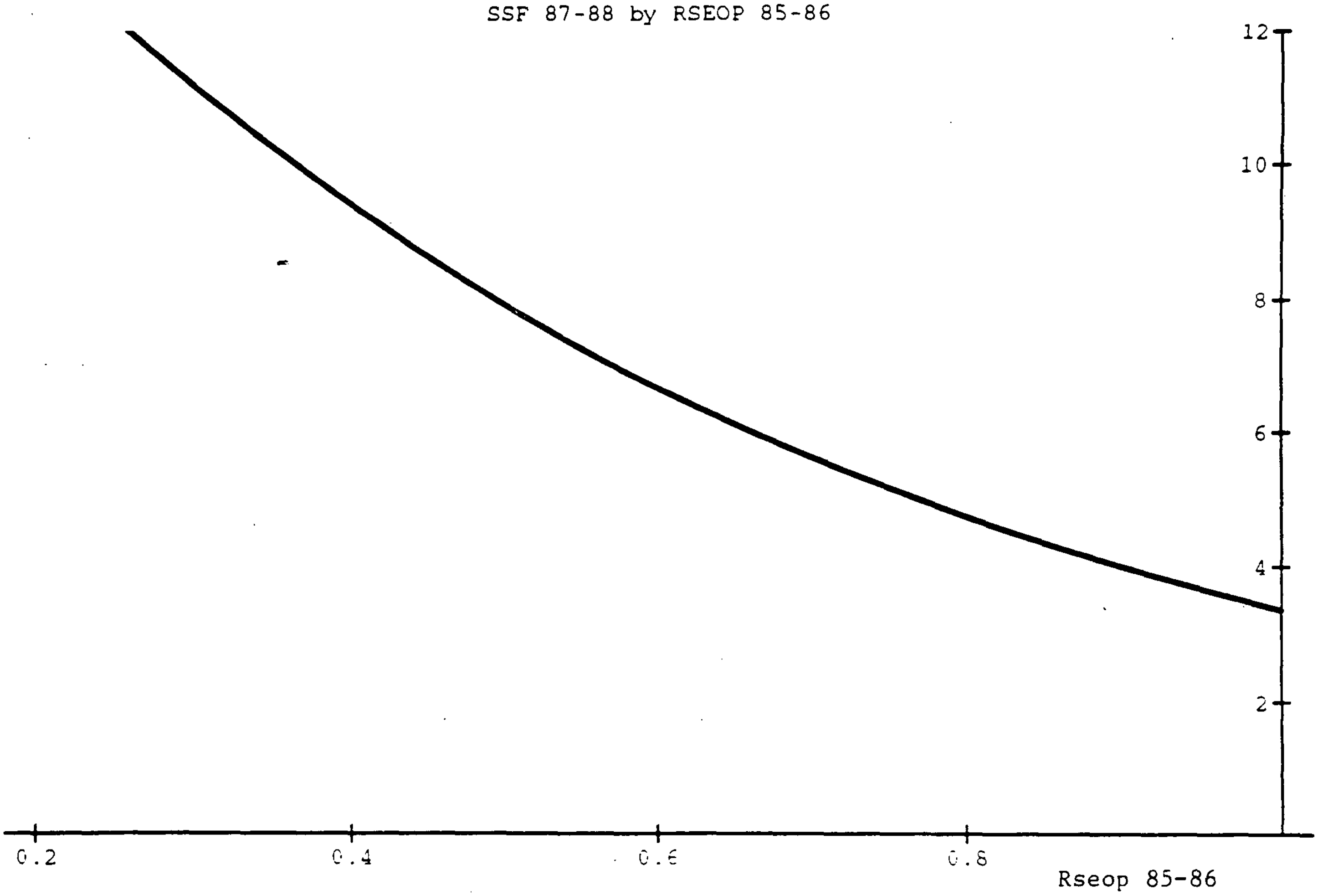
Predicted Values of Safety System Failures, 1987-88, varying ROI, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.12



Predicted Values of Safety System Failures, 1987-88, varying Operating Efficiency, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.13



Predicted Values of Safety System Failures, 1987-88, varying RSEOP, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

The nuclear utility application of resources also plays a significant role in this model. As in the significant events model, higher spending on RSEOP was associated with fewer safety system failures ($p< .05$). On average, those spending more on RSEOP had seven to eight fewer safety system failures than those with low spending (see Figure 3.13).

In addition, other power generation, plays an important role in this model ($p< .05$). As the utility focuses on other power generation technologies, it may divert attention from nuclear power generation, thus resulting in higher safety system failures (see Figure 3.14).

Finally, past safety system failures ($p< .10$) and the type of power plant ($p< .05$) are present in the model predicting change in future safety system failures. Plants with few past safety system failures tend to stay good while plants with many previous failures tend to show more in the future. Interestingly, Figure 3.15 shows that this relationship is linear rather than exponential, indicating that it is no harder to improve or degrade at either the high or low end of values represented in the data. For the type of plant, the model suggests that plants with pressurized water reactors have a lower incidence of safety system failures than boiling water reactors. The refined model for safety system failures shows significant predictors from each of the major theoretical groups of factors (problem identification, resource availability, resource allocation, business strategies). It suggests not that the theory works "better" than for other dependent variables (for all the models are highly significant) but that all the factors in the theory work in combination to allow prediction of safety system failure. The model predicts that plants that will have the fewest safety system failures in the future are pressurized water reactors which had few failures in the past, received good (low) salp scores, had good earnings, expended resources in such a way as to favor supervision engineering operations expenditures versus supervision engineering maintenance expenditures, and do not distract themselves by pursuing "other" alternative forms of energy production.

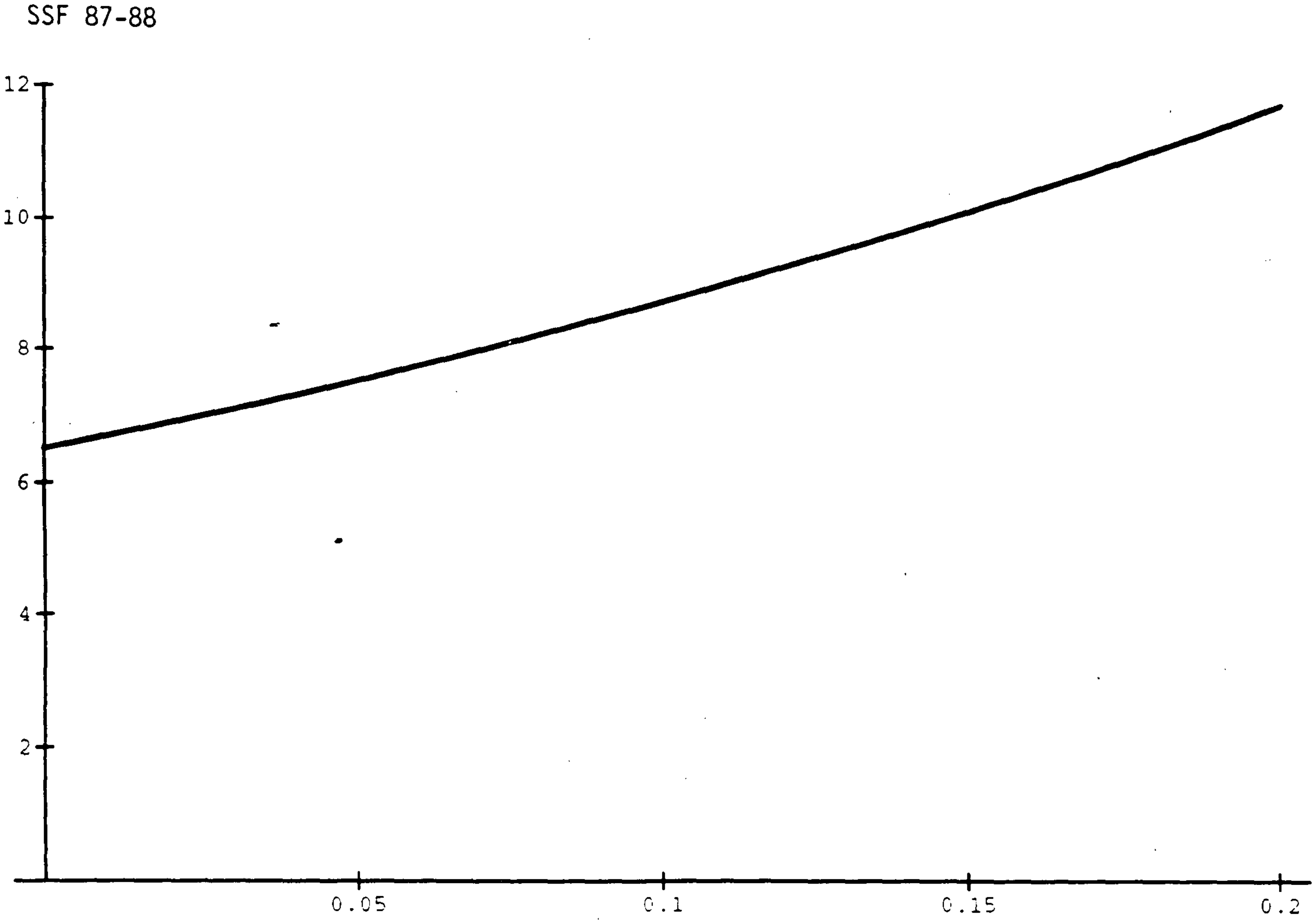
Radiation Exposure Model:

The results for ordinary least squares analysis of radiation exposure (see Table 3.9) suggest that problem identification, resource application, and past performance have a strong influence, and resource allocation plays some role as well. For problem identification, the number of major violations was positively related to radiation exposure ($p< .01$). This suggests that plants experiencing few major violations in the past have low radiation exposure in the future, while those having problems in the past continue to experience them later on. However, the model suggests that spending resources in the plant can reduce the amount of exposure in the future. Finally, as with many of the safety indicators, the past seems to be a strong predictor of radiation exposure ($p< .05$). The model as a whole explains 74 percent of the variance in the radiation variable, indicating a strong fit.

Critical Hours Model:

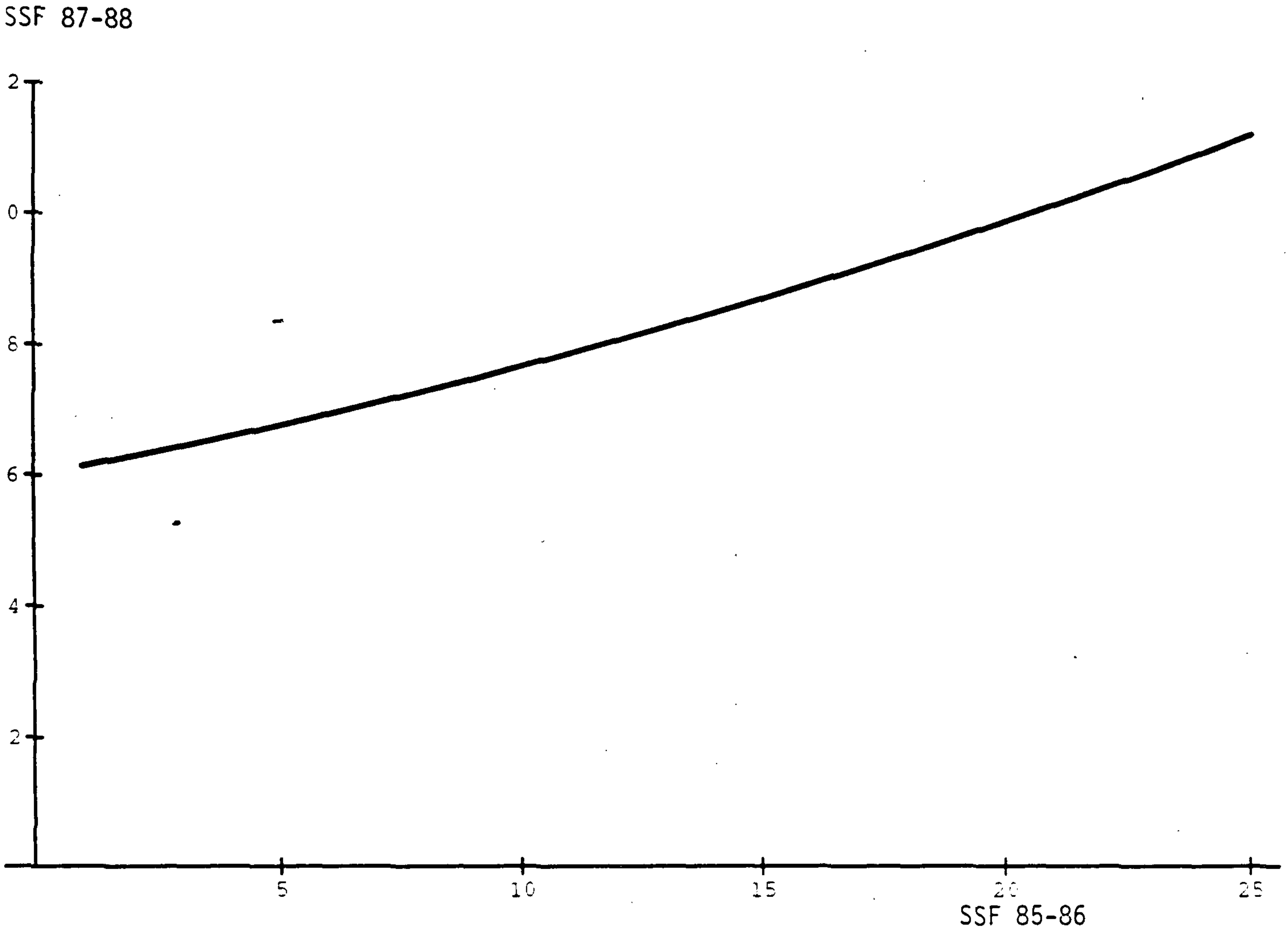
Critical hours is not explained particularly well by the model, (adjusted $R^2 = .25$). The only important predictors ($p< .05$) in this model

Figure 3.14



Predicted Values of Safety System Failures, 1987-88, varying Other Power Generation, 1984-86. All other variables controlled for by multiplying their estimated coefficients by their average.

Figure 3.15



Predicted Values of Safety System Failures, 1987-88, varying Safety System Failures, 1985-86. All other variables controlled for by multiplying their estimated coefficients by their average.

were past performance on critical hours and operating experience. Plants with high critical hours in the past have high critical hours in the future, and plants that have less experience (i.e. fewer total megawatts generated) have more critical hours.

Overall, the economic and behavioral theory used to develop the statistical models is confirmed through the statistical tests. Thus far, the discussion has focused on the significance of individual coefficients. But the overall fit of the model can be assessed as coefficients. But the overall fit of the model can be assessed as well using log-likelihood tests and F-tests. These tests examine whether the coefficients taken as a whole have a significant impact in explaining the dependent variables. For each of the final models shown in Tables 3.8 and 3.9, the test of the overall significance of the model are significant (For Poisson regression, a log-likelihood test of significance is undertaken, and for ordinary least-squares regression, F-tests are used.) Thus, not only do many of the individual concepts and their measures have significant relationships with the individual performance indicators, but the model as a whole performs well in explaining variation in the performance indicators.

3.3 Issues of Multicollinearity

Multicollinearity, (i.e., strong correlations among the independent variables) can pose problems for interpretation of regression results. The main effect of multicollinearity is to increase the variance of the coefficient estimates, therefore making it less likely that significant relationships with the dependent variable will be found. However, even with multicollinearity, the coefficient estimates are unbiased.

The correlations among the independent variables are shown in Table 3.10. The only particularly high correlation is the .70 correlation between ROI and operating expenditures. The effect of this correlation may lead us to conclude that resource availability has less impact than it in fact does (i.e., we are more likely to accept the null hypothesis). In order to examine the extent of the problem, the full model was re-run first dropping the operating efficiency variable, then excluding the ROI variable. The results of this analysis do not change the substantive conclusions of the model. Therefore, although some multicollinearity is evident in these models, it appears to have little substantive importance.

3.4 Conclusions

The overall results of this analysis suggest several key concepts which are important to understanding nuclear power safety. First, problem identification is shown to be important to both safety system failures and radiation exposure. NRC has a particularly important role to play in regard to these performance indicators. Resource availability, too, has an effect on several of the safety-related indicators. As measured by return on investment and operations efficiency, it is significantly related to both safety system failures and significant events. Resource application is an important factor which influences a number of the safety-related indicators. Both plant costs and spending on operations (and not maintenance) as a percent of total supervision and engineering prove useful in explaining safety-related performance. The findings are very strong and stable in the case of safety system failures and significant events. The measures of business strategy, on the whole, have a less stable impact; nonetheless, there is evidence in the models that distractions in various forms negatively affect performance. Alternative power production has a fairly consistent negative relationship to safety system failures and to significant events. The past has a very strong effect on nearly all the performance variables. Overall, the organizational learning model which combines elements from economic and behavioral theory has proven to be a very useful means for examining the effects of various variables on nuclear power plant performance.

Table 3.10 Correlations Among the Independent Variables

	Nomajv85		Salp	ROI	Opeff	Plant	Rseop	Prod	Td	Diver	Other	E2x
Nomajv85		1.00										
Salp	.40	1.00										
ROI	.09	-.02	1.00									
Opeff	.11	-.23	.70	1.00								
Plant	.09	-.24	-.19	-.14	1.00							
Rseop	.21	.14	.04	-.19	-.12	1.00						
Prod	-.06	.21	.11	-.16	-.22	-.01	1.00					
Td	-.15	-.11	-.26	-.01	.02	-.12	-.04	1.00				
Diver	-.10	-.19	.32	.16	-.26	.09	.07	-.27	1.00			
Other	.01	-.09	-.31	-.19	-.07	.19	-.17	.03	-.06	1.00		
E2x	-.29	-.09	.23	.19	-.29	.17	.05	-.13	.22	.06	1.0	

N=52

4.0 PROFIT GROWTH AND NUCLEAR POWER COMMITMENT AS VIOLATION AND RELIABILITY PREDICTORS

4.1 Introduction

Two of the central concepts presented in the theory in Chapter 2.0 and tested in Chapter 3.0 concerned the importance of the utility having resources available to devote to safety and the effect of utility-level strategies. In this chapter these two concepts are revisited. They are measured in different ways compared to Chapter 3.0, and they are used to predict different dependent variables than have been reported in previous studies.

In this chapter, two utility-level factors - utility profit growth and commitment to nuclear power - are examined for their ability to predict NRC violation rates and reliability rates at both the plant level and for the utility. The analyses serve two purposes. One, as utility profit growth and commitment to nuclear power are two alternative measures of key concepts presented in the theory in Chapter 2.0, (resource availability and business strategies, respectively), the analyses provide a cross-validation of the concepts and can add to the assessment of the robustness of the theoretical model. Two, analyses of the measures employed in the present analyses are grounded in different literature from the economic and behavioral theory previously used. Specifically, literature on risk bias (Kahneman and Tversky, 1979) is combined with that concerning bureaucratic stability even in the face of technological change (DiMaggio and Powell, 1983) and with analyses of the allocative role of senior management (e.g. Osborn and Jackson, 1988). Thus new theoretically-derived notions can be tested and implications from the results can be drawn to enrich the understanding of the role of organization factors in nuclear power plant safety.

This chapter begins with a description of the purpose of the study and how it is related to the need to identify leading indicators of safety. A theoretical backdrop for the study is then provided, which allows for creation of a set of propositions concerning expected relationships among the independent and dependent variables. Details of the research methodology are then provided, followed by the results. The results are discussed and interpreted first against the theory and results in Chapters 2.0 and 3.0, and then against the additional theoretical backdrop added in this chapter.

4.2 Description of Technology Employed and Its Applicability to the Problem

NUREG/CR-3215 outlines a model describing organization factors and intermediate safety criteria that are expected to yield safer commercial nuclear power plant operations. Three key aspects of the overall model are examined in this chapter. One, can measured aspects of management and organization be used to predict reliability and violation rates as two types of intermediate measures of safeness? Two, can readily available data from published sources be used to examine some of the critics' contentions regarding safeness? Three, are the selected management and organizational factors consistently related to violation and reliability rates over an extended time period.

4.2.1 Violations and Reliability as Intermediate Aspects of Safeness

The NRC has traditionally monitored conditions expected to minimize the potential occurrence of major breeches of safety in nuclear power plants. Two measures of the monitored conditions are analyzed in this chapter. One is an estimate of reliability; the second is an estimate of violations. Plant reliability is a measure of the ratio of total operating hours to total hours the plant could have operated had it experienced no forced shut-downs, after taking into account hours of nonoperation due to scheduled outages. Reliability is considered important because a plant operating as designed is expected to evidence few safety shutdowns and operate without challenges to safety systems. Plants operating in such a way will have higher reliability scores as measured in this study. More is said about the measure in Section 4.4.2.1. In a continuous process operation, reliability also reflects the efficient use of resources (See NUREG/CR-3215). Violations are issued when, in the judgment of the NRC, the utility has failed to maintain aspects of its planned defense-in-depth. As such, violations reflect the degree to which the utility conforms to regulatory requirements. While important, neither of these estimates is considered to be an ultimate measure of safeness. For instance, plant reliability might be maintained at the expense of other aspects of safeness or low reliability might well reflect the fact that safety concerns were considered more important than continuous operation. While violations reflect aspects of defense-in-depth, the absence of violations should not be equated with safeness.

Despite their limitations as accurate reflections of safeness, estimates of reliability and violations are also important on their own. Greater reliability may yield high economic returns to the utility while the number and types of violations also has economic consequences to the utility. The economic perspective on nuclear power plant safety is discussed in Section 2.1, and the vicious cycles which may arise and persist are fueled in part by violations, as discussed in Section 2.1.5.

Thus, in their role as intermediate outcomes related to safety as established in NUREG/CR-3215 and 5437, and their role in the present theory, reliability and violations are important dependent variables to investigate.

4.2.2 Measures of Organization Concepts Employed

While there are a large number of potentially important organization factors that may be examined, this chapter concentrates on two important and commonly measured factors. The first is the utility's record of profit growth. Profit is a widely used measure of organizational success and the relative growth in profitability reflects the munificence of the decision setting for senior management(See Osborn and Jackson, 1988 for an extended discussion). The second factor is the utility's commitment to nuclear power. As discussed in NUREG/CR-3215, NUREG/CR-5437, and elsewhere in this report, the proportion of total generating capacity devoted to the nuclear technology reflects a set of strategic decisions regarding the involvement of the utility in this technology. Heavily committed utilities are often considered industry leaders. Further, their heavy investment in this technology increases their financial exposure to a major accident at their facilities or even those of another utility (see Osborn and Jackson, 1988 for an extended discussion). Both measures are readily available from secondary sources and have played a prominent role in other analyses (c.f. Fiegenbaum and Thomas, 1988).

4.2.3 Consistency Over Time

While there is a natural tendency to emphasize the most recent events in this industry, prior work suggests that management and organizational factors and the forces they set in motion evolve over time (See DiMaggio and Powell, 1983; Scott, 1987; and Stinchcombe, 1965). Measures of reliability and violations for a single year may or may not reflect intermediate safety performance over a fuel cycle and predictors of those outcomes may not be stable. Over a longer period of time, if patterns exist they can be more readily spotted. This is particularly relevant in light of the lags in statistical relationships demonstrated in NUREG/CR-5437 and the power with which the past predicts the future, as demonstrated in Chapter 3.0.

Through the cooperation of COMPUSTAT, detailed longitudinal performance information for all nuclear utilities was obtained for basic research purposes. This data set was used as a basis for profit growth calculations for the years 1975 to 1987. Reliability and violations rates were analyzed for the time period 1983-1987. This was an important period in the life of the industry as utilities were instituting changes stemming from the incident at Three Mile Island.

4.3 Theoretical Perspectives

In recent years a number of organizational scholars have addressed the question of safeness in organizations which employ complex and potentially dangerous technologies. Several important conceptual arguments are reviewed in this section to support (a) the development of an index of violations, (b) the necessity to examine reliability and violations rates over time and (c) the specific equations to be tested in this chapter. Work by Perrow (1984) supports the need to develop an index of safeness, while the analysis of Starbuck and Milliken (1988) suggests that both utility and plant level outcomes should be examined. The literature on decision framing is reviewed, which suggests that very positive or very poor records of profit growth may influence the decision frame and responses of senior managers, and thus yield identifiable threats to safeness (see Osborn and Jackson, 1988).

4.3.1 Support for the Role of Violations

Perrow (1984) introduced the concept of a normal accident based on his analysis which concluded that current administrative systems may be inadequate to manage existing complex technical systems. Instead of design based accidents resulting from predictable scenarios, Perrow (1984) suggested that accidents may also occur from an accumulation of apparently minor isolated events that cumulatively interact to yield a disaster. The very tight coupling of the technical systems in such production facilities as nuclear power plants and the inherently unpredictable distribution of mistakes may combine to yield a technical system that is much more sophisticated and complex than any existing administrative system. When multiple unplanned or unexpected minor events combine in unexpected ways, events may overwhelm the limited capacity of the administrative system. The result could be a disaster. Whether one accepts the concept of a normal accident or not, the suggestion that simultaneously occurring minor events may combine with disastrous consequences should not be dismissed. Thus, an index of violations will be developed to estimate the potential threat from normal accidents.

PROPOSITION 4.1 Minor events, as well as major events, can combine to produce an accident scenario

This proposition tends to support the use of violations as a dependent variable in this study, and suggests that an index of violations (which includes minor and major violations) is justified.

4.3.2 Multiple Goals of Plants and Utilities

In their retrospective analysis of the Challenger disaster, Starbuck and Milliken (1988) isolated a syndrome they called "fine-tuning the odds." Fine-tuning is a natural process where engineers and managers separately attempt to improve their part of the system. Since the goals and "improvements" of these groups may be inconsistent and "improvements" are continued until they cause a disaster, participants may have inaccurate beliefs regarding the linkages between prior success or failure and future success or failure.

Goal conflicts between managers and engineers is far from new and can be expected. They are a central feature of the behavioral theory of firms (see Section 2.2). The additional contribution in Starbuck and Milliken's (1988) analysis is the role of beliefs regarding future performance based on the past. Over time NASA managers and engineers believed they were collectively competent and understood the technology enough to make improvements. Yet, such improvements were "experiments with uncertainty." When matched with the belief that past success yields future success, less scrutiny occurred until this fine-tuning yielded a disaster.

PROPOSITION 4.2 Goal conflicts among subunits or different levels of the organization, coupled with perceptions of past success, lead to continued local experiments which can accumulate and conflict to cause an accident.

The importance of multiple subunits and multiple levels of the organization in this research by Starbuck and Milliken suggest that utility safeness records as well as plant level outcomes should be examined in the analyses in this chapter.

4.3.3 Interactions Between Profit and Commitment in Predicting Performance Outcomes

At least three separate theoretical perspectives support a prediction of an interaction between utility profit growth and commitment to nuclear technologies and certain performance outcomes.

4.3.3.1 Resistance to Change and Limited Executive Discretion

The ability of managers to independently design, direct, and implement dramatically new choices within existing bureaucracies is limited (see Scott, 1987 for a review). Their ability to fundamentally redirect their large established bureaucracies is bounded by the history of organizations (e.g., Abernathy & Clark, 1985), the social solutions absorbed at their founding (e.g., Stinchcombe, 1965), and the social hierarchies that dominate in their environments (e.g., DiMaggio & Powell, 1983). Radical, externally induced change and severe turbulence are not only implicit, but apparently necessary conditions underlying substantive organizational change as complex systems swing from one punctuated equilibrium to another (e.g., Abernathy & Clark, 1985; Tushman & Anderson, 1986). In this vein, Osborn and Jackson (1988) cited the inability of nuclear utilities as large machine bureaucracies to shift fossil fuel cultures in order to adjust to a radically new, "competency destroying" nuclear technology (c.f., Tushman & Anderson, 1988). For instance, formal structures, training protocols and procedures designed for fossil operations may be inadequate when applied to nuclear operations. Findings reported in earlier chapters, which show the persistent influence of the past or future performance is further evidence of this view.

If change is so difficult to accomplish successfully, it could well be reflected in the relationship among commitment to nuclear power and profit growth rates when predicting violations.

PROPOSITION 4.3 Change is difficult for managers to successfully accomplish, thus the more change that is attempted the more failures are likely to occur in the implementation of changes.

Presume all utilities attempt to make as many changes as possible to show their concern for safety. Richer more heavily committed utilities could attempt more changes and with more attempts simply make many more mistakes. Heavily committed but poorer utilities make fewer attempts (with fewer mistakes), while those with comparatively low commitment simply lack the nuclear staff to institute many changes at all. Utilities in the latter category may simply follow key NRC mandates and such followership is rewarded by a lower level of scrutiny. Thus, one might expect to see an interaction between resources and commitment when predicting violation rates. The specific form of the relationship would be a linear by linear interaction reflecting the number of attempted changes by utilities with differing combinations of commitment and profit growth.

It can be argued that the shock of the TMI accident should have been the type of catastrophic event that would yield a new equilibrium. In fact, the aftermath of this accident did yield several new industry associations as well as a renewed regulatory oversight by the NRC. It is possible that the linear by linear interaction between profit growth and commitment might be detectable early in the 1980's. However, if TMI was a major shock, the interactions would fade as utilities implement the reforms required by NRC and recommended by INPO. Thus the interaction may not be characteristic of utilities over the five year study period.

4.3.3.2 Decision Framing

In Chapter 2.0 the role of managerial attention was discussed, along with effects of conditions such as profit declines which can distract attention from preeminent concerns with safety. Another view of the effects of conditions such as profit decline is found in the literature on decision framing. Depending upon how a decision is framed, executives have been shown to have a tendency toward a risk bias or a conservative bias. The two organizational factors being studied here, namely profit growth and commitment to nuclear, could be used as surrogate measures of decision frame and risk propensity, respectively. Using the word "risk" in this context raises red flags, for no executive would knowingly acknowledge making a "risky" decision when nuclear safety is at stake. The use of the term here is more clinical and is consistent with its use in the literature. As it appears in the literature it refers to a preference function which maps the trade-offs a decision maker makes between competing desired outcomes.

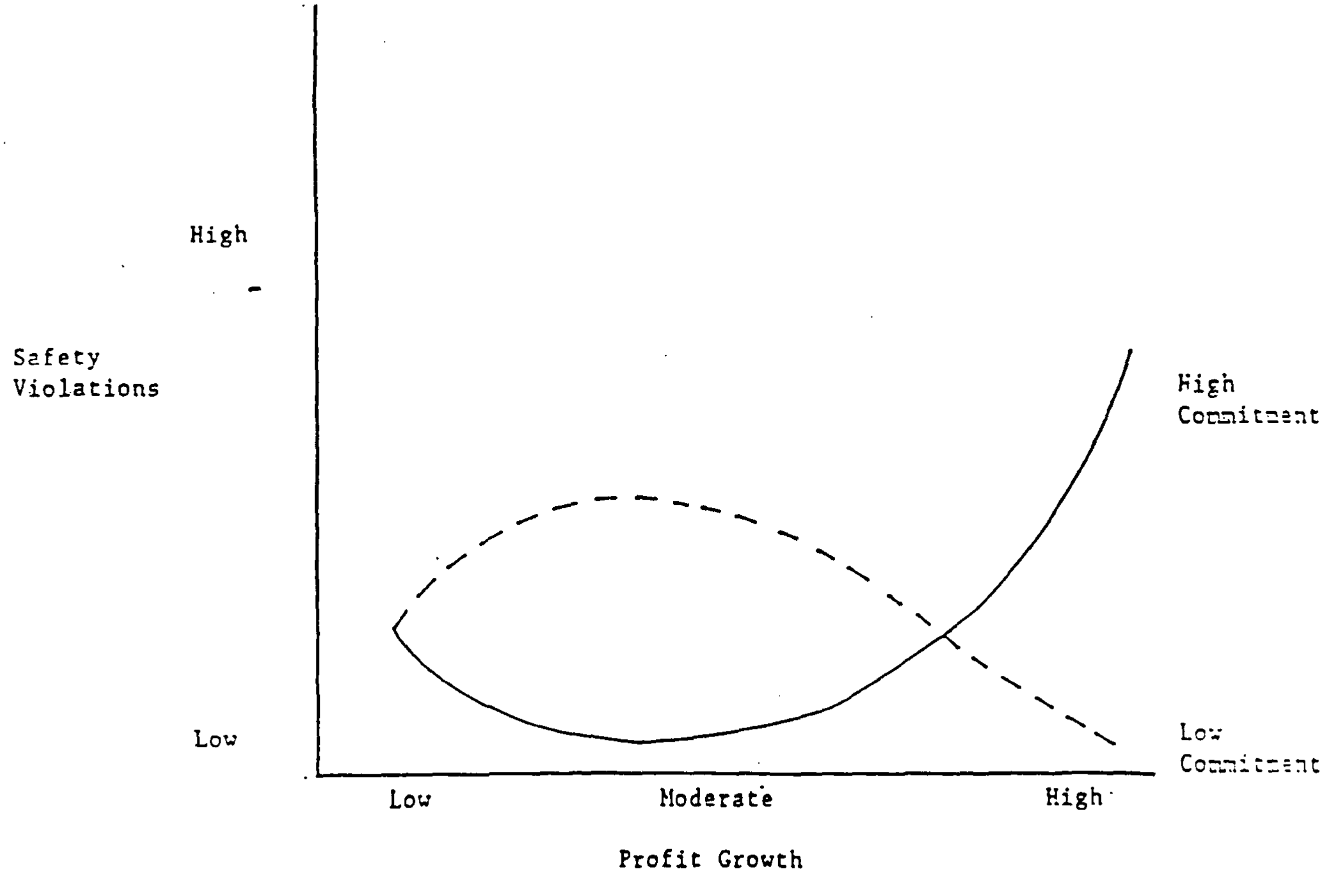
Research has shown that how a problem is framed influences decision makers' choices (Kahneman and Tversky, 1979; Feigenbaum and Thomas, 1988; Osborn and Jackson, 1988). When decision makers perceive themselves to be in a condition of gain (a positive problem frame), risk averse executive groups may be overly conservative. Under losses they may continue failed programs in attempts to recoup losses (See Fiegenbaum and Thomas, 1988). Recent work by Osborn and Jackson (1988) has extended this logic to executive groups who may be considered risk takers. Risk taking executive groups may be overly bold under conditions of gains and excessively conservative under conditions of losses.

PROPOSITION 4.4 Conditions which are perceived as positive or negative influence the posture of decision makers toward risk or conservatism.

From the work cited above, one would expect to find a sustained non-linear interaction relationship between estimates of the risk propensities of senior management and the munificence of the decision setting (i.e., decision frame) when predicting estimates of safeness. Figure 4.1 shows a

Figure 4.1

Hypothesized Relationship of the Effects of Strategic Decision Frame on Outcomes



graphical depiction of the non-linear interaction between profit growth as a measure of the decision frame and commitment as an estimate of risk propensity when predicting violations. In munificent conditions (positive frame) utilities heavily committed to nuclear technology (risk takers) may run plants with substantially worse safety records relative to non-heavily committed utilities. In less munificent conditions (negative frame) the curvilinear interaction suggests that utilities not heavily committed to the technology run plants with worse safety records relative to heavily committed utilities.

This pattern has been called "purposeful unintended consequences" (Osborn and Jackson, 1988). Unintended consequences refer to undesired safety events/conditions such as violations. The term purposeful refers to the inability and/or unwillingness of utility executives to correct their decision errors. Osborn and Jackson (1988) suggest that this inability/unwillingness to take corrective action was linked to (a) the false presumption that a reliable plant was a safe plant, (b) the assumption that utilities have an appropriate administrative system (c.f. Perrow, 1984), and (c) executive claims that they could balance public and private interests.

4.3.3.3 Leadership by Profitable or Heavily Committed Utilities

First, utilities with a historically high record of profit growth may lead the industry by maintaining better reliability and violations records. Second, utilities more heavily committed to the technology may have plants with better records on these two indirect measures of safeness. In other words, the prior overall managerial success of the utility and its commitment to the technology could be projected into higher reliability and fewer violations.

PROPOSITION 4.5 Utilities which are highly profitable and heavily committed to nuclear power production will be leaders in the industry in safety-related outcomes.

4.4 Research Method

This section of the chapter discusses the units of analysis for the statistical tests, the procedures used to calculate the variables that were analyzed, the statistical procedures used and the sequence of analysis.

4.4.1 Units of Analysis

The statistical analysis was based on two units of analysis. Because utility-wide conditions and plant safeness outcomes are to be related, both the plant and the utility were seen as appropriate units for study. Since some utilities operate more than one plant, some conventions for consistent data assignment are followed. In analyses in which the plant is the unit of analysis, when the parent utility operates more than one reactor-turbine, all of its plants are assigned the utility score for commitment and prior earnings. In these analyses an assumption is that utility commitment and profitability affects each of the plants it operates in the same way. This assumption may be arguable by some. In the analyses in Chapter 3.0, resource allocation to plants is measured, but those variables are not part of the statistical models being tested here. From 1983 to 1987 data are available on utilities with commercial operating licenses managing a total of from 63 to 82 nuclear power reactors (United States Nuclear Regulatory Commission, NUREG-0020, 1984, 1985, 1986, 1987, 1988). The second unit of analysis was the utility. Here the plant characteristics and outcomes are averaged in cases where a utility has more than one plant. Over the five year study period data are available for 41 utilities with licensed, operating facilities.

4.4.2 Measures

This section describes how the safety related criteria, predictors and controls were collected and coded.

4.4.2.1 Criteria Measures

Two measures of operating safety that could be directly linked to controlling criticality and containing radiation are plant reliability and plant violations(See NUREG/CR-3215). Raw data on the total hours of operation are provided by the NRC in NUREG-0020 (U.S.N.R.C., 1984, 1985, 1986, 1987, 1988). Using this information, raw data for each year are adjusted to eliminate the hours of nonoperation due to scheduled outages for such reasons as planned maintenance, refueling, and/or retrofitting. Plant reliability is then calculated each year as the ratio of total operating hours to total hours the plant could have operated had it not experienced any forced shut-downs. The reliability measure is based on the assumption that forced shut-downs present challenges to designed safety systems, where control of criticality is threatened and might ultimately yield a release of radiation.

As a measure of defense-in-depth, reported violations are examined (see NUREG-0020 documents, 1981). Over several years the nature and character of the violations placed in the five categories have evolved, such that by 1983 there were very few level one or two violations. While rare, level one and two violations are considered by the NRC to involve actual or high potential impact on the public. Also, most have substantial financial and operating consequences on the offending utility. Level three, four, and five violations are considered less threatening but are the types of threats to defense-in-depth, which if left uncorrected could lead to a more serious problem. Any single violation alone may be comparatively unimportant, but collectively they could signal a deterioration in defense-in-depth.

The weighting cheme for the composite violation measure is arbitrarily fixed with severity level one violations receiving a weight of five, severity level two violations receiving a weight of four, etc.. While arbitrary, these differential weights emphasize the importance of level one and two violations while maintaining the significance of multiple level four and five violations.

4.4.2.2 Independent Variables

The two independent variables are the utility's commitment to nuclear power and profit growth. Based on data available in the Department of Energy documents (D.O.E./E.I.A. 0095, 1984, 1985, 1986, 1987, 1988), commitment to nuclear power is operationalized as the ratio of utility nuclear power generating capacity to the total generating capacity of the utility (Osborn & Jackson, 1988). Profit growth is computed from data available in the COMPUSTAT Annual Utility data base. This measure is calculated for each year over the five previous years using the following formula:

$$G(X_t) = [X_t - X_{(t-1)}]/X_{(t-1)}$$

Where X_t represents the total operating income at time t, $X_{(t-1)}$ represents the total operating income at time (t-1), and $G(X_t)$ represents the fractional change in operating income from time (t-1) to time t.

The multi-year growth rate is assessed by taking the logarithm of $[C + G(X_t)]$ for all t, where C is a constant large enough to ensure that no element of the series is ever negative, and assessing the mean and standard error using this series. The logarithmic function provides a better estimate of actual growth than a simple percentage calculation because it controls for additivity in the growth estimates, whereas percentage calculations do not. For example, if some company had the following income for three consecutive years: 100, 150, and 100, their income is increased 50 percent from year one to year two, and decreased 33 percent from year two to year three. In other words, even though the actual change is the same, a percentage indicator would give the two year growth rate as 8.5 percent. The logarithmic change function would take the natural log of the change from 100 to 150 (i.e, 3.912) for years one and two, and subtract the log of the change from year two to year three (i.e, 3.912), which would result in a three year growth rate of zero.

Because the parameters of growth rate probability distributions are unknown, these profit growth estimates were subjected to a bootstrap methodology (Efron, 1981, 1985; Efron & Tibshirani, 1986) to obtain unbiased estimates of the accuracy of the observations of the sample mean of the series $\ln[C + G(X_t)]$ for each plant. The bootstrap methodology is designed to yield unbiased estimates of the parameter variability based on probability sampling (Efron & Tibshirani, 1987). Bootstrapping is a computer intensive simulation methodology which can be used in place of complicated mathematical derivations or in a distribution-free circumstance. Bootstrapping has additional advantages in that it does not require the assumption of a normally distributed criterion variable in the assessment of standard errors (Efron, 1981; Efron & Tibshirani, 1987).

Bootstrapping was performed as follows. First, for each plant, the series of five observations (i.e., the five, one-year profit growth estimates for each utility) of the variable $\ln[C + G(X_t)]$ were taken to begin assessing the mean and standard error of $\ln[C + G(X_t)]$. Second, random sampling with replacement is performed from the five observations to obtain a "bootstrap" sample with five observations. The mean of the bootstrap sample was recorded. This procedure was repeated until 1000 bootstrap sample means were recorded from each of the five observations of $\ln[C + G(X_t)]$. The mean and standard deviation of the sampling distribution of these 1000 bootstrap means served as our estimate of mean and standard error of profit growth. This procedure was repeated for the five years preceding 1983, 1984, 1985, 1986, and 1987 for each nuclear power licensee.

4.4.2.3 Controls

Following Osborn and Jackson (1988) information for plant characteristics and region were derived from licensee descriptions in the NUREG-0020 documents (U.S.N.R.C., NUREG-0020, U.S.E.I.A., 1984, 1985, 1986). Plant age was operationalized as the number of months since the plant began commercial operation. Three dichotomous variables were created indicating technological type of the nuclear reactor, the number of plants operated by a utility, and the NRC's regional location of the plant. Plant type was coded as one for plants utilizing a boiling water reactor (BWR) and zero for those operating a pressurized water reactor (PWR). The number of nuclear power plants operated by a utility was coded as zero for all utilities operating a single plant and one for all utilities operating two or more plants. Since prior work suggests that for unknown reasons violation rates were different in the Southern region (see Osborn and Jackson, 1988), regional location was coded as one for those plants operating in the NRC's Southern region and zero for plants operating in all other regions.

4.4.3 Statistical Analyses

While the research questions appear to be straightforward, statistical analysis consistent with these questions is quite complex. The analysis must recognize five difficult challenges: (1) investigating departures from linearity stretches the assumptions of standard statistical models (Blalock, 1974; Cohen & Cohen, 1983; McNeil, Kelly, & McNeil, 1975), (2) the measures used include both categorical and continuous types of data, (3) a number of control variables must be used (e.g., type of plant, region), therefore for the independent variables to show significance, they must explain variance over and above that explained by the control variables, and in the face of the reduction in degrees of freedom their presence in the model causes as well, (4) data analysis needs to be consistent for two units of analysis - plant and utility, and (5) some of the violations measures occur very infrequently. No single statistical method is ideally suited to meet all of these challenges. Taking all things into account, a special form of multiple regression analysis was used, as recommended by Osborn and Jackson (1988) and Cohen and Cohen (1983).

A series of hierarchical regression models were built by the sequential addition of control variables, main effects, curvilinear terms, linear interactions, and curvilinear interactions. Across these models the regression weights may be highly unstable because the non-linear terms are very highly correlated with the linear terms. Fortunately, the overall R-square (proportion of variance explained) is comparatively unaffected by the high intercorrelations among the predictors (Cohen & Cohen, 1983). Thus, the interpretation emphasizes the incremental change in R-square(proportion of variance change) attributable to the addition of sequentially more complex terms as opposed to trying to interpret the regression coefficients of individual variables, since they are quite unstable and sensitive to the order in which terms are entered. For example, to assess the potential importance of the interaction of profit growth and commitment on plant reliability, the R-square from two equations is compared using an F-test to determine if they are significantly different. One equation would contain the controls, the linear terms for profit growth and commitment while the second would include all these terms plus the interaction (commitment times profit growth). If the difference in explained variance (R-squared of the equation with the interaction term minus the R-square of the equation with just the controls and linear terms) is statistically significant, then the conclusion is that the interaction term explains additional variance. Interpretation of exactly how the interaction term is related to the criterion is based on a graphical interpretation rather than beta or regression weights, since the regression weight for a single term is not stable.

4.4.4 Sequence of Analysis

The analysis proceeded in four phases. Phase one involved an examination of safeness at the plant level within each year as measured by plant operating reliability and the various levels of violations (levels 1-5). In phase two the data was averaged over the five year period. This averaging across yearly time periods provides much more stability in the data. The regression equations predicting plant safeness were then recalculated. Phases three and four weighted the measure of violations and added the utility level of analysis. While phase three of the data analysis involved analyzing safeness, as indexed by operating reliability and the composite violations index within each of the five years at the utility level, in phase four, the utility level data were averaged over the five year period and the weighted safety violations composite were regressed on profit growth, commitment, their respective interactions, and the control variables.

4.5 Results

After presenting the means and standard deviations for the variables of interest, this section presents the results for the relationships among the dependent variables over time, the linear linkage of the two predictors or independent variables to the dependent variables and the more complex interactive analyses.

4.5.1 Basic Relationships

Table 4.1 reports means and standard deviations for all variables in each year at both the plant and the utility level for subsequent replications. As discussed in Section 4.4.1, utility-level measures of violations and reliability represent an average of the plants operated by the utility. Plant-level measures of commitment and profit growth are the parent utility's measures on the same. Table 4.2 reports the intercorrelations of the variables averaged over the five year period at the plant level. This correlation matrix is similar to the year-by year correlations.

Table 4.1

Means and Standard Deviations for the Plant and Utility Level Data for Each Year[a]

		1983		1984		1985		1986		1987		Average	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
South	(P)*	.37	.49	.36	.48	.36	.48	.33	.47	.33	.47	.33	.47
	(U)*	.24	.44	.27	.45	.25	.44	.24	.44	.24	.44	.24	.44
BWR	(P)	.35	.48	.35	.48	.34	.48	.35	.48	.35	.48	.35	.48
	(U)	.36	.44	.35	.44	.32	.43	.34	.44	.34	.44	.34	.44
Single Plant	(P)	.83	.38	.81	.39	.79	.41	.80	.40	.80	.40	.80	.40
	(U)	.67	.48	.62	.49	.60	.50	.59	.50	.59	.50	.59	.50
Plant Age	(P)	101.83	45.87	104.52	53.31	106.28	60.22	107.61	66.12	119.61	66.12	98.75	61.70
	(U)	100.26	42.90	104.73	48.39	104.57	57.51	107.90	60.87	119.90	60.87	101.42	57.53
Growth	(P)	.13	.07	.15	.07	.12	.05	.10	.06	.10	.06	.12	.04
	(U)	.12	.07	.14	.07	.12	.06	.10	.06	.09	.06	.11	.05
Commitment	(P)	.38	.25	.38	.24	.38	.24	.39	.24	.41	.24	.39	.24
	(U)	.39	.29	.37	.28	.38	.27	.38	.27	.39	.26	.38	.26
Reliability	(P)	.89	.18	.88	.18	.87	.17	.82	.28	.84	.26	.86	.15
	(U)	.87	.20	.87	.20	.88	.17	.85	.24	.88	.17	.87	.13
Level 1 Violations	(P)	.03	.16	.00	.00	.04	.19	.00	.00	.00	.00	.01	.04
	(U)	.02	.16	.00	.00	.07	.26	.00	.00	.00	.00	.02	.06
Level 2 Violations	(P)	.21	1.00	.00	.00	.12	.58	.05	.21	.02	.15	.08	.23
	(U)	.20	.96	.00	.00	.13	.65	.09	.29	.02	.15	.09	.23
Level 3 Violations	(P)	1.11	1.43	1.49	2.38	1.58	2.80	1.37	2.09	1.18	3.08	1.27	1.31
	(U)	.79	1.15	1.23	2.19	.96	1.50	1.29	1.75	1.15	2.19	1.18	1.15
Level 4 Violations	(P)	8.75	5.46	12.38	10.07	11.58	8.44	10.98	7.96	10.14	7.08	10.82	6.06
	(U)	9.39	5.33	10.79	6.54	11.06	6.35	12.21	8.63	10.23	6.13	11.10	5.40
Level 5 Violations	(P)	7.14	4.68	5.32	3.93	4.88	4.05	3.39	2.98	2.05	2.16	4.76	2.75
	(U)	7.61	4.44	5.04	3.46	4.68	4.06	3.26	2.35	3.08	2.40	4.76	2.27
Weighted Violations	(P)	29.21	15.90	34.55	26.99	33.43	24.91	29.60	21.40	26.87	19.33	30.56	17.28
	(U)	28.81	13.64	30.64	18.82	30.04	19.24	29.93	20.08	25.85	14.31	29.50	13.29

[a] At the plant level of analysis, the sample sizes for each year were: 62 for 1983; 69 for 1984; 76 for 1985; 82 for 1986; and 84 for 1987. At the utility level of analysis, the sample sizes for each year were: 32 for 1983; 35 for 1984; 39 for 1985; 40 for 1986; and 41 for 1987.

* P = Plant level of analysis; U = Utility level of analysis

Correlations among the five severity levels of safety violations ranged from -.17 between level one and level three violations to .72 between level four and five violations. Additionally, the correlations between adjacent levels of violations were substantial (e.g., .61 between levels three and four violations) for each adjacent pair except levels two and three ($r = .05$, $p > .05$). There was no strong break in the pattern of intercorrelations among the five levels of safety violations. Therefore, subsequent analyses were conducted either within violation severity level or using the weighted violations score.

The correlations of region, type, and number of reactors with the violations criteria appeared sufficiently important to warrant incorporating those variables as controls in subsequent analyses. Although the age of the reactor appeared unrelated to both operating reliability and safety violations, it was related with profit growth ($r = -.34$, $p < .01$). These correlational results partially support general contentions made in the industry that type of reactor and region are important factors in safety analyses. Additionally, these results replicate the work of several other authors showing regional differences in the issuance of violations by NRC. (e.g. See Olson et al ,1984 and Osborn and Jackson, 1988).

4.5.2 Relations of the Dependent Variables to each Other and Across Time

Table 4.3 reports the intercorrelations of the weighted safety violations composite and operating reliability over the five year period at the utility level. These correlations address (1) Starbuck and Milliken's (1988) question regarding the relation of prior success or failure with future success or failure and (2) the nuclear industry's general contention that a reliable facility is a safe facility.

The correlations for adjacent years indicate that the number of violations is significantly correlated and somewhat stable across years (r ranges from a low of .33, $p < .05$ to a high of .63, $p < .01$), Operating reliability of each plant is also correlated and even more stable across adjacent years (r ranges from a low of .60, $p < .05$ to a high of .77, $p < .01$).

Same year relations between safety violations and reliability were mixed. In three of the five years there was no relation between the weighted violations and operating reliability. These results are consistent with findings reported in NUREG/CR-5437, with the independence of performance indicators reported in Section 2.2.1.1. of this report, and with the analysis of Starbuck and Milliken (1988). However, in 1985 and 1986 fewer violations were associated with higher levels of reliability.

With respect to the general contention in the nuclear industry that a reliable plant is a safe plant, the data are quite mixed. Of the five within year correlations between weighted violations and reliability, only two are

Table 4.2

Intercorrelations Among Averaged Study Variables at the Plant Level of Analysis

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. South[a]	1.00												
2. Single Plant[b]	.20	1.00											
3. Plant Age	-.10	.01	1.00										
4. BWR[c]	-.11	-.04	.19	1.00									
5. Growth	.26*	.08	-.34**	.31**	1.00								
6. Commitment	-.14	-.00	.09	.04	-.05	1.00							
7. Reliability	-.17	.06	.06	.07	-.30**	-.13	1.00						
8. Weighted Violations	.37**	-.15	-.14	.14	.37**	-.03	-.55**	1.00					
9. Level 1 Violations	-.07	-.23*	-.04	.07	.10	-.15	-.31**	.03	1.00				
10. Level 2 Violations	.08	-.05	-.16	.02	.19	-.11	-.28**	.25*	.66**	1.00			
11. Level 3 Violations	.32**	-.04	.05	.23*	.27**	.19	-.41**	.67**	-.17	.05	1.00		
12. Level 4 Violations	.33**	-.13	-.15	.12	.35**	-.01	-.55**	.95**	.11	.24*	.61**	1.00	
13. Level 5 Violations	.25*	-.04	-.10	.17	.39**	.08	-.46**	.72**	-.08	.11	.55**	.72**	1.00

N = 84

* p < .05

** p < .01

[a] 1 = Southern region, 0 = other

[b] 1 = Multiple plants, 0 = other

[c] 1 = Boiling Water Reactor, 0 = Pressurized Water Reactor

Table 4.3

Correlation of Utility Safeness Critieria Over Time

	1	2	3	4	5	6	7	8	9	10
1. 1983 Weighted Violations	1.00									
2. 1984 Weighted Violations	.33*	1.00								
3. 1985 Weighted Violations	.44**	.57**	1.00							
4. 1986 Weighted Violations	.25	.37*	.63**	1.00						
5. 1987 Weighted Violatons	.19	.31*	.54**	.62**	1.00					
6. 1983 Reliability	-.12	-.03	.14	-.08	.23	1.00				
7. 1984 Reliability	-.04	-.11	-.07	-.26	-.16	.77**	1.00			
8. 1985 Reliability	-.11	-.44**	-.31*	-.51**	-.03	.61**	.76**	1.00		
9. 1986 Reliability	-.25	-.70**	-.59**	-.53**	-.29	.04	.25	.63**	1.00	
10. 1987 Reliability	-.19	-.56**	-.47**	-.33*	-.23	.09	.38*	.51**	.60**	1.00

N = 41

* $p < .05$

** $p < .01$

statistically significant. Of the four correlations between operating reliability in one year and safety violations in the subsequent years, only the relation between reliability in 1985 and safety violations in 1986 supports the industry's contention ($r = -.53$, $p < .01$). None of the other three correlations are significantly different from zero. However, reversing the contention and positing that a safe plant is a reliable plant seems more tenable. Three of the four relations between violations in one year and reliability in the subsequent year are significant. Each of these indicated that fewer safety violations are related with higher levels of operating reliability in the subsequent year. In sum, the measures used in these analyses do support the notion that a safe plant is a reliable plant; however, this relation is not transitive. For any year, a reliable plant does not appear to be any safer than an unreliable plant. However, over the five year period (see Table 4.2), weighted violations at the utility level and reliability did significantly covary.

4.5.3 Linear Relationship Between Independent and Dependent Variables

Table 4.4 shows year by year regression results for plant reliability and three of the five levels of plant safety violations. Levels one and two were not included in this analysis since they showed very low incidence in any of the five years (Table 4.1). Table 4.5 shows the same analyses but for five year averages also at the plant level of analysis. Table 4.6 presents results for the weighted violations measure at the utility level of analysis. As noted in Section 4.4.1, the utility level measure represents the average of the plants, if it operates more than one.

While the exact statistical procedure is somewhat complex, interpretation of the findings is actually quite simple. The reader need only examine the column on the R-square change to see if the addition of a particular term added substantial proportions of explained variance. Thus, beyond statistical significance which is shown, the reader can use their insights as a basis for judging the importance of the proportion of variance explained by a particular model.

Using Table 4.6 as the exemplar for discussion purposes, the last column contains the results for predicting average weighted violations for all utilities. The .21 (first row last two columns) suggests that in the Southern region there were many more violations and the knowledge of the region accounts for some 21 percent of the variance in the average weighted violations over the five year study period. While plant age explains five percent of the variation this is not statistically significant, yet utilities with more than one plant did have a significantly higher number of weighted violations. The change in R-square for the single plant control term is .08 and the overall proportion of variance explained at this stage of the analysis is .35. Moving down the column, the change in R-square attributable to the term growth squared times commitment is .26. At this point in the analysis some 65 percent of the variance in average weighted violations is explained. Figure 4.1 provides a graphical interpretation of this interaction.

Table 4.4

Results of Regression Analyses Predicting Plant Operating Reliability and Safety Violations by Year[1]

	Operating Reliability									
	1983		1984		1985		1986		1987	
Variable	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
South	.02	.02	.00	.00	.01	.01	.08	.08*	.11	.11**
BWR	.02	.00	.00	.00	.01	.00	.10	.02	.13	.02
Single Plant	.03	.01	.00	.00	.02	.01	.10	.00	.14	.01
Plant Age	.10	.07*	.00	.00	.05	.03	.10	.00	.15	.01
Growth (G)	.12	.02	.01	.01	.05	.00	.17	.07*	.30	.15**
Commitment (C)	.13	.01	.02	.01	.19	.14**	.17	.00	.32	.02
G^2	.13	.00	.02	.00	.21	.02	.17	.00	.44	.12**
C^2	.16	.03	.03	.01	.21	.00	.21	.04	.44	.00
GXC	.17	.01	.03	.00	.24	.03	.22	.01	.50	.06**
$G^2 X C$	.19	.02	.13	.10**	.27	.03	.27	.05*	.55	.05**
$G X C^2$	.19	.00	.13	.00	.27	.00	.28	.01	.55	.00
$G^2 X C^2$	...[2]	...	.14	.01	.36	.09**	.28	.00	.57	.02
	Level Three Violations									
South	.01	.01	.00	.00	.05	.05*	.13	.13**	.03	.03
BWR	.13	.12**	.08	.08*	.15	.10**	.21	.08**	.03	.00
Single Plant	.16	.03	.10	.02	.16	.01	.23	.02	.03	.00
Plant Age	.16	.00	.10	.00	.21	.05*	.23	.00	.07	.04
Growth (G)	.16	.00	.11	.01	.26	.05*	.23	.00	.08	.01
Commitment (C)	.16	.00	.18	.07*	.35	.09**	.26	.03	.09	.01
G^2	.16	.00	.19	.01	.43	.08**	.26	.00	.10	.01
C^2	.18	.02	.21	.02	.44	.01	.26	.00	.12	.02
GXC	.19	.01	.22	.01	.48	.04*	.26	.00	.14	.02
$G^2 X C$	.23	.04	.30	.08*	.48	.00	.27	.01	.14	.00
$G X C^2$	.24	.01	.37	.07*	.52	.04*	.27	.00	.14	.00
$G^2 X C^2$	...[2]	...	.44	.07*	.62	.10**	.27	.00	.14	.00
	Level Four Violations									
South	.01	.01	.17	.17**	.11	.11**	.10	.10**	.21	.21**
BWR	.01	.00	.21	.04	.11	.00	.10	.00	.23	.02
Single Plant	.01	.00	.22	.01	.12	.01	.14	.04	.28	.05*
Plant Age	.06	.05	.22	.00	.17	.05	.16	.02	.29	.01
Growth (G)	.06	.00	.23	.01	.20	.03	.18	.02	.30	.01
Commitment (C)	.16	.10**	.26	.03	.20	.00	.19	.01	.30	.00
G^2	.32	.16**	.27	.01	.20	.00	.20	.01	.32	.02
C^2	.33	.01	.29	.02	.20	.00	.22	.02	.33	.01
GXC	.41	.08**	.37	.08**	.20	.00	.22	.00	.33	.00
$G^2 X C$	.51	.10**	.46	.09**	.22	.02	.22	.00	.33	.00
$G X C^2$	.51	.00	.46	.00	.24	.02	.22	.00	.34	.01
$G^2 X C^2$	...[2]	...	.50	.04*	.28	.04	.28	.06*	.40	.06**
	Level Five Violations									
South	.01	.01	.03	.03	.11	.11**	.13	.13**	.20	.20**
BWR	.07	.06	.06	.03	.12	.01	.13	.00	.26	.06*
Single Plant	.07	.00	.06	.00	.14	.02	.13	.00	.29	.03
Plant Age	.08	.01	.07	.01	.14	.00	.16	.03	.29	.00
Growth (G)	.14	.06*	.07	.00	.16	.02	.26	.10**	.29	.00
Commitment (C)	.17	.03	.11	.04	.16	.00	.26	.00	.30	.01
G^2	.31	.14**	.13	.02	.17	.01	.27	.01	.30	.00
C^2	.32	.01	.14	.01	.21	.01	.27	.00	.31	.01
GXC	.38	.06*	.23	.09*	.22	.01	.27	.00	.36	.05*
$G^2 X C$	.49	.11**	.35	.12**	.24	.02	.28	.01	.44	.08**
$G X C^2$	.49	.00	.35	.00	.30	.06*	.30	.02	.44	.00
$G^2 X C^2$	...[2]	...	.46	.11**	.30	.00	.37	.07**	.45	.01

[1] There were 63 observations in 1983; 69 in 1984; 76 in 1985; 84 in 1986; and 84 in 1987

[2] Variable is a linear combination of previous predictors.

* $p < .05$ ** $p < .01$

Table 4.5

Regression Analyses Predicting Plant Violations Within Severity Level and Operating Reliability Averaging Across the Five Years

	Level 1		Level 2		Level 3		Level 4		Level 5		Reliability	
Variable	R^2	ΔR^2	R2	ΔR^2	R2	ΔR^2	R^2	ΔR^2	R2	ΔR^2	R2	ΔR^2
South	.00	.00	.01	.01	.11	.11**	.19	.19**	.09	.09**	.06	.06*
BWR	.01	.01	.01	.00	.14	.03	.20	.01	.15	.06**	.06	.00
Single Plant	.03	.02	.01	.00	.14	.00	.23	.03	.17	.02	.06	.00
Plant Age	.03	.00	.04	.03	.15	.01	.26	.03	.18	.01	.06	.00
Growth (G)	.04	.01	.04	.00	.17	.02	.27	.01	.21	.03	.17	.11**
Commitment (C)	.06	.02	.05	.01	.20	.03	.28	.01	.24	.03	.23	.06*
G^2	.07	.01	.06	.01	.20	.00	.31	.03	.28	.04	.29	.06*
C^2	.07	.00	.06	.00	.20	.00	.32	.01	.29	.01	.29	.00
GXC	.08	.01	.07	.01	.21	.01	.35	.03	.36	.07**	.40	.11**
G^2XC	.08	.00	.12	.05*	.28	.07**	.48	.13**	.55	.19**	.40	.00
GXC^2	.10	.02	.12	.00	.29	.01	.49	.01	.55	.00	.40	.00
G^2 X C^2	---1	---	---1	---	---1	---	---1	---	---1	---	.41	.01

1 Variable is a linear combination of previous predictors.

N = 84

* $p < .05$

** $p < .01$

Table 4.6

Regression Analyses Predicting Utility Weighted Safety Violations for Each Year and Across the Five Years[a]

	Weighted Violations											
	1983		1984		1985		1986		1987		Average	
Variable	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
South	.02	.02	.10	.10	.26	.26••	.09	.09	.23	.23••	.21	.21••
BWR	.02	.00	.13	.03	.28	.02	.09	.00	.26	.03	.22	.01
Plant Age	.04	.00	.14	.01	.30	.02	.13	.04	.26	.00	.27	.05
Single Plant	.04	.00	.16	.02	.37	.07	.20	.07	.37	.11•	.35	.08•
Growth (G)	.06	.02	.16	.00	.42	.05	.23	.03	.37	.00	.35	.00
Commitment (C)	.06	.00	.18	.02	.42	.00	.25	.02	.39	.02	.36	.01
G^2	.23	.17••	.19	.01	.42	.01	.26	.01	.39	.00	.36	.00
C^2	.23	.00	.27	.08	.47	.04	.28	.02	.39	.00	.37	.01
GXC	.23	.00	.30	.03	.47	.00	.29	.01	.39	.00	.39	.02
G^2XC	.31	.08	.41	.11•	.47	.00	.31	.02	.47	.08•	.65	.26••
GXC^2	.32	.01	.46	.05	.49	.02	.31	.00	.49	.02	.65	.00
G^2XC^2	.32	.00	.53	.07	.60	.11•	.38	.07	.52	.03	.66	.01

[a] The sample sizes for each year were: 32 for 1983; 35 for 1984; 39 for 1985; 40 for 1986; 41 for 1987; and 41 for the five year average.

• $p < .05$ •• $p < .01$

The contention that utilities with high commitment or high profit growth would have higher plant reliability and/or fewer violations is not generally supported. The basic correlations in Table 4.2 suggest that higher profit growth is associated with lower reliability and a higher weighted violations rate. The commitment variable is not significantly related to the reliability or violations measures.

In the regression analyses, controlling for region, number of plants, plant age and type of reactors, much the same pattern is found. For plant operating reliability, utility profit growth is a significant predictor in two of five years while utility commitment to nuclear is a significant predictor in only one of the five years. When significant, for the year to year correlations, higher utility profit growth is associated with lower not higher plant reliability (c.f. Table 4.2). Across the five years (See Table 4.5) profit growth and commitment are significant predictors of plant reliability but not violation rates. For the weighted safety violations measure at the utility level of analysis, (Table 4.6), neither profit growth nor commitment is a significant predictor.

4.5.4 Linear Interactions For Profit Growth and Commitment

The linear linkages between profit growth and reliability reflected in the significant negative correlations in Table 4.2 suggest that utilities with more discretionary resources had more failures in terms of lower plant reliability.

The linear effects of the two independent variables is not very consistent across years or units of analysis. As shown in Table 4.4 only one of the five linear interactions of commitment times profit growth is significant when predicting operating reliability year by year. Across all five years (Table 4.5) this linear interaction is significant. For violations the results are also mixed. For level three and four violations, only three of ten interactions are significant (See Table 4.4) Across the five years, the linear interaction is significant for only level five violations (Table 4.5). For weighted violations (See Table 4.6) the linear interaction term was not significant in any of the regression analyses.

4.5.5 Curvilinear Interactions

With respect to plant reliability, Table 4.4 shows that in four of the five years the curvilinear interactions provided significant incremental information over and above the controls, main effects, curvilinear terms, and linear interactions. In 1984, 1986, and 1987 the growth-quadratic by commitment-linear interaction (G^2xC) was significant, whereas in 1985 the growth-quadratic by commitment-quadratic interaction (G^2xC^2) is significant. With respect to levels three, four, and five safety violations, the curvilinear interactions consistently increase the explained variance; however, there is little stability across years as to which interaction is statistically significant.(See Table 4.4).

Results across the five year study period (See Table 4.5) also demonstrate the importance of the curvilinear effects as well as identify the growth-quadratic by commitment-linear interaction (G^2xC) as the best representation of the safety violations data. In violation severity levels 2-5 the curvilinear interactions are important; the proportion of additional variance attributable to the quadratic by linear interaction (G^2xC) ranged from .05 to .19. Unfortunately, no systematic relation between the predictors and level one violations can be discerned. The inability to predict these most severe violations may be due to their infrequency. With respect to reliability, no curvilinear interactions are evident on the averaged data.

Table 4.6 reports the results of the utility level analyses. The curvilinear interactions are important predictors of weighted safety violations in 1984, 1985, and 1987 (see Table 4.6). However, because of small sample size (N ranged from 32 in 1983 to 41 in 1987), statistical power is severely limited (Cohen, 1989). If Cohen's (1989) suggestion of using a higher alpha level (e.g., .10) is followed when the number of observations is limited and small, the curvilinear interactions are significant predictors in all five years. However, as with the plant level data, there is little consistency in the pattern of interactions across the five years. The growth-quadratic by commitment-linear interaction (G^2xC) was significant in two of the five years and across the five year average, whereas the growth-quadratic by commitment-quadratic (G^2xC^2)was significant in one year.

On the averaged utility data the growth-quadratic by commitment-linear interaction (G^2xC) again appears to be most important in predicting the weighted safety violations. The proportion of variance attributable to this curvilinear interaction is 0.26, over and above the controls, linear and curvilinear main effects, and linear interactions.

In Figure 4.1, a growth-quadratic by commitment-linear interaction is depicted. The interaction suggests that utilities with low commitment to nuclear power, the rate of violations initially climbs with profit growth, then declines as profit growth exceeds some moderate level. Conversely, for utilities with high commitment to nuclear power, violations initially decline as profit growth increases, only to increase as profit growth exceeds some moderate level.

4.6 Discussion

The analyses reported in this chapter provide further evidence that organizational factors are potentially important predictors of safeness for both nuclear plant and utility levels of analyses. The proportion of explained variance in weighted violations for utilities across the five year period attributable to the growth-quadratic by commitment-linear interaction (G^2xC) wa 0.26. It is quite clear that the analysis of organizational factors has considerable potential for helping to protect the public health and safety. Results as to the role of profit growth and commitment may be viewed as further validation of the concepts of resource availability and business strategy (see Section 2.3). And interpreted against the theoretical backdrop provided earlier in this chapter (Section 4.3), the findings suggest some interesting and important implications.

4.6.1 Discussion of the Curvilinear Results

The apparent reaction evidenced in the violation rates to changes in profit growth by heavily committed and not heavily committed utilities is dramatically evident in two years (1984 and 1987), and appears to be potentially very important over the five year averaged study period. The results suggest that there should be further investigations into the importance and persistence of classic decision errors by senior utility management resulting from the decision frame. The general form of the interaction between commitment and profit growth is consistent with prior work by Kahneman & Tversky (1979). The pattern is virtually identical to that suggested by "purposeful unintended consequences," Osborn and Jackson (1988).

The most stable and important term across all analyses was the growth-quadratic by commitment-linear interaction (G^2xC). Figure 4.1 depicts this interaction for utilities with comparatively low and high levels of commitment. As plotted for the index of violations, it is quite easy to see the departures from linearity. If this pattern is found for violations in more recent years, it would suggest that acceleration in profit growth rates has dramatic-but quite different linkages to violations depending on the utility's commitment to the technology.

4.6.2 Issues of the Linkage Among Intermediate Aspects of Safeness

Earlier in this report the independence of various safety indicators has been detailed (Section 2.2.1.1). In the present chapter it is shown that while a plant with more violations may tend to be less reliable in the future, the relation between violations and reliability is far from perfect. The myth that reliable plants are safer plants is not supported. The linkage among dependent variables appears quite weak. Management appears to confront a more complex and difficult issue than merely how to increase reliability or cut violations to simultaneously improve efficiency and safeness.

However, when there is an assumption that reliable plants are safe plants, there may well be a false search for and replication of "good" plants. These exemplars, which are high on operating reliability, may be copied, while Figure 4.1 practices and policies promoting non-reliability related aspects of safeness in "poor" plants might be cited as examples of bad management. In sum, borrowing could yield less, not greater safeness.

One interesting aspect of the relationship among the criteria over time deserves further comment. There were often high correlations year to year on the same criterion. This suggests that stable patterns and/or long-term cycles persist. This finding validates results reported in Chapter 3, which reported that the past is the strongest predictor of future performance on the NRC performance indicators. Further work should proceed on identifying when, how and if positive performance cycles can be established or conversely, how negative performance cycles (vicious cycles) can be broken.

4.6.3 The Complexity of Managing for Multiple Constituencies

There can be little question that managing a nuclear utility involves uncertainty of outcomes and process and potential risk. Future research should recognize the complexities of managing for multiple constituencies. Senior utility executives may seek to maintain their positions by balancing many partially conflicting demands from many potentially important constituencies. That is, executives face the "normal" problems of organizational life (c.f., Katz & Kahn, 1978). Unfortunately, they may not be unbiased and their decisions may partially reflect their decision frame. Whether this pattern of "purposeful unintended consequences" persists or has recently been corrected needs to be investigated.

The pattern of results reported in this chapter is not consistent with a pattern of consistent improvement in reliability or violations. When predicting violations the curvilinear interaction did not fade with time. Over the five year period, the curvilinear interaction was significant for level two, three, four, and five violations at the plant level and explained substantial proportions of variance in the utility weighted violations measure for three of the five years with an R-square change of 0.26 across all five years. This interaction was consistent with the predicted bias for the violations measure that suggested both risk taking and risk aversion affected by decision frame.

Perhaps this overall pattern of findings reveals the challenges and complexity facing senior utility managers and their organizations. If so, more attention needs to be given to the effects of comparatively small variations in specific types of risk taking/aversion under dramatically improving or deteriorating conditions where the effects of decision errors are magnified.

4.7 Conclusions

The empirical analyses reported in this chapter, which use profit growth and commitment to nuclear technology to predict reliability and violations, again shows that even indirect measures of management and organization predict substantial proportions of variance in outcomes considered relevant for the public health and safety of the commercial nuclear power generating industry. For example, when predicting the weighted violation rates for utilities over the five year study period from 1983 to 1987 some sixty-five percent of the variance can be explained. A total of thirty-one percent of the variance can be attributable to two indirect measures of management and organization over and above controls for region, type of plant, the number of plants operated by a utility and the region in which the utility operates.

Given the severe limitations of this singular study of using only one time period and of using only two available indirect measures, definitive conclusions cannot be made. However, the results suggest the following:

1. Measured aspects of management and organization can be used to predict reliability and violation rates as two types of intermediate measures of safeness.

2. Available data from published sources can be used to examine some of the critics' contentions regarding safeness. However, the data did not support the notion that more heavily committed utilities or those with high profit growth rates had plants with higher reliability records or lower violation rates.

3. The selected indirect measures of management and organizational factors consistently were related to violation and reliability rates over an extended time period.

4. The pattern of results is consistent with a very specific prediction of risk bias known as "purposeful unintended consequences."

5.0 EXTENDING THE ANALYSES - ADDITIONAL STATISTICAL STUDIES

5.1 Overview of Two Additional Statistical Studies

Two logical questions arise upon completion of the work reported in Chapters 3.0 and 4.0. The first question concerns the stability of the statistical models derived from the organizational learning theory and used to explain change in the performance indicators. The performance indicator data used was for 1987-88, and the independent variables were measured in 1985-86. In this chapter, we use performance indicator data for 1989-90, and independent variable measures for 1987-88, and re-estimate the same models in order to assess the stability of the models from one time period to the next. The second questions arises from the analyses, reported in Chapter 4.0, in which a measure of senior executives' decision frame was used to predict reliability and violation rates. The logical next question is determine how the same measure of decision frame performs in predicting the NRC performance indicators. Two projects were undertaken to address these issues. The analyses of the stability of the models explaining performance indicators are reported in section 5.2. The ability of decision frame to explain performance indicators is examined in section 5.3

5.2 The Stability of the Organizational Learning Model

The purpose of this section is to assess the stability of the statistical models derived from the theory of organizational learning found in chapter 2.0. By re-estimating these models in a later time period, 1989-90, the consistency of the relationships found in 1987-88 can be evaluated. To conduct this analysis, new data were collected for the later time period and the statistical models presented in chapter 3.0 were re-estimated and comparisons made with the earlier results.

The dependent variables in this section are measures of the performance indicators in 1989-90: Scrams, Significant Events, Safety System Actuations, Safety System Failures, Radiation Exposure, and Critical Hours. The independent variables in the statistical models represent organization factors hypothesized to influence the performance indicators, thus they are measures taken one and two years prior, 1985-86 in the original models, and 1987-88 in the research reported on in this section.

5.2.1 Overview of the Theory

Underlying the statistical models is the theory of organizational learning presented earlier in which problems are recognized via such means as past performance, SALP score evaluations, and violations. The utility then has to have the resources to formulate solutions to the problems, and these resources have to be applied in way that help implement the solutions. The problems can be better diagnosed and the solutions better implemented if the utility has the capacity to focus its attention on its nuclear power operations. If its attention is distracted by other priorities dictated by its business strategies, it is likely to be less successful in solving its problems. Thus five concepts are central to the research--past performance, problem recognition, resource availability, resource allocation, and business strategies that focus, or fail to focus, the utility's attention. Past performance is a critical component of the model because it is assumed that the forces of inertia represented by past performance constrain the nuclear utility from solving its problems and improving its performance. Poor performance breeds further poor performance, and good performance furthers good performance, unless attention is focused on problem solving and resources are available.

In earlier chapters, numerous variables represented these concepts. They were used to test the model's overall predictive ability. For this examination of the model, the variables that performed best in the 1987-88 time period have been re-estimated in the later time period. This strategy of using the same variables to measure the concepts is a fairly rigid test of the theory. Alternatively, we could have tested the model using a variety of independent variables as measures for the concepts (as we did earlier) to see if the concepts continued to have explanatory power, even if measured by different indicators. Ideally, individual coefficients would exhibit a high degree of stability across time periods, but given the frequent yearly changes in the performance indicators such stability is unlikely. However, the model as a whole can be evaluated from period to period using significance test of the overall fit of the model.

5.2.2 Dependent Variables

The first step was to create graphs of the performance indicators to detect any trends which might affect the stability of this analysis. Graphs of the performance indicators for 1985-1990 are shown in Figures 5.1-5.6.

Overall, these graphs demonstrate a general downward trend in the occurrence of the performance indicators. Scrams, in particular, reveal a sharp downward trend from 1985 to 1990. This is undoubtedly due in part to the scram reduction campaign conducted by the NRC and carried out by the utilities during this time period. This trend is evident in other performance indicators as well (significant events and safety system actuations). It is less pronounced in the case of radiation exposure and not apparent in the same way for safety system failures and critical hours.

The fact that a number of the variables are radically trending downward makes replication of the earlier analyses particularly difficult. The system's properties are rapidly changing as indicated by the graphs. Exact replication of the findings cannot be expected. What is valuable to examine is whether the model as a whole as derived from the organizational learning theory, still has a strong influence on the performance indicators. Significant variation in the individual parameters making up the model is likely. Moreover, as the measures get smaller, less variance among the dependent variables is left to be explained by the independent variables, particularly as the dependent variables move closer to zero. Therefore, many of the relationships found earlier when there was more overall variation may no longer be evident. However, while exact replication of the significant parameters in the model is unlikely, the overall predictive power of the model can be determined and interpreted.

5.2.3 Description of Independent Variables

The following independent variables, chosen from the refined representation of the model found in chapter 3.0, have been included in the analysis.

Past performance--measured by:
Past values of the dependent variable (PAST)

Problem identification--measured by:
Major violations (NOMAJV 87)
SALP scores (SALP 87)

Resource availability--measured by:
Return on investment (ROI 86-87)
Operating efficiency (OPEF 86-87)

Resource application--measured by:
Plant costs per megawatt capacity (PLANT 86-87)
Ratio of spending on engineering for operations supervision to spending on engineering for both maintenance and operations supervision (RSEOP 86-87)

Business strategy--measured by:
Extent of emphasis on
Transmission and distribution (TD 86-87)
Other power generation (OTHR 86-87)
Power production (PROD 86-87)

Experience and type--measured by
Age x reactor size x historic capacity (E2X)
Boiling water reactor or pressurized water reactor (TYPE, where 1=BWR)

5.2.4 The Methods

As before, Poisson regression models are used to predict the performance indicators which are event counts (i.e. scrams, significant events, safety system actuations, safety system failures); and ordinary least squares regression models are used to predict the continuous variables, which more nearly conform to a normal distribution (i.e. radiation exposure and critical hours). The plant population of publicly held nuclear power plants is identical in earlier and current analyses, but the number of plants is slightly different due to availability of data.

5.2.5 Results of Updated Analyses

The results of tests of the models for each of the performance indicators for 1987-88 are shown in column 1 of Tables 5.1-5.6. These are identical to the results presented in Chapter 3 and are shown again here for comparison with the 1989-90 results presented in column 2 of Tables 5.1-5.6.

Table 5.1

Poisson Regression Estimation: Scrams

	SCRAM 87-88		SCRAM 89-90	
	Estimated Coefficient	t-value	Estimated Coefficient	t-value
NOMAJV	-0.02002	-0.42	0.0076	0.04
SALP	-0.01630	-0.39	-0.0304	-0.52
ROI	4.98850	0.60	6.9491	1.15
OPEF	4.62775	0.66	-9.6132	-2.37**
PLANT	-0.83358	-1.78*	-0.0001	-1.10
RSEOP	-0.05897	-0.15	0.2120	0.39
PROD	0.83917	0.99	-0.6133	-0.55
TD	0.03346	0.80	-0.1062	-0.77
OTHR	1.97085	1.10	0.0001	0.09
E2X	-0.73159	-2.07**	0.0002	0.53
TYPE	0.00171	0.01	-0.1155	-0.61
PAST SCRM	0.03712	2.60**	0.0202	0.91
CONSTANT	0.72313	1.06	1.4677	1.06
Estimated R-Squared	.35		.27	
Log-Likelihood	174***		150***	
N=	58		57	

* p <.10
** p <.05
*** p < .01

Table 5.2

Poisson Regression Estimation: Significant Events

	SE 87-88		SE 89-90	
	Estimated Coefficient	t-value	Estimated Coefficient	t-value
NOMAJV	-0.05990	-0.63	-0.11957	-0.45
SALP	0.05916	0.86	0.03547	0.34
× ROI	-28.06955	-2.18**	2.17923	0.15
OPEF	15.80293	1.44	4.96652	0.67
PLANT	0.13155	0.18	-0.00001	-1.53
× RSEOP	-1.31302	-2.06*	0.27347	0.25
PROD	1.35779	1.02	-1.43605	-0.61
TD	-0.02651	-0.41	-0.00482	-0.24
OTHR	3.48614	1.28	0.00009	1.16
E2X	0.52246	0.97	0.00001	2.09**
TYPE	0.18013	0.64	0.46620	1.33
PAST SE	0.08348	2.17**	0.35901	2.99**
CONSTANT	1.57756	1.48	-2.60666	-0.89
Estimated R-Squared	.35		.40	
Log-Likelihood	50**		20	
N=	58		57	

* p <.10
** p <.05

Table 5.3

Poisson Regression Estimation: Safety System Actuations

	SSA 87-88		SSA 89-90	
	Estimated Coefficient	t-value	Estimated Coefficient	t-value
NOMAJV	-0.13685	-1.67*	0.18362	1.00
SALP	-0.07693	-1.23	0.03831	0.49
ROI	-6.04450	-0.50	-2.10758	-0.29
OPEF	10.22831	1.03	-3.18203	-0.72
PLANT	0.12361	0.20	0.00001	-1.38
RSEOP	0.86815	1.46	0.16773	0.26
PROD	1.55706	1.27	-1.92135	-1.37
TD	0.00504	0.09	-0.19442	-1.17
OTHR	-1.73478	-0.64	-0.00001	-2.53**
E2X	-0.66162	-1.24	0.00001	0.25
TYPE	0.43518	1.97**	-0.54951	-2.05**
PAST SSA	0.11801	3.07**	0.06145	1.06
CONSTANT	0.18067	0.19	2.41619	1.39
Estimated R-Squared	.38		.26	
Log-Likelihood	80**		66**	
N=	58		57	

* p <.10
** p <.05

Table 5.4

Poisson Regression Estimation: Safety System Failures

Number of major violations

Return on investment

	SSF 87-88		SSF 89-90	
	Estimated Coefficient	t-value	Estimated Coefficient	t-value
NOMAJV	-0.08388	-2.44**	-0.01043	-0.10
SALP	0.18500	5.04**	-0.01598	-0.36
ROI	-11.99240	-1.92*	-6.40619	-1.16
OPEF	12.76592	2.28**	12.82417	4.07**
PLANT	-0.08813	-0.23	0.00001	-1.00
*** RSEOP	-1.72002	-5.79**	-1.46623	-3.14**
* PROD	-0.46810	-0.69	-2.23643	-2.12**
** TD	-0.01903	-0.50	-0.36723	-3.83**
OTHR	2.92894	2.14**	0.00001	-1.65
E2X	0.28987	1.10	0.00001	0.17
TYPE	0.57131	4.49**	0.41656	2.80**
PAST SSF	0.02561	1.79*	0.08365	5.00**
CONSTANT	1.36765	2.59**	1.95266	1.75*

wrong sign

signs differ?

Operating efficiency = (earnings [illegible] taxes)/total assets.

TYPE [illegible] = 1 [illegible] = 0

Estimated R-Squared .74 .60

Log-Likelihood 1156** 896**

N= 58 57

* p <.10
** p <.05

* [illegible] : ([illegible] from [illegible] for [illegible]) / [illegible]

** TD = Transmission & Distribution [illegible] / nuclear power plant costs.

*** ~~RSEOP~~, the ratio of operations supervision and engineering spending over total supervision and engineering (including maintenance) in 1985 and 1986 (RSEOP).

Table 5.5

Ordinary Least Squares Regression: Radiation Exposure

	RAD 87-88		RAD 89-90	
	Estimated Coefficient	t-value	Estimated Coefficient	t-value
NOMAJV	123.52000	4.05**	-197.05000	-3.24**
SALP	-34.58615	-1.31	112.25800	4.41**
ROI	3267.16000	0.71	3461.67000	1.40
OPEF	-3176.76000	-0.80	-396.06500	-0.25
PLANT	-490.50600	1.86*	0.00040	2.05**
RSEOP	-328.31800	-1.36	-132.69200	-0.61
PROD	-276.24500	-0.63	342.30000	0.77
TD	21.40343	0.80	159.90700	3.46**
OTHR	125.08700	0.09	0.00001	2.34**
E2X	229.91900	1.03	0.00035	2.09**
TYPE	160.05400	1.30	40.37155	0.53
PAST RAD	0.51029	5.19**	0.36815	4.83**
CONSTANT	651.30600	1.44	-1510.58000	-2.88**
Adjusted R-Squared	.73		.57	
F-test	7.6**		7.3**	
N=	49		57	

* p <.10
** p <.05

Table 5.6

Ordinary Least Squares Regression: Critical Hours

	CRTH 87-88		CRTH 89-90	
	Estimated Coefficient	t-value	Estimated Coefficient	t-value
NOMAJV	-335.74100	-1.14	840.02600	1.88*
SALP	15.73186	0.06	-600.20000	-3.69**
ROI	11334.10000	0.22	-17152.10000	-1.05
OPEF	-1654.09000	-0.04	-10385.80000	-1.04
PLANT	-2841.20000	-1.15	-0.00222	-1.74
RSEOP	2149.87000	0.87	2567.81000	1.89*
PROD	2748.42000	0.55	3680.36000	1.26
TD	153.95400	0.50	68.67076	0.23
OTHR	3831.94000	0.26	0.00001	0.29
E2X	-5836.91000	-2.71**	-0.00237	-2.36**
TYPE	-1150.54000	-1.10	262.93600	0.54
PAST CRTH	0.62653	2.70**	0.41794	4.56**
CONSTANT	6194.73000	1.20	16702.00000	5.05**
Adjusted R-Squared	0.25		0.42	
F-test	3.18**		5.2**	
N=	53		57	

* p <.10
** p <.05

Table 5.7
Correlations of Independent Variables 1987-88

Correlations:	NOMAJV87	ROI878	OPEF878	PLANT878	RSEOP878	PROD878
NOMAJV87	1.0000	.2894	.1324	.1103	-.2581	-.1497
ROI878	.2894	1.0000	.7385**	-.2495	-.2514	.0141
OPEF878	.1324	.7385**	1.0000	-.2918	-.2135	-.0788
PLANT878	.1103	-.2495	-.2918	1.0000	.0834	-.1739
RSEOP878	-.2581	-.2514	-.2135	.0834	1.0000	-.0368
PROD878	-.1497	.0141	-.0788	-.1739	-.0368	1.0000
TD878	-.2160	-.1064	.2585	-.0464	-.2181	-.1522
OTHT878	.2926	-.0264	-.0217	-.1009	.0175	-.2651
E2X	.2556	.3171*	.2929	-.1662	.0073	.0820
TYPE	-.0304	-.2132	-.2577	.2620	.2807	.0573
SSA878	-.0740	-.2157	-.0258	-.1105	-.1185	.0541
SSF878	.5220**	.1892	.0998	-.1012	-.2305	-.1422
SE878	.2383	.0328	.1064	-.1246	-.2411	.0033
SCRM878	-.0633	-.2217	-.2116	-.1291	-.1998	-.0043
RAD878	.2767	.0660	.0011	-.0681	.0158	-.1712
CRTH878	-.4168**	.0826	.1366	-.1074	.0201	.1644

1-tailed Signif: * - .01 ** - .001

Correlations:	TD878	OTHT878	E2X	TYPE	SSA878	SSF878
NOMAJV87	-.2160	.2926	.2556	-.0304	-.0740	.5220**
ROI878	-.1064	-.0264	.3171*	-.2132	-.2157	.1892
OPEF878	.2585	-.0217	.2929	-.2577	-.0258	.0998
PLANT878	-.0464	-.1009	-.1662	.2620	-.1105	-.1012
RSEOP878	-.2181	.0175	.0073	.2807	-.1185	-.2305
PROD878	-.1522	-.2651	.0820	.0573	.0541	-.1422
TD878	1.0000	-.2831	-.1126	-.0593	.3295*	-.1555
OTHT878	-.2831	1.0000	.1202	.1415	-.0779	.3176*
E2X	-.1126	.1202	1.0000	.0569	-.2308	.1307
TYPE	-.0593	.1415	.0569	1.0000	.0537	.1155
SSA878	.3295*	-.0779	-.2308	.0537	1.0000	.1504
SSF878	-.1555	.3176*	.1307	.1155	.1504	1.0000

Table 5.7 (continued

```
  SE878         .1277      -.0767      .1845     -.2533       .0978       .3107*
  SCRM878       .2780      -.0052     -.3432*    -.0899       .2875      -.0081
  RAD878       -.1452       .3504*     .1962      .2284      -.0086       .3861*
  CRTH878       .1212       .1413     -.1676     -.1511      -.1177      -.3235*

     1-tailed Signif:  * - .01   ** - .001


Correlations:  SE878      SCRM878    RAD878     CRTH878

  NOMAJV87      .2383      -.0633      .2767     -.4168**
  ROI878        .0328      -.2217      .0660      .0826
  OPEF878       .1064      -.2116      .0011      .1366
  PLANT878     -.1246      -.1291     -.0681     -.1074
  RSEOP878     -.2411      -.1998      .0158      .0201
  PROD878       .0033      -.0043     -.1712      .1644
  TD878         .1277       .2780     -.1452      .1212
  OTHT878      -.0767      -.0052      .3504*     .1413
  E2X           .1845      -.3432*     .1962     -.1676
  TYPE         -.2533      -.0899      .2284     -.1511
  SSA878        .0978       .2875     -.0086     -.1177
  SSF878        .3107*     -.0081      .3861*    -.3235*
  SE878        1.0000      -.0722      .2971     -.3969*
  SCRM878      -.0722      1.0000     -.1341      .1445
  RAD878        .2971      -.1341     1.0000     -.6446**
  CRTH878      -.3969*      .1445     -.6446**   1.0000

N of cases:    57         1-tailed Signif:  * - .01   ** - .001
```

5.2.5.1 Scram Model

Scrams again are significantly explained by the model as a whole, as evident by the significant log-likelihood test. The only significant variable is operating efficiency (OPEF), a measure of resource availability. Higher resource availability is associated with a lower number of scrams. Past performance, experience, and plant spending no longer bear significant coefficients in the model explaining scrams.

5.2.5.2 Significant Events Model

For significant events, the model as a whole did not have a significant impact in explaining the dependent variable for 1989-90. However, even though the model as a whole is not significant the more significant events a plant experienced in the previous time period (1987-88), the more it had in 1989-90 as well. In addition, the more operating experience a plant has, the more significant events it experiences.

The past is a strong and stable predictor in the models for significant events in both 87-88 and 89-90. Variables representing resource availability (ROI) and resource allocation (RSEOP) lose their significance in the later time period. There are very few significant events recorded on average, and the number have declined over time, so perhaps there is simply not much variation in performance among plants to be picked up by these rather complex models.

5.2.5.3 Safety System Actuations Model

The model as a whole remains significant in its ability to explain safety system actuations. Safety system actuations in 1989-90 are influenced by the business strategy being followed by the utility as well as the type of reactor. The more the utility focused on other forms of power production (OTHR) in 87-88, the fewer safety system actuations in 89-90. Thus, safe performers on safety system actuations had expanded their overall energy production by means of alternative sources of power in the prior time period. In a reversal from the models for 87-88, pressurized water reactors had fewer safety system actuations. Comparing the two time periods for safety system actuations, the individual variables which explain performance are not very stable.

5.2.5.4 Safety System Failure Model

For this performance indicator, the model as a whole as well as the individual variables are rather stable from time period to time period. The main exception is major violations and SALPs. In previous years they were predictive of safety system failures, but not in 89-90. In both time periods, the higher the operating efficiency (OPEF), the more safety system failures. However, ROI, which was significant in 87-88 is not significant in 89-90. In both time periods, the higher the ratio of operations supervision and engineering spending over total supervision and engineering (including maintenance) spending the fewer safety system failures. In the earlier time period, the more the utility focused on generating power through other means than nuclear, the more safety system failures. In the later time period, the more it focused on production the fewer safety system failures. In both time periods, boiling water reactors showed fewer safety system failures. Past performance on the dependent variable was a significant predictor of future performance in both time periods. Overall, this model is strong and stable.

5.3.5.5 Radiation Exposure

Ordinary least squares regression models were used for radiation exposure. The amount of variance explained by the model is quite high in both time periods. The one powerful, stable variable from one time period to the next is past performance on the dependent variable. The more radiation exposure in 85-86, the more in 87-88, and the more exposure in 87-88, the more in 89-90. Other variables are not as stable. The results for 89-90 show that higher levels of radiation exposure were related to fewer major violations and higher SALP scores. In the previous time period, more major violations were associated with more radiation exposure. Similarly, plant costs per megawatt capacity reverses itself. Higher plant costs in 85-86 are associated with lower radiation exposure in 87-88, while higher plant costs in 87-88 are associated with higher exposure rates in 89-90. The strategy variables play a significant role in 89-90, where greater focus on transmission and distribution, and greater attention to other forms of power generation are associated with higher radiation exposure.

5.2.5.6 Critical Hours Model

The amount of variance explained from one time period to the next with the model goes up from .25 to .42. Across both time periods, critical hours is associated with past performance and experience: the more critical hours in the previous time period, the more in both 87-88 and 89-90; and the greater experience (total megawatts generated), the fewer critical hours. In 89-90 several additional variables show up as significant: the more major violations and the lower the SALP score in 87-88, the more critical hours in 89-90; the higher the ratio of supervision engineering operations spending relative to total supervision engineering (operations + maintenance), the higher the number of critical hours; and the higher the investments in plant per megawatt hour the fewer critical hours.

5.2.5.7 Multicollinearity Analysis

As in the earlier analyses, the specified models were examined to see if multicollinearity (i.e., strong correlation among the one or more of the independent variables) posed a problem in interpreting the results. Collinearity among the independent variables can inflate the variance of regression coefficients, making it more difficult to find significant t-statistics. This examination of multicollinearity is an especially important analysis to undertake for the models specified here, since one of the independent variables in each of the models of nuclear safety performance was past values of the safety measures. Since the independent variables are thought to be correlated with the dependent variable, it is also possible that they will be correlated with past values of the safety performance indicators.

Generally, the analysis of the correlations among the independent variables in the models showed relatively low correlations. In particular, the past values of the performance indicators and critical hours did not correlate strongly with other independent variables.

However, a few strong correlations were apparent from the correlation analysis and warrant further consideration. Operating efficiency (OPEF) was relatively strongly correlated with ROI (.74). In order to examine the scope of the problem, the poisson and regression models were re-estimated by selecting subsets of these correlated variables to see if it would lead to changes in the significance test for any of the coefficients. The results of this analysis showed no change in the significance tests. Overall, multicollinearity does not appear to be a significant problem in the models of the performance indicators.

5.2.6 Discussion

Consistent across the two time periods is the fact that the model as a whole significantly explains the safety indicators. Moreover, models that were the strongest in the earlier time period showed the greatest stability in the later time period. Safety system failures and radiation exposure were the performance indicators which best conformed to the theory as specified in the Poisson and ordinary least squares regressions in the 87-88 time period. These two models were again the strongest performers in the later time period. Several of the important concepts in the theory had a strong and consistent influence in both time periods. For safety system failures, resource availability, resource application, business strategy, production experience, and past performance were significantly related to the number of failures a plant experienced. For radiation exposure, resource allocation and past performance had an important influence in both time periods.

For the other performance indicators (i.e, safety system actuations, significant events, scrams, and critical hours) the individual variables did not reveal the same stability in the second time period. The exception among these variables is past performance which continued to have a fairly consistent impact on the performance indicators in both time periods.

The instability that was evident across the two time periods in the models' significant coefficients may be attributable to a number of causes. First, the dependent variables were generally trending downward toward zero, leaving less variance in the performance indicators for the model to explain. This downward trend may be due to the fact that plant operators are learning to manage for safety over time, and therefore this downward trend and the instability in the statistical models is due to the improvements that they made in performance between the two time periods.

With respect to scrams, the downward trend may have an economic motive. Lowering the number of scrams can boost the productive efficiency of a plant. It is in the utilities' interests to break the cycle of poor past performance on scrams, and, indeed, the evidence does suggest that they broke this cycle in 1989-90 (there is no significant relationship between prior and current scram performance).

While utility attention shifted to scrams in 1989-90, the evidence suggests that it shifted away from significant events, where the influence of the past grew and the positive efforts of having resources available (ROI) and deploying these resources in the form of operations supervision and engineering diminished.

Other power generation reveals itself to have an inconsistent effect over the two time periods. Sometimes the re-directing of resources away from nuclear and toward alternative power production positively affects safety (e.g. safety system actuations in 1989-90) and sometimes it negatively affects safety (safety system failures 1987-88 and radiation 1989-90). The NRCs ability to get the utilities to pay attention to problems remains focused in the two time periods on the most obvious of safety indicators, that is in 1987-88, safety system failures and in 1987-88 and 1989-90 radiation exposure. It appears as if a shift takes place in 1989-90 from operations supervision and engineering only having an impact on safety variables (significant events and safety system failures) to its having an impact on production (critical hours) and safety (safety system failures) in the later time period. The increase in predictive power of the production model (critical hours) in 1989-90 suggests a movement in industry learning from safety. Along with scrams, these findings suggest that a safety threshold improvement was reached after 1987-88, and in 1989-90, the industry moved back to business as usual with production and financial considerations gaining in importance.

From this analysis we can conclude that the model as a whole works over time. The <u>combination</u> of variables representing the concepts in the model have a significant impact on the safety measures in both time periods. The system functions in a way that the variables <u>in combination</u> significantly affect the dependent variables. However, in different time periods individual variables change sign and take on greater or lesser significance. Within the time periods and across the time periods, there is this variance which makes the simple use of any subset of predictors impossible. The model as a whole stands up as a diagnostic--as used in the qualitative chapter (see chapter 6.0). The statistical results support the use of the model in this way, not in a way that would rely on specific independent variables as invariant predictors.

5.3 Purposeful Unintended Consequences and Safeness

The purpose of this section is to extend the analysis of prior performance and the percent nuclear to incorporate the five NRC performance indicators. Prior analyses used the percent nuclear, as a measure of risk propensity, and prior earnings growth, as a measure of the decision frame facing senior utility management, to predict reliability and violation rates. The analyses incorporated a number of control variables including (1) NRC region, (2) type of plant (BWR versus PWR), (3) the number of plants operated by a utility (scored 1 versus more than 1) and (4) plant age (number of months since commissioning). The five additional criteria are (1) unplanned automatic scrams, (2) safety system actuations, (3) significant events, (4) safety system failures and (5) collective radiation exposures.

Overall the analyses suggest that the curvilinear interaction between prior earnings growth (growth) and the percent nuclear (commitment) predicts unique variance, over and above the controls, for utility safety system actuations and utility significant events. Interpretation of the findings is consistent with the notion of purposeful variables that are not well-explained by our other models unintended consequences. However, no significant interaction effects were found for scrams, safety system failures or radiation exposures at the utility level of analysis. For scrams, plant age (older plants had fewer scrams) and the curvilinear component of the percent nuclear (utilities with intermediate levels of nuclear power generating capacity had more scrams) were the significant predictors. For safety system failures type of plant was the only significant predictor (BWRs had more safety system failures). For radiation exposure again BWRs had more problems and older plants had a poorer record of collective exposures.

5.3.1 Background

In 1988 Osborn and Jackson (1988) coined the phrase purposeful unintended consequences to show the threat to public health and safety arising from the complex interplay among technical, institutional and executive choice conditions within organizations operating high risk technologies. Based on elements of prospect, agency and institutional theory the prediction of purposeful unintended consequences is straight forward. There will be a significant non linear interaction between the decision frame facing utility executives and their collective risk propensities when predicting the safeness of their operations.

It is most convenient to discuss purposeful unintended consequences in terms of the risk propensities of senior utility executives. Utilities with a high proportion of their operating capacity in nuclear facilities have risked the future of their utility on this technology. They may be considered technological risk takers. Conversely, those with a more conservative portfolio of energy generating technologies may be considered technologically risk averse. Under normal conditions, the decisions of risk takers and risk avoiders is not expected to systematically vary. However, under more extreme situations or decision frames the degree of risk avoidance or risk taking can be extremely important. Essentially the actions of risk takers is exaggerated under conditions of gains or losses. Under gains the risk takers become overly bold and are expected to take more safety risks. Under losses they become conservative and exhibit less risky actions. Conversely, risk avoiders remain conservative under gains but may become bold under losses. These tendencies are expected to become more extreme as the decision frame moves to increasingly positive or negative. Thus, there is the expectation of a non-linear interaction between the decision frame and risk propensity when predicting elements of safeness.

The term purposeful unintended consequences is used to help show how these risk biased tendencies can continue over time. It is not that executives are considered naive or unknowing but instead make a number of incorrect simplifying assumptions to manage this complex technology. These assumptions are (1) an efficient plant is a safe one, (2) their current administrative systems are well suited to safely manage the technology and (3) they are unbiased choice makers being unaffected by the apparent dual representation of both stakeholders and the general public. These assumptions cannot be fully tested here. Only the pattern of interaction between the apparent risk propensity and the decision frame was examined.

Earlier work suggested that the non-linear interactive combination of risk propensity and decision frame was related to violations. Here there is an attempt to extend this to the five measures of safeness proposed by the Nuclear Regulatory Commission. Specifically, the number of unplanned automatic scrams, safety system actuations, significant events, safety system failures and the collective radiation exposures will be used as criteria.

5.3.2 Measurement

5.3.2.1. Risk Propensity and Decision Frame

The measurement of risk propensity and decision frame is far from straight forward. Indirect measurement of risk propensity was necessary. As noted earlier, we assume that senior management groups heading utilities with a high proportion of nuclear generating technology are risk takers and vice versa. Support for such an assumption rests upon the history of the utility and its ability to socialize its members to accept the decision of the predecessors. Within the nuclear industry, utilities with a greater proportion of their total generating capacity are considered more committed to the technology. Thus, the variable is labeled commitment in all tables.

The measurement of the decision frame is a bit more complex. The indirect measure rests on the profit history of the firm. Based on the COMPUSTAT Annual Utility data base the five year profit growth rate was calculated using the following formula:

$$G(X_t) = [X_t - X_{(t-1)}]/X(_{t-1}).$$

Where Xt represents the total operating income at time t, X(t-1) represents the total operating income at time (t-1) and $G(X_t)$ represents the fractional change in operating income time (t-1) to time t.

To assess the multi-year growth rate, we took the logarithm of $\{C + G(X_t)$ for all t, where C was a constant large enough to ensure that no element of the series was ever negative and assessed the mean and standard error. Because the parameters of growth rate probability distributions are unknown, we subjected these estimates to a bootstrap methodology (Efron, 1981, 1985; Efron & Tibshirani, 1986) to obtain unbiased estimates of the accuracy of the observations of the mean of the series $\ln\{C + G(X_t)$ for each plant.

This procedure was applied to data for the five year period covering 1983-1987. The average of this series was then taken and is labeled growth on all tables.

Additional Dependent Variables

In 1986, the Nuclear Regulatory Commission discussed five performance indicators as described in NUREG/CR 5437. These five indicators, used as the dependent variables in these analyses, are

Unplanned Automatic Scram (Scram) - measured here as the mean for 1984-1988

Safety System Actuation (SSA) - the mean from 1984 to 1988 was taken

Significant Events (SE) - the mean from 1985 to 1988 was taken

Safety System Failures (SSF) - the mean from 1984 to 1988 was taken

Collective Radiation Exposure (RAD) - the mean from 1983 to 1988 was taken

5.3.2.2 Controls

Since the decision frame and the proportion nuclear are far from the only potentially important predictors of safeness, a number of control variables were incorporated into this analysis. Specifically based on prior analyses the following variables were incorporated: (1) Southern Region (based on prior work the south appeared to differ from other regions), (2) BWR (to separate BWRs from PWRs), (3) Single Plant (to control for utilities with more than one facility) and (4) Plant Age (number of months since commissioning).

5.3.3 Statistical Procedures

The analysis followed the recommendation of Blalock (1974) Cohen & Cohen (1983 and McNeil, Kelly & McNeil (1975) for analyses calling for the use of both categorical and continuous data and for dealing with the potential problems of multicolinearity. Specifically, a series of hierarchical regression models with the sequential addition of control variables, main effects, curvilinear terms, linear interactions and the curvilinear interactions were built. Since regression weights may be highly unstable and the overall R-square is comparatively unaffected by multicolinearity, the interpretation emphasizes the incremental change in R-square. In simple terms, the incremental R-square is expected to provide significant unique variance if the variable is a unique predictor of the criterion in question.

The analyses proceeded to first examine relationships for all 84 plants where data were available and then for all 41 utilities. Since some of the events triggering NRC safety indicators are relatively rare, only data for the five year average were considered in this analysis.

5.3.4 Results

Table 5.8 presents the means and standard deviations for this sample of plants (N=84) and utilities (N=41). Tables 5.9 and 5.10 present basic correlation matrices for the two levels of analysis. As can be seen from these tables the correlations among the various interactive components to be tested is quite high.

Table 5.11 presents results of hierarchical regression analysis for the plant level of analysis. Here there was no discernible pattern across the five criteria for any interactions between the two predictors. For Scrams, BWR plants had fewer such events, as did younger plants. Utilities toward the average had fewer scrams while those of average commitment tended to have more. For the SSA criterion again younger plants had fewer actuations and utilities with less commitment had fewer reported incidents. None of the predictors was related to significant events, while for the SSF criterion the only significant predictor was BWR. For cumulative radiation BWRs and older plants had more exposures.

For the utility level of analysis reported in Table 5.12, there were several significant interactive findings. The curvilinear terms G-squared times C was a significant predictor for both SSA and SE criteria. Plant age was the major factor in predicting scrams with older plants having fewer scrams; for SSF, BWRs had substantially more safety system failures. For collective radiation exposures, BWR and plant age were significant factors.

On balance the data are supportive of the curvilinear interaction for SSA and SE at the utility level of analysis.

5.3.5 Discussion

Across all five of the NRC safeness criteria it is quite clear that different predictions are important for different criteria. The relationships involving the controls and these criteria are discussed at length in another section of the report. Here it is quite obvious that the two indirect measures of utility management and organization had differential effects on the criteria. At the plant level of analysis lower commitment was related to significantly higher levels of safety system actuations. None of the management and organization factors predicted safety system actuations, significant events, safety system failures or collective radiation exposures. For scrams the squared terms for growth and commitment were significant. The signs on these terms were reversed, suggesting that utilities with moderate growth had higher scrams while those with moderate commitment had fewer scrams.

Perhaps most interesting were the significant curvilinear interactions predicting safety system actuations and significant events for the utility level of analysis. These interactions are consistent with the predictions of purposeful unintended consequences in that more extreme numbers of safety system actuations and significant events were found for highly committed utilities with robust records of growth (and vice versa) compared to utilities with more average levels of commitment and growth.

While the results are still too tentative to draw definitive conclusions, one point seems quite clear. Management and organizational factors may have a substantial impact on the collective performance of the plants owned by a single utility. It is clear that the search for plant safeness cannot stop at the plant gate. More analyses are needed.

Table 5.8

Means and Standard Deviations used in Prediction of Plant Safety

Variable	Plant Level n=84 Mean	SD	Utility Level n=41 Mean	SD
Scram	3.25	2.00	3.49	1.96
SSA	1.78	1.60	1.85	1.19
SE	1.33	.85	1.40	.69
SSF	2.52	1.64	2.32	1.58
RAD	456.71	253.39	444.78	245.47
South	.33	.47	.24	.44
BWR	.35	.48	.34	.44
Plant Age	98.75	61.70	100.15	57.24
Single Plant	.80	.40	.59	.50
Growth (G)	.12	.04	.11	.05
Commitment (C)	.39	.24	.38	.26

Table 5.9

Plant Level
Correlations Among Predictors and Safeness Criteria

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. SCRAM																
2. SSA	.38															
3. SE	.29	.22														
4. SSF	-.08	.23	.14													
5. RAD	-.13	-.03	.25	.41												
6. South	-.14	.05	.15	.19	.07											
7. BWR	-.23	.06	-.20	.55	.44	-.09										
8. Single	-.17	.00	-.09	-.01	.04	.17	-.01									
9. Age	-.62	-.40	-.09	-.03	.29	-.09	.19	.01								
10. Growth(G)	.17	.10	.00	.23	-.07	.27	.14	.20	-.42							
11. Commit(C)	-.14	-.21	-.17	.00	.01	-.14	.02	-.10	.08	-.34						
12. G2	.13	.04	-.03	.21	-.10	.21	.15	.18	-.42	.98	-.26					
13. C2	-.11	-.18	-.15	-.06	.00	-.17	.00	-.13	.11	-.41	.97	-.32				
14. GxC	-.12	.11	-.16	.27	-.01	.16	.21	.14	-.14	.48	.55	.51	.41			
15. G2xC	-.13	-.08	-.12	.31	-.04	.24	.25	.19	-.18	.71	.25	.74	.11	.93		
16. GxC2	-.16	-.14	-.19	.16	-.01	.04	.18	.05	.02	.10	.80	.15	.73	.88	.69	
17. G2xC2	-.21	-.09	-.15	.27	-.03	.20	.26	.14	-.03	.42	.48	.45	.37	.95	.92	.88

N=84

Correlations > .26 are significant at .05 level
Correlations > .36 are significant at .01 level

Table 5.10

Utility Level
Correlations Among Predictors and Safeness Criteria

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. SCRAM																
2. SSA	.52															
3. SE	.21	.33														
4. SSF	-.09	.16	.17													
5. RAD	-.28	-.06	.29	.62												
6. South	-.09	.11	.07	.15	.11											
7. BWR	-.22	.09	-.09	.63	.60	.03										
8. Single	-.19	.04	-.09	-.12	.04	.13	-.03									
9. Age	-.73	-.37	-.05	.05	.41	-.15	.15	.03								
10. Growth(G)	.40	.31	.02	.07	-.24	.26	.04	.14	-.62							
11. Commit(C)	-.19	-.37	-.20	-.08	-.03	-.22	-.08	-.19	.15	-.50						
12. G2	.37	.23	-.01	.05	-.25	.19	.05	.12	-.62	.98	-.41					
13. C2	-.17	-.34	-.16	-.12	.00	-.22	-.08	-.17	.18	-.53	.97	-.43				
14. GxC	-.02	-.10	-.20	.12	-.17	.05	-.01	-.01	-.27	.35	.51	.37	.38			
15. G2xC	.11	-.03	-.12	.17	-.19	.17	.05	.09	-.41	.71	.09	.73	-.04	.87		
16. GxC2	-.10	-.22	-.23	.02	-.08	-.09	-.04	-.09	.01	-.13	.85	-.08	.79	.83	.49	
17. G2xC2	-.04	-.06	-.20	.16	-.13	.10	.02	.04	-.17	.33	.44	.35	.32	.96	.88	.81

N=41

Correlations > .26 are significant at .05 level
Correlations > .36 are significant at .01 level

Table 5.11

Plant Level
Regression Analysis Predicting Five Performance Indicators

	Scram		SSA		SE		SSF		RAD	
Variable	R-Square	R-Square Change	R-Square	R-Square Change	R-Square	R-Square Change	R-Square	R-Square Change	R-Square	R-Square Change
South	.02	.02	.00	.00	.02	.02	.04	.04	.01	.01
BWR	.08	.06*a	.01	.00	.06	.04	.35	.32**	.20	.20**
Single Plant	.10	.02	.01	.00	.07	.01	.36	.00	.20	.00
Plant Age	.45	.35**a	.18	.17**a	.07	.00	.37	.01	.25	.05*
Growth	.45	.00	.19	.02	.07	.00	.37	.00	.26	.01
Commitment	.47	.02	.25	.05*a	.10	.03	.37	.00	.26	.00
G2	.52	.05**a	.28	.04	.10	.00	.38	.01	.28	.02
C2	.57	.05**	.31	.03	.11	.00	.39	.01	.28	.00
GxC	.57	.00	.32	.01	.11	.00	.40	.00	.31	.03
G2xC	.58	.00	.35	.03	.13	.03	.40	.00	.31	.01
GxC2	.58	.01	.35	.00	.15	.02	.42	.02	.34	.03
G2xC2	--- [1]	---	--- [1]	---	--- [1]	---	--- [1]	---	--- [1]	---

[1] Variable is a linear combination of previous predictors

N=84

*p<.05 Reported significance is that of variable upon entry
**p<.01

Table 5.12

Utility Level
Regression Analysis Predicting Five Performance Indicators

	Scram		SSA		SE		SSF		RAD	
Variable	R-Square	R-Square Change	R-Square	R-Square Change	R-Square	R-Square Change	R-Square	R-Square Change	R-Square	R-Square Change
South	.01	.01	.01	.01	.01	.01	.02	.02	.01	.01
BWR	.06	.05	.02	.01	.01	.01	.41	.39**	.37	.36**
Single Plant	.09	.04	.02	.00	.03	.01	.42	.01	.37	.00
Plant Age	.60	.51**a	.16	.14*a	.03	.00	.42	.00	.49	.12**
Growth	.60	.00	.17	.00	.03	.00	.42	.00	.50	.01
Commitment	.63	.03	.26	.09*a	.09	.06	.42	.00	.50	.00
G2	.65	.02	.38	.12*a	.09	.00	.43	.01	.50	.00
C2	.73	.07**	.47	.09*	.10	.02	.46	.03	.50	.00
GxC	.73	.01	.47	.01	.11	.01	.48	.02	.50	.00
G2xC	.75	.02	.60	.13**	.33	.22**	.49	.01	.51	.00
GxC2	.75	.01	.62	.02	.36	.03	.49	.00	.54	.03
G2xC2	.77	.02	.63	.01	.38	.02	.49	.00	.58	.05

N=41

*p<.05 Reported significance is that of variable upon entry
**p<.01

a = Beta is negative

5.4 Conclusion

The extensions of analyses found in earlier chapters provide a more comprehensive and systematic look at the deferments of safety indicators both on two theories - the learning/problem solving theory, and the theory of purposeful-unintended consequences. Not surprisingly, learning/problem solving is best at explaining scrams, safety system failures, radiation exposure, and critical hours; while purposeful unintended consequences is best at explaining significant events and safety system actuations. These results make sense given the nature of these different dependent variables.

6.0 INVESTIGATION OF PROCESSES OF PROBLEM SOLVING AND LEARNING IN NUCLEAR POWER PLANTS

6.1 Introduction

Over the past decade, the research question concerning the role of organizational factors in nuclear power plant safety has changed substantially. The question is no longer, "Do organizational factors influence plant safety?" Numerous incident investigations and empirical analyses within the nuclear and other safety-sensitive industries have answered this question in the affirmative (NUREG/CR-3737; Perrow, 1984; Starbuck and Milliken, 1988). Nor are the questions exclusively, "What are the important organizational factors", and "How do organizational factors affect plant safety?" While much has yet to be learned about the nature and size of organizational influences under varying conditions, several recent theoretical discussions and empirical analyses have begun to address these questions (NUREG/CR-3215 NUREG/CR-5437; NUREG/CR-5538; Osborn and Jackson, 1988). The research question can now be phrased as follows: "Given that organizational factors are crucial to plant safety performance, what should utility management and the Nuclear Regulatory Commission (NRC) do to assure that organizational factors contribute to, rather than detract from, safe performance?"

An initial reaction to this question might be to develop standards for organizational factors for all commercial nuclear power plants. Such standards would include detailed guidance on reporting relationships, the configuration of tasks within and among departments, limits on spans of control, the ideal number of vertical ranks, recommended coordination and communication mechanisms, and the like. However, such an approach may be of limited use for both utility management and regulators. Existing organizational theory and research very strongly suggest that effective organizations can and must take substantially different forms depending on the demands of the specific organizational context and the history of the specific organization. To apply common design and management requirements to all nuclear power plants would not be sensitive to the need of individual utilities to respond to the contingencies of size, local culture, labor relations, ownership structure, design and age of plant, and the countless other factors that management must take into account when devising a workable organizational strategy. While an idealized model can inform and guide the regulatory process, it does so more by providing an inventory of organizational factors and relationships among those factors for consideration on a case-by-case basis. Results reported in earlier chapters support this view. The statistical analyses produce different profiles of predictor variables for each performance indicator, and when different measures of key concepts are used, the results are substantially the same. Thus, it is not the measured variables, but the combination of organizational conditions present that explain performance.

How should the NRC take organizational factors into account in the discharge of its duty to protect public health and safety? One answer can be found in the NRC's program of measuring and monitoring performance. The development of programmatic performance indicators, including organizational performance indicators, is part of this effort. By developing reliable indicators of performance, particularly if those indicators are capable of identifying problems before they become significant, the NRC is in a better position to determine the overall adequacy of nuclear power plant management and organization and, working with licensee management, to engage in a program of improvement.

However, the very process of improvement is, in itself, not well understood. The theory and analyses represented in Chapters 2.0 and 3.0 represent considerable progress toward the goal. Fuller understanding is important, because, when plant performance has degraded to the point that it raises substantial NRC concern, the NRC needs to be in the position to judge with some confidence that the utility's plan for improving performance is sound and has a substantial chance for success. However, few objective criteria exist for evaluating these plans. Further, organizational theory and utility experience indicate that the process of improvement or learning cannot be reduced to the development and application of formal improvement programs. While these programs are essential in a degraded plant, detailed attention must also be applied to more general organizational factors including management style, plant culture and values, availability and use of resources (technical and capital) and the nature of inter-departmental relations, if the formal programs are to meet with success. Logically developed improvement programs, even those that have worked well at other sites, can frequently fail at the point of implementation. A better understanding of the factors that lead to improvement and the strategies for implementing an improvement program is thus required.

In order to further develop indicators of organizational effectiveness, an effort has been undertaken in this project to understand and document the organizational context of learning in nuclear power plants. This effort examines among others, factors introduced in Chapter 2.0 and analyzed across the population of plants in Chapter 3.0. The present research consists of a review of highly detailed Diagnostic Evaluations (DE) conducted by the NRC's Office for the Analysis and Evaluation of Operational Data (AEOD), and an analysis of interviews from seven case studies. The purpose of this chapter is to report on the results of this work in order to answer the following questions:

- What is the relationship between organizational learning and safety performance in nuclear power plants?
- What does the process of learning look like? What are its essential elements?
- What organizational factors appear to promote or inhibit organizational learning?
- What factors should the NRC look for in evaluating the ability of a plant to improve its level of safety performance through learning?

6.2 Method

Two primary sources of information are used to support the analysis. The first source is a systematic review of eight NRC Diagnostic Evaluations (DE). The DEs are intensive investigations of the root causes of actual or potential performance problems at selected nuclear power plants. In most cases, a plant is selected by the NRC for a DE when it displays below average performance over several years. This criterion is not absolute. At least two of the DEs, Perry and McGuire, were based on either more diffuse concerns with corporate management or because of a more specific and shorter-term performance issue. The exact nature of the DE depends on the performance problems triggering the NRC's concern. Thus, different investigation protocols have been used for the different DEs, leading to some differences in the types of organizational factors evaluated and the level and type of information available to address the issues surrounding organizational learning. Nonetheless, the DEs provide a rich and generally consistent source of information about management and organization factors in general, and the problems associated with organizational learning in particular.

The DEs reviewed for this analysis were:

- Zion
- Dresden
- Palo Verde
- Brunswick
- Perry
- McGuire
- Arkansas Nuclear One (ANO)
- Fermi.

The review consisted of abstracting from the DEs any information associated with plant improvement programs, operating experience review programs, equipment performance and trending programs, root-cause analysis, safety performance review programs, and quality assurance programs, including corrective action programs. Also abstracted from the DEs was information on any organizational factors that were specifically cited as contributing to the level of performance of the various learning-oriented programs.

The second basic source of information comes from a series of case studies of organizational learning conducted at seven plants. The case study methodology included in-depth, on-site interviews with corporate- and plant-level personnel. Eighty-nine interviews were completed using a formal interview protocol. The methodology included reviewing plant documentation of improvement and operating experience assessment programs. The case studies were devised to get directly at the process of learning and the management and organizational factors that either promoted or inhibited learning at the various sites. As opposed to the DEs, the case studies focused on better than average performers. Thus, these case studies are more useful for presenting positive information on learning in nuclear power plants.

The case studies include six commercial nuclear power plants and one DOE research reactor. In all cases, the organizations show a recent history of sound performance. Most of the organizations were small by industry standards, with four of the commercial units highly similar in size, basic design, and operating philosophy. Two of the sites were larger, more complex organizations. The DOE reactor operated in a unique regulatory and production environment. Although interpretations drawn from these case studies may not be generalizable to the broader range of plants, valuable, if only initial information is available from these case studies. Individual and plant names are excluded from this analysis to guarantee confidentiality.

The data collection method used at each utility and plant site involved interviews of 12 to 20 individuals including plant management, the heads of major plant functions (e.g., operations, maintenance, engineering, QA), and individuals charged with responsibility for the major plant improvement programs (e.g., the Human Performance Evaluation Systems (HPES), operating experience review, equipment history programs). Using a standard interview protocol, questions were asked about the organization and performance of the plant, and the nature of the plant improvement programs. The respondents were also asked if the programs had contributed to improved performance, how this contribution was made, where the programs had failed and why, and how the programs could be improved. From these questions, considerable information on the organizational context of learning was obtained, including information on problem discovery and solution implementation, the role of inter-department cooperation in learning, the significance of corporate support and resources, the need for prioritization, and strategies for follow-through and evaluation. Based on this information and the experience using the interview protocol in the field, a more comprehensive set of questions for assessing learning and improvement in nuclear power plants has been developed. These questions and a methodology for their use are provided in Appendix E.

6.3 The Relationship of Learning to Plant Safety

The theoretical discussions in NUREG/CR-3215, NUREG/CR-5241, and NUREG/CR-5437 all point to the significance of learning in assuring plant safety performance. In NUREG/CR-3215, the case is made in terms of the need for innovation. With respect to nuclear power plants, it is argued that much is still being discovered relative to such factors as:

- The risk-significant interactions of components and systems
- Factors contributing to the wear and aging of components
- The performance of components and systems under extreme conditions
- The interaction of the operator and the maintainer with plant hardware.

The central hypothesis of this analysis is: the more the plant can learn from research, from industry experience, and from its own operating experience, the fewer safety significant problems it will experience over time. This perspective is illustrated by the TMI-2 accident, an accident that may have been avoided had the utility been better able to learn from industry operating experience (i.e., Davis Besse). While it has been argued that within a complex, tightly coupled system, there will never be a complete understanding of the relationships among components and systems (Perrow, 1982), learning is still likely to lead to significant improvement.

The argument made in NUREG/CR-5241 is somewhat different. Here, there is an additional concern with the role of learning in managing backlog. Plant systems are constantly degrading through use. As plants age, the burden of maintaining the plant becomes increasingly demanding as more and more components reach the end of design life. Only through effective preventive and corrective maintenance can the plant stay ahead of the effects of aging. The ability to stay ahead of degradation is strongly influenced by the ability to learn from operating experience. In cases where inadequate design, incorrect maintenance or operation, or human performance errors lead to premature failure of components, the burdens on maintenance and plant expenditures are unnecessarily increased. Organizations that can learn from operating experience and solve root causes of premature failure can reduce the amount of resources directed at corrective maintenance activities. Organizations that cannot learn from operating experience see their maintenance and corrective action backlogs grow to the point where they are sometimes overwhelmed by the volume of work to be conducted, and enter a significant downward performance spiral.

This scenario is illustrated by several of the DEs. In four of the plants reviewed poor root-cause analysis and inadequate management support for corrective actions were viewed by the NRC inspection team members as significant contributors to the continued material degradation of the plant and the inability of the plant to avoid what were fundamentally avoidable performance problems. In three of these cases, plant operators had reached the point of no longer requesting maintenance on certain key items because they felt that either the maintenance would not be performed, or that it would be performed without fixing the underlying problem.

Finally, in NUREG/CR-5437, another aspect of the relationship of organizational learning to plant safety is introduced. By emphasizing problem solving and improvement, management can create an environment and communicate values that have a positive impact on plant safety. For example, worker involvement in problem solving may improve plant morale, increase attention to the early identification of problems, and improve solutions. The worker may derive satisfaction from the experience of being listened to as an expert by management and co-workers, which in turn, increases commitment to the plant. Being part of the process of problem discovery and solution implementation is inherently rewarding, and can offset some of the tedium associated with other aspects of some jobs in nuclear power plants. Thus, the problem-solving orientation may also increase the worker's attention to the job, as the worker tries to understand the implications of his own and the system's performance. In several of the case studies, workers cited problem-solving activities and management support for worker participation in problem solving as key aspects of plant success and key contributors to staff morale. Thus, the emotional benefits accruing from a problem-solving orientation in the plant may have additional positive effects on worker performance and plant safety. A common characteristic among the seven case study plants was the positive effects of a problem-solving and organizational-learning environment. Each of the plants rewarded employees who discovered problems and participated in developing solutions. Each plant structured problem-solving teams that included key personnel (management and workers) from a variety of functions in the plant (operations, engineering, maintenance, and training).

The DEs also provide support for this perspective, although in the negative. In three of the plants, workers cited management as being unresponsive, or even punitive when problems were brought to their attention. The NRC inspection team members noted that this type of management reaction significantly lowered morale and communicated to the workers that safety was not valued, and that workers' concern for quality of performance was not warranted.

To summarize, there are several ways that an environment oriented toward organizational learning contributes to plant safety performance:

- By avoiding unnecessary, repeat failures, either through a review of the plant's own operating experience or through a review of outside experience and research
- By fostering innovation and discovery to offset existing design deficiencies and the effects of plant aging
- By stimulating open communication, cooperative problem discovery, and implementation of solutions
- By promoting work attitudes and behaviors that are consistent with safe performance in general
- By encouraging management and workers to jointly recognize and diagnose problems and implement and assess solutions for better plant safety performance.

6.4 The Process of Learning

Understanding the role of learning in nuclear power plant safety first requires a discussion of what is meant by learning. Generally, learning is knowledge or skill acquired by instruction, study, or experience. It is the modification of a behavioral tendency by experience and from an understanding of the lessons learned from that experience. Organizational learning in the nuclear power plant setting is essential for improvement in safety performance.

Several different, though related approaches can be taken to the concept. NRC, the Institute for Nuclear Power Operations (INPO), and others have observed that the same problems seem to reoccur at poor performing plants, while the case study analysis finds that plants characterized by a learning orientation seem to have a lower number of recurring problems.

Nuclear power plant learning can be investigated using organizational outcomes. An organization can be said to have learned if it manifests an improvement in a particular outcome. From the safety perspective, an organization has learned if it avoids repetitive errors and failures, either in a general class of phenomena (e.g., a decline in the number of scrams) or a more specific class of phenomena (e.g., a decline in the number of scrams induced by poorly written operating procedures). This approach to assessing learning underlies the statistical analyses conducted under other tasks in this project (see earlier chapters). It has the problem that it is much better at measuring learning at the lower end of the learning process than at the upper end. Once a plant has minimized the number of measurable performance problems, it is difficult to measure plant improvement. This approach has a built-in "ceiling effect".

Learning can be manifested in ways that are difficult to measure. For example, an organization that routinely searches its environment and learns from the operating experience of others, from theoretical discussions by experts, or from other authoritative sources may end up preventing problems in the future. Even though the error or failure rate may not change, learning has happened. While this aspect of learning is conceptually straightforward, it causes a significant measurement problem - how to assess the number of failures avoided. Understanding this type of learning depends on the observation of learning-relevant behavior.

This leads to the third perspective on learning - learning as a process. Figure 6.1 outlines progressive stages of the learning process. Each stage in the learning process is interactive with all other stages, but generally a linear process from problem identification, problem diagnosis, solution implementation, through tracking occurs in a well-working organization. When the focus is shifted from the discrete problem to be solved to the more general processes of problem solving and learning, there is a parallel set of steps: performance assessment, performance analysis, improvement innovation, and evaluation. Organizations that have developed these processes have institutionalized learning. Figure 6.1 illustrates both the discrete and the more general processes of learning. The following sections discuss the findings from the DE and case study plants for each of the four stages of learning.

6.4.1 Problem Identification/Performance Assessment

The first stage in the learning process involves identifying problems or areas that could be improved. To start the learning process, it is necessary to identify a deviation from a desired state. If everything appears to be working as well as possible, learning is unnecessary, and learning behavior is largely inefficient. If there is a deviation from expectations, however, both the stimulus and the need for learning may be present.

Problem identification, is often a complex phenomena. Problem identification is not simply a matter of the number of problems experienced. Some problem-laden plants are unable or unwilling to recognize the number of problems they have. On the other hand, some of the high-performance plants observed in this study were highly active in the problem identification area.

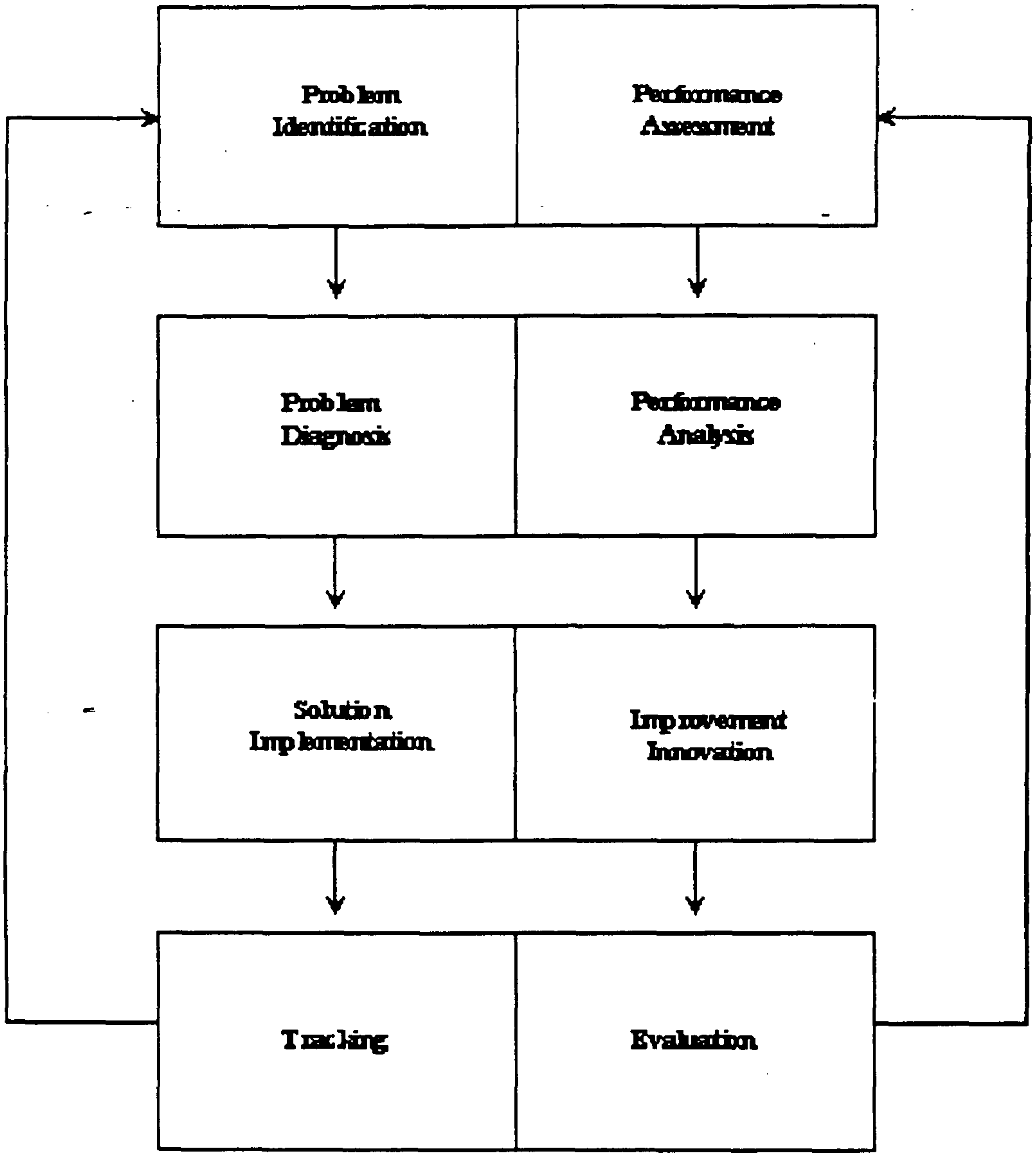


Figure 6.1

Nuclear Power Plant Organizational Learning Process

Of primary concern is the value placed on problem identification, and nuclear power plant organizations vary substantially in the degree to which they promote problem identification. A significant contrast is between those organizations that view problem identification as a first step to improvement and those that view problem identification as an impediment to the normal conduct of business. Across the case study and the DE plants reviewed, considerable variation was observed in the basic orientation to problem identification.

In the case of one DE plant, inoperable equipment was so common that it had ceased to be viewed as a problem important enough to warrant action. In the cases of two other DE plants, workers reportedly feared that the identification of problems would lead to punishment by management.

Several of the good performing plants created an environment of inquiry, pride and ownership in the plant. For example, in one of the case study plants, checking gauges regularly, although not required, led to an observation that the pressure in three had dropped. The resultant investigation led to the prevention of an outage and a savings of hundreds of thousands of dollars. All of the seven plants distribute operating experience documents widely and incorporate them in the training programs to increase employee awareness of operating problems.

Even in good plants, the ability to identify significant problems can sometimes degrade. In three of the case study plants, several respondents stated that their long history of good performance had led to overconfidence, resulting in a series of avoidable forced outages. The respondents indicated that they had temporarily lost their ability to identify developing problems.

A key difference is the "problem-space" that is searched to identify problems. For example, some plant organizations search only that problem space represented by their own operating experience. These organizations are essentially blind to the lessons to be learned from the operating experiences of other nuclear power plants and related industries. This pattern of behavior was evident from one of the DE plants, where the plant had not even adopted the lessons learned from a DE conducted two years earlier in another plant belonging to the same utility. Apparently, the plant did not have established processes for learning from external experience. In the case of another DE plant, the operating experience review program was so ineffective and poorly staffed that the relevant parts of the organization were not gaining access to information about external operating experience. Thus, this organization was not effective in integrating external operating experience into its problem space.

All of the case study plants searched widely to identify problems (e.g., vendor manuals, computerized operating experience information, newsletters). The case study plants had management-worker teams actively seeking to identify and solve problems, conducting root-cause analysis, and implementing programmatic corrective actions. In contrast, the DE plants appeared to be more likely to investigate problems only when there was a significant impact on production or in response to INPO or the NRC.

Some plants have complex formal and informal systems for expanding the problem-space searched to include other plants, both in the U.S. and elsewhere, and expend considerable resources on this activity. In general, this characterized all of the case study plants and at least one of the DE plants. In these cases, plant personnel were extensively involved in owners' group committees, EPRI projects, and using INPO supported data bases. Several of them had aggressive programs to increase the awareness of personnel including encouraging them to attend industry meetings, to participate in INPO assessments, and visit other plants to expose them to problems, and solutions being considered and adopted elsewhere. One plant manager quipped that he wanted a culture that subscribed to the saying, "borrowed or stolen with pride". This involvement reflected a recognition that there is plant-specific value in reviewing the experiences of other utilities in the search for excellence. Interviews from the case studies supported the notion that this investment, if properly managed, can improve the safety performance and operating efficiency of the plant.

An issue mentioned at most of the case study plants concerned managing the large amount of performance data available. Because of the virtual explosion in the amount of information available from in-house assessment and trending programs, and from industry-based information systems, some respondents felt that they were being overwhelmed with data. Most organizations are still struggling to develop the decision, rules, and data processing techniques that allow for the efficient distribution of data to end-users within the plant. A number of the individuals interviewed who were responsible for making industry experience data available to end-users commented on the difficulty of finding the right screens to apply to the raw data to determine when extraneous information is being passed on and when essential information is being withheld. End-users, in turn, complained about having too much information passed on to them in some cases, and too little in others. In a number of the plants, individual departments continued to engage in parallel or even redundant analyses of industry data because the proper division of labor and decision rules from their perspective, had not yet been struck. Thus, while an aggressive problem identification program seems to characterize the learning organization, even in the better performing plants some conflict exists on how to institutionalize and support problem identification.

It is important to note that the industry, as a whole, has dramatically increased its attention to problem identification in the past ten years. It is not surprising, then, that individual plants are still struggling to institutionalize this process. Issues that need to be addressed include how to computerize the wealth of information, how to tailor it to alternative end-users, and how to organize the performance assessment function within the plant. Each of these issues can generate considerable organizational controversy in addition to difficult technical challenges. One key point of controversy is the extent to which this function is centralized or decentralized within the plant. While centralization appears to promote efficiency, assure a broad consideration of problems, and address the needs of upper management as end-users, decentralization appears to increase the fidelity of information and the sense of ownership that is necessary to support corrective action. While an answer to this controversy does not automatically present itself, several of the plants attempted to answer it by staffing the centralized function with individuals with expertise and credibility in the various end-user departments.

The problem-space considered can vary in terms of the types of failures that trigger problem identification. One of the case study plants had dropped significantly in SALP performance. The staff's attitude was that they had to find out why. Extensive investment in problem discovery and solution definition occurred. There was a collective "embarrassment" by the plant personnel about their performance which caused plant management to increase its investment in learning. In some plants, problems may go unrecognized until an external agent, such as INPO or the NRC brings them to the plant's attention. This pattern was identified in at least one of the DE plants. Some plants may only recognize that a problem exists when major equipment failure causes an unscheduled shutdown. At the other extreme, in some plants problem-identification is triggered by less significant events, such as when an operator realizes that he almost made a mistake (e.g., left out a step in a procedure), and the problem-solving apparatus is activated to try to understand why the mistake nearly happened. In the DOE facility surveyed, plant management expressed a great need for the development of methods for identifying and understanding these near misses.

In terms of the formal definition of the problem, plants vary in terms of the degree to which they search for human-performance root causes as well as equipment-performance root causes, and the extent to which they include problem precursors as part of the problem space. Several of the poorly performing DE plants, for example, had not established any variant of INPO's Human Performance Evaluation System (HPES). All of the case study plants, had strong HPES programs in place. Several of them had provided HPES training to large numbers of workers so that they could participate more effectively in the determination of root causes of failure. Similarly, most of the poorly performing DE plants were cited for having insufficient root-cause analysis programs. Specifically, they were found to have exerted little or no effort in tracing back from the proximate cause of equipment failure to the root causes of the failure. This placed them in a situation of making repeated errors and never recognizing or fixing the underlying problem. Six of the DE plants reviewed were reported to have poor root-cause programs, with the NRC evaluators citing this fact as being a major contributor to repeated equipment failures and degraded plant safety performance. In the case study plants, aggressive and sophisticated root-cause analysis programs existed, and were well linked to methods for securing corrective actions, including formal training programs.

The technical organization of the plant can also influence the approach taken to problem identification. Certain systems (e.g., balance of plant systems) can be treated by management and staff as outside of the normal problem-search space for safety concerns. The existence of the non-safety related category of components can lead to certain types of problems, including safety-related root causes, remaining undetected. At times, regulatory pressures and initiatives have had the effect of limiting the problem space searched by a particular utility, either by creating categories of problems that are outside of regulatory concern, or by emphasizing a particular type of problem to the point that the utility is distracted from other aspects of the legitimate problem space.

Similarly, in a plant dominated by operations culture, maintenance-related problems may be placed outside of the problem space. A preliminary conclusion from the case studies is that plants that maintain a balance of influence among plant functions (e.g., operations, maintenance, and engineering), and that have positive working relationships among these functions along with effective means of communication and training, seem to be in a good position to more systematically and comprehensively recognize and characterize the nature and causes of problems. Organizational rank may also be a factor, with management activities placed outside the problem space and direct worker activities placed within.

Thus, in many ways, organizational and technical factors can shape the way that problems are defined at the plant. To assure that problems are fully identified, at least within acceptable cost/benefit limits, both organizational and technical barriers to problem identification must be overcome.

6.4.2 Problem Diagnosis/Performance Analysis

The second stage in the learning process is problem diagnosis. While it has some obvious overlap with problem identification, organizations vary substantially in the amount of effort devoted to understanding the nature of the problems noted. This activity goes beyond the discovery of the existence of the problem to the clarification of what the problem is. This clarification has both a technical basis and an organizational basis. The technical basis involves establishing fact: what caused the failure, what was the precise nature of the failure, what were the effects of the failure on related systems and components? To answer these questions, technical input from a variety of sources (e.g., chemical analyses, design engineers, human factors experts) may be required. The process of providing these inputs, however, is organizational in nature, and is affected by such factors as the level of resources available to support problem diagnosis, the skills of the technical staff, and the ability of the organization to assimilate relevant technical information from outside the organization.

The organizational basis of problem diagnosis also involves establishing the organizational meaning of the problem: what individuals or groups are responsible, who should have input into defining the nature of the problem, and what type of evidence qualifies as fact? Factors such as the nature of labor-management relations, relations among plant groups, and the relative power of different groups, help condition the organizational interpretation of the problem.

Problem diagnosis can be divided into three types of activities:

Classification: The problem fits into a particular category of problems. It is like or unlike problems previously encountered.

Causal analysis: The problem resulted from prior conditions and actions.

Consequence analysis: The problem is important or not important for specifically identified reasons.

Across the DEs and case studies, the activities of classification, causal analysis, and consequence analysis were handled in different ways, were subject to different impediments, and contributed differently to long-term safety performance.

One key area of difference was the availability and quality of technical resources. One of the primary deficiencies noted in the DEs was the level of technical support for problem diagnosis. Many of the plants experienced poor equipment performance, including significant numbers of repeat failures. All eight of the plants reviewed were evaluated as having poor root-cause diagnosis systems. A number of factors were cited as contributing to the inadequacy of the root-cause analysis systems:

- Inadequately trained or inexperienced engineering support (four plants)
- Lack of on-site engineering support coupled with poor support from corporate engineering (three plants)
- Inadequate staffing of engineering support relative to the backlog (four plants)
- Lack of training in root-cause analysis, including human error analysis (two plants)
- Lack of root-cause analysis skills and technical knowledge among maintenance, operations, or quality assurance staff (four plants)
- Lack of equipment history data to support trend and pattern analysis (three plants)
- Poor communications among departments, leading to a restriction of information flow concerning failure and cause information (three plants)
- Lack of trust between departments or between management and labor, leading to blame-placing or hiding of root-cause information (three plants)
- Lack of interest on the part of workers to get to the bottom of recurring problems due to lack of management follow-through in the past (three plants).

The case study plants, on the other hand, present the opposite picture. In all of the plants visited, repeat failures were uncommon, and the root-cause analysis efforts appeared to be well developed, supported, and successful. The emphasis on root-cause analysis in the seven plants had increased significantly in the past few years. Some of the factors that appeared to contribute to this success were:

- Strong, on-site engineering
- Strong linkages among operations, maintenance, engineering and training in doing root-cause analysis
- Low turnover among plant personnel, leading to a high level of resident plant knowledge
- Excellent communications (formal and informal) among departments, leading to the open sharing of failure and cause information
- Formal programs for broadening workers' experience and plant knowledge including SRO training for plant engineers, involvement of maintenance in the design support for plant modifications, involving operators in root-cause analysis and other task force activities, involvement of plant staff in industry activities such as owners' groups, and job rotation for management personnel
- Good labor-management relations leading to labor buy-in to improvement programs and a non-punishment orientation toward personnel errors. The non-punishment orientation was viewed by managers of the high performing plants to be a necessary condition for the type of open flow of information that allows for the discovery of true root causes
- High credibility and trust in the individuals responsible for the various root-cause programs, based on plant knowledge and experience, strong technical ability, and good people skills
- Well-developed equipment history data programs, and a high level of participation on the part of workers in recording information on equipment failures
- A manageable backlog of problems so that technical support for root-cause analysis was not overburdened
- Well-developed systems for identifying the importance of a failure so that appropriate resources could be directed toward it
- Good work attitudes, including a sense of ownership in the plant and the equipment
- Management and the work force actively and jointly seeking to identify and find the reasons for problems.

Both the DEs and case studies demonstrate that the ability of the plant to successfully diagnose the nature, causes, and consequences of problems, is strongly tied to organizational factors. Where management does not allocate sufficient technical resources, where communication among departments and between labor and management is inhibited by organizational structure or a lack of trust, and where plant personnel are taught to take a very narrow view of their roles and responsibilities, root causes are not as likely to be discovered, and the problem-diagnosis will be inadequate.

6.4.3 Solution Implementation/Improvement Innovation

As in the case of the previous learning steps, the implementation of solutions and innovations has a technical and an organizational basis. The case study plants and the DE plants provide several important points of contrast in terms of how effectively solutions and innovations are formulated and implemented.

6.4.3.1 Solution Formulation

One of the major weaknesses reported among the DE plants was their inability to develop and implement solutions to ongoing equipment and programmatic failures. One of the major causes of this failing was the lack of appropriate technical expertise for the development of technically sound solutions. In contrast, one of the strong points of the case study plants was the uniform availability of this technical expertise. This contrast can be made in three specific areas: engineering expertise; the technical expertise present in QA, operations, and maintenance; and the ability and willingness of the organization to access the technical expertise and experience of the wider industry.

The availability of engineering support has several dimensions. One key dimension is the quality of that expertise. Such expertise was clearly lacking in two of the DE plants. All of the case study plants and several of the DE plants, however, were noted for having highly available, highly qualified engineering expertise within the company. In the case study plants, this meant not only that degreed engineers were available, but that they had extensive plant knowledge and experience. In most of these plants, engineering support was located on site, and their average level of plant experience was quite high. In two of the case study plants, certain aspects of engineering support were located off site, a fact that was judged to constitute a programmatic weakness by several of the department managers interviewed at those sites. Several of the case study plants had moved additional engineering support on site in the preceding few years in order to achieve a higher level of integration with on-site activities.

One of the most consistent findings from the DE plants is that the location of engineering support off site affected the quality of engineering support provided to the plant. Because off-site engineers sometimes lack plant knowledge, and because the drawings, specifications, and procedures with which they must work are frequently poor or out of date, the solutions that are developed off site frequently are judged by on-site personnel to be inadequate. When plant personnel are confronted by these inadequate solutions, they become less likely to communicate with and rely on engineering support in the future. Thus, the quality of technical support for solution formulation and implementation depends on the physical and organizational location of plant engineering, and the quality of relations and communications between engineering and the other plant functions.

Engineering is not the only potential source of technical solutions. Maintenance and operations also have a technical role in formulating solutions to problems. In fact, all of the high performing case study plants were characterized by the involvement of personnel from the many relevant departments in the development and implementation of technical solutions. Management and the work force in general also served as resources that made solution formulation more effective.

The first requirement for promoting wider involvement in solution formulation is access to the process of solution formulation. At the high performing plants, operators, maintainers, and others were not only expected to assist in the development of solutions, but organizational resources and mechanisms were provided to assure that they did. This included the creation of special task forces, with operators and maintainers working with engineers to diagnose the problems and come up with solutions.

The advantages of opening up the process to non-engineering staff are several. Respondents at two of the case study plants indicated that this strategy leads to better technical solutions, since the people with hands-on experience frequently have information and insights not available to the engineering staff. These people also tend to be more aware of the operating history of the equipment, including its typical failure modes. Another advantage is that by involving plant staff in the development of the technical solution, they are more likely to cooperate and assist in the implementation of the solution. When staff are not involved in the development of the solution, as suggested by several of the DEs, they are more likely ignore or actively oppose the implementation of the solution.

This logic is even more evident for non-engineered solutions. A typical response to human performance problems is to make modifications to training. In several of the case study plants, increased emphasis is being placed on involving the affected departments (operations, maintenance, health physics) in designing the modifications to training, based on reviews of internal and external events. One training manager mentioned that this leads to greater acceptance and an overall improvement in the quality of the material.

The second major requirement necessary to promote wider participation in solution formulation is technical training. In four of the case study plants, information was provided to indicate that several mechanisms were used to expand the technical knowledge available to both engineering and non-engineering staff. One of these mechanisms was to provide financial support and encouragement for operators to earn engineering and other science degrees. A second mechanism was the provision of SRO training for engineering staff. A third mechanism was to provide opportunity for job rotation among managers and supervisors to give them wider exposure to the plant and the organization. A fourth mechanism was to recruit and assign individuals with engineering and plant experience to the QA organization. A fifth mechanism was integrating lessons learned from the operational data and root cause analysis into the training program. In the context of a team approach to solution formulation, a broader and higher level of technical expertise can then be directed to the solution of problems.

In contrast, several of the DE plants were criticized for not involving non-engineering staff in the solution of problems. For example, seven of the eight plants were evaluated as having poor teamwork among the plant functions. One was specifically mentioned as having a lack of technical ability within maintenance and an inability of maintenance to compensate for this weakness by working closely with engineering.

The third area where the DE plants and the higher performing case study plants varied was in the ability of the respective organizations to search the experience of the wider industry to find solutions which could be adapted for the specific problems facing the plant.

All of the case study plants displayed a management philosophy that promoted learning from the environment. This included positive working relationships with INPO, EPRI, vendors, and vendor groups. Staff at these plants kept informed about vendor-developed solutions for hardware problems, and the current status of key research and development issues (e.g., advances in predictive maintenance technologies). Management supported participation by plant personnel in conferences and workshops, participated with EPRI in developmental projects, and appeared open to input from INPO and the NRC concerning operational deficiencies. Plant personnel appeared to be discerning and intelligent consumers of industry experience. Rather than accepting particular approaches uncritically, plant management and staff evaluated the applicability of the industry experience to their own situations, and evaluated the benefits of the solution relative to the costs.

In contrast, the DE plants typically were not prepared to identify and adapt external solutions. For example, one plant was cited for a weak level of attention to vendor notices. Another was cited for failing to adopt improved procedures for the maintenance of motor-operated valves. Another was cited for failing to make the improvements resulting from an earlier diagnostic at another plant in the same utility. One plant was also cited for being too quick to react to external pressure from the NRC or INPO by adopting the solution that they perceived to be the favorite one of the external agencies without thinking through implications and necessary adaptations for their own unique situation.

6.4.3.2 Solution Implementation

The development and implementation of sound technical solutions must take place within an organizational context that can either facilitate or inhibit the effectiveness of the solutions. One of the most important elements of this context concerns budgetary resources. The size of the budget relative to need will determine the ability of technical solutions to be developed and implemented. Among the case studies and the DE plants alike, budgetary issues, resource allocation, and regulatory impact, play a significant role in the effectiveness of solution formulation and implementation.

No plant in the nuclear industry is immune from resource limitations. This is particularly true since deregulation has increased competition among utilities, Public Utility Commissions (PUCs) have become more aggressive in limiting rate increases, and increases in operating costs have eroded the cost advantage nuclear once held over other fuels. Even among the higher performing case study plants, the potential exists for having inadequate resources to develop and implement solutions to important operational problems. However, among these plants, several steps were being taken to assure that, to the extent possible, resources were being efficiently allocated. These included:

- Systematic methods for establishing priorities among competing needs. These methods included risk-based assessments (based on PRA, RCM, etc) of the significance of the operational problem, cost-benefit analyses of alternative solutions, and detailed forward-looking performance goals to organize and direct budgets. These mechanisms helped assure that scarce resources were not being wasted on low priority items.

- Bottom-up budgeting, with resource expenditures planned on the basis of inputs from those individuals and groups with first-hand experience of plant needs. In one case, management was experimenting with a variation of zero-based budgeting.

- Group decision making about budget allocations for improvement programs to help establish plant priorities and facilitate buy-in on the part of all plant personnel.

- Widespread education of plant personnel as to the nature of the budgeting process, and methods for determining the cost/benefit ranking of improvement programs.

Among the DE plants, however, the budgeting process frequently was not as well managed. Three of the DE plants were criticized for having inadequate resources available for solution formulation and implementation. This included inadequate staffing of the engineering function, resulting in high levels of backlog for design change requests, root cause analysis and procedure modifications. This, in turn, resulted in slow or inadequate development of technical solutions. Six of the DE plants also suffered from inadequate resources to implement solutions once they were developed. The problem was often not simply a matter of funds available. Another important aspect was managerial attention. These plants also suffered from one or more of the following:

- Corporate management being distracted by other projects.

- The lack of systematic mechanisms for assessing the importance of competing needs: no risk-based models for prioritization, no plant-level goals, and poor teamwork among plant functions in developing priorities. As a consequence, plant management frequently was not allocating resources toward the most important problems.

- Excessively large backlogs of unresolved items, making the need for a priority system and for management attention particularly important.

- Lack of involvement of plant staff in the budgeting and resource allocation process.

It is widely accepted in the organization and management literature that a predictable way to encounter problems in solution implementation is to not involve the affected persons in the process of formulation of the solution. Organizations successfully implement change. Thus, some of the findings that bear on successful implementation were reported in the previous section. Two additional observations from the case studies and DE plants can be added here.

First, the effective plants paid particular attention to the organizational issues associated with solution implementation. Plant management typically expended considerable effort to involve organized labor in the planning stages, thus achieving labor buy-in with the solutions. In general, solutions were formulated with the input and review of all affected parties. This made the implementation of the solutions much easier. The DE plants apparently did not engage in similar types of behavior.

One area where both the DE and the case study plants appeared to have problems was when the solution to the performance problem involved a reorganization of the plant. These reorganizations were typically disruptive in the short run at the better plants, and in the long run among some of the other plants. The reorganizations, at minimum, seemed to cause a loss of morale on the part of managers who lost responsibility and authority during the reorganization, and in general caused concern on the part of the work force about the direction of the plant. Among two of the DE plants, this disruption was severe. This indicates the need for care and skill on the part of upper management when reorganization is considered.

6.4.4 Tracking and Evaluation

Tracking and evaluation are also important stages in organizational learning. Once solutions have been identified and implemented, there remains the question of whether the solutions will be effective. To address this issue, organizations must have effective programs to evaluate changes and the problems identified must find their way back into the process of assessing, analyzing, and determining whether new or modified solutions are needed. Again, the high performing case study plants tend to approach the processes of tracking and evaluation differently than do the DE plants.

One of the key areas where the case study and the DE plants differ concerns the level of development of the formal systems for tracking performance. In general, the case study plants used a wide range of plant performance indicators. In all cases, the indicators far exceeded the list recommended by INPO and those tracked by NRC. Of particular importance to learning, however, were the specific programs for tracking corrective actions. In general, these programs indicated a very low level of corrective action backlog, indicating that problems that were being identified were also being solved. Technically competent staff with knowledge of the plant were employed to lead the task of tracking corrective actions. There was also an effort to have these individuals serve as facilitators for improvements, as well as monitor whether the improvement schedule was being met.

In contrast, the DE plants appeared to have less developed assessment systems. Three of the plants were cited as having weak QA programs, and one plant did not have a corrective action tracking system. In addition, several of the DE plants were evaluated as having weak management involvement in oversight of the various improvement programs. In contrast, the seven case study plants had well established assessment systems and corrective action tracking systems.

Shaping the effectiveness of the formal systems are several organizational factors. First, the nature of vertical communication appears to be very important in assessment and feedback. Where information is not allowed to flow up to management, relevant facts on plant and program performance will not be available for management decision making. Such communication is particularly inhibited when lower ranks and management fail to trust one another. Another important organizational factor for assessment and feedback is the nature of interdepartmental relations. Where these relations are good, feedback on the effectiveness of new programs or technical solutions can flow freely. Where the relations among departments are bad or not well developed, this information is not exchanged. In one of the case study plants, and in several of the DE plants, the existence of a large number of independent, non-integrated tracking programs, each the unique possession of a part of the organization, inhibited the effective use of performance information in plant improvement.

Most of the better performing case study plants had excellent horizontal and vertical communications, with regard to identifying and analyzing of problems, formulating and implementing solutions, and assessing the impact of solutions. They were open, organizations coupled with low staff turnover, "hands-on" management, and a feeling of "ownership" by both management and workers.

6.5 Learning and Change

The current economic and institutional context of the nuclear power industry is characterized by unprecedented change. There is increasing economic pressure, brought on by deregulation, increased competition from other energy sources, and greater financial oversight by Public Utility Commissions. There are major new technological demands resulting from plant aging, innovation, and unanticipated performance issues. There has also been a noticeable increase in what is accepted by the NRC, INPO, the public, and even the industry itself as an adequate level of safety performance. All of these factors have increased the importance of learning as a primary adaptive strategy, primarily because the context in which the plant operates allows less and less tolerance for failure and inefficiency. In short, the nuclear power industry is being confronted by some of the similar challenges facing many U.S. industries in the context of increased global competition.

Responding to these challenges appears to be stimulating a significant transformation in the organization of nuclear power plants. Plant organization was historically highly bureaucratic, emphasizing both extensive compartmentalization of work and a top down control and decision structure for managing the risks associated with nuclear power. Several of these features reflect the traditions within which nuclear power was born (e.g., the traditional electrical utility and the nuclear navy). While this strategy may have been adequate in the environment of ten to twenty years ago, it may not be sufficiently adaptive today. The bureaucratic, top-down approach may fail at two important points relative to organizational learning: it does not easily promote the upward flow of the detailed information required by the more demanding performance standards and it does not promote integration at the level of the worker, where solutions are typically implemented.

All seven of the case study organizations were experimenting with a transformation of their basic organizational structure and principles of operation. All seven were involved in some type of change whereby people lower in the organization would become increasingly involved in identifying, diagnosing, and proposing solutions for performance problems. Some of the plants referred to this change as empowerment, others as ownership, and others as total quality.

While there is insufficient information to characterize this change fully, or to assess its effects, it tends to have a few key characteristics:

- An increasingly active role of department heads working with the plant manager to set the strategic direction of the plant. Decisions previously made at utility headquarters are increasingly being made at the plant level.

- An increased emphasis on teamwork across functional boundaries. This requires a different mode of operation among the line departments than had previously characterized many plants. Whereas competition or even conflict was permitted under previous operating principles, joint problem solving, customer-client relations, and new coordinating mechanisms (such as plant-wide planning and scheduling committees and highly developed outage planning organizations), characterize the new principles.

- An increasing emphasis on participation at the lowest levels of the organization. This is manifested in involvement in problem solving teams, formal programs for getting workers' input into decisions, and numerous programs for recording workers' observations about operating problems and trends.

- A transformation in leadership emphasizing teamwork, participative decision-making, and communication skills.

Because many of these changes are occurring within a short period of time, one of the key challenges facing a utility is to manage the change process itself. In the interviews conducted, two important strategies were mentioned most often in relation to successful change management, including:

- Preparing the organization for change. This included providing training in leadership development to support the increasingly central role of middle management, cross-training of workers to support the increased need for teamwork, systems-knowledge training to support the development of norms of ownership, total quality training, root-cause analysis training, and so forth. In some cases, preparing the organization for change included significant personnel changes, particularly at the management level.

- Setting reasonable priorities. The successful management of change involves setting reasonable priorities, both in terms of what is most important to do, and in terms of what is a reasonable workload.

Thus, in evaluating a plant's ability to institute and benefit from a learning environment, the organization's ability to manage the change that accompanies learning must also be evaluated.

6.6 Assessing the Learning Capacity of Nuclear Power Plants

Both the case studies and the review of the DEs have pointed to key factors that increase or inhibit the learning capacity of the plants. These factors can be somewhat more systematically represented by the matrix presented in Table 6.1. In this matrix, four types of capacity are identified:

- Organizational capacity, which refers to the extent to which the organizational structure facilitates the type of interaction that is supportive of organizational learning. This includes well developed coordination among functions, free flow of information both vertically and horizontally, etc.

- Management capacity, which refers to the ability of management to provide the leadership to effect change, to manage change, and to facilitate widespread participation in problem solving.

- Cultural capacity, which includes the presence of norms and beliefs that support a learning organization. These include trust, ownership, openness, and participation.

- Technical capacity, which refers to the ability of the organization to bring technical skill and other resources to bear on problem identification, end analysis, and the development and implementation of technical solutions. This includes information about industry and in-plant operating experience.

These capacity factors can be arrayed against the stages of organizational learning, as reflected in Table 6.1. An overall assessment of the learning capacity of the plant can be conducted by collecting information relevant to each cell. Examples of the type of information needed are provided in the matrix. A more detailed set of questions developed to generate the information can be found in Appendix E.

Table 6.1
Organizational Learning Assessment Matrix For Nuclear Power Plants

Capacity Dimensions	Steps in the Learning Process			
	Problem Identification/ Performance Assessment	**Problem Diagnosis/ Performance Analysis**	**Solution Implementation/ Improvement Innovation**	**Tracking/Evaluation**
Structural Capacity	• Opportunities and incentives for employee participation • Formal programs and activities to increase exposure to problems experienced by other plants and functional groups • Clear responsibilities/ accountabilities (ownership) • Clearly established and coordinated problem-identification responsibilities and efforts • Well-established producers for scheduled monitoring of equipment	• Role and usefulness of performance oversight groups(resource to functional groups) • Involvement functional groups in problem analysis (both engineering and relevant non-engineering groups)	• Enfranchisement for developing solutions • Opportunities for employees to learn from other plants and other functional groups • Strategies for promoting cooperation and coordination of improvement efforts (teamwork) • Manageable problem backlog • Methods for standardizing solutions	• Widespread communication of results • Opportunities to learn from successes and failures

Table 6.1 continued

	Steps in the Learning Process			
Management Capacity	• Accessibility to and active promotion of employee input • Programs for recognition of employee input • Facilitation of problem-identification efforts • Allocation of resources and effective budgeting process	• Expanding root-cause analysis to include management and organizational contributors	• Management efforts to search for new solutions and innovations • Delegation of authority to formulate and implement solutions • Adequate implementation support and involvement • Systematic methods for determining priorities and allocating resources • Effective budgeting process • Affording opportunities for input and encouraging buy-in to solution formulation and implementation • Managing opposition and promoting strategies to intestests of groups	• Establishing clear improvement commitments and monitoring progress • Recognition of successes • Orientation to turn failures into positive learning experiences • Top-level acceptance of responsibility for failures • Top-level acceptance of responsibility for failures — lack of blaming

Table 6.1 continued

	Steps in the Learning Process			
Capacity Dimensions	**Problem Identification/ Performance Assessment**	**Problem Diagnosis/ Performance Analysis**	**Solution Implementation/ Improvement Innovation**	**Tracking/Evaluation**
Cultural Capacity	• Norm of participation • Openess • Trust • Sense of ownership	• Norm of cooperation in root-cause investigations • Openness • Trust	• Cooperation • Widespread acceptance of innovation/change • Shared responsibility	• Cooperation
Technical Capacity	• Amount of training devoted to problems experienced by other plants • Technical resources and methods for searching a wide problem space • Methods for coordinating and centralizing information • Process for determining appropriate information to disseminate to the relevant end-users	• Extensiveness and scope of root-cause analysis • Range of root-cause training • Data base management and processing software • Technical expertise (availability, depth, breadth) for classifying and interpreting issues • Combining technical expertise and people skills	• Methods for accessing accumulated knowledge and expertise on implementation techniques and strategies • Methods for reporting experiences in implementing changes	• Analysis of success/ failures • Modification of performance assessment and analysis in response to the lessons learned

7.0 CONCLUSIONS

At the beginning of the research effort it was hoped that the results might yield individual "best" predictors of future performance on the NRC safety-related performance indicators. As the data was assembled and examined it became evident that something more subtle and complex was likely going on. For the entire population of the publicly-owned plants, the numbers of occurrences of safety-related incidents on nearly all of the indicators was trending downward in a fairly dramatic fashion (Figure A.1). When the data were examined graphically it showed that the best performing plants maintained a low number of occurrences of safety-related events while the worst performing plants became better over the time period (see Appendix A.). Thus the key questions to answer were what allowed for improvement to occur, and what allowed plants to sustain their good records and not degrade their performance on safety-related measures? The focus of the project was on organizational factors. Thus began an effort to find theoretical roots that would lead us to a manageable set of organizational concepts, that could in turn be brought together in a testable theory to explain performance and improvement of performance on safety-related indicators.

The primary theory which serves as the backbone of this report is a theory of organizational learning, rooted in economics and behavioral theories of organization. It is fully developed into an explanatory theory and testable propositions in Chapter 2.0. Then the theory is tested in Chapter 3.0. In each case the theory yields statistically-derived models that are significant in explaining plant performance on the NRC performance indicators at the p=.05 level or better. The derived models are retested with data from a later time period, and again each model except for one (significant events) proves to be statistically significant (Chapter 5.0). The coefficients of the various parameters of the models vary in terms of which ones are significant drivers in the models, but the models as a whole remain relatively stable and robust. Thus a primary conclusion from the research is that performance on safety-related performance indicators can be significantly explained by concepts of problem identification, resource availability, resource allocation, focussed attention through business strategies, and past performance. These cohere in an explanation that is consistent with a theory of organizational learning as set forth in Chapter 2.0.

In an effort to further explore concepts associated with learning and improvement, qualitative studies were undertaken and are reported in Chapter 6.0. Whereas the data for the statistical studies were confined to publicly-available data for the entire population of plants, in the qualitative studies, data were gathered from diagnostic evaluations and site visits. Learning was conceptualized as a process, described in two ways, in terms of response to a specific problem and in terms of a general organizational process. The steps in the process relative to each were problem identification/performance assessment, problem diagnosis/performance analysis, solution implementation/improvement innovation, and tracking/evaluation. There is notable correspondence between the concepts which are tested in Chapter 3.0 (i.e. problem identification, resource availability, resource allocation, focussed attention, and past performance) and the conclusions drawn from studies of the learning process reported in Chapter 6.0 and summarized in Table 6.1. Specifically, we can draw several conclusions from the correspondence between the two studies:

1. Good performing plants and plants that improve their performance have means to recognize and diagnose problems, either through attention to NRC oversight of their operations or through internal organizational mechanisms, which include how they organize and involve employees and coordinate separate groups, how they emphasize accountability, provide resources to support problem solving and learning, and through norms that produce commitment and openness.

2. The availability of resources and how they are allocated emerge as central findings in both the statistical and qualitative studies. Many of the practices observed in the qualitative studies that support good performance require expenditure of resources. It is not surprising that availability of resources played an important role in the statistical models. But the qualitative studies showed that it is essential to also look beyond the availability of resources to how they are allocated. The statistical models also find that resource allocation plays a role in the models, but they are more limited in their ability to explain exactly how resources can be deployed to support learning and improvement in performance. The importance of investment in the plant and the relative emphasis of proactive problem solving as opposed to reactive problem solving (measured by the ratio of investment in supervision engineering operations as a percent of total supervision engineering operations and maintenance) emerged from the statistical studies as important. Similarly, the qualitative studies showed that investment in people paid off, especially training in problem solving and making technical expertise available on premises. Furthermore, the qualitative studies showed that investment in the systematic acquisition and use of information was central to performance. No matter how munificent and available resources are, there are always many demands upon them. Thus, it is not surprising that the qualitative studies found that the better performing plants had systematic methods for determining priorities and allocating resources.

3. Mechanisms for focusing attention or conversely, avoiding distraction from plant safety performance, emerge on both the quantitative and qualitative studies. In the studies in Chapter 3.0 attention was reflected in a measure of the utility business strategy. In Chapter 4.0 the effect of commitment to nuclear production was studied. The qualitative studies reinforce the importance of mechanisms for focusing attention on safety, and identify a number of specific mechanisms. These include communication lines which are open for learning about problems, reward practices which empower problem solvers, proactive scanning of the environment for information and experiences from which to learn, and clear signals from managers of the importance of safety. These are but some of the many attention-focusing practices that were observed in the case studies.

A number of additional conclusions may be drawn from these studies. The following focus on results of the various studies taken individually:

4. Central concepts in the theory of safety in nuclear power plants (Chapter 2.0), which have roots in the economic and behavioral theories of a

firm, are effective in predicting safety-related performance in plants. Furthermore, the patterns of results can be logically interpreted in light of the proposed theory. While the central concepts of the theory, taken together, are not necessary to predict each performance indicator, they combine in different ways across indicators such that:

*Past performance on a given performance indicator generally predicts future performance.

*Improvement is most likely to occur when NRC problem identification plays a role, resources are available, the resources are allocated to a set of problem solving activities, and utility attention is not diverted by the pursuit of business strategies unrelated to nuclear production.

5. Different performance indicators have different sets of explanatory concepts which predict them. Some are only predicted by their past performance, while others have fuller sets of predictors which explain improvements in operations. It is the sets of concepts (or "profiles") which are predictive and explanatory, and not the individual variables. The individual variables are representative of the broader concepts. The statistical analyses are viewed as validation of the broader model, not the individual measures.

6. The theory shows that plant performance is influenced by utility-level factors in addition to plant-level factors. Valid plant profiles must include such utility-level variables as financial condition, allocation of resources, and business-level strategies.

The sets of concepts, or profiles, taken together are robust and could serve as the basis for a set of diagnostic measures for evaluating nuclear power plant safety and alerting regulators to potential problems. The promise is in using <u>the theory as a whole as a framework</u> for tracking measures that represent the concepts.

If striking oscillations take place in the patterns then the theory suggests that further investigation by NRC may be called for. For instance, aberrations in utility profitability, debt, and operating efficiency might call for NRC investigations about their impact on nuclear performance. So too, changes in resource allocation to the categories of expenses classified as supervision and engineering for operations versus maintenance might require NRC assessment of impacts. If a utility decides to deemphasize nuclear operations by focussing on other business or power generation strategies, this should alert NRC. A combination of many changes at once means a likely impact on nuclear power plant performance. NRC should question utility and plant staff about the ramifications of these changes. How is the nuclear organization going to absorb utility-wide change? How is it going to adjust to it? What will be the likely impact on its performance? (A series of good questions to ask is found in Appendix E).

7. The analyses done in this study suggest utility profitability coupled with degree of commitment to nuclear power generation sets a decision

frame which in turn may lead to risk-oriented decisions by utility executives. This finding, discussed in Chapter 4.0 and expanded upon in Chapter 5.0, warrants further investigation with respect to explaining significant events and safety system actuations.

8. Organizational factors that are measurable exert a clear and consistent influence over time on safety-related performance. The factors require a lag time to show influence, but once they do, inertial forces cause the influence to persist over time. Thus, plants get drawn into beneficent or vicious cycles from which they do not readily depart. When they do depart, for better or worse, it is due to changes in organizational factors described in the derived models in Chapter 3.0.

9. Improvement in safety-related performance can be obtained through management attention to processes of organizational learning and the context in which such learning processes occur. Specific contextual factors which seem most promising for management and the NRC to attend to, as reported in Chapter 6.0 are:

- The level and quality of technical resources available relative to the need for these resources

- The ability of the organization to deliver those resources to the other line organizations (operations, maintenance)

- The ability of the organization to allocate the technical resources to where they are most needed through a sound process of establishing priorities among competing demands

- The ability to communicate and facilitate the flow of appropriate information among departments, groups, and ranks in the organization

- The ability to involve all affected personnel in the definition of the problem and the development and implementation of solutions

Appendix E provides an example protocol for how the NRC can begin to assess plant capabilities in these areas.

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Appendix A

Graphical Analyses of Resource Availability, Problem Identification, and Resource Allocation Variables

A.1 Introduction

Exploratory graphical analyses have been carried out as part of the present research to examine whether "better" performing plants show patterns of differences from "poor" performing plants on certain variables used as independent variables in this research. Specifically, the purpose of the graphical analyses was to observe whether the best and poorest plants on various NRC performance indicators also showed systematic differences in resource availability, resource allocation, and problem identification measures.

A.2 Construction of Plant Categories

The entire sample of nuclear power plants in the U.S. has been divided into three categories – the top 10 percent (with respect to five of the NRC's performance indicators: scrams, safety system actuations, significant events, safety system failures, release of radiation, as well as critical hours), the middle 80 percent, and the bottom 10 percent. Critical hours measure production efficiency, while the other performance indicators (PIs) are used by the NRC to assess different aspects of safety.

Definitions of the PIs are provided below:

-- Scrams are automatic reactor shutdowns that indicate that something is wrong since they are initiated to prevent the reactor from exceeding safety settings and limits. An automatic shutdown challenges and degrades safety systems, but what is wrong could threaten plant safety. Thus, an absence of scrams is viewed as an indicator of good performance.

-- Safety system actuations take place when setpoints for systems are reached (or spurious or inadvertent signals for those setpoints are generated) and a major safety system, such as the emergency core cooling system and AC emergency power, is activated. Any unplanned actuation of a safety system indicates that the safety setpoint or limit has been reached.

-- Significant events are identified by NRC staff through detailed screening of operating experience data. They involve "the degradation of important safety equipment, unexpected plant response to a transient or major transient, discovery of a major condition not considered in the plant safety analysis, or degradation of fuel integrity, primary coolant pressure boundary, containment boundary, or important associated structure (Interoffice Task Group, 1986; p. 45)." Consideration is given to reported safety equipment failures and operator maintenance, surveillance, or procedural errors that are potentially major. Specific attention also is paid to incidents involving multiple system failures or failures that have common cause applications.

-- Safety system failures signify that a safety system is unable to perform its intended function during a time that the reactor is in an operating mode that would ordinarily require that the system be able to function. Component failure or the removal of components for maintenance are causes of safety system failures. Plant safety is threatened since safety systems that might be needed are inoperable. For pressurized water reactors (PWRs) such safety systems might include emergency power, high pressure safety injection, and auxiliary feedwater systems. For boiling water reactors (BWRs) the high pressure core spray system and the reactor core cooling or isolation condenser system have been added to the list of safety systems.

-- Collective radiation exposure is a measure of the average collective radiation exposure to utility employees, contractors and visitors by unit. This indicators is an indirect measure of plant safety since plants with low collective radiation exposure are generally regarded as being well-managed in the control of plant contamination and efficient in the administration of the ALARA (maintaining radiation exposures as low as reasonably achievable) program.

Although the NRC uses these performance indicators, it should be pointed out that they provide just one input to NRC's decision making. There are many more inputs that NRC staff receives to characterize plant safety performance. Furthermore, the indicators have yet to be fully validated, and hence it is unknown as to the extent to which they have the ability to capture actual plant safety. For instance, the PIs do not include the balance of plant (BOP) portion of plant performance, while experience shows that this is a very important part of plant safety.

However, other issues such as data availability and objectivity justify using the PIs. Arguments that compensate for the potential limitations of the PIs include:

-- NRC's information about performance (and industry's) comes primarily from these data (e.g. scrams, safety system failures, safety system actuations) supplemented with analyses of other causal factors (e.g. human errors and procedures). So, the PIs are likely to capture, on a higher level, the same kind of lower level information the NRC routinely uses.

-- The lack of richness of information is compensated for by the many years of data available. Thus, this study assesses many years of high level data (it takes the macroscopic view). The longer time frame provides for a fairly objective and consistent trend of safe plant performance.

The graphical evidence and the subsequent statistical analyses are designed to help in understanding performance indicator improvement between

1985 and 1989 (See Figure A.1).[1] For the purposes of the graphical analyses, the top 10 percent for each performance measure are those with the fewest scrams, safety system actuations, significant events, and safety system failures, the least amount of radiation released in 1985-89, and the most critical hours.[2] Being in the top 10 percent in one category, however, does not mean that a plant is in the top 10 percent in another category. Different plants are in different categories (i.e. top 10 percent, middle 80 percent, and lowest 10 percent) with respect to different performance indicators. The actual assignment of plants to different categories is shown in Table A.1 and is discussed below.

-- For scrams complete data were available on 88 plants. In the best performing group there were 8 plants with a mean of .45 scrams per year during the time period, in the worst performing group there were 8 plants with a mean of 6.28 scrams per year during the time period, and in the middle there were 72 plants with a mean of 2.54 scrams per year during the time period.

-- For safety system actuations complete data were available on 91 plants. In the best performing group there were 10 plants with a mean of .24 safety system actuations per year during the time period, in the worst performing group there were 10 plants with a mean of 3.59 safety system actuations per year during the time period, and in the middle there were 71 plants with a mean of 1.43 safety system actuations per year during the time period.

-- For significant events complete data were available on 91 plants. In the best performing group there were 14 (see footnote on Table A.1) plants with a mean of .23 significant events per year during the time period, in the worst performing group there were 10 plants with a mean of 2.70 significant events per year during the time period, and in the middle there were 67 plants with a mean of 1.23 significant events per year during the time period.

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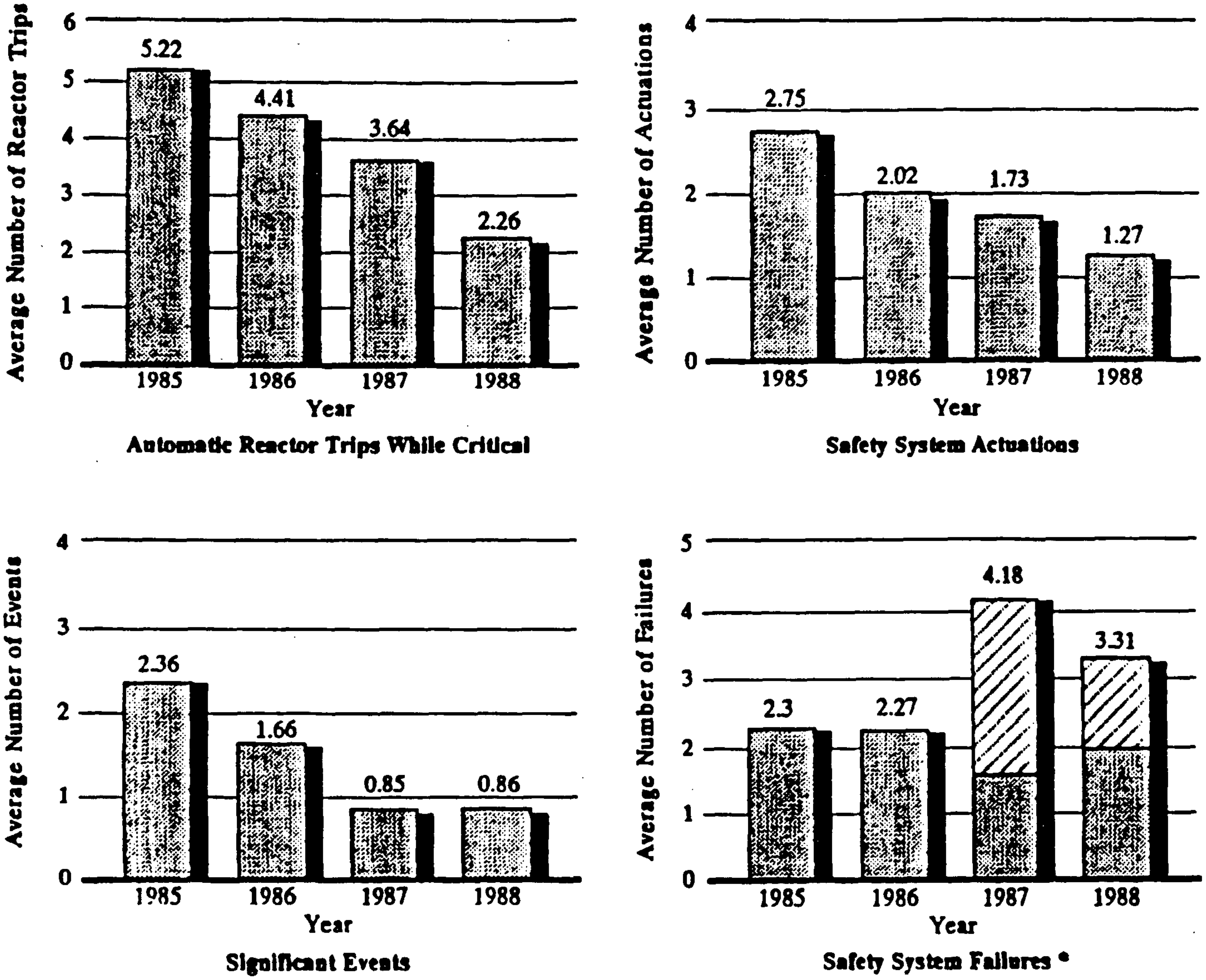
[1] The average annual number of automatic reactor trips while critical, scrams, which indicate that a reactor has had to be automatically shut down because some safety parameter was exceeded, declined from 5.22 per plant in 1985 to 2.26 per plant in 1988. The average annual number of safety system actuations went down from 2.75 per plant to 1.27 per plant during this period. The average number of significant events declined from 2.36 per plant to .86 per plant, and the average number of safety system failures declined from 2.3 per plant to under 2 per plant (in constant terms).

[2] Plants were also divided according to the top 20 percent, mid 60 percent, and bottom 20 percent in these categories. The results of the graphical analysis when done with this division of plants were substantially the same.

Figure A.1



Automatic Reactor Trips While Critical

Safety System Actuations

Significant Events

Safety System Failures *

* The hatched area represents the additional data resulting from reclassifying safety system failures

Safety Improvements in NPP's

Table A.1
Plant Categories by Performance Levels

Performance Measure	Top 10%	Bottom 10%
Scrams	Brown's Ferry 1, 2, & 3 Fort St. Vrain Fort Calhoun Prairie Island 2 Shoreham Sequoyah 1	Robinson 2 Salem 2 Waterford 3 Summer Wash. Nuclear 2 Grand Gulf Byron 1 Callaway
n = 88		
mean (x)	(.45)	(2.54)
Safety System Actuations	Big Rock Point San Onofre 1 Haddam Neck Quad Cities 1 Oconee 1 Salem 1 Zion 1 Brown's Ferry 3 Farley 1 Susquehanna 2	Nine Mile Pt. 1 Palisades Diablo Canyon 1 Cooper Station Crystal River 3 Brunswick 1 Sequoyah 1 McGuire 1 Grand Gulf Palo Verde 1
n = 91		
mean (x)	(.24)	(3.59)
Significant Events	Yankee-Rowe Big Rock Point Quad Cities 1 & 2 Rock Island 1 Cooper Station Kewaunee Prairie Island 2 Sequoyah 1 & 2 Beaver Valley 1 St. Lucie 1 & 2 Farley 1	Indian Point 2 Turkey Point 3 & 4 Crystal River 3 Diablo Canyon 2 Fermi 2 Trojan Arkansas 2 McGuire 1 Catawba 1
n = 91		
mean (x)	(.23)	(2.70)

Table A.1 (continued)

Safety System Failures	Big Rock Point Ginna Diablo Canyon 1 Indian Point 3 Three Mile Island 1 Prairie Island 2 Shoreham Beaver Valley 1 Farley 1 & 2 Waterford 3 St. Lucie 2	Oyster Creek Quad Cities 1 Brown's Ferry 3 Brunswick 1 & 2 Duane Arnold Fitzpatrick Fermi 2 McGuire 1
n = 91 mean (x)	(.58)	(6.4)
Radiation Exposure	Yankee-Rowe Big Rock Point Prairie Island 1 & 2 Calvert Cliffs 1 & 2 Davis-Besse	Oyster Creek Indian Point 2 Peach Bottom 2 & 3 Brunswick 1 & 2 Milestone 2
Mean (x)	n = 73 (139.5 rems/yr)	(408.9 rems/yr)
Critical Hours	Yankee-Rowe Millstone 1 Monticello Prairie Island 1 Point Beach 2 Prairie Island 2 St. Lucie 1 Farley 1	Brown's Ferry 1 & 2, 3 Fort St. Vrain Peach Bottom 3 Pilgrim Sequoyah 1 & 2
n = 84 mean (x)	(7344 hrs/yr)	(1693.3 hrs/yr)

*The selection point for differentiating the top and bottom 10% was not always precise, due to the presence of a small cluster of plants near the cut-off point.

-- For safety system failures data were available on 91 plants. In the best performing group there were 12 plants with a mean of .58 failures per year during the time period, in the worst performing group there were 9 plants with a mean of 6.4 failures per year during the time period, and in the middle there were 70 plants with a mean of 2.85 failures per year during the time period.

-- For radiation data were available on 73 plants. In the best performing group there were 7 plants with a mean of 139.5 rems per year during the time period, in the worst performing group there were 7 plants with a mean of 913.1 rems per year during the time period, and in the middle there were 59 plants with a mean of 408.9 rems per year during the time period.

-- For critical hours data were available on 84 plants. In the worst performing group there were 8 plants with a mean of 1693.3 critical hours per year during the time period, in the best performing group there were 8 plants with a mean of 7344.0 critical hours per year during the time period, and in the middle there were 68 plants with a mean of 6001.9 critical hours per year during the time period.

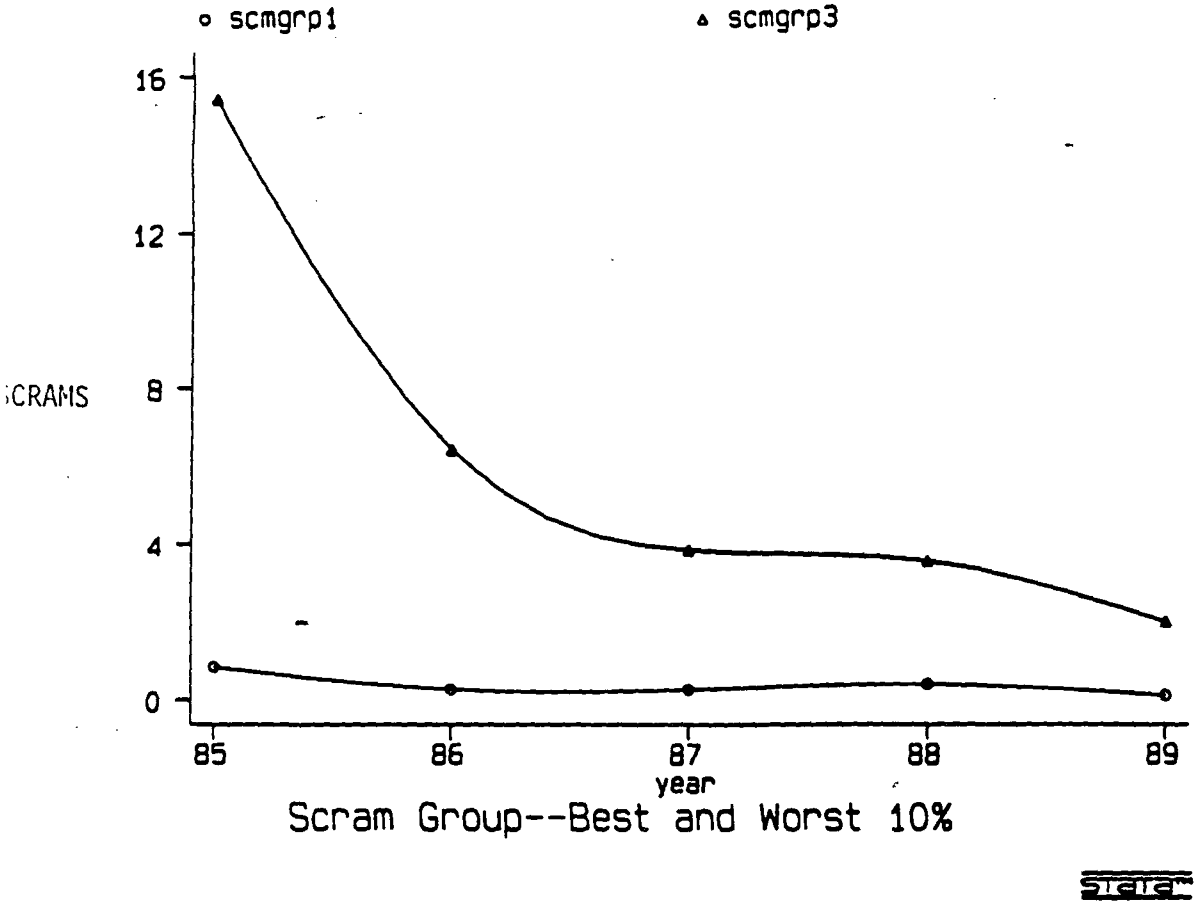
Over time, the performance of the best and worst performing plants tended to converge as the data presented in Figures A.2-A.7 indicate.

Performance of the Different Plant Categories. The graphs in Figures A.8-A.49 (beginning of page 18) show how well the different categories of plants did on resource availability, problem identification (cited regulatory violations), and resource allocation variables. Their performance on the resource availability and problem identification variables is lagged; the performance of the different plant categories in a prior (1980-85) time period is plotted. Performance on the resource allocation variables is concurrent; the performance of the different plant categories in the same (1985-89) time period is plotted.

The variables chosen to represent resource availability, problem identification, and resource application are illustrative of the kinds of variables that can be used in such analyses. Different measures of the same concepts could have been used if the data had been readily available. What is important are the overall concepts used in the model (see Figure 2.1) and not the particular measures that have been used to represent them in particular analyses. In Chapter 3.0 several variants are introduced for measuring the concepts, the purpose being to validate the overall robustness of the concepts in the model rather than particular measures themselves.

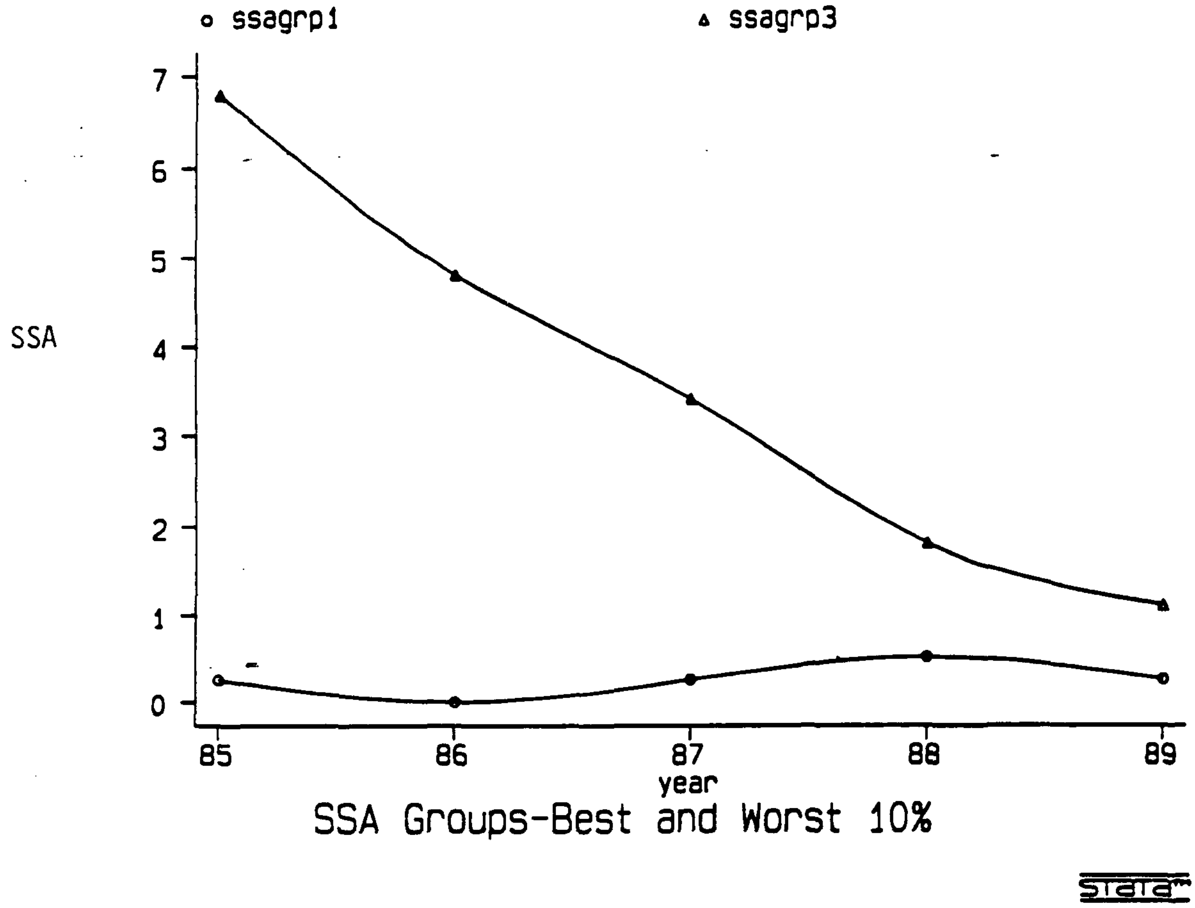
The resource availability variables which have been used in the graphical analyses are utility ROA and debt/equity ratio; the problem identification variables are the number of major and minor violations; and the resource allocation variables are total nuclear power operations and maintenance spending, nuclear power operations spending, and nuclear power maintenance spending. Again, variations on these representations are to be found in other parts of the report. The important point is the overall pattern of the relationships between the concepts in the model (see Figure 2.1); the

Figure A.2



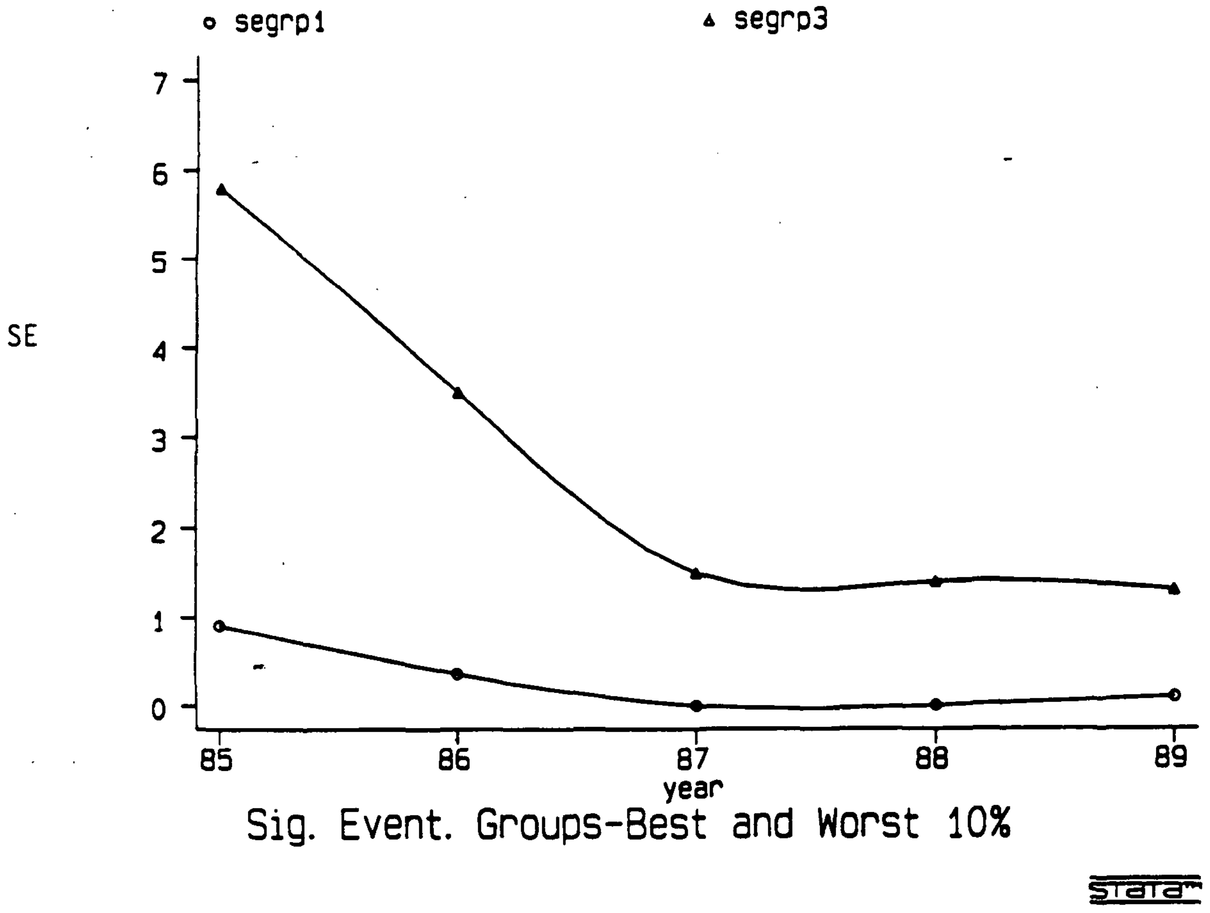
Scram Group--Best and Worst 10%

Figure A.3



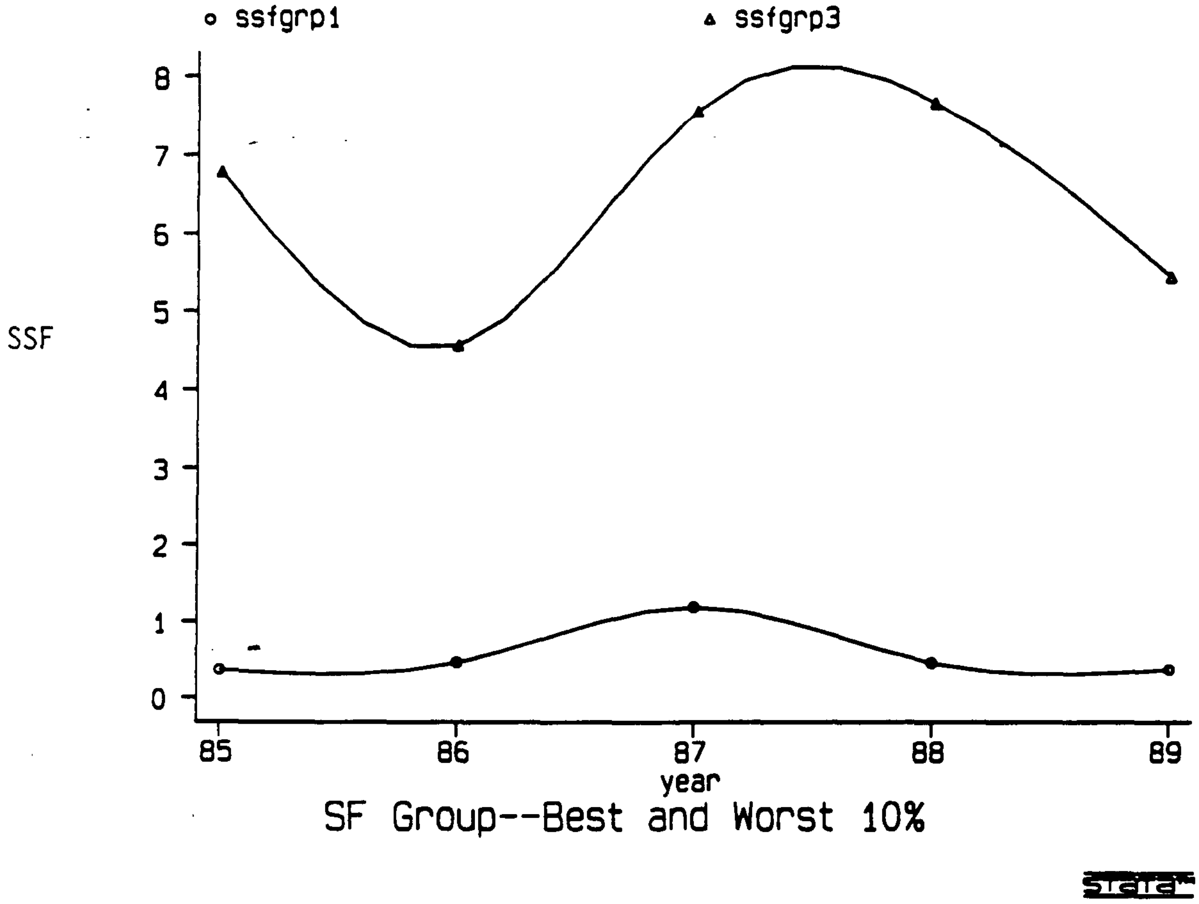
SSA Groups-Best and Worst 10%

Figure A.4



o segrp1
▲ segrp3
SE
7
6
5
4
3
2
1
0
85
86
87
88
89
year
Sig. Event. Groups-Best and Worst 10%
Stata™

Figure A.5



○ ssfgrp1
▲ ssfgrp3
SSF
0
1
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8
85
86
87
88
89
year
SF Group--Best and Worst 10%
Stata™

Figure A.6

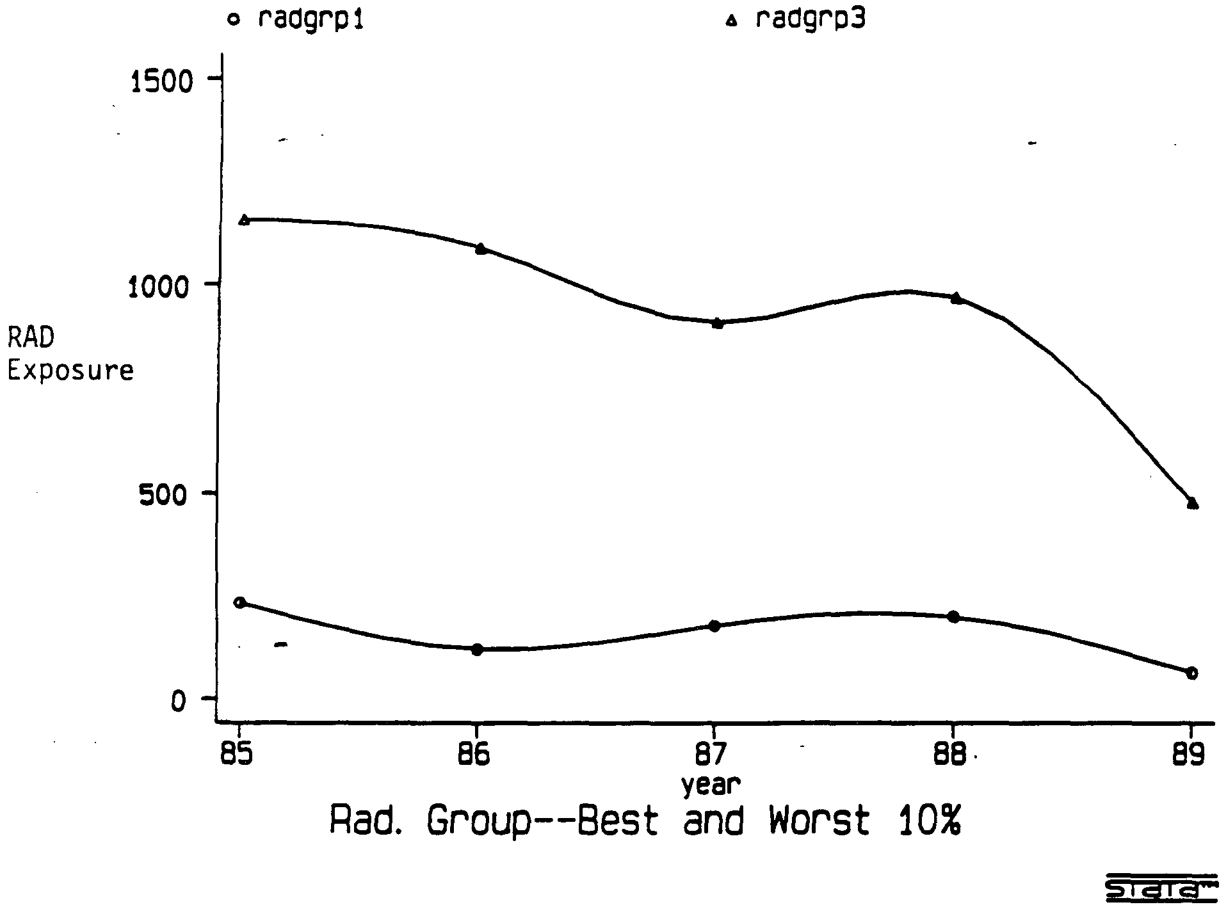
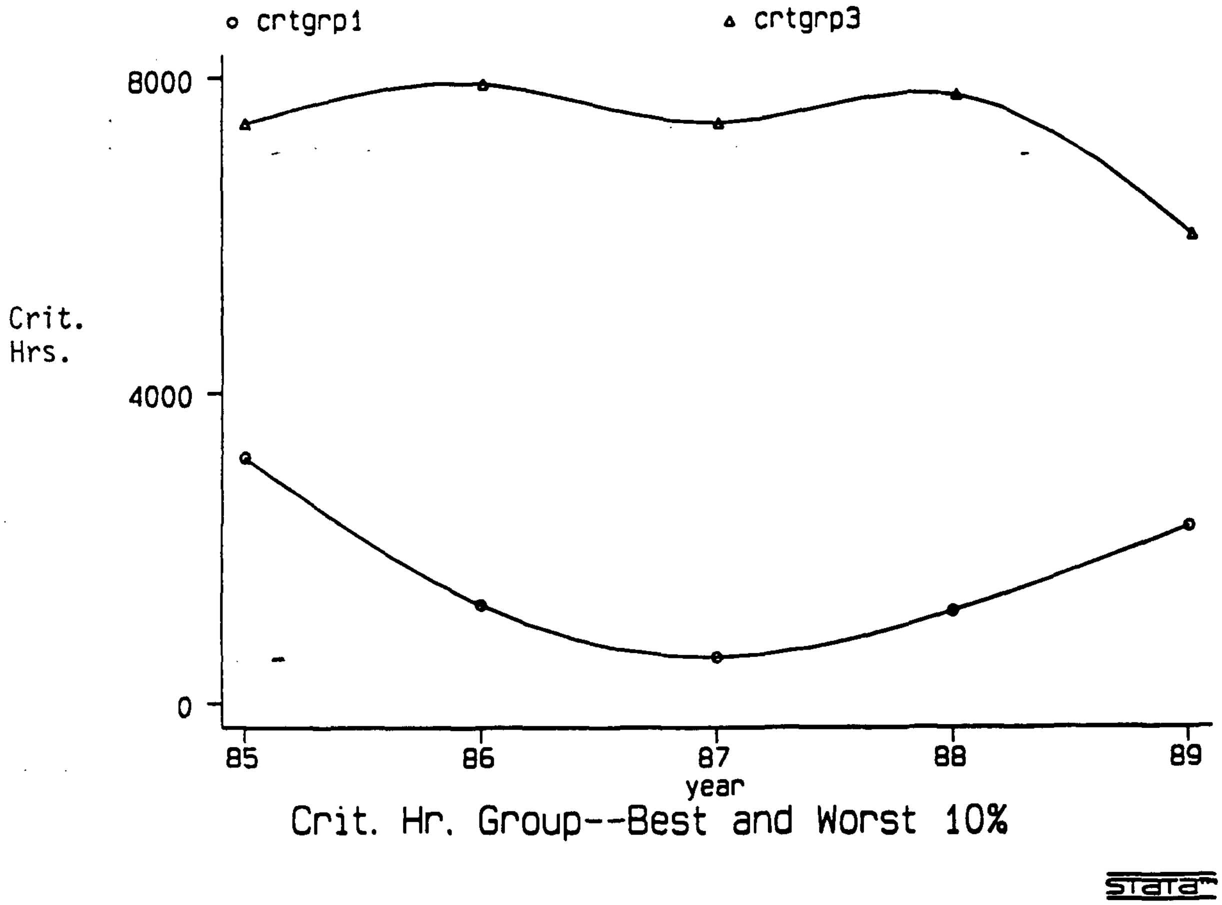

o radgrp1
▵ radgrp3
1500
1000
500
0
RAD Exposure
85
86
87
88
89
year
Rad. Group--Best and Worst 10%
Stata

Figure A.7



(In this graph, crtgrp 1 is the worst 10%;
crtgrp 3 is the best 10%)

particular measure used in an analysis is less important. Figures A.8-A.49 are shown following the discussion of their contents on the next few pages. The figures begin on page 162.

A.3. Graphical Evidence

A.3.1 Resource Availability as Measured by Profitability

The results with respect to the profitability of the utilities that own and operate nuclear power plants are fairly clear and consistent. With the exception of scrams (Figure A.8), more profitable plants in 1980-85 perform better on each of the performance indicators in 1985-89. Less profitable plants perform worse. This evidence is summarized below:

> The most profitable plants in 1980-85 have the least number of safety system actuations in 1985-89 (Figure A.9).
> The least profitable plants in 1980-85 have the most significant events in 1985-89 (Figure A.10).
>
> The most profitable plants in 1980-85 (except for 1984) have the least number of safety system failures in 1985-89 (Figure A.11).
>
> The least profitable plants in 1980-85 have the most radiation release in 1985-89 (Figure A.12).
>
> The least profitable plants in 1980-85 have the fewest critical hours in 1985-89 (Figure A.13).

Prior resource availability, at least in the form of return on assets (ROA), is followed by better subsequent performance on all criteria except scrams. It is not immediately clear why prior resource availability does not relate to scrams. One speculation could be that scrams have direct impact on financial results and therefore are managed with top priority with whatever resources are available.

A.3.2 Resource Availability as Measured by Debt

The debt to equity ratio in 1980-85 relates to performance on several of the measured indicators in 1985-89. Along with debt comes the financial pressure to repay the debt. Utility income must first service the debt before remaining profits can be channeled to other purposes. Plants that face this pressure appear to not perform as well as plants that are free from it. The graphical evidence is summarized below:

> Plants with lower debt/equity ratios in 1980-85 have fewer scrams in 1985-89 (Figure A.14).
>
> Plants with lower debt/equity ratios in 1980-85 have fewer safety system actuations in 1985-89 (Figure A.15).
>
> Plants with lower debt/equity ratios in 1980-85 have fewer significant events in 1985-89 (Figure A.16). while plants with

higher debt/equity ratios in 1980-85 have the most significant events in 1985-89.

Although there is an interesting escalation in 1985 in the debt ratios of plants with the least number of safety system failures, no clear pattern exists between debt and safety system failures (Figure A.17).

Plants with higher debt/equity ratios in 1980-85 have more radiation releases in 1985-89 (Figure A.18), and plants with lower debt/equity ratios in 1980-85 had the lowest amount of radiation releases in 1985-89.

Plants with lower debt/equity ratios in 1983-85 have more critical hours in 1985-89 (Figure A.19).

In general, better subsequent nuclear power plant performance is associated with lower debt/equity ratios in prior periods, except for safety system failures. Predictors of safety system failures are picked up in the statistical models reported in Chapter 3.0.

A.3.3 Regulatory Enforcement as Measured by Major and Minor Violations

Plants from more profitable utilities and under less financial pressure from high relative debt burdens generally have the better performing nuclear power plants. The inference is that they have the resources to devote to safety. The economic theory, however, also suggests that problem identification or correction activity via regulation is needed. Two types of regulatory information receive graphical representation -- data on major and minor violations.

The findings with respect to major violations are summarized below: Figure A.20 shows that plants with the most major violations in 1980-85 have the least scrams in 1985-89.

Figure A.21 shows that plants with the most major violations in 1981-84 have the least safety system actuations in 1985-89.

Figure A.22 shows that plants with the fewest major violations in 1980-84 have the least significant events in 1985-89.

Figure A.23 shows that plants with fewer major violations in 1980-85 have fewer safety system failures in 1985-89.

Figure A.24 shows that plants with fewer major violations in 1980-85 have less radiation in 1980-85.

Figure A.25 shows that plants with fewer major violations in 1980-85 have more critical hours in 1985-89.

The pattern for minor violations is very similar: fewer violations in the earlier period is followed by fewer safety incidents such as significant events and safety system failures, and more critical hours in the next period, and more scrams. The exception to the same patterns between major and minor violations is found in safety system actuations, where major and minor violations have different effects.

> Figure A.26 shows that plants that have more minor violations in 1980-85 have fewer scrams in 1985-89.
>
> Figure A.27 shows that plants that have fewer minor violations in 1983-85 have less safety system actuations in 1985-89.
>
> Figure A.28 shows that plants that have fewer minor violations in 1980-85 have less significant events in 1985-89.
>
> Figure A.20 shows that plants that have fewer minor violations have less safety system failures in 1985-89.
>
> Figure A.30 shows that plants that have fewer minor violations have less release of radiation in 1985-89.
>
> Figure A.31 shows that plants that have fewer minor violations have more critical hours in 1985-89.

For scrams, violations appear to serve an error correction function. That is, the more violations in 1980-85, the fewer the scrams in 1985-89. While for the other performance measures, the more violations in 1980-85 the poorer the performance in 1985-89.

A.3.4 Resource Allocation as Measured by Operations and Maintenance Expenditures

Resources may be available, from profits or the capacity to raise debt capital (although profits are affected by the level of debt service required), and problems may be identified by regulators, but distinct spending patterns are also necessary to correct problems once they have been identified. Three types of expenditures have been examined graphically: combined operations and maintenance expenditures (O&M) and the separate components of this combined category, that is spending on operations and spending on maintenance.

The analysis here, as opposed to the earlier analyses, does not look at the impact of prior patterns on future performance, but rather examines the effects of concurrent spending patterns on current performance. The presumption is that shifts in resource allocations have nearly immediate effect on performance. The pattern for all the categories of resource allocation is clear. Better performing plants in 1985-89 spend less in these years in all categories, operations and maintenance combined, operations, and maintenance:

> Figure A.32 shows that plants with fewer scrams in 1985-89 have spent less on operations and maintenance in 1985-89, while those with more scrams have spent more, Figure A.33 that plants with more scrams have spent more on operations, and Figure A.34 that

plants with fewer scrams have spent less on maintenance, and those with more scrams have generally spent more on maintenance.

Figure A.35 shows that plants with more safety system actuations in 1985-89 have spent more on operations and maintenance in 1985-89, Figure A.36 that they have spent more on operations, and Figure A.37 that they have spent more on maintenance.

Figure A.38 shows that plants with fewer significant events in 1985-89 have spent less on operations and maintenance expenditures in 1985-89, Figure A.39 that they have spent less on operations, and Figure A.40 that they have spent less on maintenance.

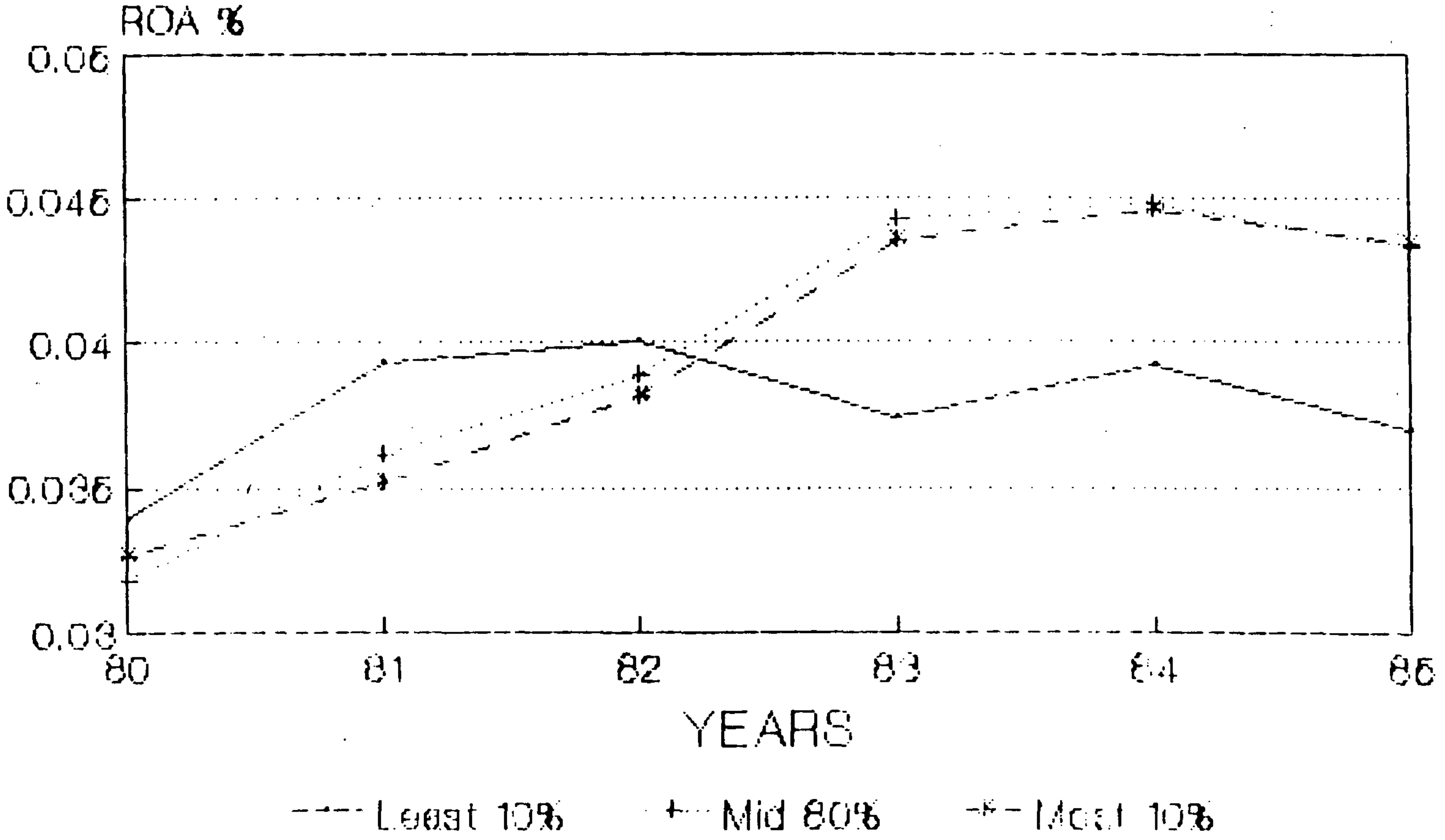
Figure A.41 shows that plants with fewer safety system failures in 1985-89 have spent less on operations and maintenance in 1985-89, Figure A.42 that they have spent less on operations, and Figure A.43 that they have spent less on maintenance. Plants with more safety system failures have spent more on operations and maintenance (Figure A.41 and more on operations, except in 1989 (Figure A.42).

Figure A.44 shows that plants with more radiation releases in 1985-89 have spent more on operations and maintenance in 1985-89, Figure A.45 that they have spent more on operations, and Figure 2.46 that they have spent more on maintenance. Also, Figures A.44 - A.46 show that plants with less radiation releases have spent less in all three categories of expenditures.

Figure A.47 shows that the plants with more critical hours in 1985-89 have spent less on operations and maintenance expenditures in 1985-89, Figure A.48 that they have spent less on operations, and Figure A.49 that they have spent less on maintenance.

Overall, the pattern is that the better performing plants in 1985-89 spend less in these years, and the poorer performing plants more.

Two questions can be posed. First, why are the worst performers spending more? An answer may be that they have been cited for more violations and are spending more because they are aware of more problems. A second question is from where do the worst performers get their funds to spend money on operations and maintenance? From the analyses that have been done so far, it can be inferred that it is not from their profits, since the worst performers have been less profitable than the best performers. However, they also have had higher debt/equity ratios, so they must be drawing on debt to fund the expenditures. Thus, the pattern that seems to exist is one in which poor performers have more problems and less profit and go into debt to fund a higher level of expenditures to deal with these problems. The debt, in turn, must be serviced from income, leading to lower profits and less resources available to invest in proactive safety improvements. A summary of the graphs follows the presentation of them on page 204.



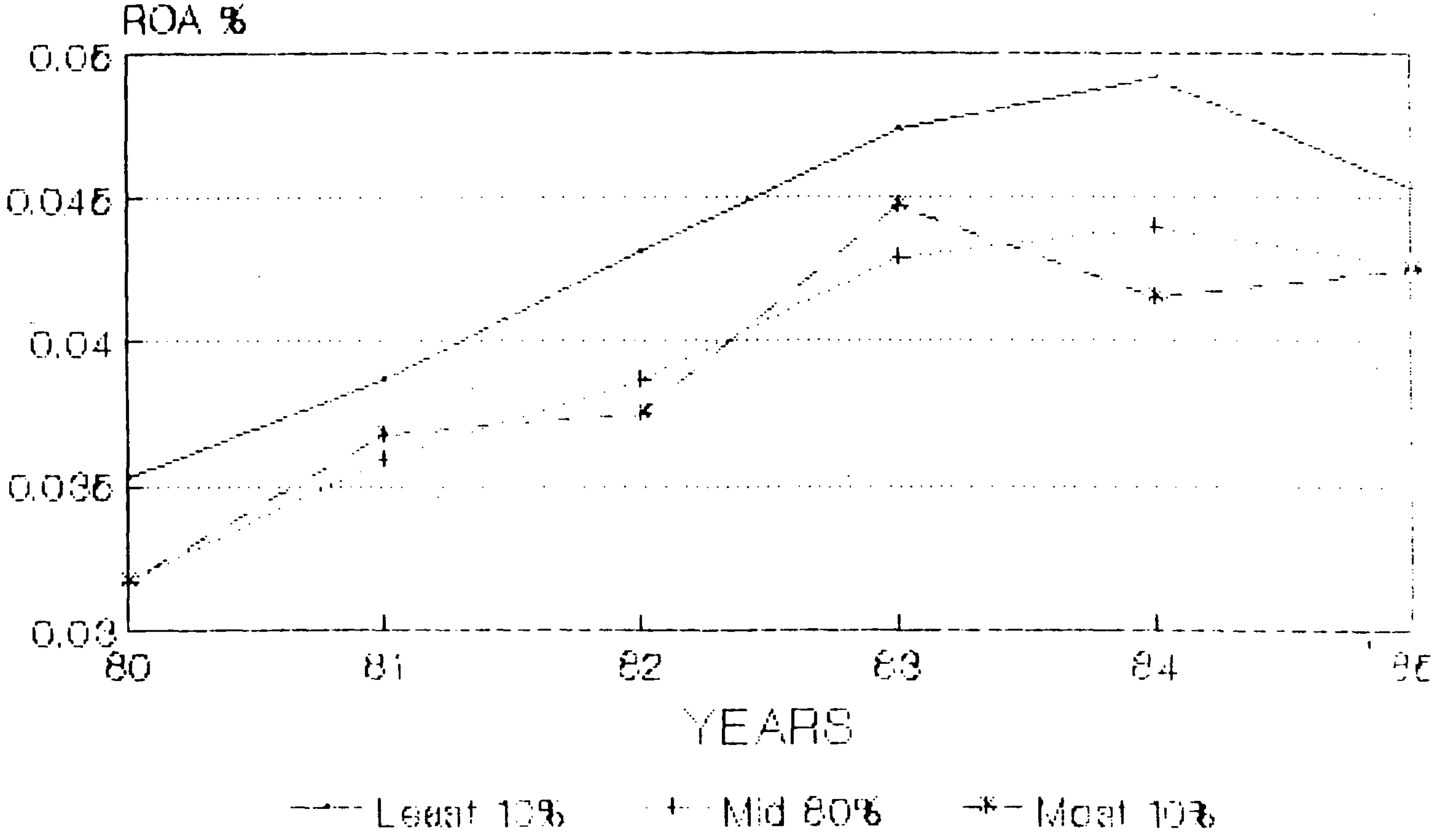
ROA SCRAMS
UPPER AND LOWER 10%

1980-1985

Figure A.8

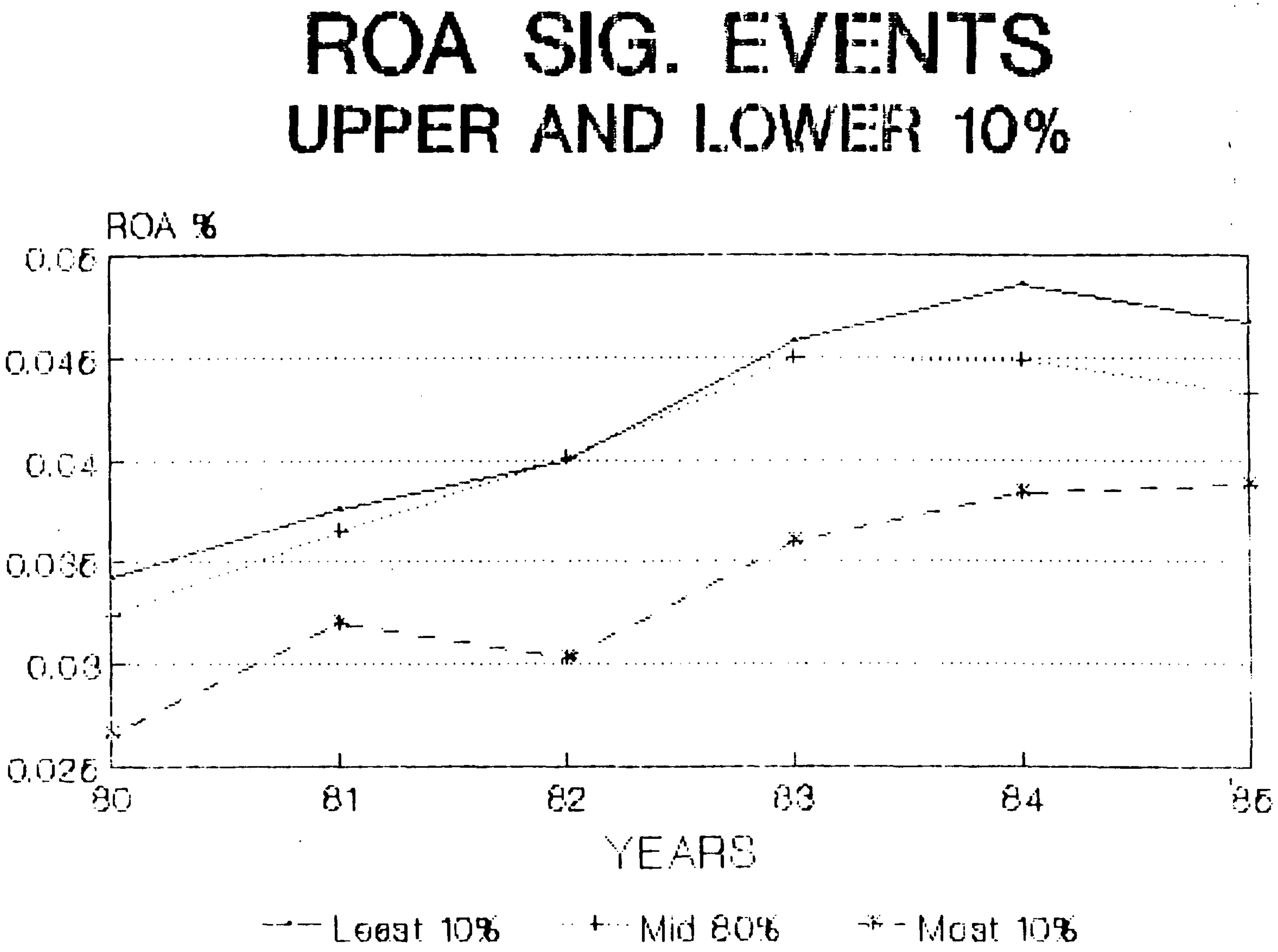
ROA SSA

UPPER AND LOWER 10%



1980-1986

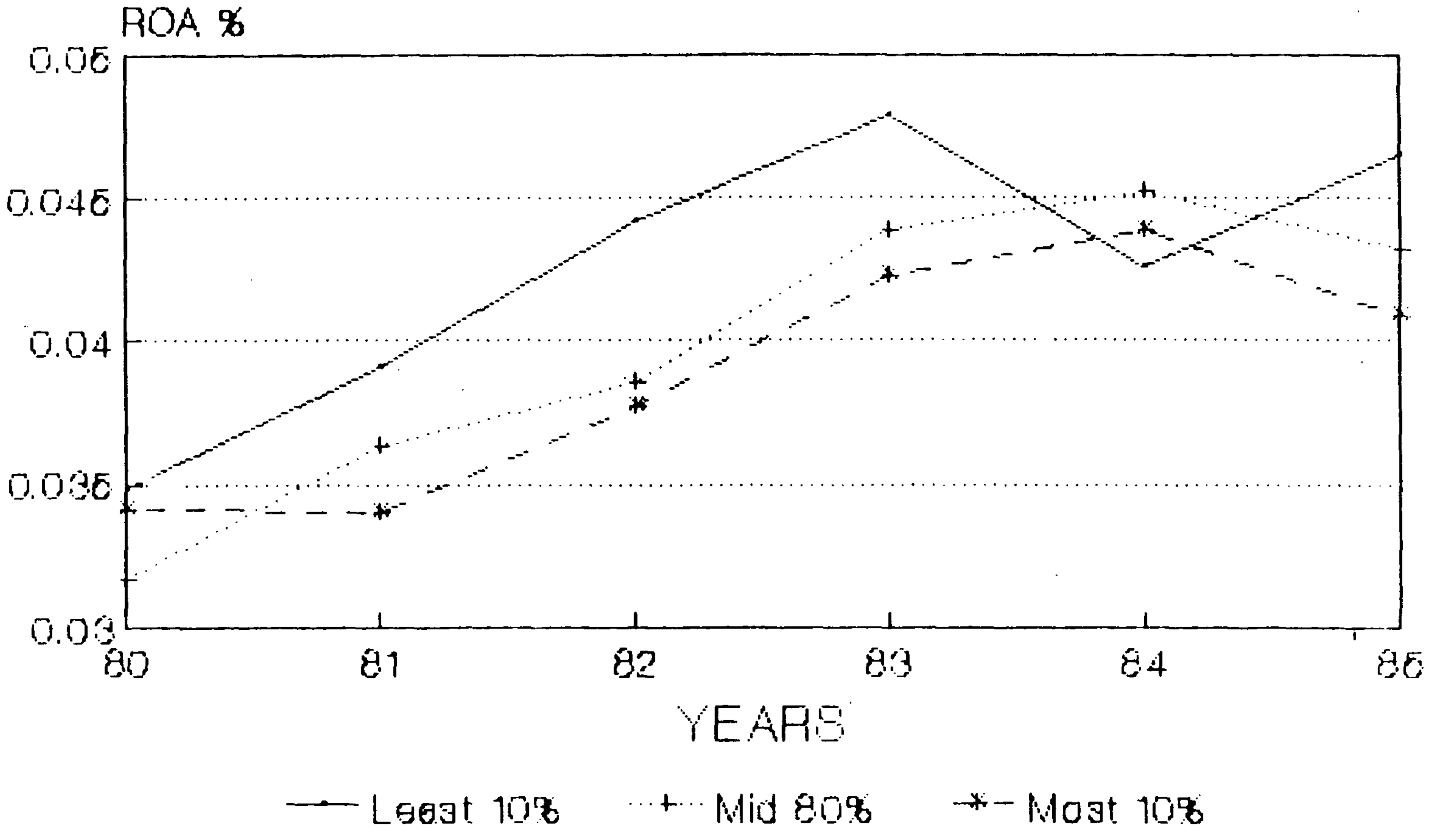
Figure A.9



1980-1985

Figure A.10

ROA SSF
UPPER AND LOWER 10%



1980-1985

Figure A.11

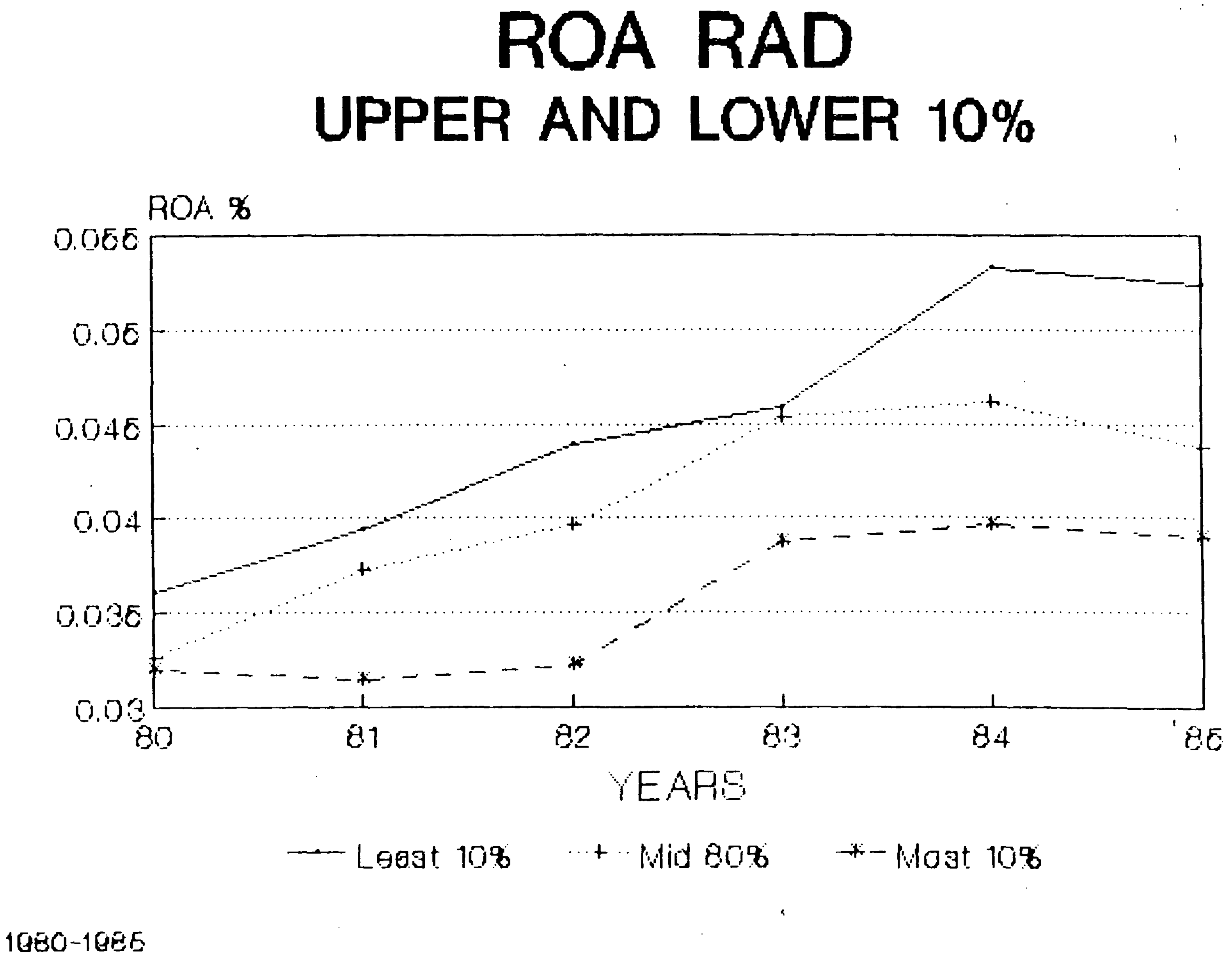

ROA RAD
UPPER AND LOWER 10%
ROA %
0.055
0.05
0.045
0.04
0.035
0.03
80
81
82
83
84
85
YEARS
Least 10%
Mid 80%
Most 10%
1980-1985

Figure A.12

ROA CRITICAL HRS

UPPER AND LOWER 10%

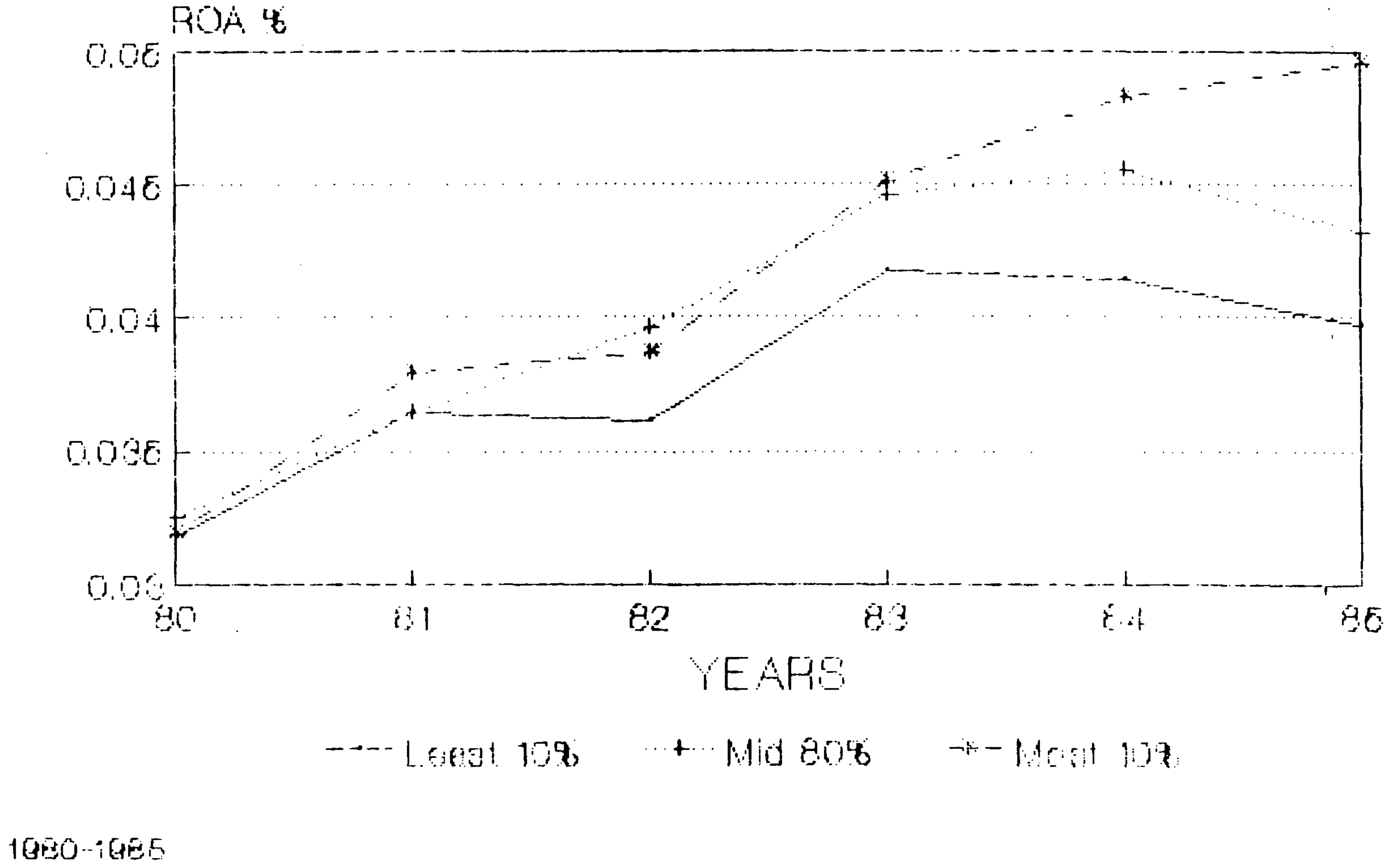
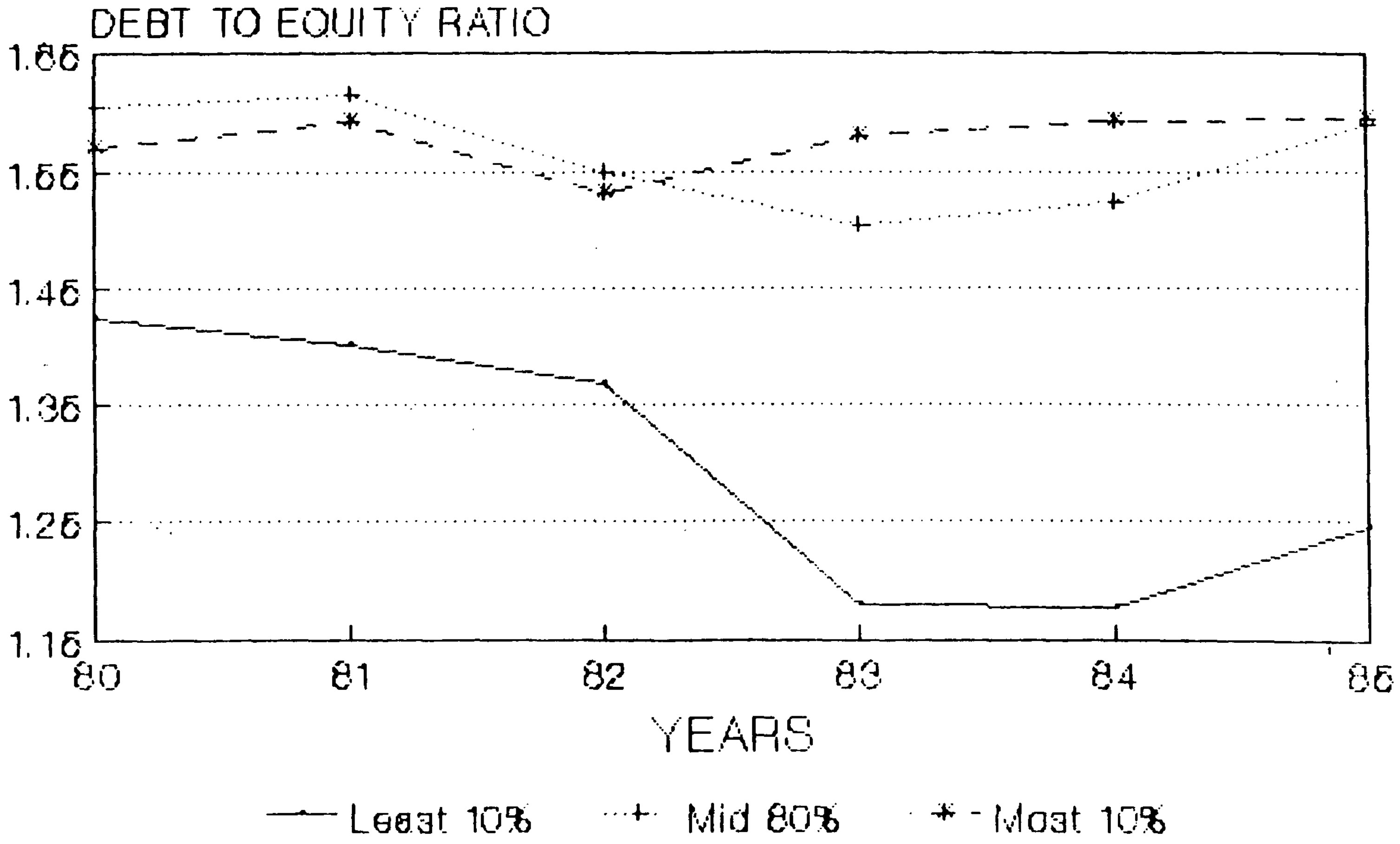


Figure A.13

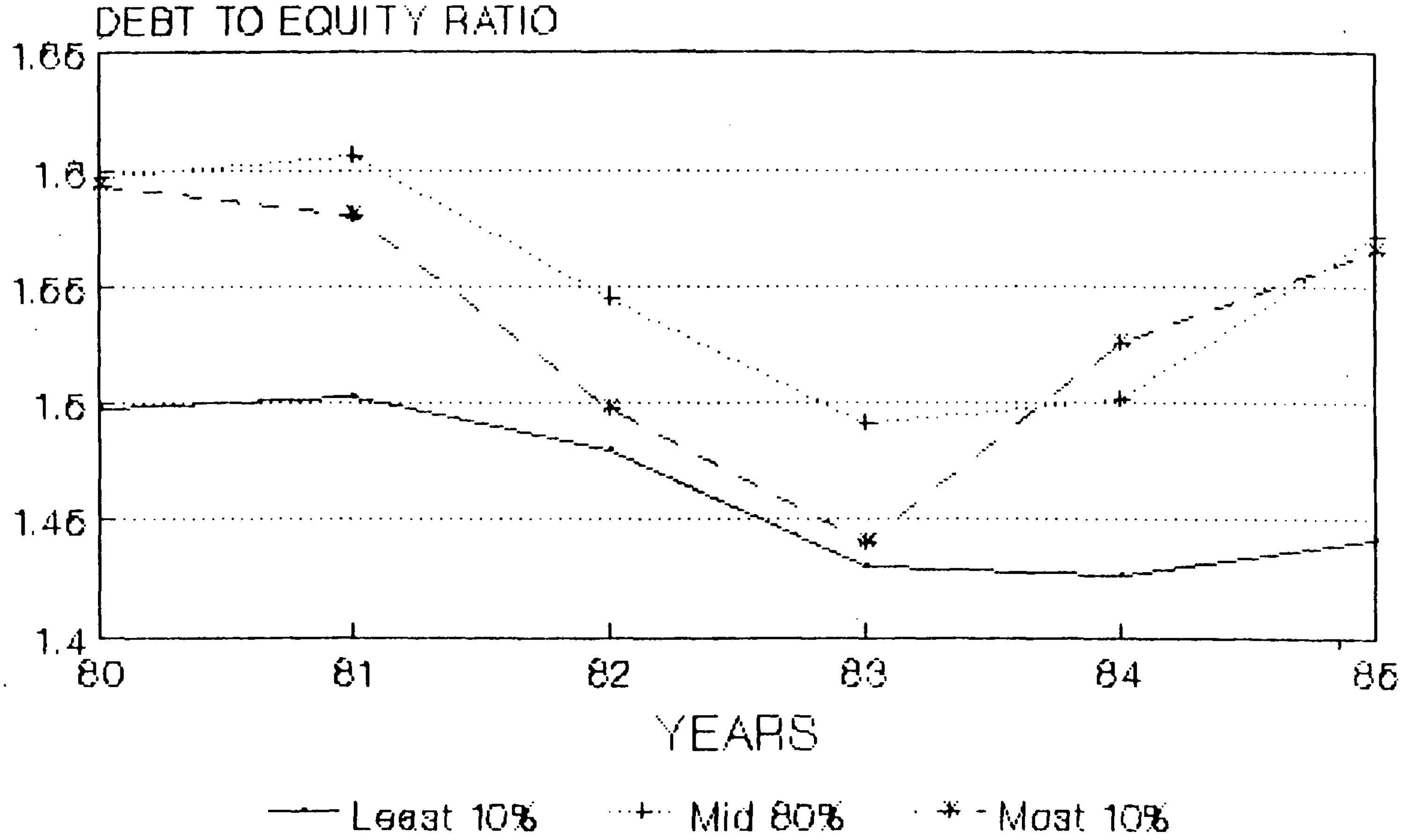
DEBT TO EQUITY VS SCRAMS
UPPER AND LOWER 10%



1980-1985

Figure A.14

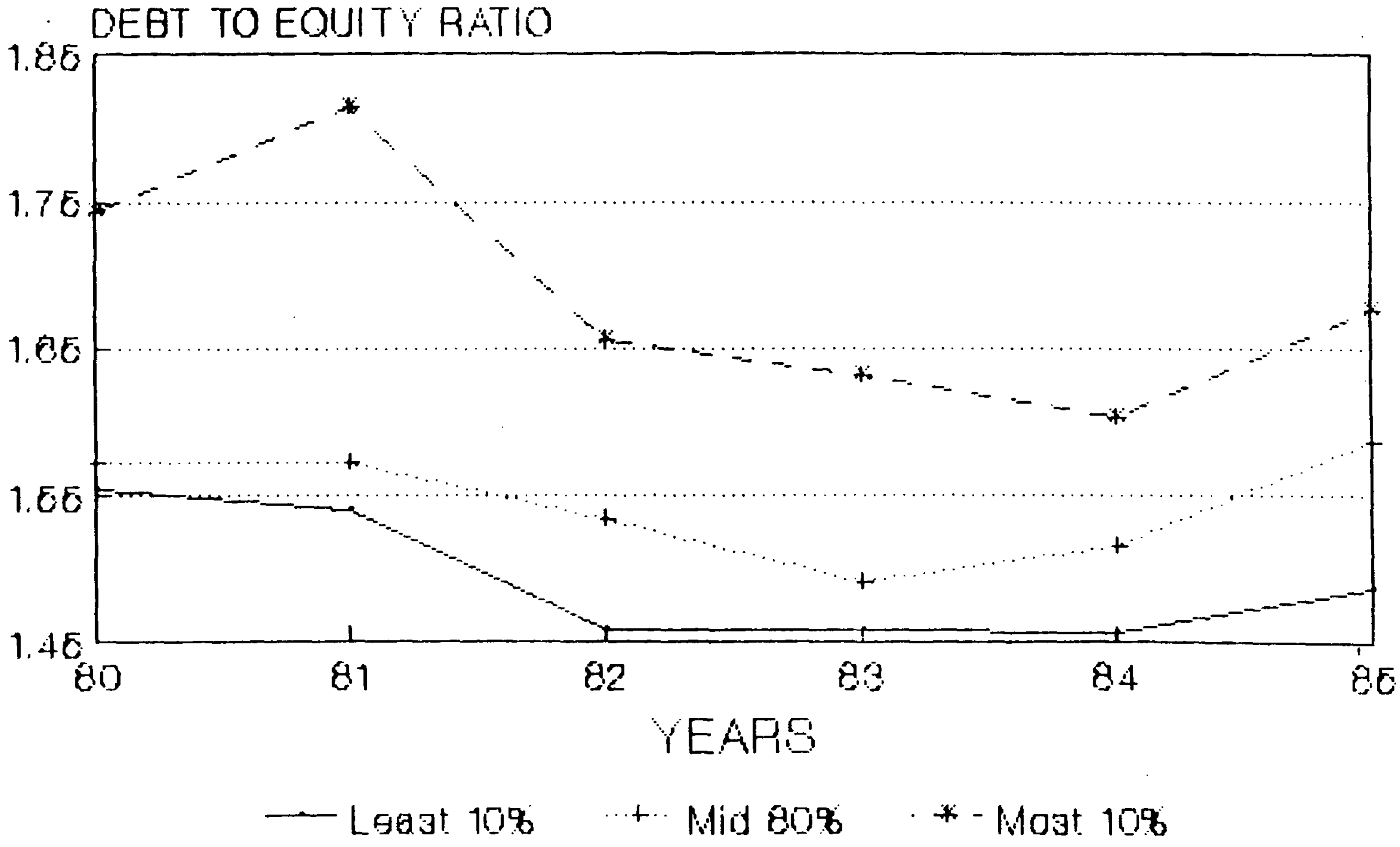
DEBT TO EQUITY VS SSA
UPPER AND LOWER 10%



1980-1985

Figure A.15

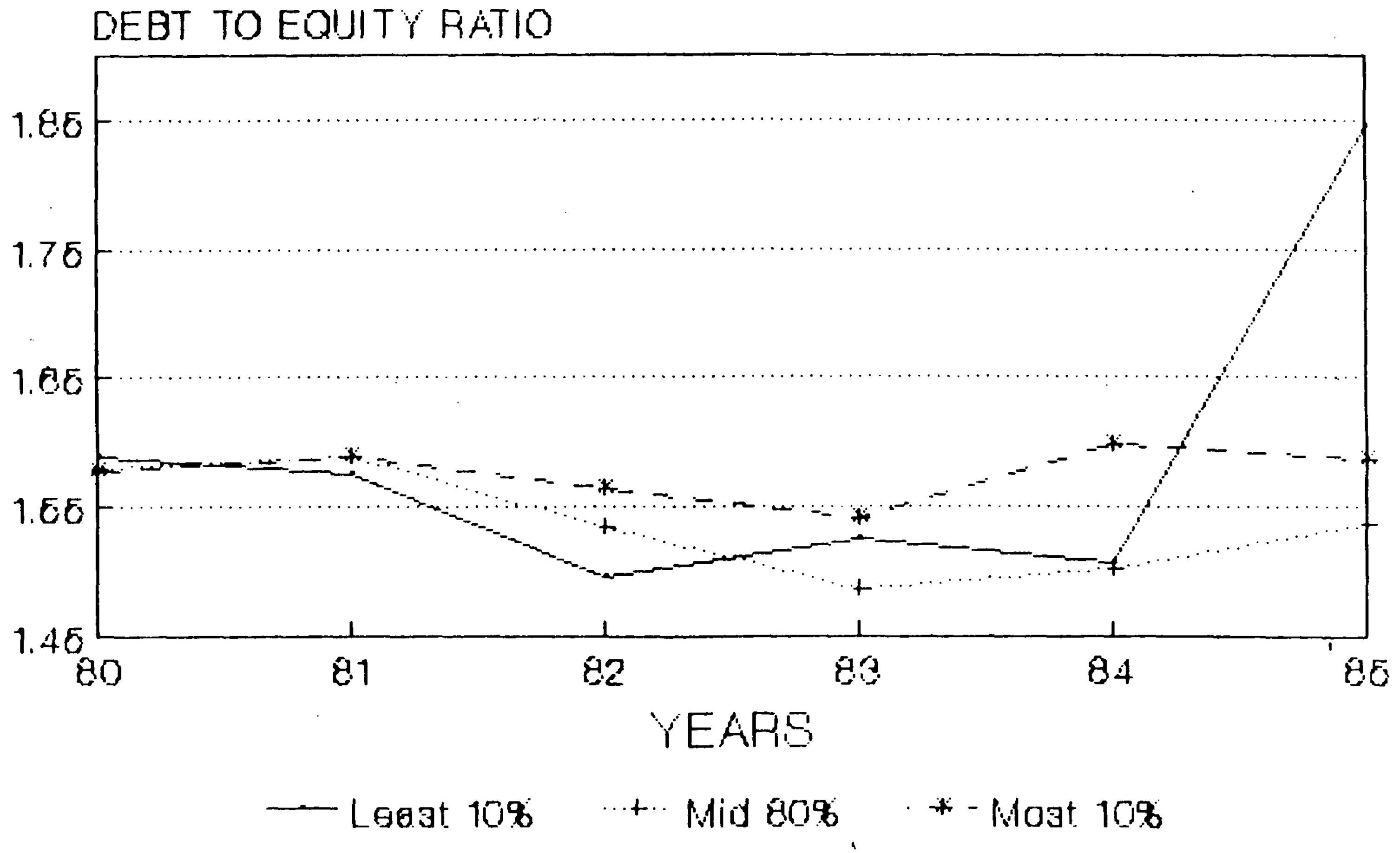
DEBT TO EQUITY VS SIGNIFICANT EVENT
UPPER AND LOWER 10%



1980-1985

Figure A.16

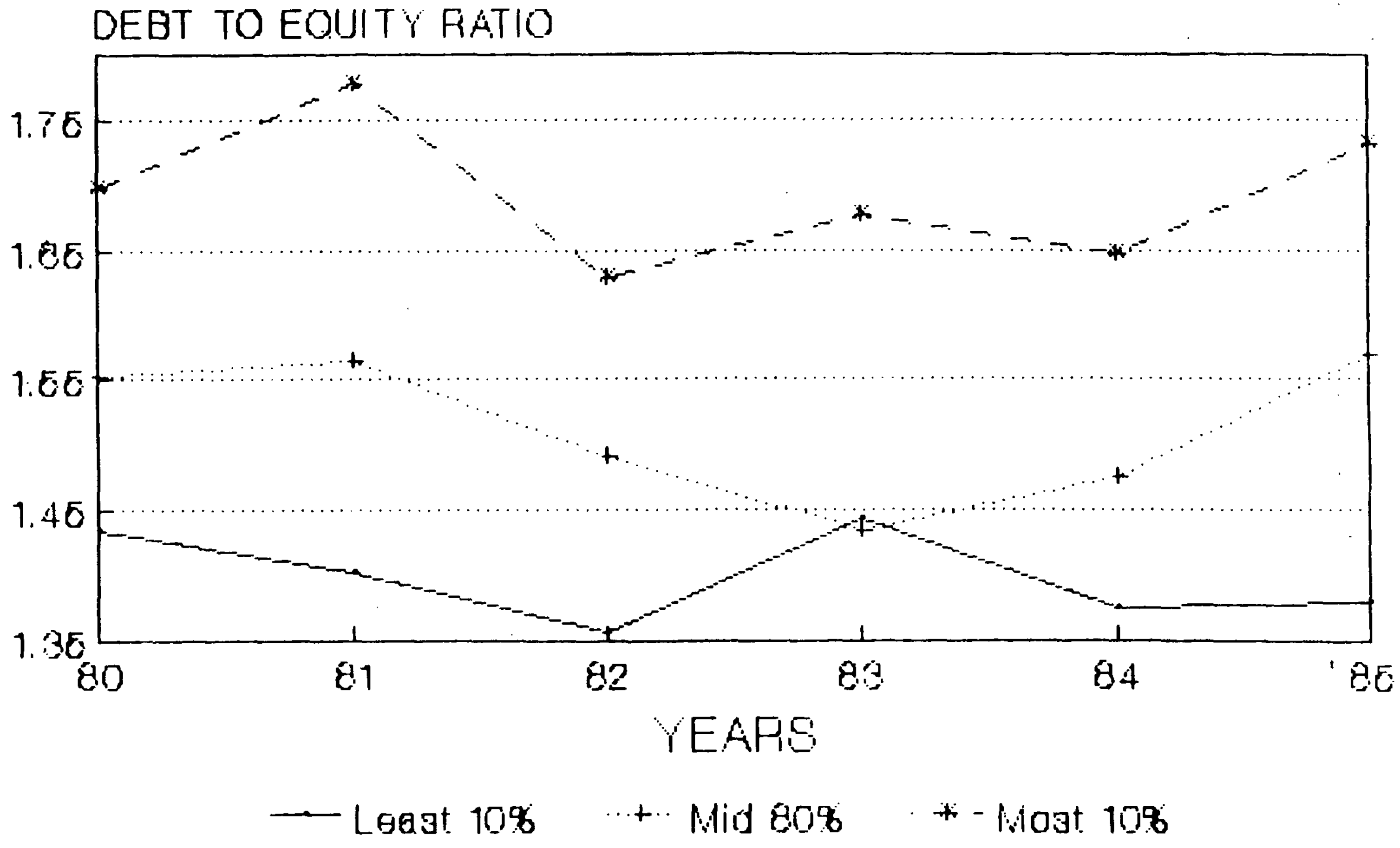
DEBT TO EQUITY VS SSF
UPPER AND LOWER 10%



1980-1985

Figure A.17

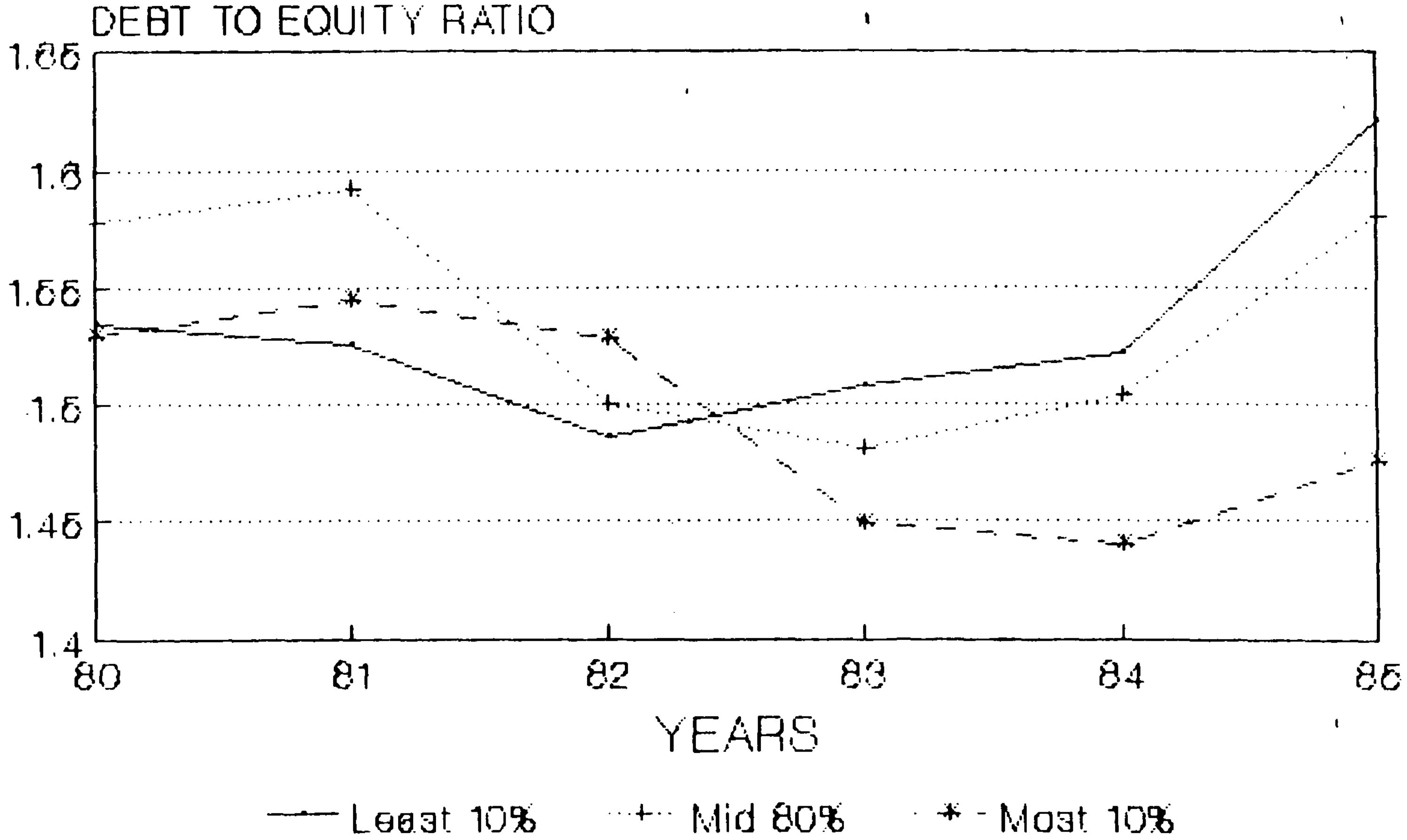
DEBT TO EQUITY VS RADIATION
UPPER AND LOWER 10%



1980-1985

Figure A.18

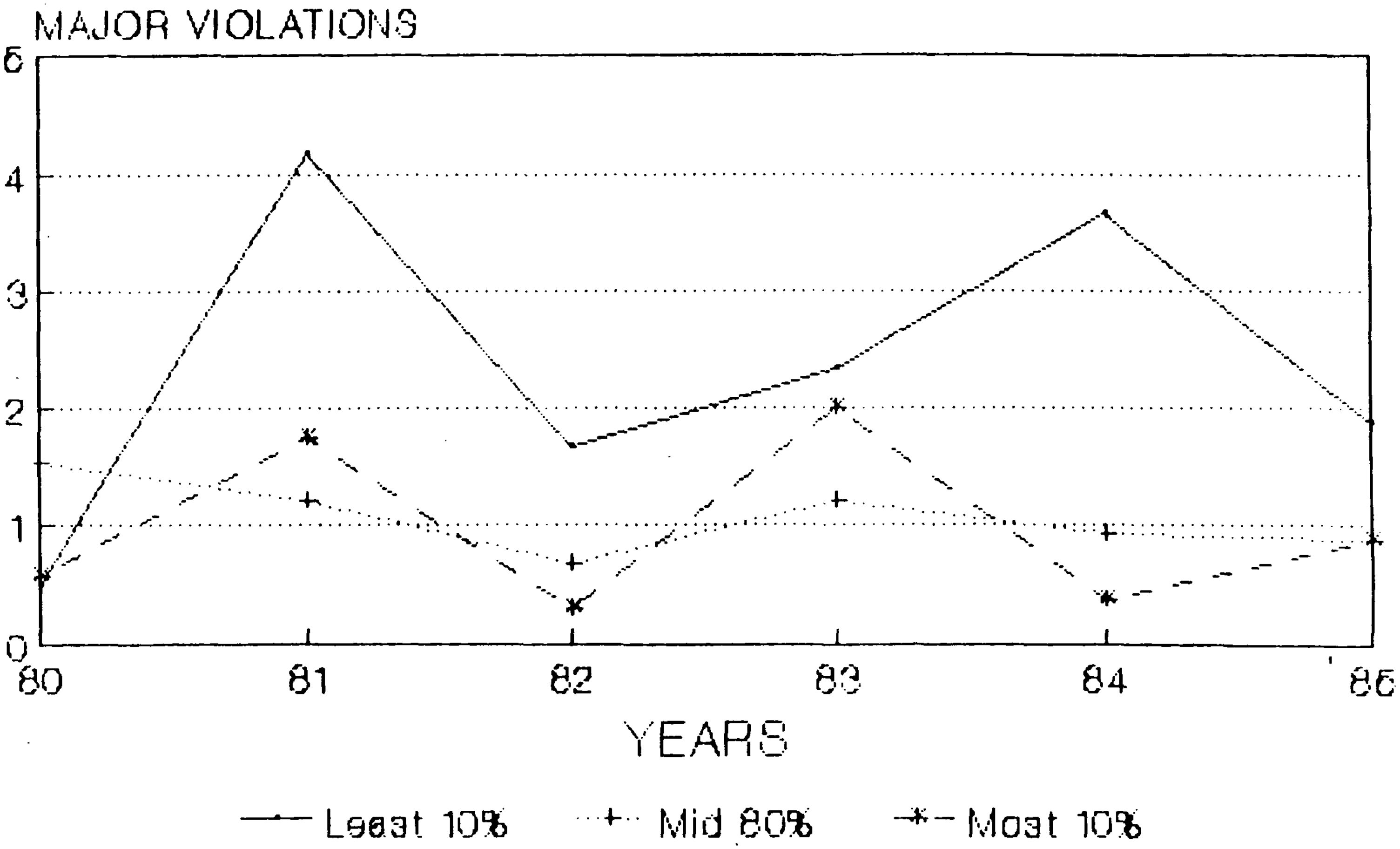
DEBT TO EQUITY VS CRITICAL HRS
UPPER AND LOWER 10%



1980-1985

Figure A.19

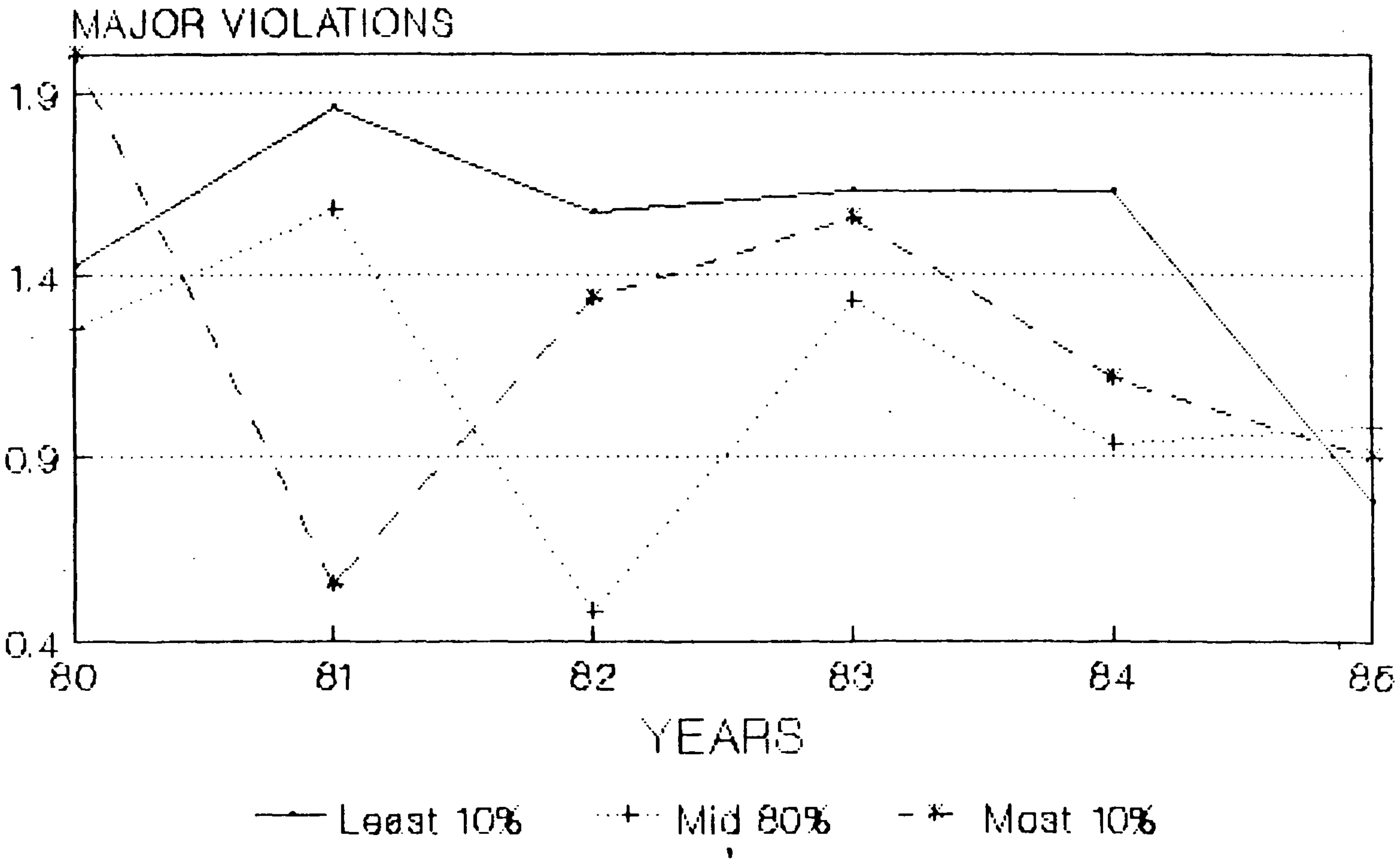
MAJOR VIOLATIONS / SCRAMS
UPPER AND LOWER 10%



1980-1985

Figure A.20

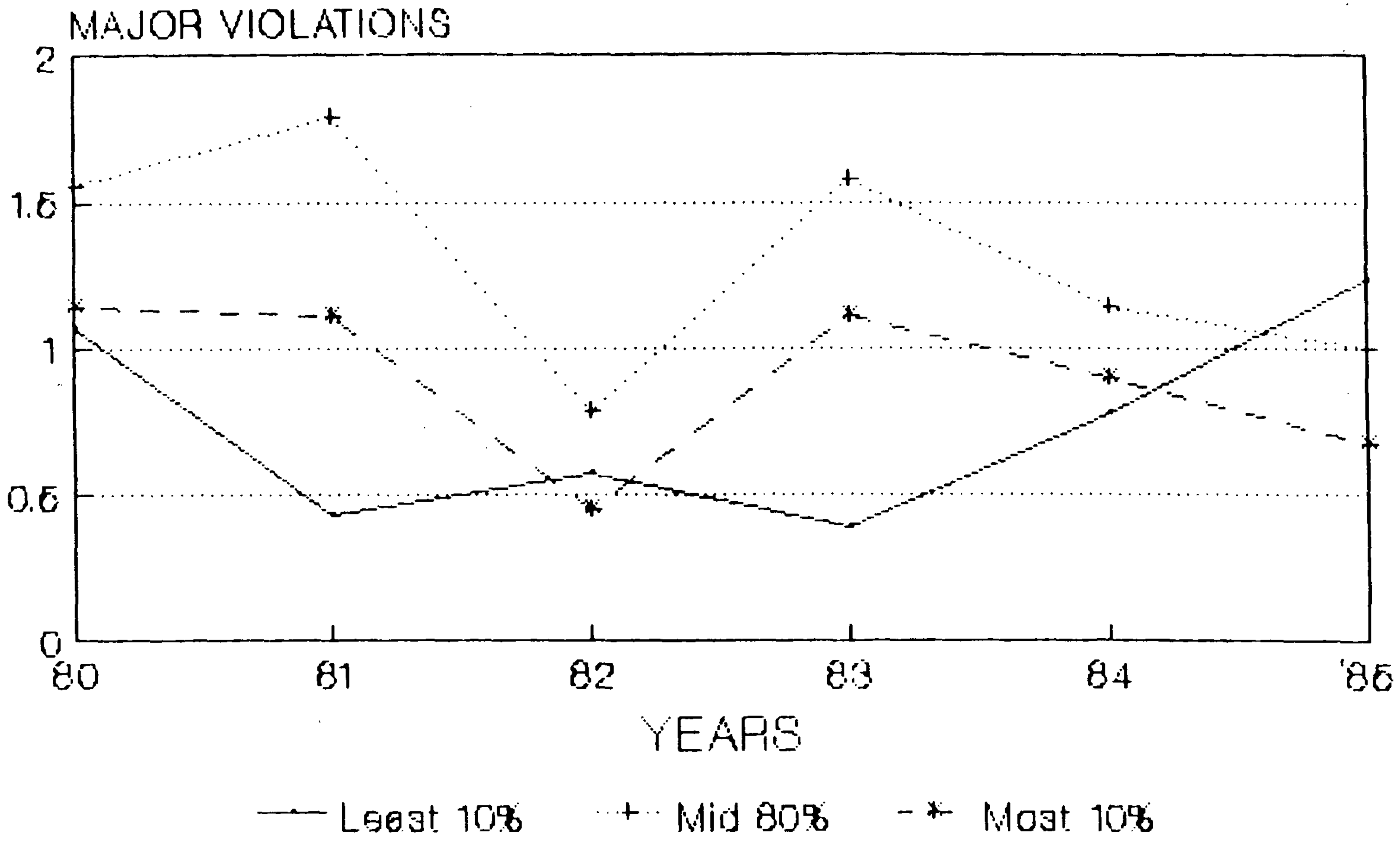
MAJOR VIOLATIONS / SSA
UPPER AND LOWER 10%



1980-1985

Figure A.21

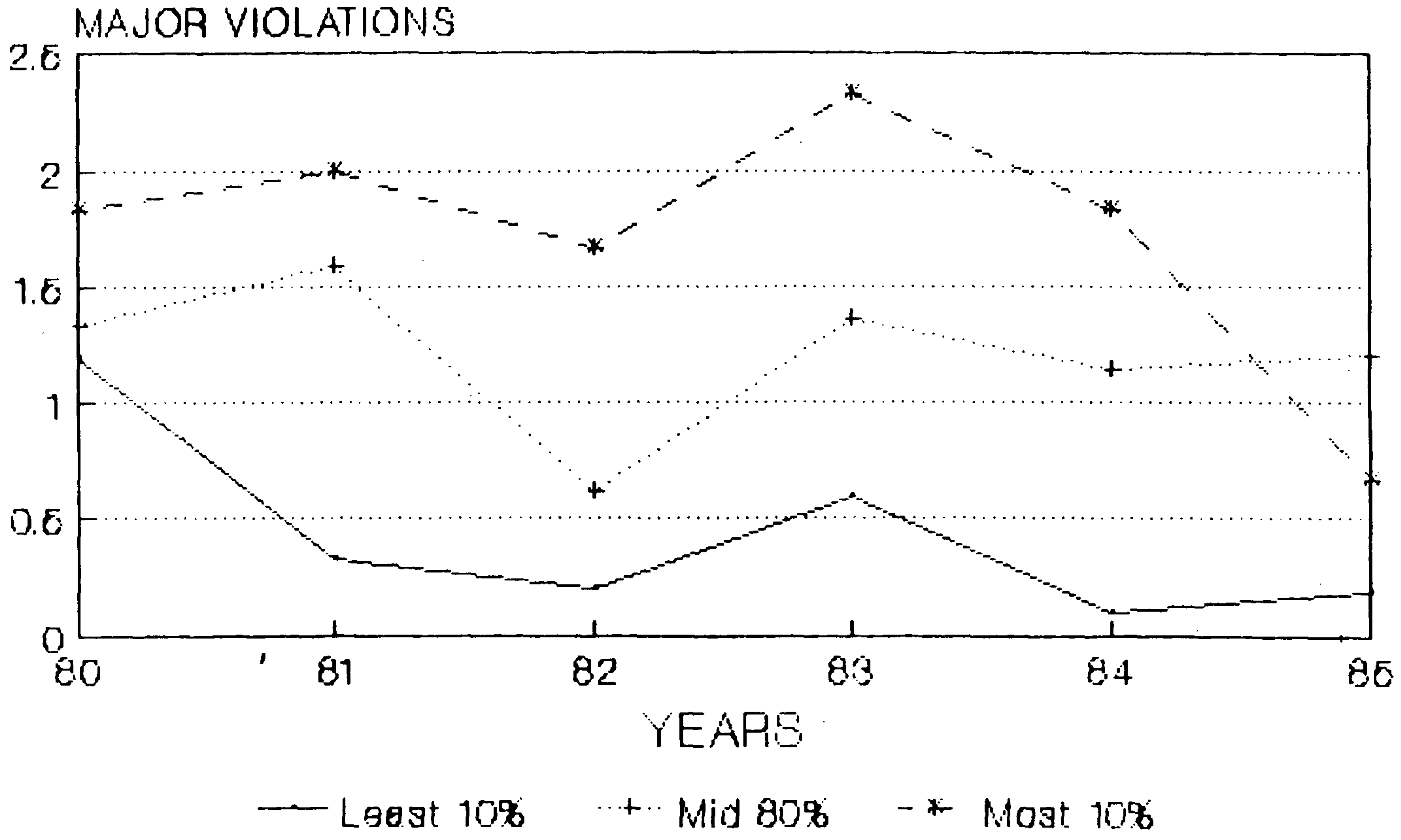
MAJOR VIOLATIONS / SIG. EVENTS
UPPER AND LOWER 10%



1980-1985

Figure A.22

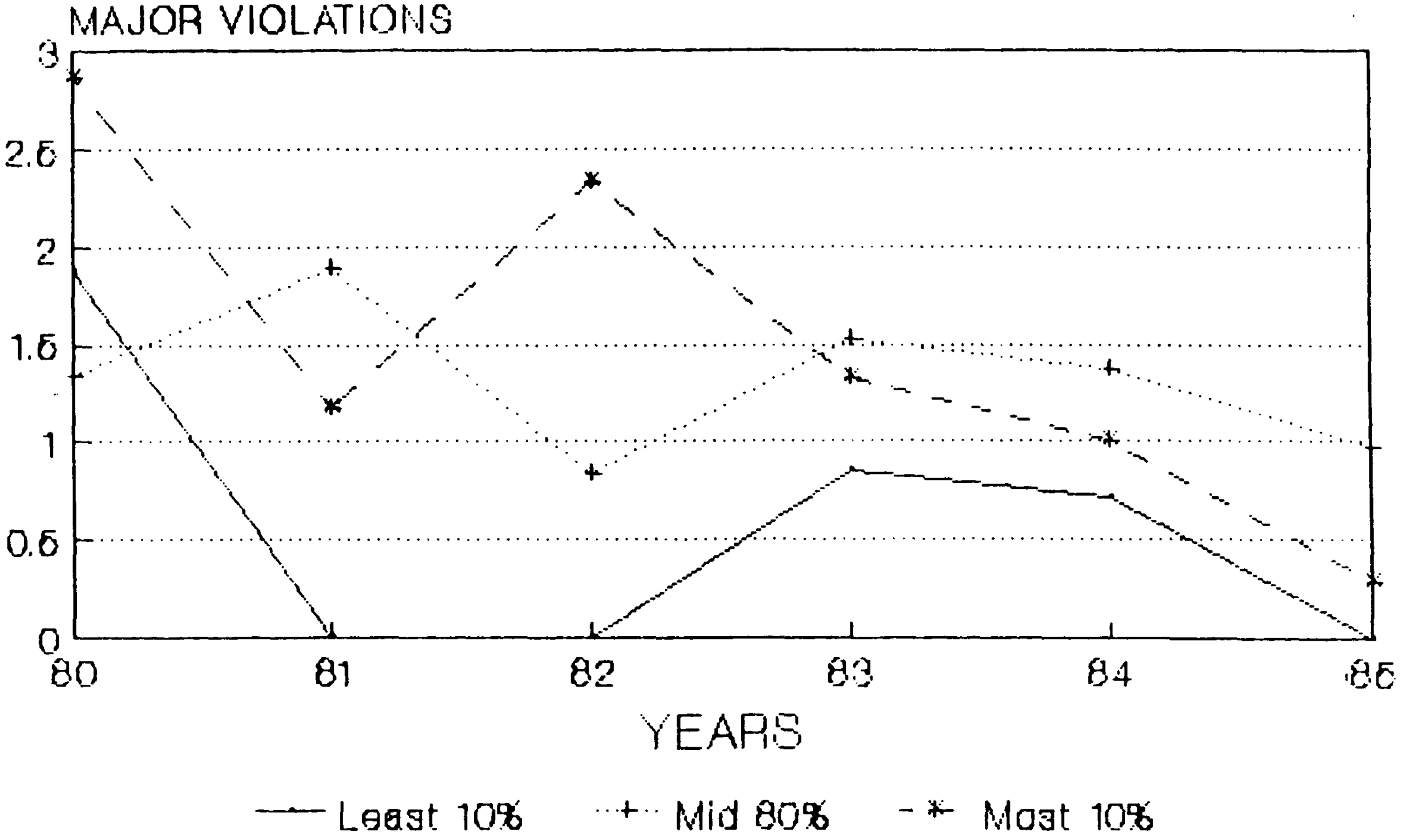
MAJOR VIOLATIONS / SSF
UPPER AND LOWER 10%



1980-1985

Figure A.23

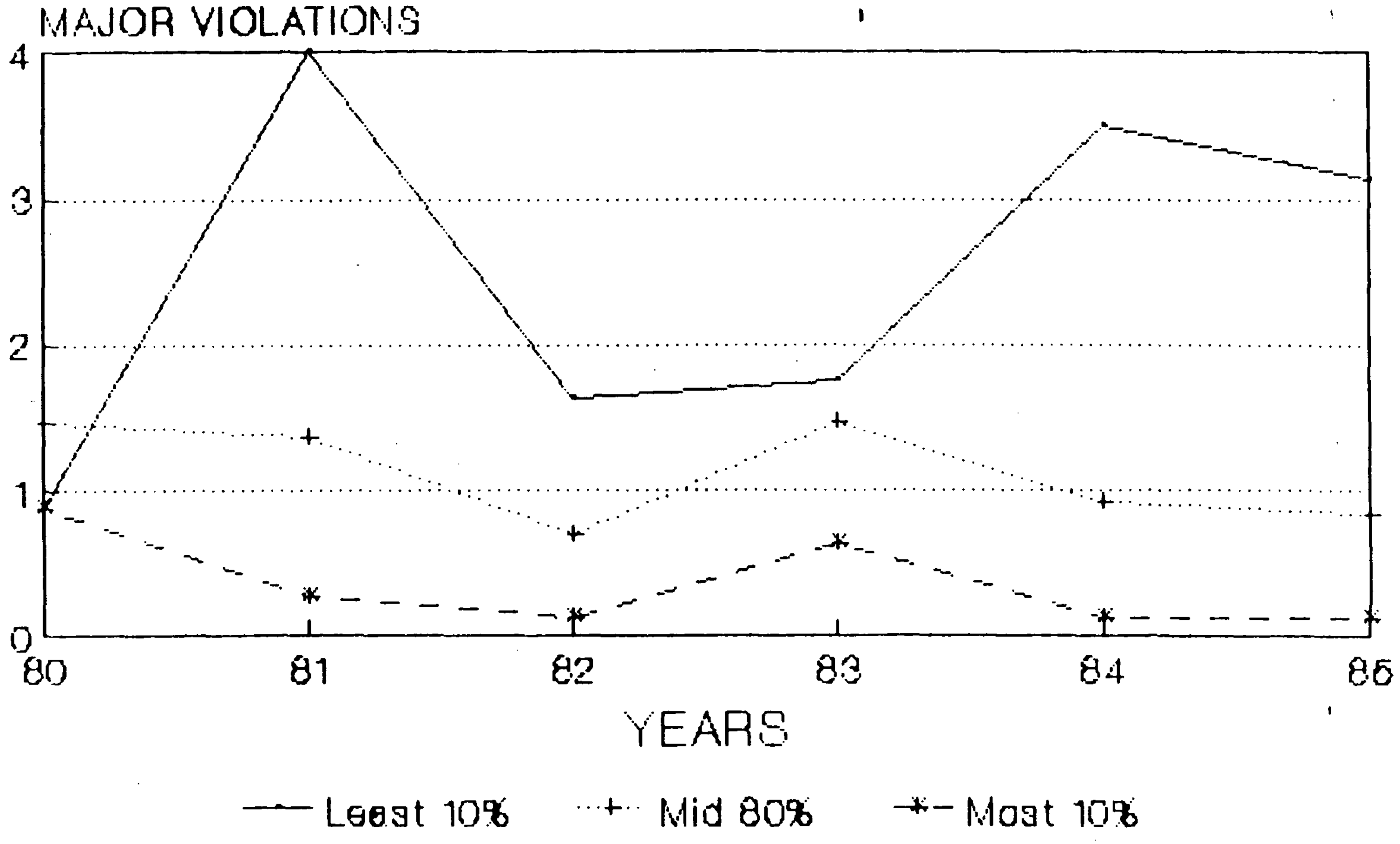
MAJOR VIOLATIONS / RADIATION
UPPER AND LOWER 10%



1980-1985

Figure A.24

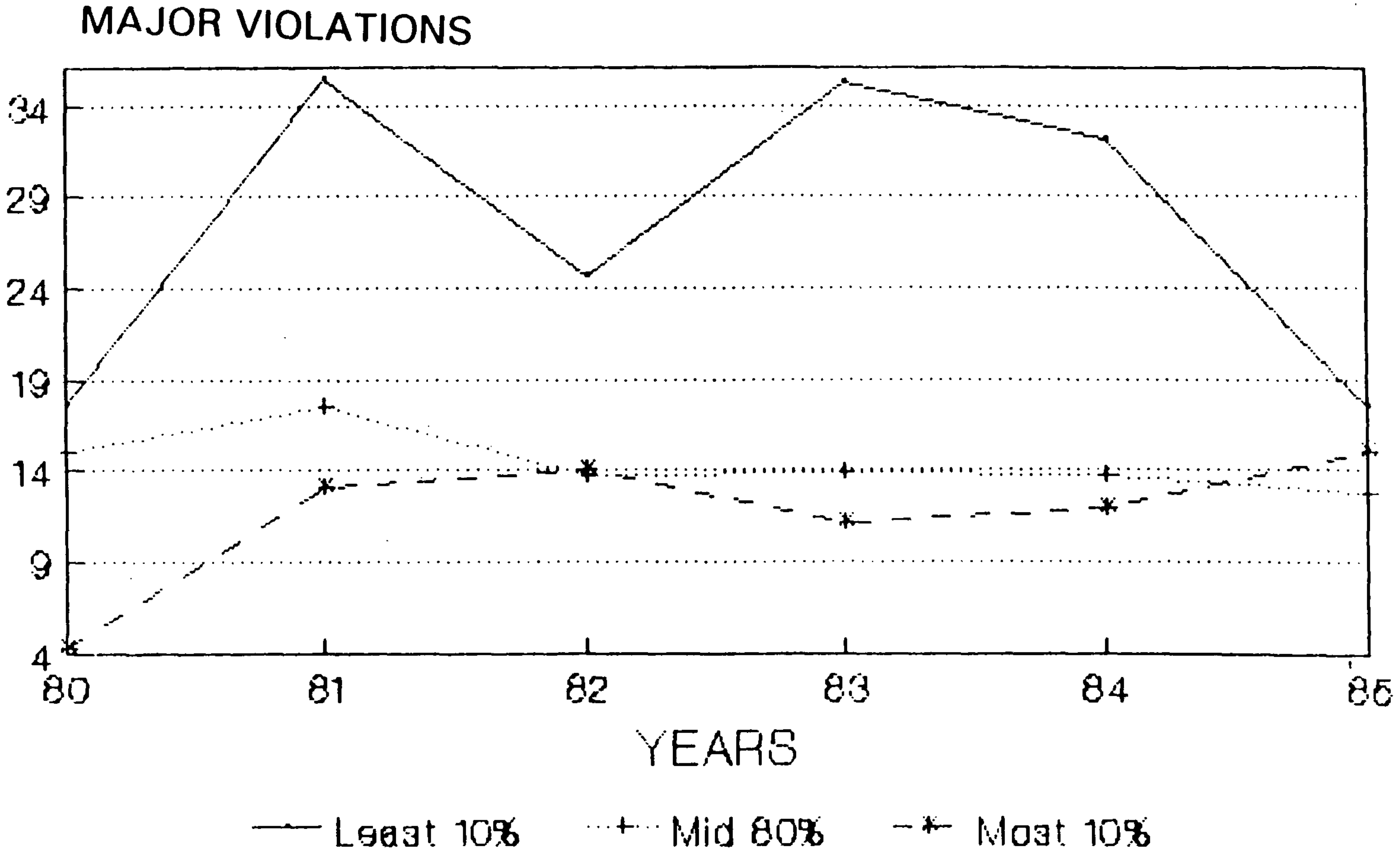
MAJOR VIOLATIONS / CRITICAL HOURS UPPER AND LOWER 10%



1980-1986

Figure A.25

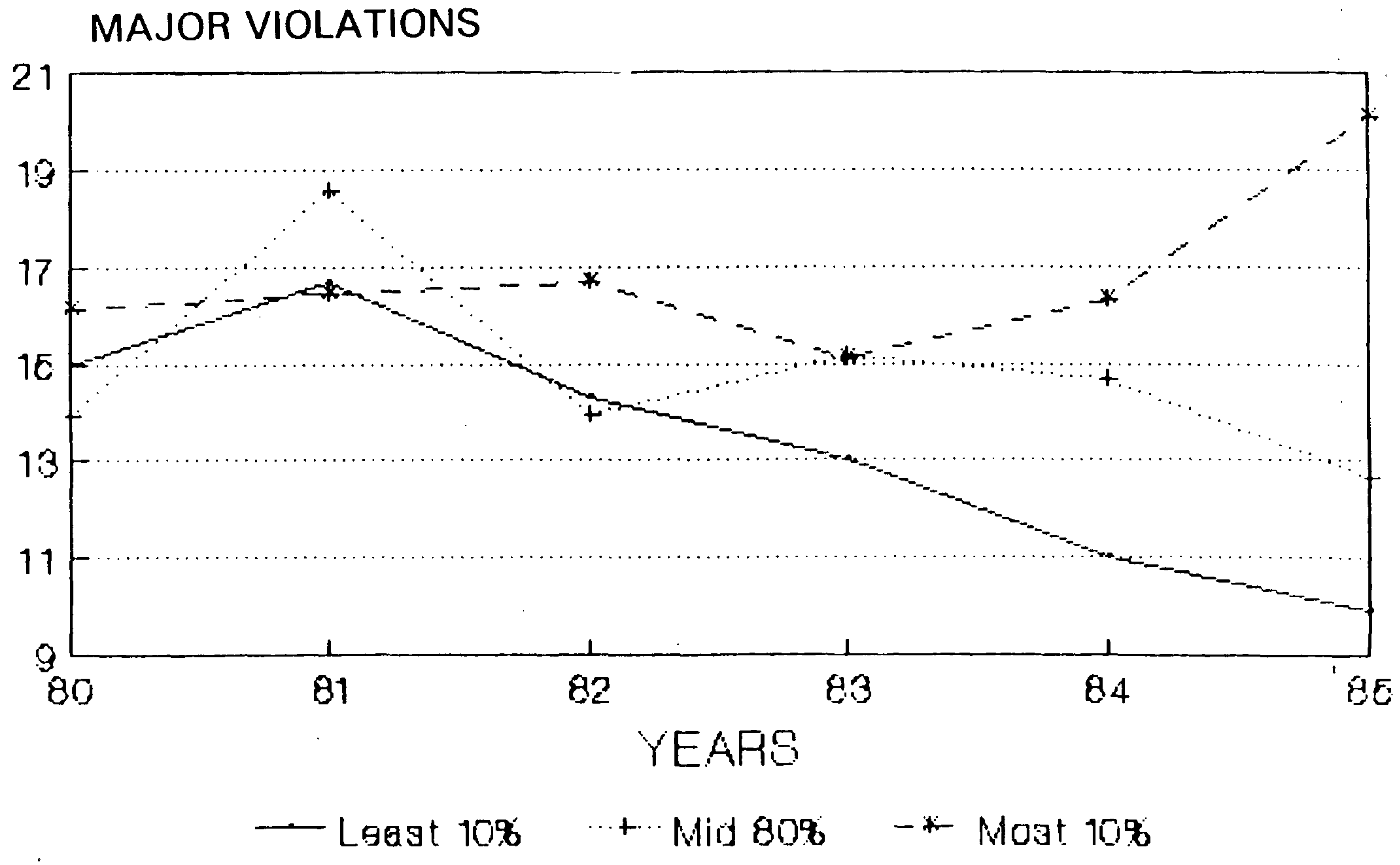
MINOR VIOLATIONS / SCRAMS
UPPER AND LOWER 10%



1980-1985

Figure A.26

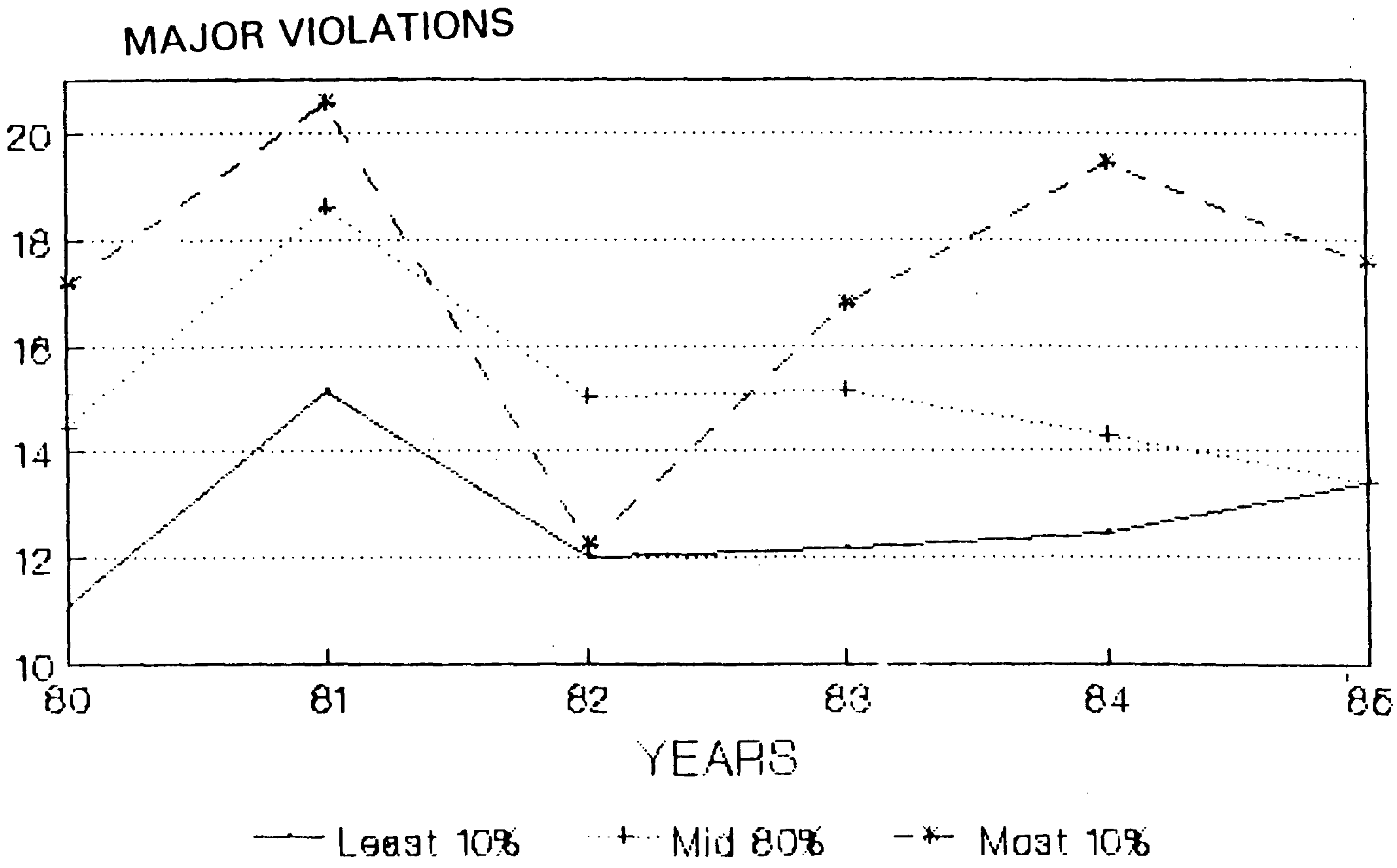
MINOR VIOLATIONS / SSA
UPPER AND LOWER 10%



1980-1985

Figure A.27

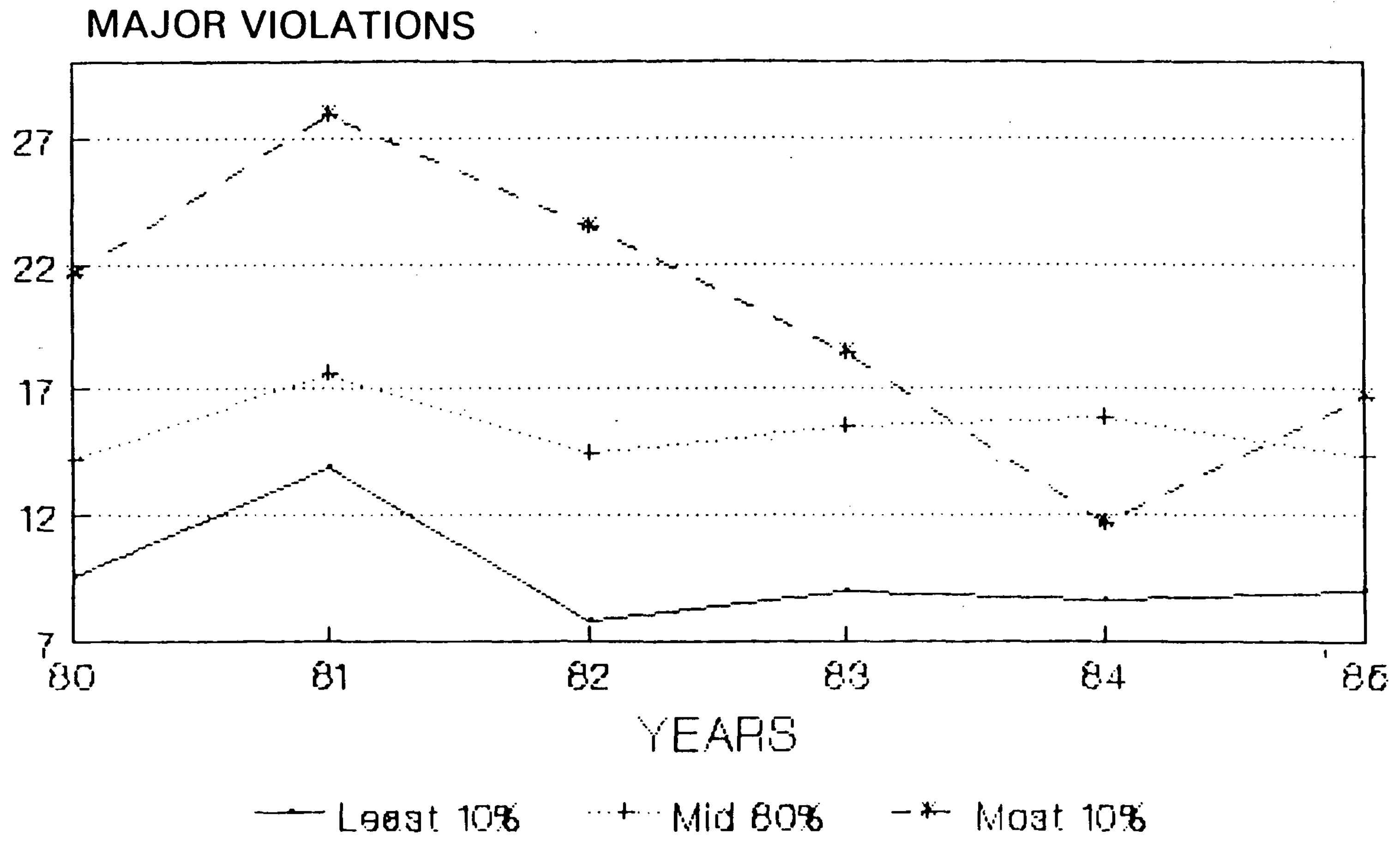
MINOR VIOLATIONS / SIG. EVENTS
UPPER AND LOWER 10%



1980-1986

Figure A.28

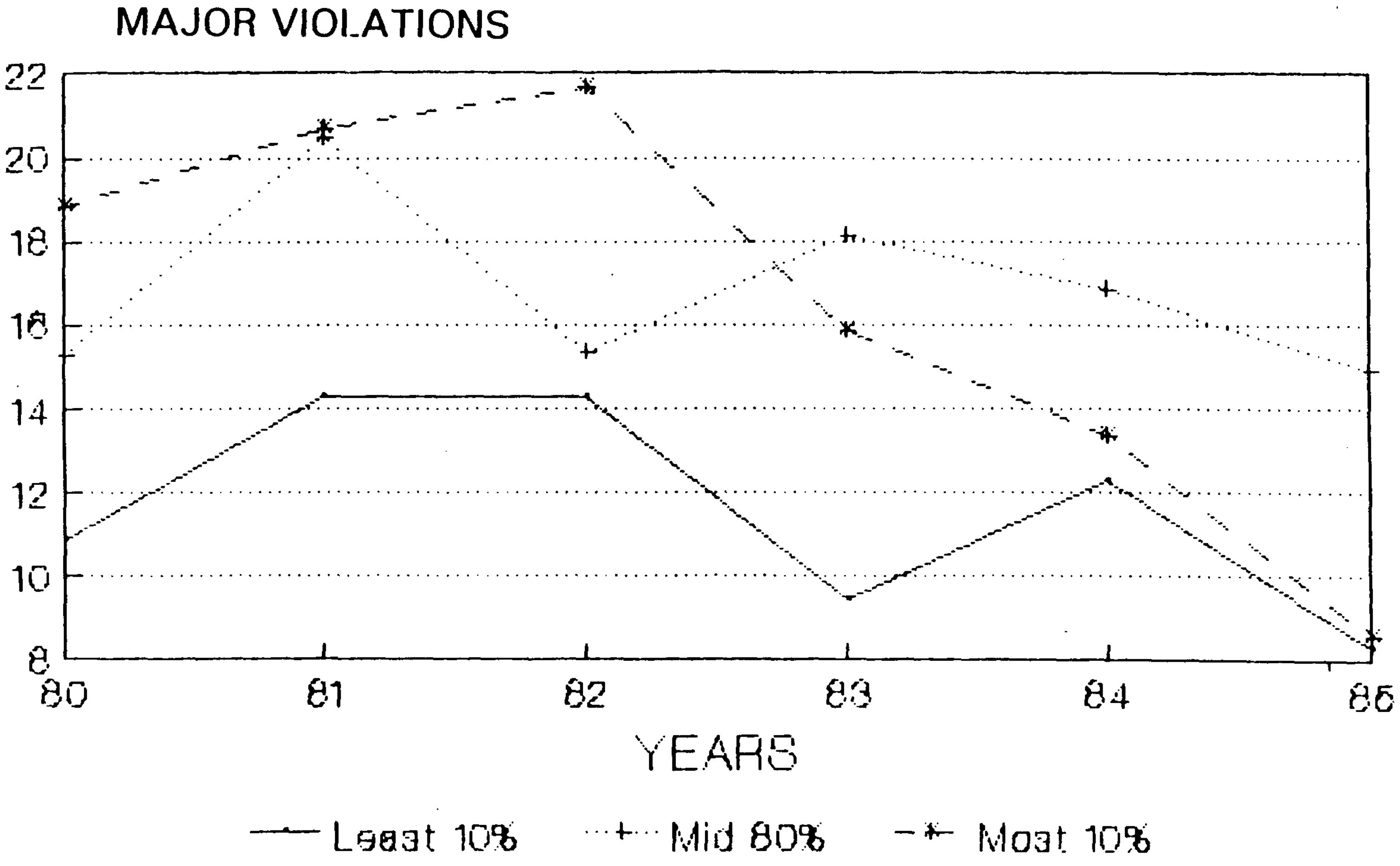
MINOR VIOLATIONS / SSF
UPPER AND LOWER 10%



1980-1985

Figure A.29

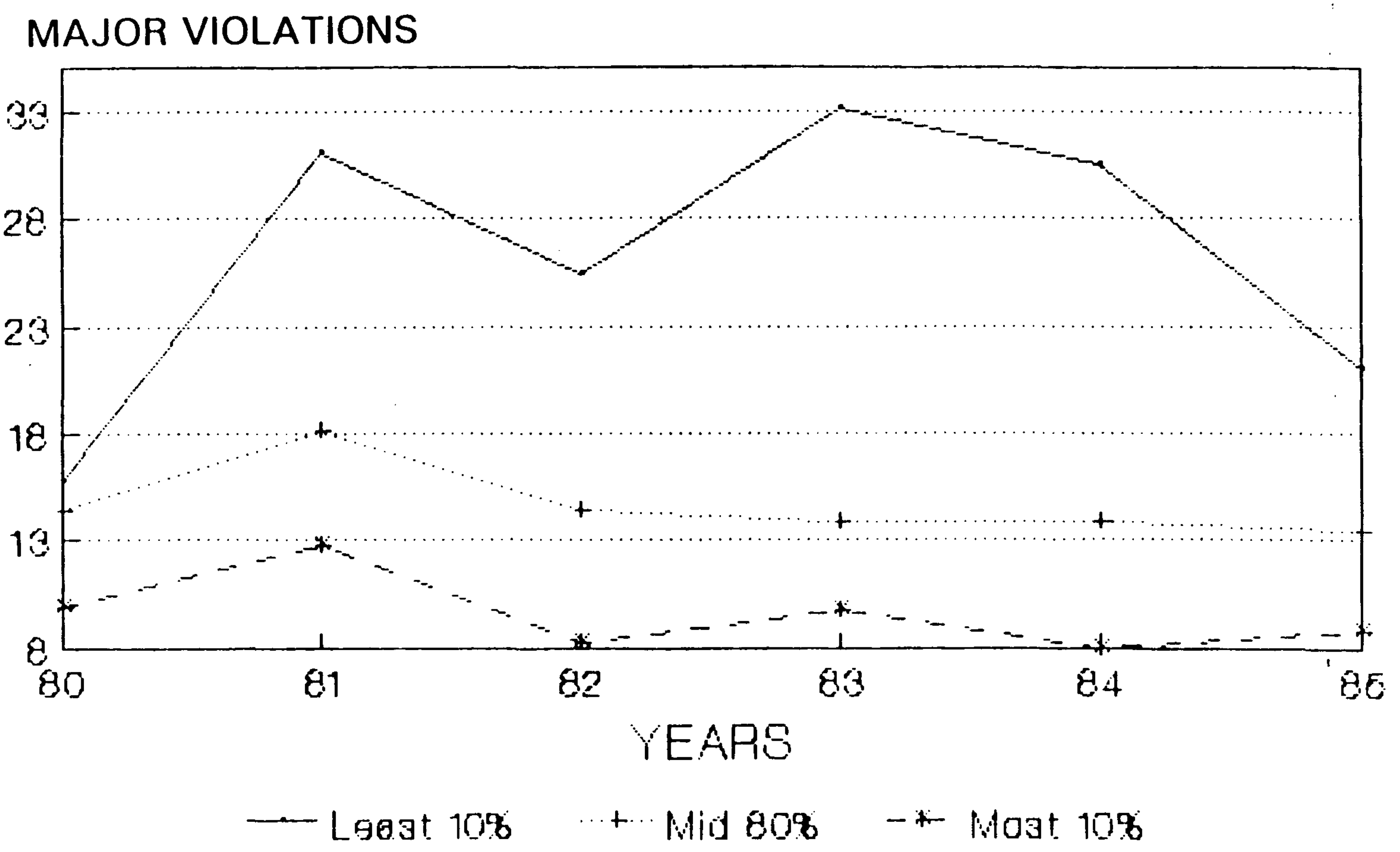
MINOR VIOLATIONS / RADIATION
UPPER AND LOWER 10%



1980-1985

Figure A.30

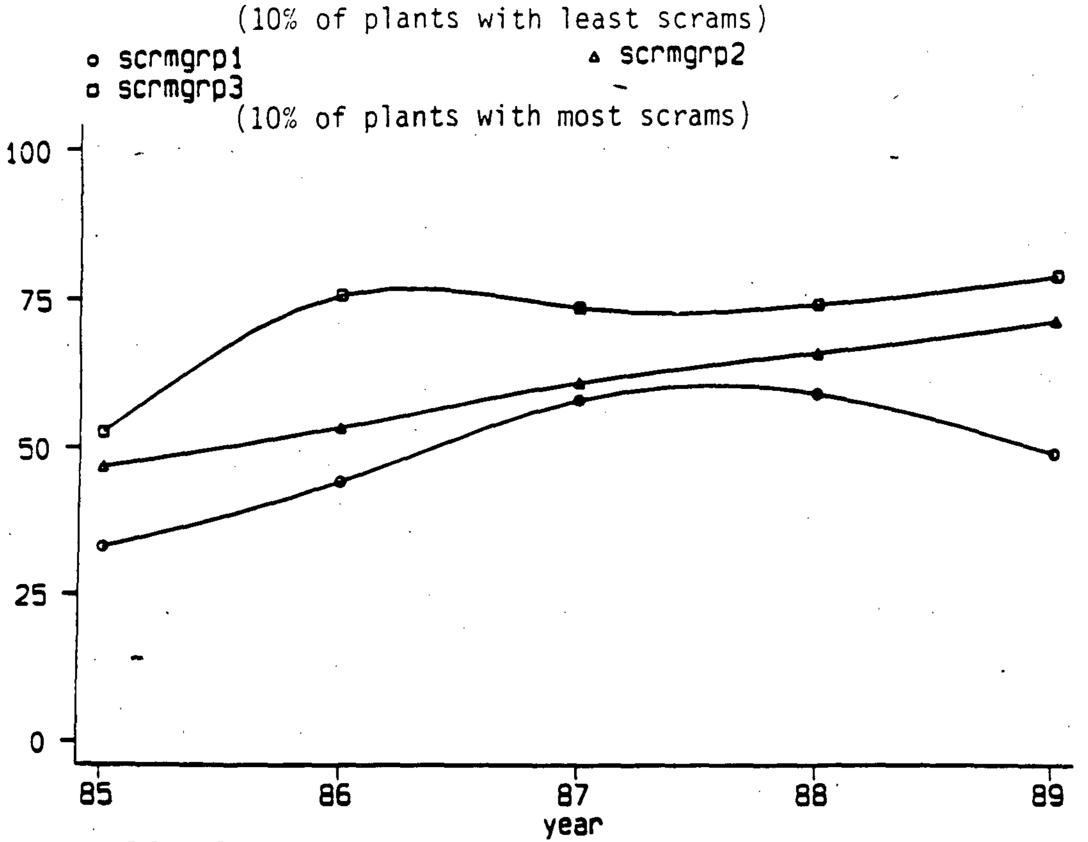
MINOR VIOLATIONS / CRITICAL HOURS UPPER AND LOWER 10%



1980-1985

Figure A.31

Figure A.32



O&M Expenditures by Scram Group--10%

Figure A.33

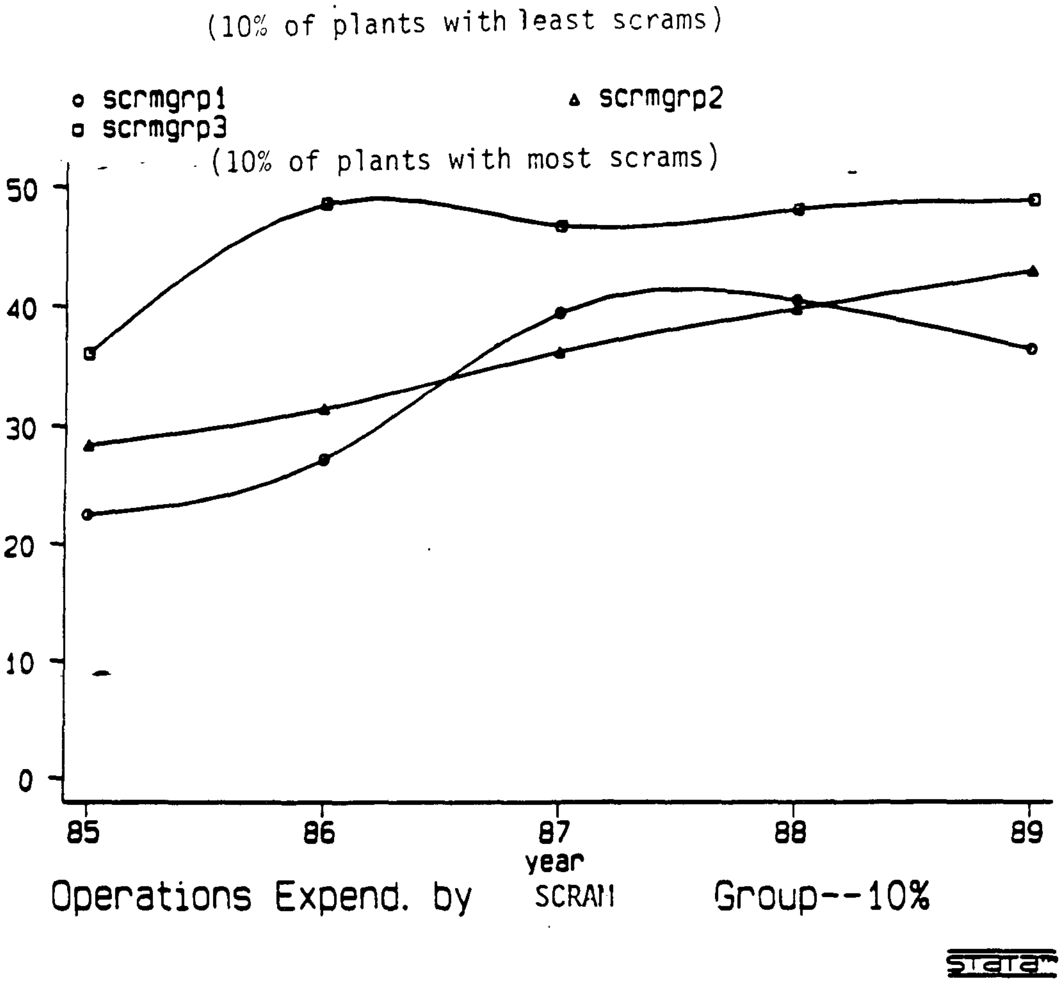
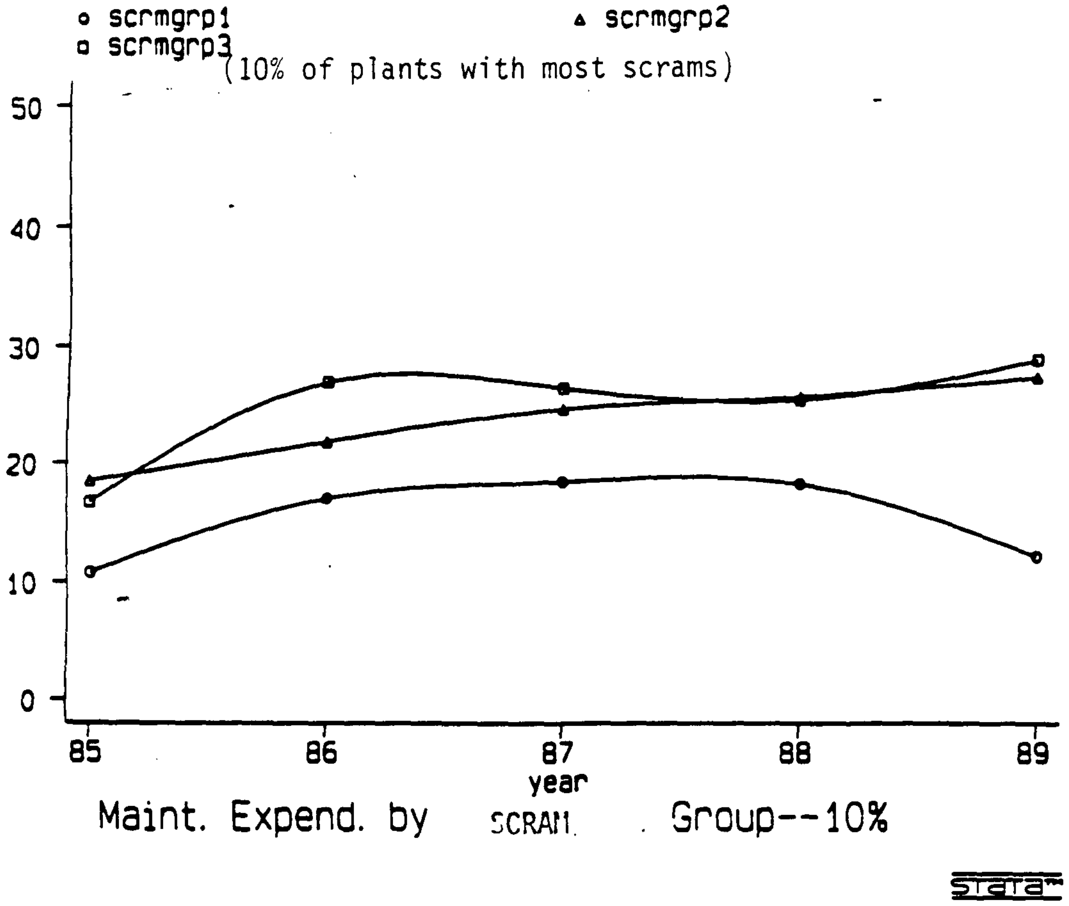

(10% of plants with least scrams)
○ scrmgrp1
▲ scrmgrp2
□ scrmgrp3
(10% of plants with most scrams)
50
40
30
20
10
0
85
86
87
88
89
year
Operations Expend. by SCRAM Group--10%
Stata

Figure A.34

(10% of plants with least scrams)



(10% of plants with most scrams)

Figure A.35

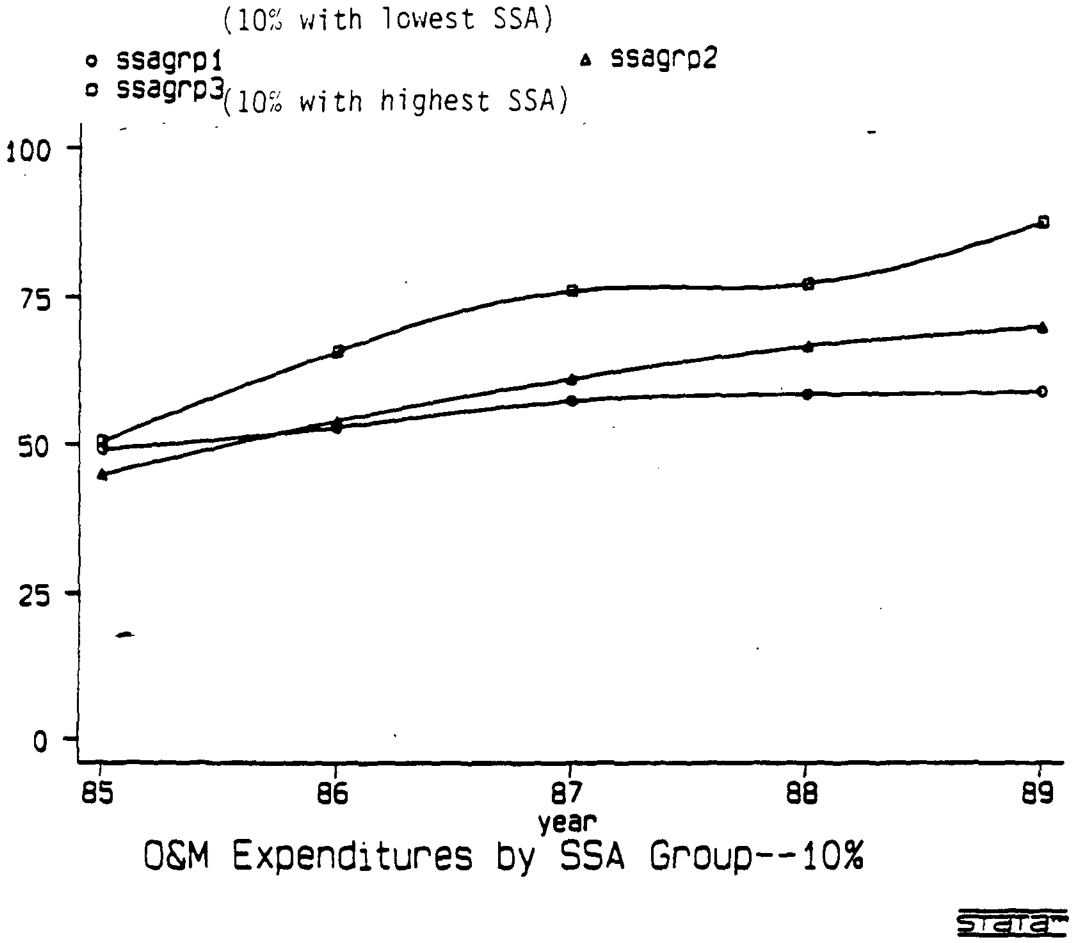

(10% with lowest SSA)
o ssagrp1
▵ ssagrp2
□ ssagrp3
(10% with highest SSA)
100
75
50
25
0
85
86
87
88
89
year
O&M Expenditures by SSA Group--10%
Stata™

Figure A.36

(10% with lowest SSA)

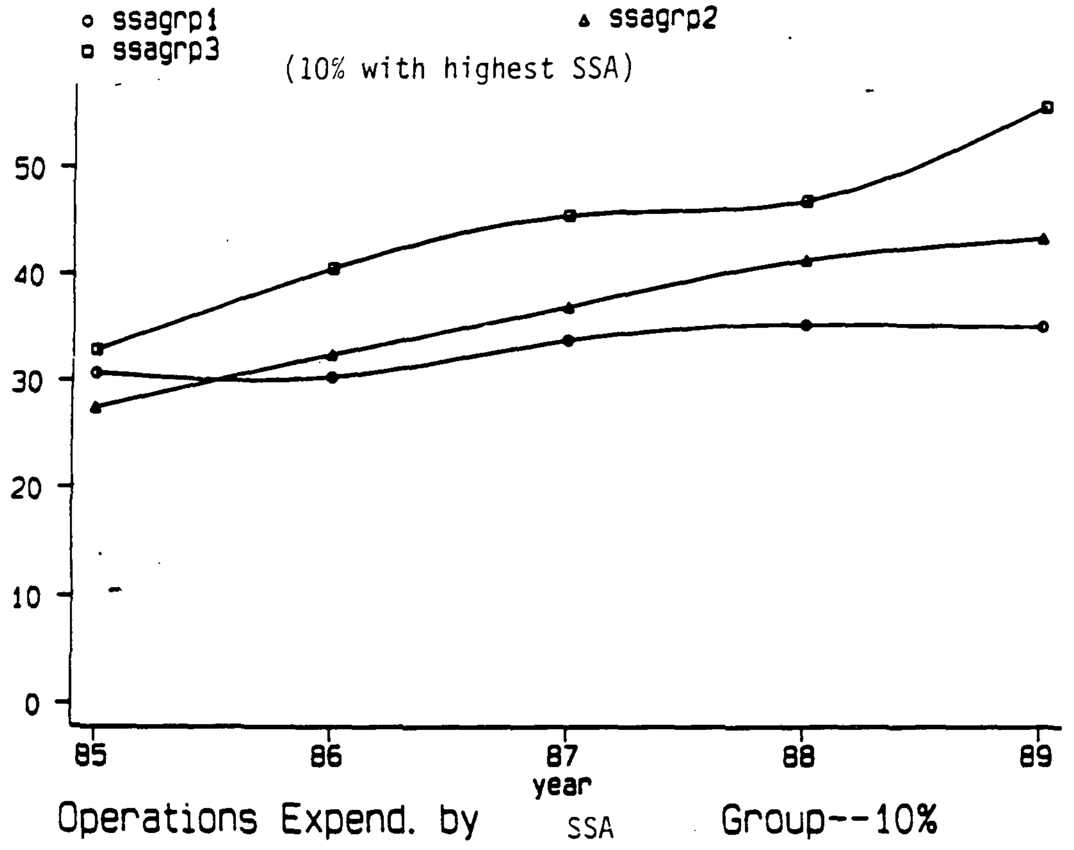
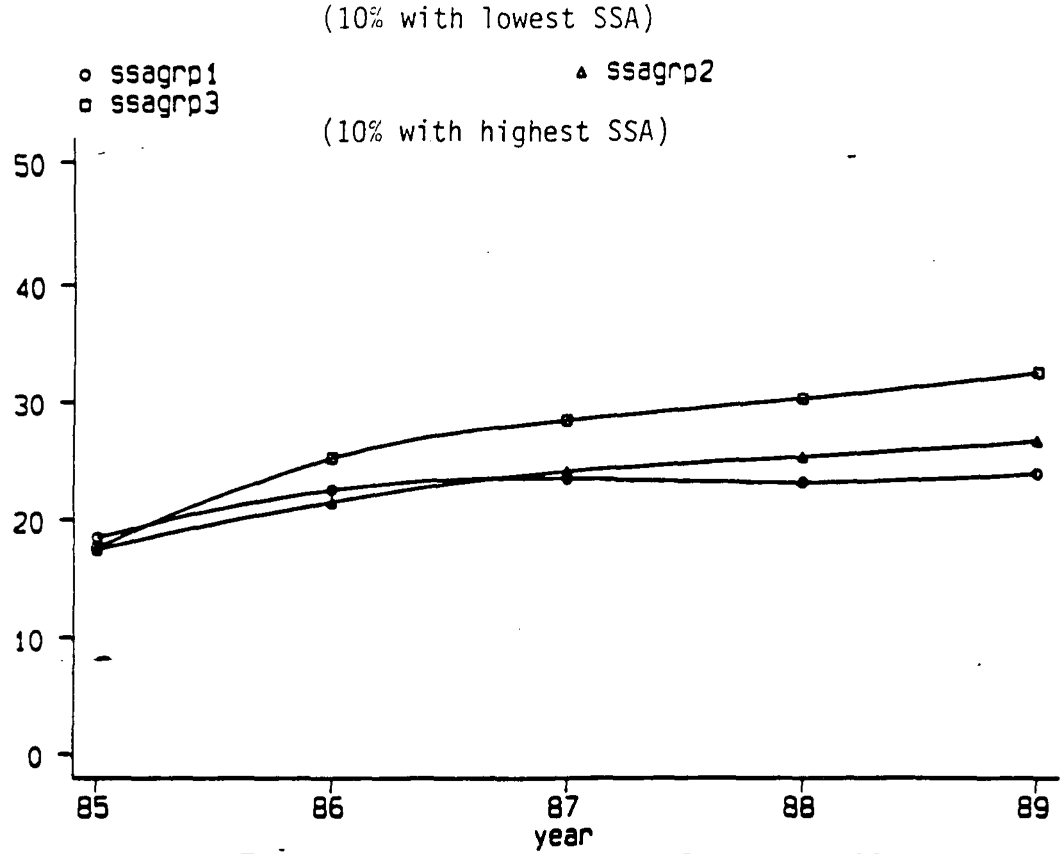
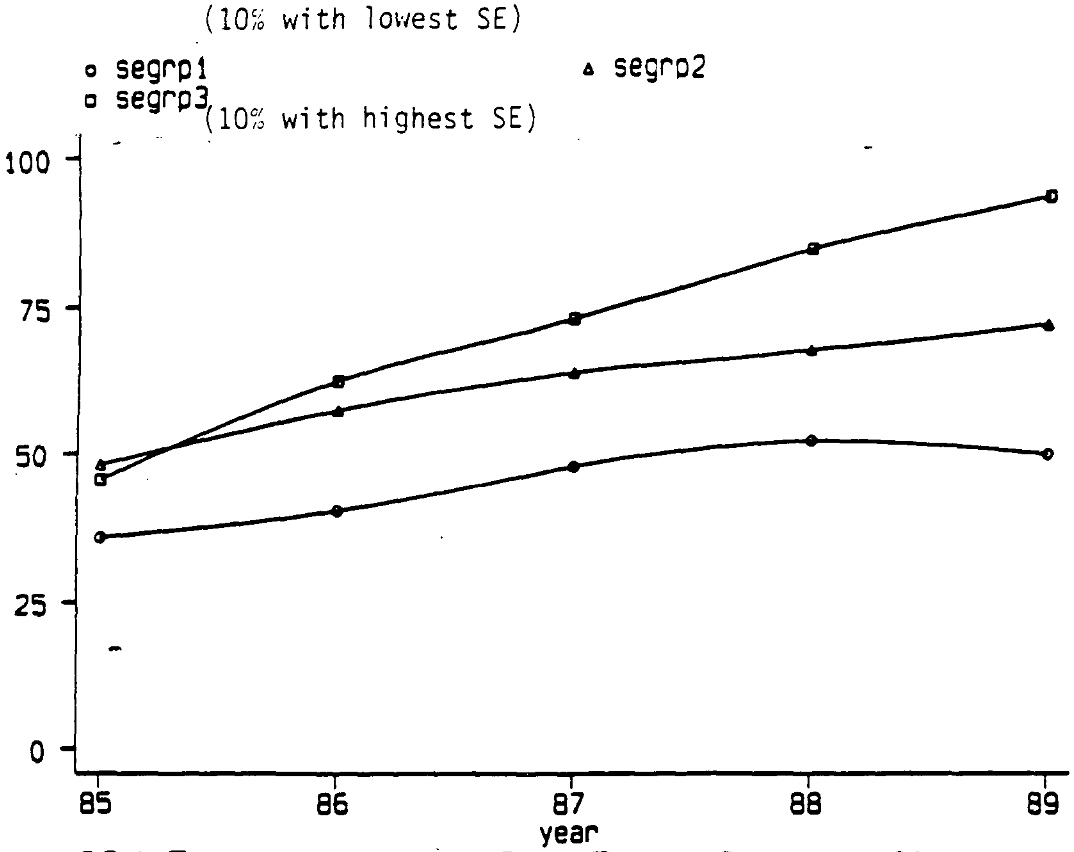


Figure A.37



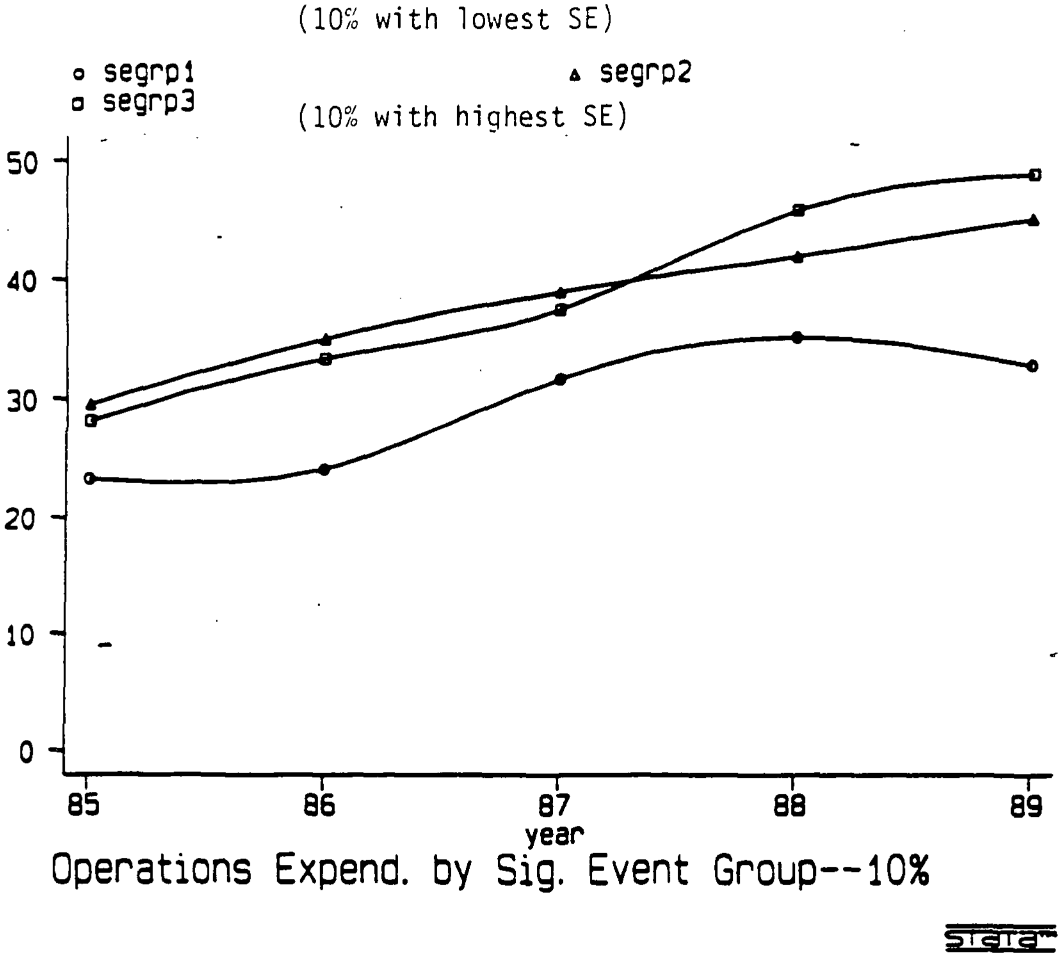
Maint. Expend. by SSA Group--10%

Figure A.38



O&M Expenditures by Sig. Event Group--10%

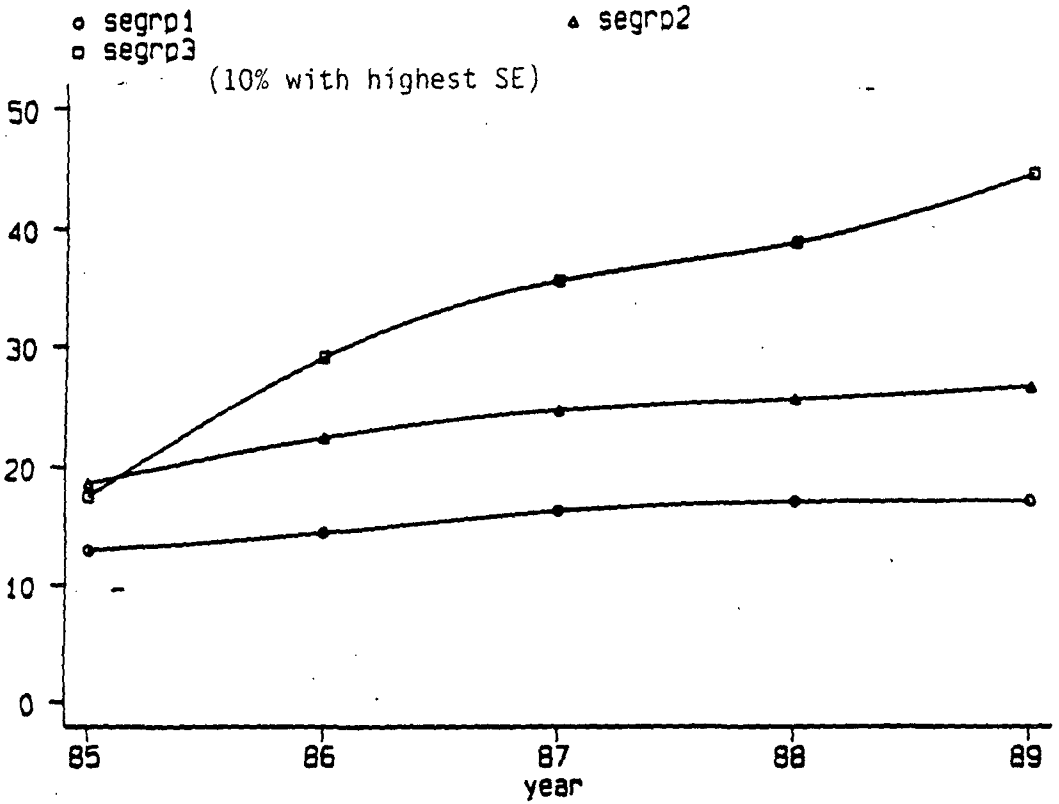
Figure A.39



Operations Expend. by Sig. Event Group--10%

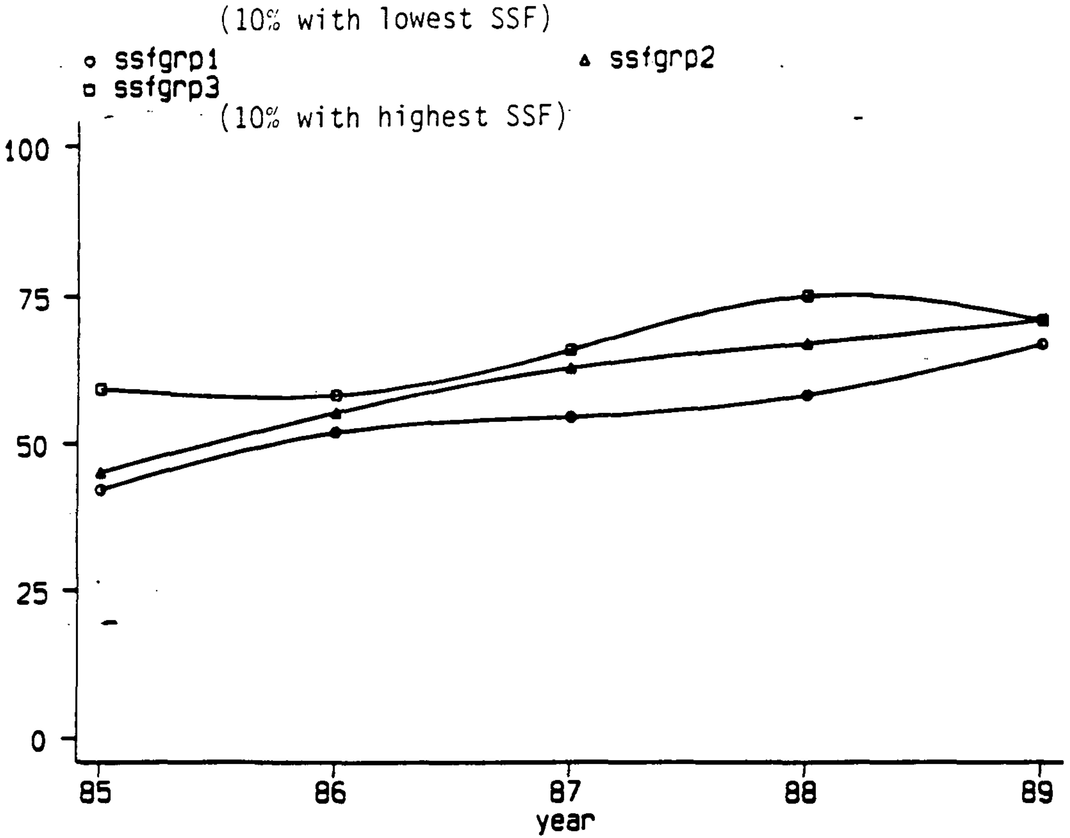
Figure A.40

(10% with lowest SE)



Maint. Expend. by Sig. Event Group--10%

Figure A.41



O&M Expenditures by SSF Group--10%

Figure A.42

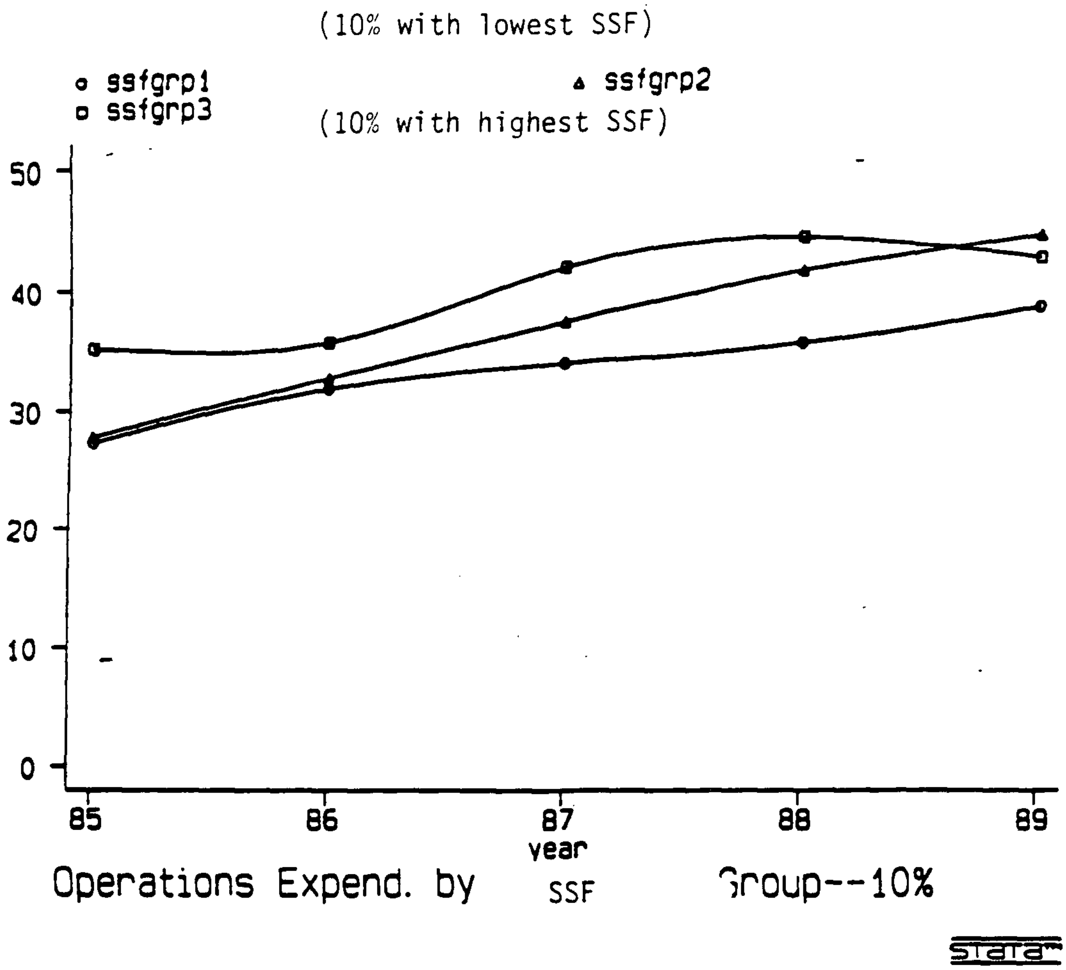
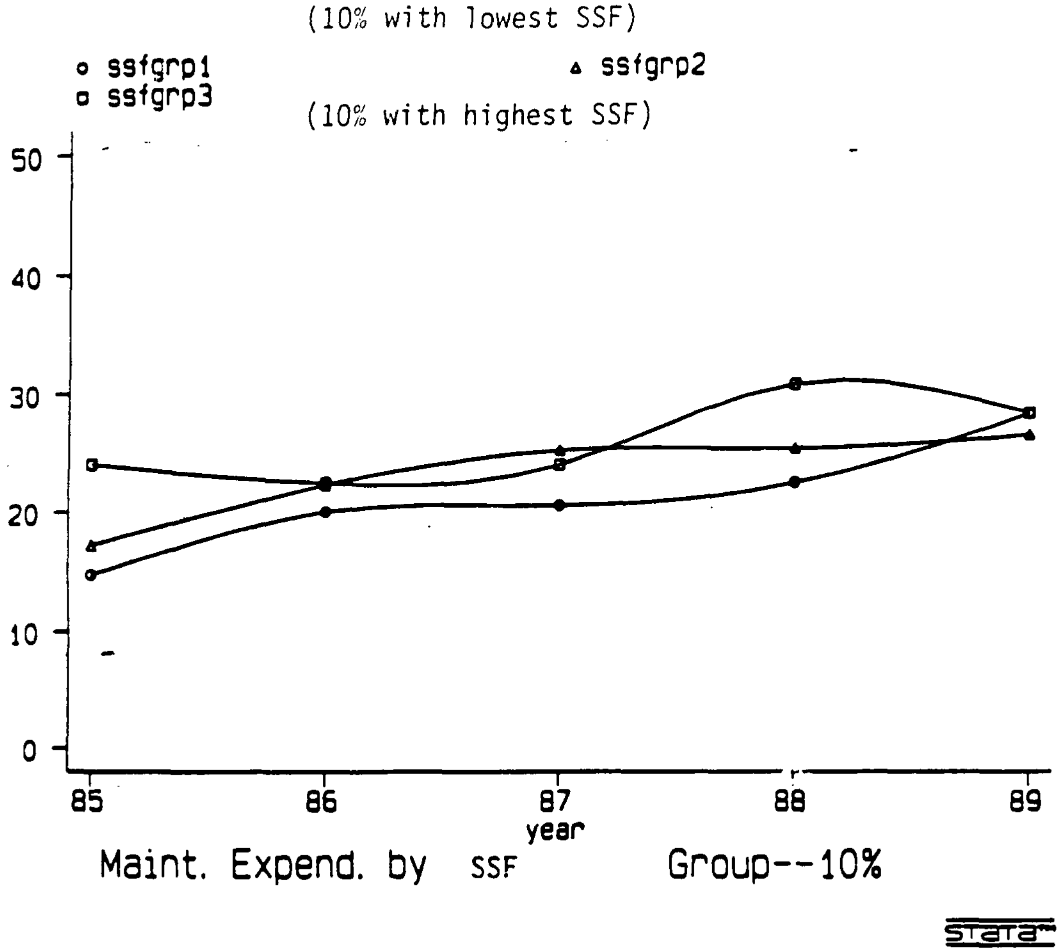
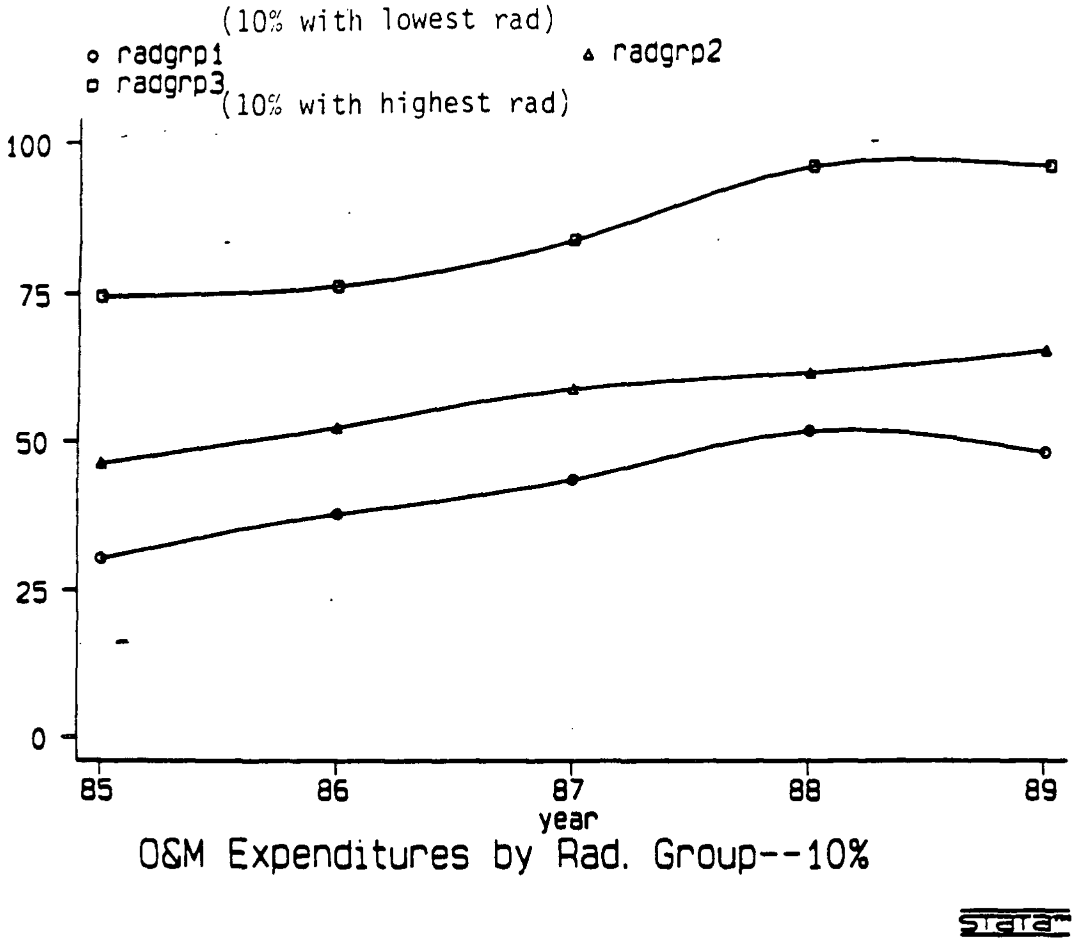

(10% with lowest SSF)
ssfgrp1
ssfgrp2
ssfgrp3
(10% with highest SSF)
50
40
30
20
10
0
85
86
87
88
89
year
Operations Expend. by SSF Group--10%
stata

Figure A.43



Maint. Expend. by SSF Group--10%

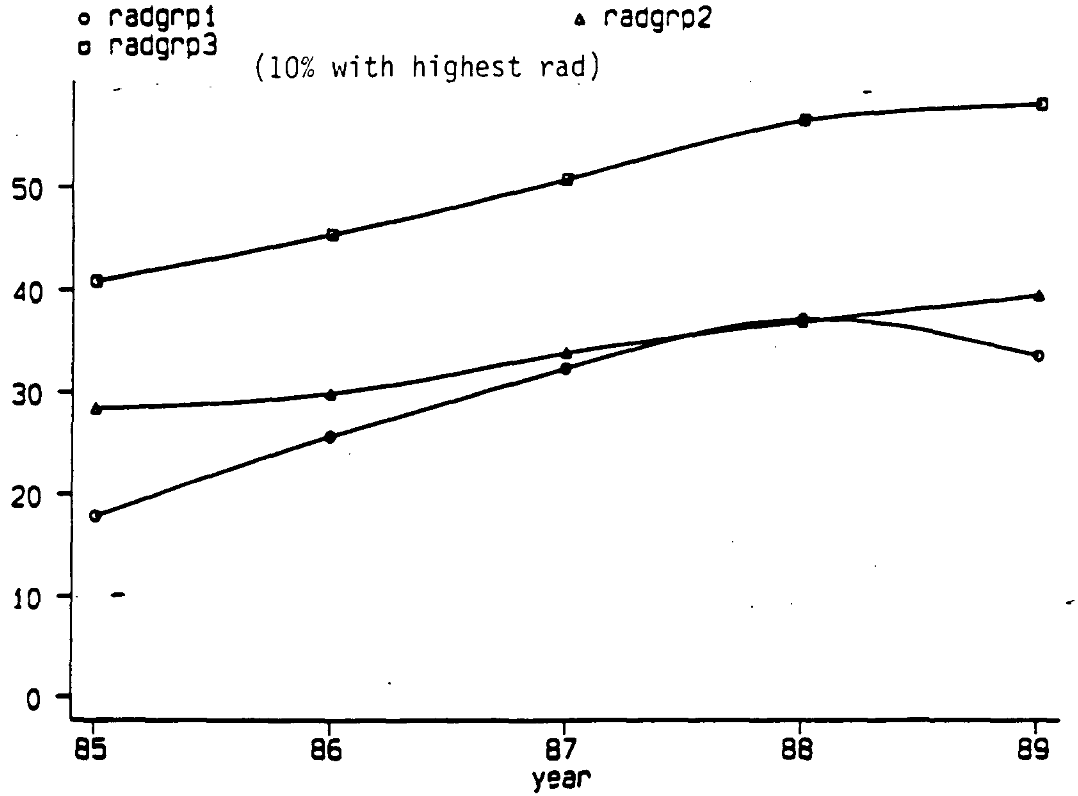
Figure A.44



O&M Expenditures by Rad. Group--10%

Figure A.45

(10% with lowest rad)



(10% with highest rad)

Operations Expend. by RAD Group--10%

Figure A.46

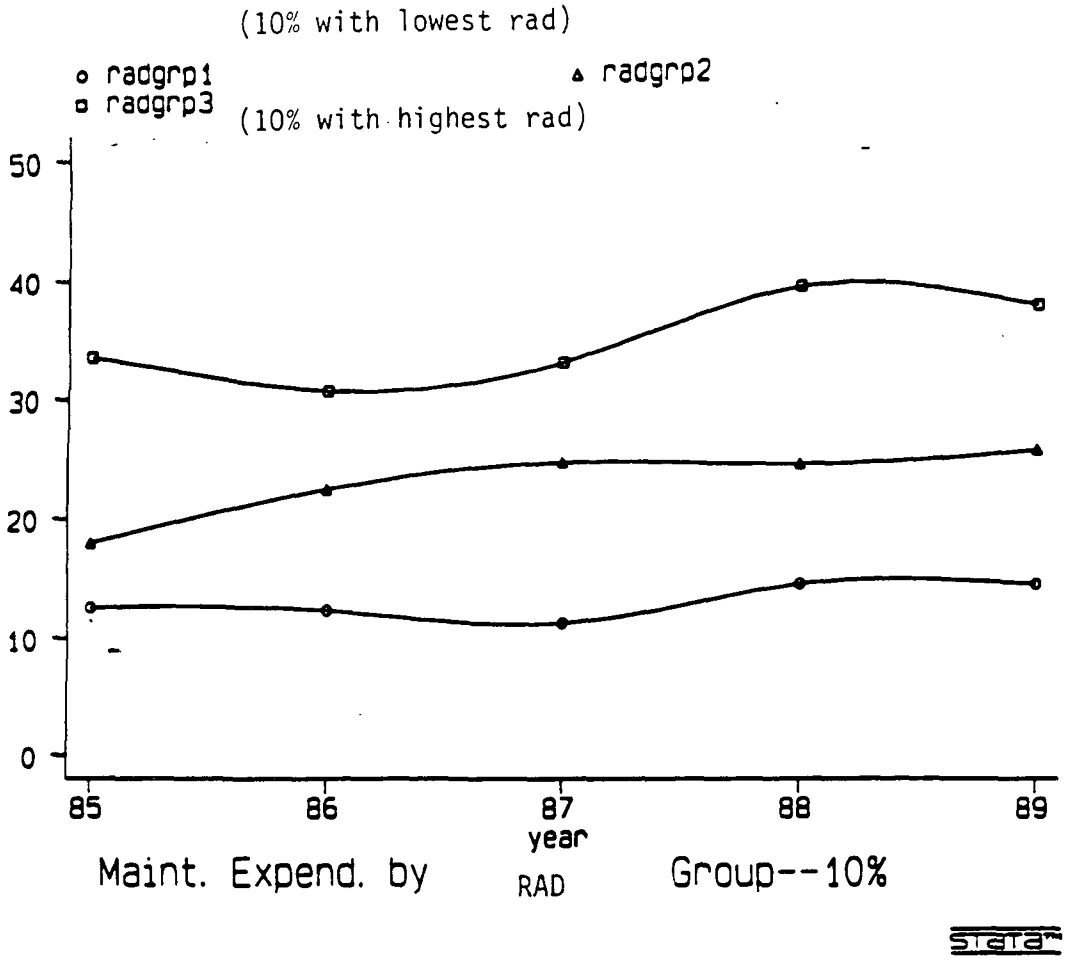
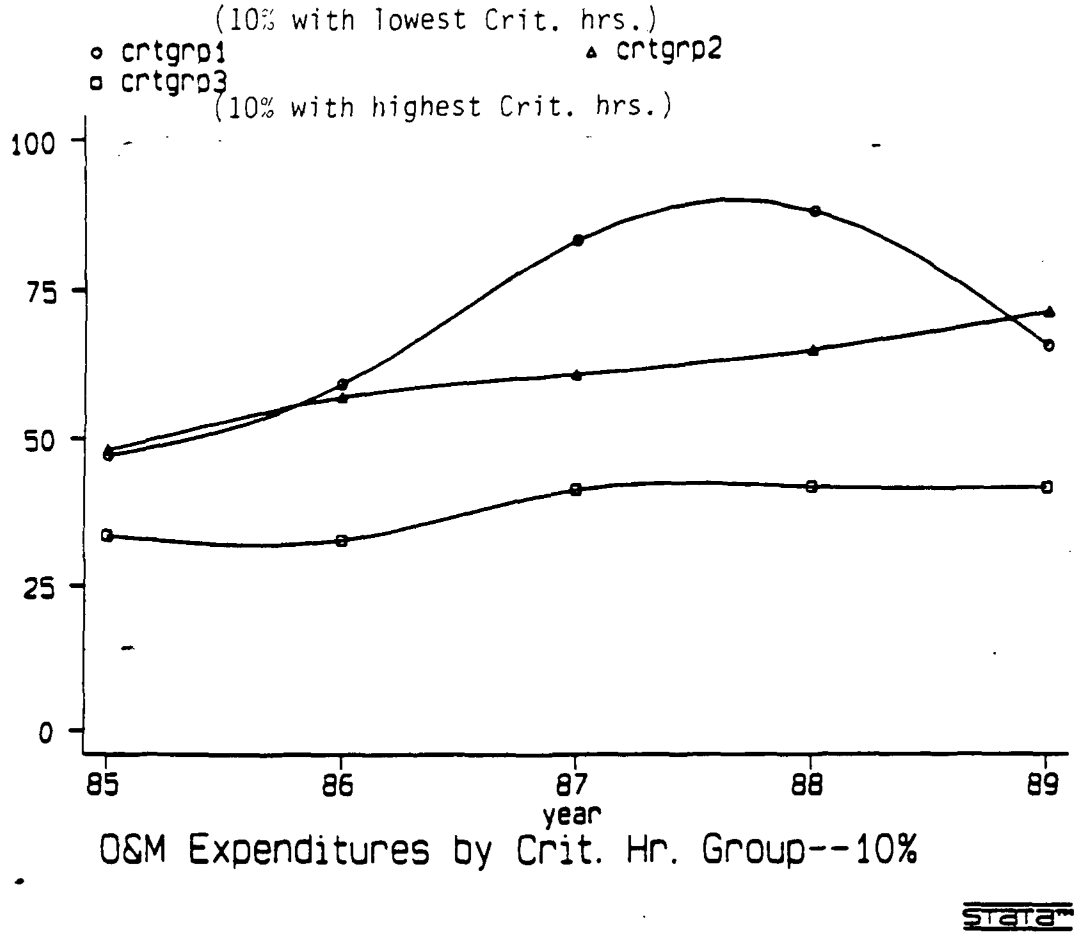

(10% with lowest rad)
o radgrp1
▲ radgrp2
□ radgrp3
(10% with highest rad)
50
40
30
20
10
0
85
86
87
88
89
year
Maint. Expend. by RAD Group--10%
Stata™

Figure A.47



O&M Expenditures by Crit. Hr. Group--10%

Figure A.48

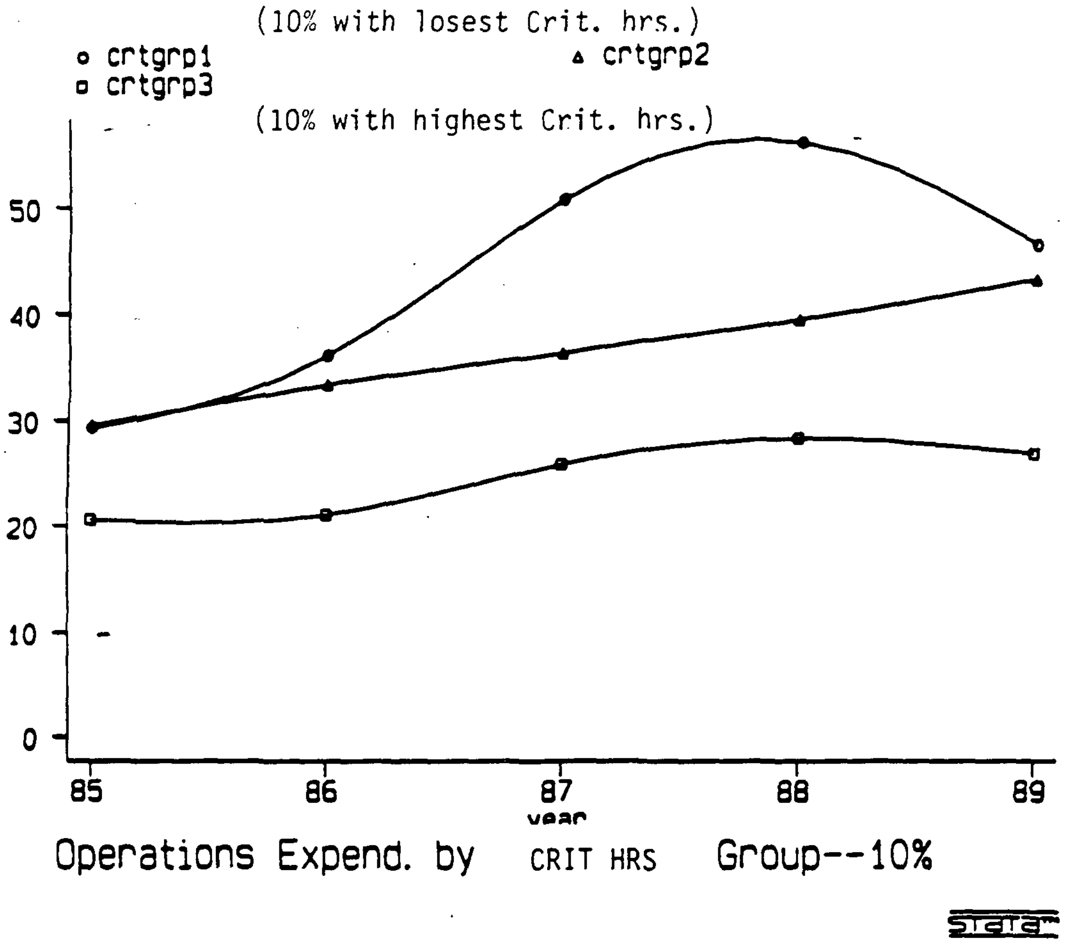
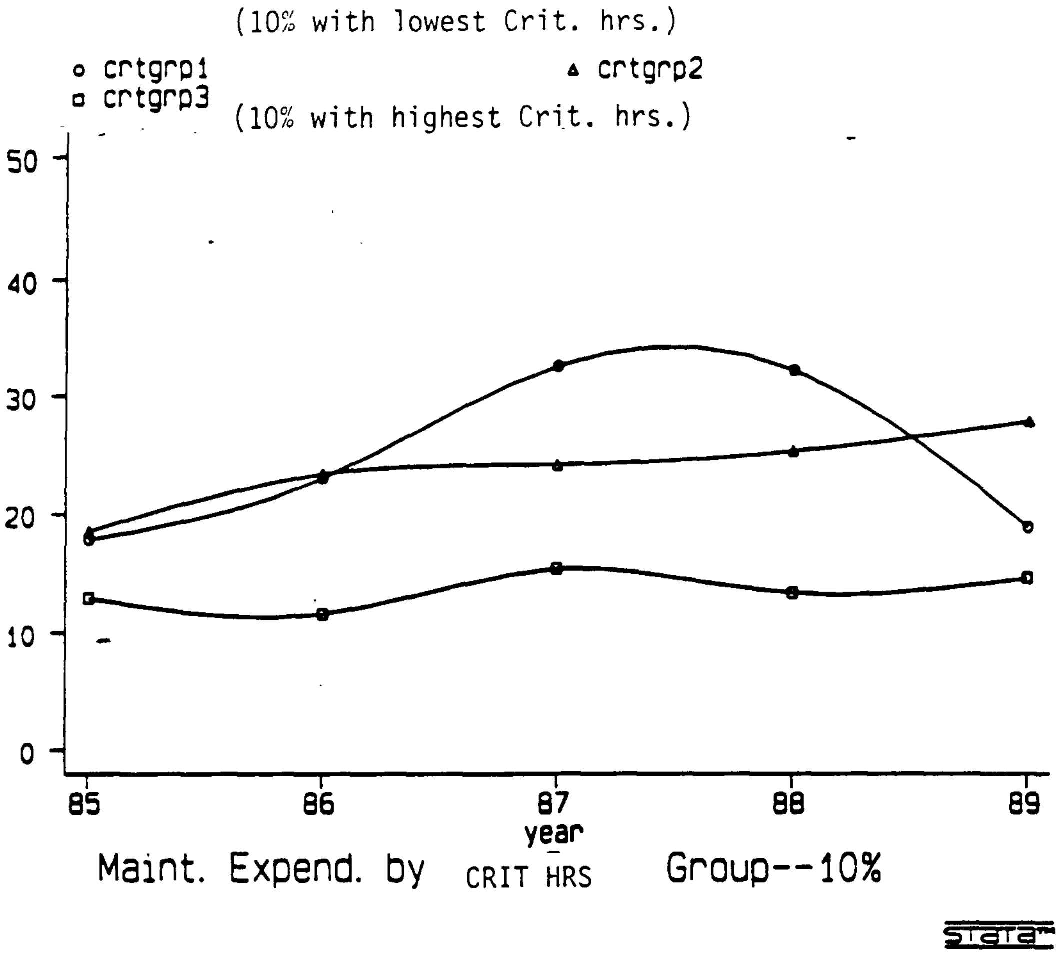

(10% with losest Crit. hrs.)
crtgrp1
crtgrp2
crtgrp3
(10% with highest Crit. hrs.)
50
40
30
20
10
0
85
86
87
88
89
year
Operations Expend. by CRIT HRS Group--10%
Stata

Figure A.49


(10% with lowest Crit. hrs.)
o crtgrp1
▵ crtgrp2
▫ crtgrp3
(10% with highest Crit. hrs.)
50
40
30
20
10
0
85
86
87
88
89
year
Maint. Expend. by CRIT HRS Group--10%
Stata

A.4 A Summary: Vicious and Beneficent Cycles

A summary of the graphical analyses is found in Table 2.1. For ease of reading it is repeated here as Table A.2. The summary suggests the existence of vicious and beneficent cycles. Poor performers have less profit and more debt and are cited for more major and minor violations in the prior period. In the next period they have to spend more to operate and maintain their nuclear power plants -- which in turn may mean less profitability and more debt in the following period. Good performers, on the other hand, have more profit and less debt and are cited less for major and minor violations in the prior period. In the next period they have to spend less to operate and maintain their nuclear power plants -- which in turn may mean more profit and less debt in the following period.

The cycles of poor and good performance suggest that nuclear power plants are inertial systems which are hard to change. In inertial systems what brings about change? How can the poor performers be extracted from the cycle of poor performance, and what would indicate that the performance of plants with good records was degrading? These are the types of questions taken up next in this chapter.

In ending this section, it is necessary to reiterate that the type of graphical analyses presented here have many limitations. First, they involve no statistical tests of whether the differences between the high, medium, and low performing plants are significant. Second, they do not include all the relevant variables in a single model which tests for the combined significance of the variables; thus, they do not control for the presence of other variables that may have a significant effect on the outcomes. Third, the complete set of items that can be used to represent the variable categories -- resource availability, regulation, and resource application has not been exhausted. All relevant variables which represent the categories have not been used. Thus, while suggestive, the graphical analysis presented here only provides circumstantial evidence about the relationships between resource availability, regulation, expenditures, and performance. The conclusions are tentative.

Table A.2
The Graphical Evidence: A Summary

	1980-85				1985-89		
	Resource Availability		Problem Identification		Resource Application		
1985-89	ROA	Debt	Major	Minor	O&M	Op.	Main.
SCRAMS	+*	+	-	-	+	+	+
SSA	-	+*	-*	+*	+	+	+
SIG.EVTS	-	+	+*	+	+	+	+
SSF	-	0	+	+	+	+	+
RAD	-	+	+	+	+	+	+
CRIT HRS.	+	-	-	-	-	-	-

+ indicates a positive pattern of relationship between the performance indicator and the predictor variables;

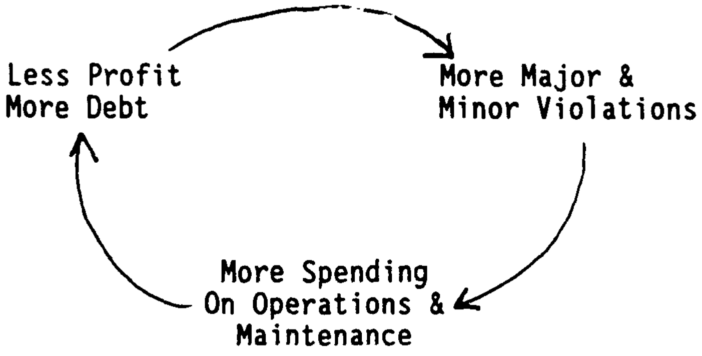
- indicates a negative pattern of relationship

*qualified by the observation that one or two years show exceptions to the pattern

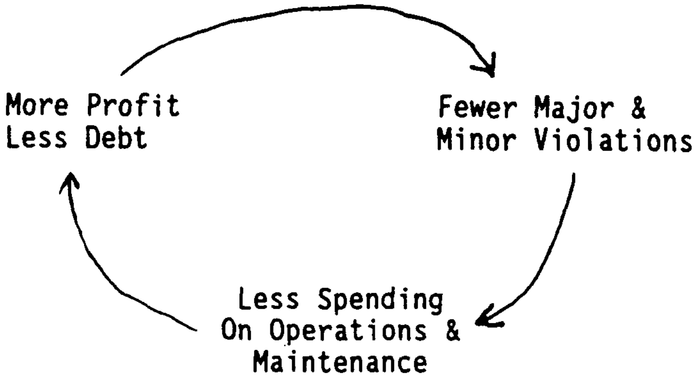
See Table A.2 Visual summary of the graphical evidence on next page.

Table A.2 (continued)

The Vicious Cycle of the Poor Performing Plants



The Beneficent Cycle of the Good Performing Plants



Appendix B

Factor Analyses on Six Enforcement Variables

A second factor analysis similar to that conducted on the performance indicator (Section 2.2.1.1) has been carried out on the six enforcement variables listed below:

1) Minor Violations = MINVIO
2) Major Violations = MAJVIO
3) Deviations = DEV
4) Inspection Hours = INSPHR
5) Number of Inspections = INSPNO
6) Licensee Event Reports = LER

It uses the years 1982-83, 1984-85, and 1983-85, and has been repeated with a seventh variable:7) Systematic Assessment of Licensee Performance = SALP. For this variable the 1985 scores, the only complete ones which are available, have been used. The purpose is to determine if a stable underlying problem identification factor exists. What has been found is summarized below:

	84-5	82-3	83-5
MINVIO	A	B	B
MAJVIO	B	B	B
DEV	A	B	B
INSHR	A	A	A
INSNO	A	A	B
LER	B	A	A
N	77	75	76

	84-5	82-3	83-5
MINVIO	A	A	A
MAJVIO	A	A	A
DEV	B	A	A
INSHR	C	B	B
INSNO	C	B	A
LER	A	B	B
SALP85	A	A	A
N	77	75	76

Without the SALPs, minor violations, deviations, inspection hours, and number of inspections form one factor in 1984-85, and major violations and LERs form another factor. This breakdown suggests that factor "A" consists of less serious problems and factor "B" is made up of more serious problems. For 1982-83, the factors change, with minor violations, major violations, and deviations forming one factor, and inspection hours, number of inspections, and LERs forming another factor. LERs move into the less serious "A" factor category and minor violations move into the more serious "B" factor category. For 1983-85, the logic of two categories, one consisting of less serious and one of more serious problem identification factors does not show itself as strongly. LERs and inspection hours constitute the "A" or less serious problem identification factor, and minor violations, major violations, deviations, and the number of inspections form the "A" more serious factor.

When the SALPs are included in the analysis, the labels change: the "A" factor is the more serious problem identification category and the "B" factor the less serious problem identification category. SALPs are always an "A" factor item. They always belong in the more serious problem category. In 1984-85, there are three factors. Deviations, the "B" factor, come between the most serious "A" factor items (minor violations, major violations, LERs, and SALPs) and the least serious "C" factor items (inspection hours and number of inspections). For 1982-83, LERs move into the less serious problem identification category, deviations move into the more serious category, and the third factor disappears. When 1983-85 is examined, LERs remain in the less serious category and deviations in the more serious category, but number of inspections jumps into the more serious category.

The >.5 correlations between problem identification variables are shown below:

Correlations Above .5	1984-85	1982-83	1983-85
MINVIO	MAJVIO INSNO SALP	MAJVIO INSNO SALP DEV	MAJVIO INSNO SALP
MAJVIOL	SALP		SALP

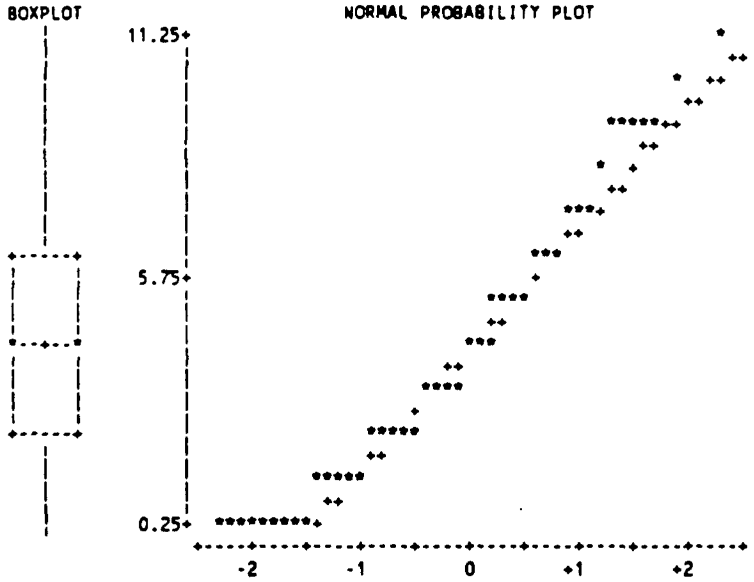
As can be seen minor violations, major violations, and SALPs are the most encompassing problem identification variable and they are very related to each other. Minor violations are also highly correlated with the number of inspections.

Two kinds of factors seem to appear, one which picks out more serious problem and one which picks out less serious problems; however, these factors are not stable over time. Minor violations, major violations, and SALPs are highly correlated and seem to be measuring pretty much the same thing. While some relations exists among safety indicators and among enforcement indicators, these are not stable or enduring. Each indicator appears to represent a separate safety or enforcement dimension, as the behavioral theory suggests.

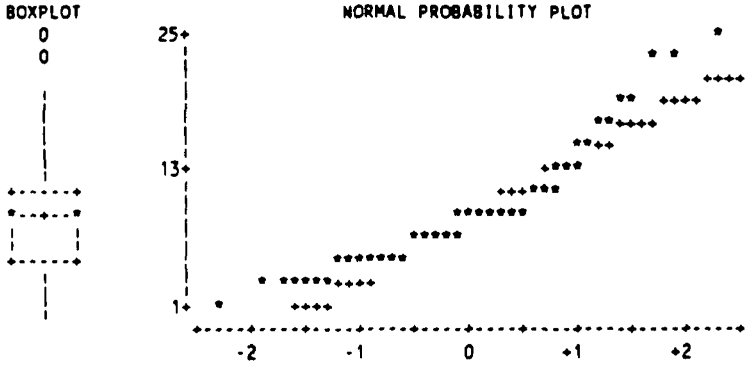
APPENDIX C

Normality Tests For Four Performance Indicators

```
VARIABLE=SCRAM78            TOTAL SCRAM FROM 1987 TO 1988

                 MOMENTS                               QUANTILES(DEF=4)                 EXTREMES

N              58  SUM WGTS          58  100% MAX    11     99%        11     LOWEST   HIGHEST
MEAN      4.12069  SUM              239   75% Q3      6     95%      9.05          0         9
STD DEV    2.7471  VARIANCE     7.54658   50% MED     4     90%         9          0         9
SKEWNESS 0.553189  KURTOSIS   -0.357854   25% Q1      2     10%         1          0         9
USS          1415  CSS          430.155    0% MIN     0      5%         0          0        10
CV        66.6661  STD MEAN    0.360712                      1%         0          1        11
T:MEAN=0  11.4238  PROB>|T|      0.0001  RANGE       11
SGN RANK    742.5  PROB>|S|      0.0001  Q3-Q1        4
NUM ^= 0       54                        MODE         2
D:NORMAL 0.141104  PROB>D          <.01

STEM LEAF                     #
  11 0                        1
  10
  10 0                        1
   9
   9 0000                     4
   8
   8 0                        1
   7
   7 0000                     4
   6
   6 000000                   6
   5
   5 0000000                  7
   4
   4 000000                   6
   3
   3 000000000                9
   2
   2 000000000                9
   1
   1 000000                   6
   0
   0 0000                     4
     ----+----+----+----
```



```
VARIABLE=SCRAM56            TOTAL SCRAM FROM 1985 TO 1986

                 MOMENTS                               QUANTILES(DEF=4)                 EXTREMES

N              58  SUM WGTS          58  100% MAX    25     99%        25     LOWEST   HIGHEST
MEAN       8.7069  SUM              505   75% Q3     11     95%     22.05          1        18
STD DEV   5.23822  VARIANCE     27.4389   50% MED     8     90%      17.1          2        19
SKEWNESS  1.32257  KURTOSIS     1.64169   25% Q1      5     10%         3          3        22
USS          5961  CSS          1564.02    0% MIN     1      5%      2.95          3        23
CV        60.1617  STD MEAN    0.687811                      1%         1          3        25
T:MEAN=0  12.6588  PROB>|T|      0.0001  RANGE       24
SGN RANK    855.5  PROB>|S|      0.0001  Q3-Q1        6
NUM ^= 0       58                        MODE         8
D:NORMAL 0.184585  PROB>D          <.01

STEM LEAF                     #
  24 0                        1
  22 00                       2
  20
  18 00                       2
  16 00                       2
  14 00                       2
  12 000                      3
  10 00000                    5
   8 00000000000000          14
   6 0000000000              10
   4 00000000000             11
   2 00000                    5
   0 0                        1
     ----+----+----+----
```



```
VARIABLE=SE78             TOTAL SIGNIFICANT EVENTS FROM 1987 TO 1988

                 MOMENTS                                QUANTILES(DEF=4)                    EXTREMES

N                  58 SUM WGTS          58 100% MAX           6     99%            6      LOWEST    HIGHEST
MEAN          1.72414 SUM              100  75% Q3            3     95%          4.1           0          4
STD DEV       1.47247 VARIANCE     2.16818  50% MED           2     90%            4           0          4
SKEWNESS     0.839464 KURTOSIS    0.691432  25% Q1         0.75     10%            0           0          4
USS               296 CSS          123.586   0% MIN           0      5%            0           0          6
CV            85.4035 STD MEAN    0.193345                           1%            0           0          6
T:MEAN=0       8.9174 PROB>|T|      0.0001 RANGE              6
SGN RANK          495 PROB>|S|      0.0001 Q3-Q1           2.25
NUM ^= 0           44                      MODE               0
D:NORMAL     0.171322 PROB>D          <.01

STEM LEAF                      # BOXPLOT                        NORMAL PROBABILITY PLOT
   6 00                        2     |        6.25+                                            *****
   5                                 |            |
   5                                 |            |                                                +++
   4                                 |            |                                            ++++
   4 0000                      4     |            |                                      *****+
   3                                 |            |                                      +++
   3 0000000000               10  +-----+     3.25+                               *******
   2                              |     |         |                               +++
   2 00000000000000           14  *-----*         |                        *******
   1                              |  +  |         |                       +++
   1 00000000000000           14  |     |         |                 *******
   0                              +-----+         |                ++++
   0 00000000000000           14     |        0.25+ *****************
     ----+----+----+----+                         +----+----+----+----+----+----+----+----+----+----+
                                                      -2        -1          0        +1        +2
```

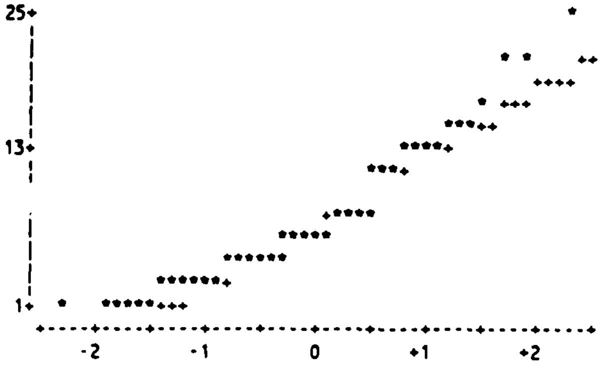
```
VARIABLE=SE56             TOTAL SIGNIFICANT EVENTS FROM 1985 TO 1986

                 MOMENTS                                QUANTILES(DEF=4)                    EXTREMES

N                  58 SUM WGTS          58 100% MAX          17     99%           17      LOWEST    HIGHEST
MEAN                4 SUM              232  75% Q3            5     95%         9.05           0          7
STD DEV       2.75935 VARIANCE     7.61404  50% MED           4     90%            7           0          9
SKEWNESS      2.06008 KURTOSIS     7.81435  25% Q1            2     10%            1           0          9
USS              1362 CSS              434   0% MIN           0      5%            0           1         10
CV            68.9839 STD MEAN    0.362321                           1%            0           1         17
T:MEAN=0      11.0399 PROB>|T|      0.0001 RANGE             17
SGN RANK          770 PROB>|S|      0.0001 Q3-Q1              3
NUM ^= 0           55                      MODE               4
D:NORMAL     0.203353 PROB>D          <.01

STEM LEAF                      # BOXPLOT                        NORMAL PROBABILITY PLOT
  17 0                         1     *        17.5+                                                *
  16                                              |
  15                                              |
  14                                              |
  13                                              |
  12                                              |
  11                                              |
  10 0                         1     0            |                                            *  ++++
   9 00                        2     |            |                                        *** +++
   8                                 |            |                                        ++++
   7 000                       3     |            |                                    +***
   6 00                        2     |            |                                 ++**
   5 00000000000              11  +-----+         |                             *******
   4 000000000000             12  *--+--*         |                        ******
   3 000000000                 9  |     |         |                    ****+
   2 0000000000               10  +-----+         |              *******++
   1 0000                      4     |            |          **** +++
   0 000                       3     |         0.5+  *******  ++++
     ----+----+----+----+                         +----+----+----+----+----+----+----+----+----+----+
                                                      -2        -1          0        +1        +2
```

```
VARIABLE=SSA78            TOTAL SAFETY SYSTEM ACTUATION FROM 1987 TO 1988

                 MOMENTS                              QUANTILES(DEF=4)                    EXTREMES

N                  58  SUM WGTS           58 100% MAX         6    99%             6     LOWEST    HIGHEST
MEAN          2.18966  SUM             127  75% Q3          3    95%          5.05          0          5
STD DEV       1.75176  VARIANCE      3.06866  50% MED         2    90%             5          0          5
SKEWNESS     0.449851  KURTOSIS    -0.775463  25% Q1          1    10%             0          0          5
USS                453  CSS           174.914   0% MIN         0     5%             0          0          6
CV            80.0016  STD MEAN     0.230017                        1%             0          0          6
T:MEAN=0      9.51952  PROB>|T|       0.0001  RANGE           6
SGN RANK        540.5  PROB>|S|       0.0001  Q3-Q1           2
NUM ^= 0           46                         MODE            0
D:NORMAL     0.165262  PROB>D           <.01

STEM LEAF                     #  BOXPLOT                       NORMAL PROBABILITY PLOT
   6 00                       2     |        6.25+                                           *****+
   5                                |            |                                           +++
   5 000000                   6     |            |                                   *******+
   4                                |            |                                      +++
   4 00000                    5     |            |                                *** +++
   3                                |            |                                +++
   3 00000000000             11  +-----+     3.25+                          ******
   2                             |     |         |                          +++
   2 0000000000              10  *--+--*         |                      *****
   1                             |     |         |                     ++
   1 000000000000            12  +-----+         |                *******
   0                                |            |               +++
   0 000000000000            12     |        0.25+ ****************
     ----+----+----+----+                         +----+----+----+----+----+----+----+----+----+----+
                                                      -2        -1         0        +1        +2
```

```
VARIABLE=SSA56            TOTAL SAFETY SYSTEM ACTUATION FROM 1985 TO 1986

                 MOMENTS                              QUANTILES(DEF=4)                    EXTREMES

N                  58  SUM WGTS           58 100% MAX        15    99%            15     LOWEST    HIGHEST
MEAN          4.13793  SUM             240  75% Q3          6    95%            13          0          9
STD DEV       3.30044  VARIANCE      10.8929  50% MED         4    90%           8.1          0         10
SKEWNESS      1.29029  KURTOSIS      1.98741  25% Q1          2    10%             0          0         13
USS               1614  CSS           620.897   0% MIN         0     5%             0          0         13
CV            79.7607  STD MEAN     0.433369                        1%             0          0         15
T:MEAN=0      9.54828  PROB>|T|       0.0001  RANGE          15
SGN RANK          689  PROB>|S|       0.0001  Q3-Q1           4
NUM ^= 0           52                         MODE            4
D:NORMAL      0.17184  PROB>D           <.01

STEM LEAF                     #  BOXPLOT                       NORMAL PROBABILITY PLOT
  15 0                        1     0        15.5+                                               *
  14                                             |
  13 00                       2     0            |                                         ***
  12                                         12.5+                                               ++
  11                                             |                                             +++
  10 0                        1     |            |                                       *  +++
   9 0                        1     |         9.5+                                      *+++
   8 000                      3     |            |                                   ***+
   7 00                       2     |            |                                 +*+
   6 00000                    5  +-----+      6.5+                              +***
   5 00000                    5  |     |         |                           +***
   4 0000000000              10  *--+--*         |                        *****
   3 000000000                9  |     |      3.5+                    ****
   2 0000000                  7  +-----+         |                ****+
   1 000000                   6     |            |            *****+
   0 000000                   6     |         0.5+ ***********+++
     ----+----+----+----+                         +----+----+----+----+----+----+----+----+----+----+
                                                      -2        -1         0        +1        +2
```

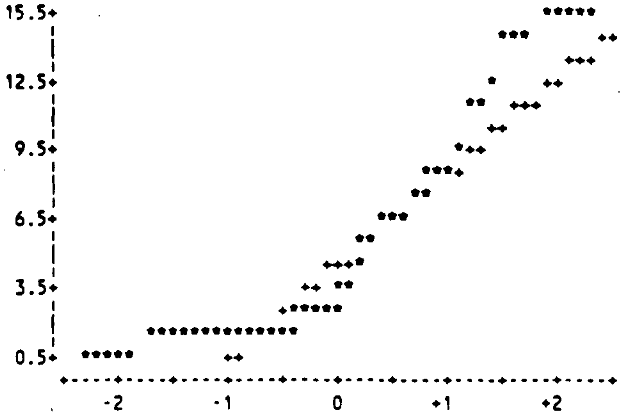
```
VARIABLE=SSF78           TOTAL SAFETY SYSTEM FAILURE FROM 1987 TO 1988

                  MOMENTS                              QUANTILES(DEF=4)                 EXTREMES

N                58  SUM WGTS         58  100% MAX      24      99%       24      LOWEST    HIGHEST
MEAN        7.82759  SUM             454   75% Q3       11      95%    20.05           0         15
STD DEV     5.09949  VARIANCE    26.0048   50% MED       7      90%       15           1         16
SKEWNESS    1.02614  KURTOSIS    1.19766   25% Q1        4      10%        2           1         20
USS            5036  CSS         1482.28    0% MIN       0       5%        1           1         21
CV          65.1477  STD MEAN   0.669596                         1%        0           2         24
T:MEAN=0      11.69  PROB>|T|     0.0001  RANGE         24
SGN RANK      826.5  PROB>|S|     0.0001  Q3-Q1          7
NUM ^= 0         57                       MODE           5
D:NORMAL   0.124445  PROB>D        0.024

STEM LEAF                        #  BOXPLOT
  24 0                           1     0
  22
  20 00                          2     |
  18                                   |
  16 0                           1     |
  14 000                         3     |
  12 000000                      6     |
  10 00000                       5  +-----+

   8 00000000                    8  |     |
   6 0000000000                 10  *--+--*
   4 00000000000                11  +-----+
   2 0000000                     7     |
   0 0000                        4     |
     ----+----+----+----
```

NORMAL PROBABILITY PLOT

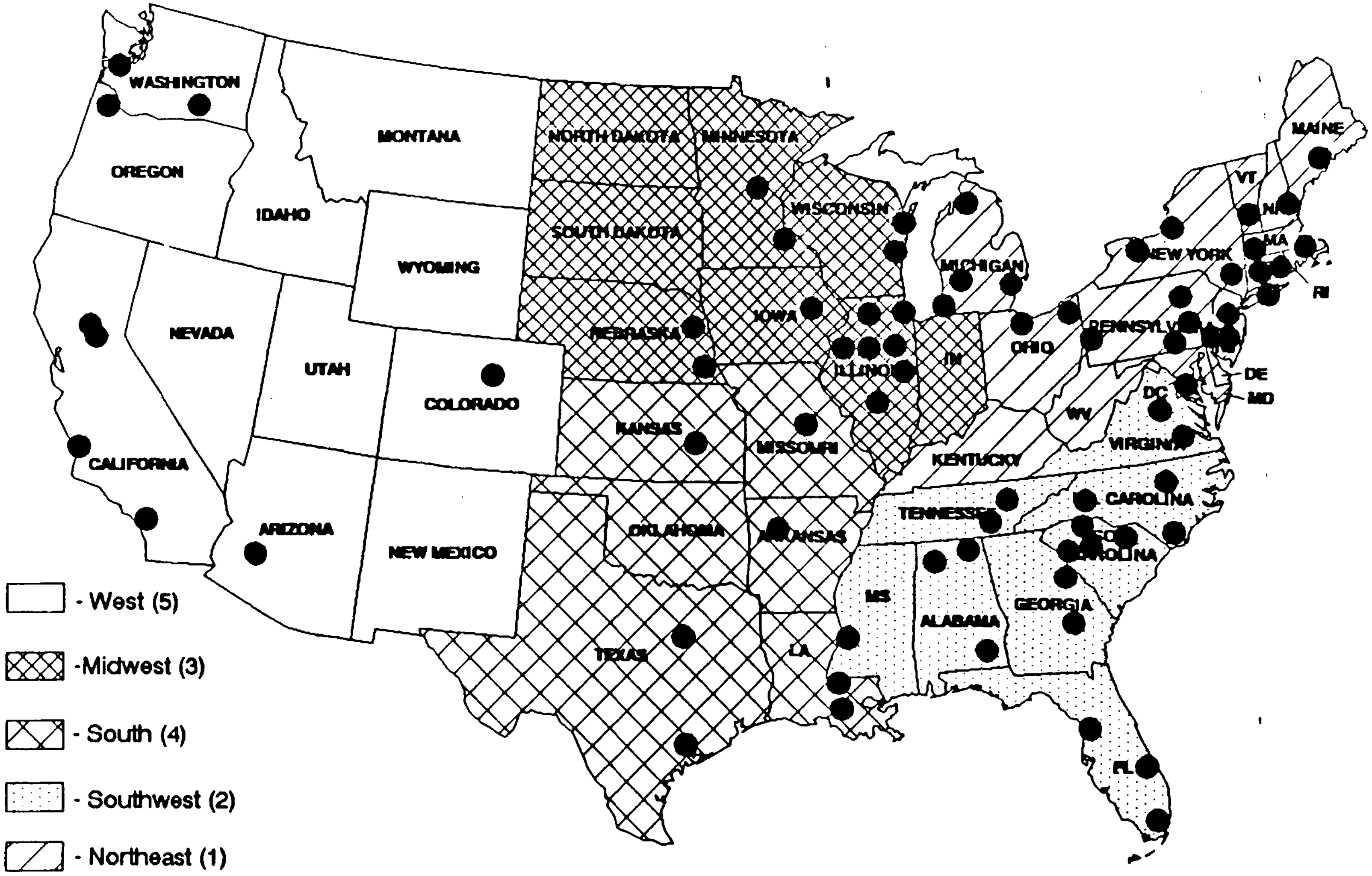


```
VARIABLE=SSF56           TOTAL SAFETY SYSTEM FAILURE FROM 1985 TO 1986

                  MOMENTS                              QUANTILES(DEF=4)                 EXTREMES

N                58  SUM WGTS         58  100% MAX      15      99%       15      LOWEST    HIGHEST
MEAN        4.44828  SUM             258   75% Q3        7      95%    14.05           0         12
STD DEV     4.12171  VARIANCE    16.9885   50% MED     2.5      90%     11.1           0         14
SKEWNESS    1.13569  KURTOSIS   0.433143   25% Q1        1      10%        1           1         14
USS            2116  CSS         968.345    0% MIN       0       5%     0.95           1         15
CV          92.6586  STD MEAN   0.541207                         1%        0           1         15
T:MEAN=0    8.21917  PROB>|T|     0.0001  RANGE         15
SGN RANK        798  PROB>|S|     0.0001  Q3-Q1          6
NUM ^= 0         56                       MODE           1
D:NORMAL   0.223742  PROB>D         <.01

STEM LEAF                        #  BOXPLOT
  15 00                          2     |
  14 00                          2     |
  13                                   |
  12 0                           1     |
  11 00                          2     |
  10                                   |
   9 0                           1     |
   8 0000                        4     |
   7 000                         3  +-----+
   6 000000                      6  |     |
   5 000                         3  |     |
   4 00                          2  |  +  |
   3 000                         3  |     |
   2 000000000                   9  *-----*
   1 000000000000000000         18  +-----+
   0 00                          2     |
     ----+----+----+----
```

NORMAL PROBABILITY PLOT



LOCATION OF NUCLEAR POWER PLANTS IN THE UNITED STATES



Appendix E

Interview Guide

Organizational Learning Project

This appendix provides a series of questions for obtaining information required to investigate the organizational learning model proposed in this chapter. The questions do not constitute a single interview protocol. Rather, this Appendix is intended to function as a question bank which can be used to develop interview protocols appropriate to different categories of interviewees. Many questions will require some rewording depending upon whether they are asked of general plant employees, managers, or persons with specialized expertise in the technical aspects involved in the learning process.

The majority of the questions are categorized by the particular steps comprising the learning process. These questions explore how organizational, management, technical, and cultural capacity dimensions affect the learning process at each step. Unlike the learning steps, the specific content of each of the capacity dimensions is partially deductive. Although some of the questions were based on theories of organizational learning, some of the specific questions pertaining to the learning capacity dimensions were added during the process of conducting the site visits and appraising the information obtained from respondents. As a result, not all of these questions have been field tested.

In addition to the four sets of questions corresponding to each of the steps in the learning process, a special section of questions was developed to address the plant's experience with developing and implementing specific improvement programs. Focusing on particular improvement programs allows an investigation of how the learning steps were exercised in these particular cases.

A short set of introductory and summary questions are also provided. The introductory questions are intended to place the investigation process in a context by determining general perceptions regarding plant performance and the overall learning orientation at the plant. The summary questions are directed at determining how respondents perceive the linkage between changes in plant performance and learning capacity.

The Appendix is divided into seven sections:

- Section A contains a few introductory questions.
- Section B contains questions that correspond to "Problem Identification/Performance Assessment".
- Section C contains questions that correspond to "Problem Diagnosis/Performance Analysis".

- Section D contains questions that correspond to "Solution Implementation/Improvement Innovation".

- Section E contains questions that correspond to "Tracking and Evaluation".

- Section F contains questions directed at the plant's experience with specific improvement programs.

- Section H contains a few summary questions.

Each of the sections is preceded by a short overview describing the general focus, purpose, and capacity dimensions being addressed. The overview also indicates where other types of investigatory techniques would be of use in supplementing the information obtained through interviews.

This battery of questions is an initial step toward developing a complete set of interview guides directed at different categories of employees. In order to obtain a truly comprehensive body of evidence, the interview strategy should cover all the substantive areas of interest, as well as target all relevant levels and groups within the organization. At this point, the Appendix represents an attempt to cover the important substantive areas. The next step would be to use this Appendix to develop interview guides appropriate to each level and group to be targeted in the organization. Each substantive area should be investigated from several different perspectives, i.e., the perspective of utility management, upper plant management, middle-level supervisors, non-supervisory employees, and specialized technical personnel. The relevant hierarchical levels should be investigated across different functional groups as well, such as operations, maintenance, technical, and engineering. This is necessary since some of the capacity dimensions involve the degree of cooperation and sharing across organizational groups and the extent to which decision-making processes are perceived to contribute to common goals. Several interviews should be conducted at each level for each functional group. The interviews directed at each group will differ in terms of the type of questions that are stressed and the amount of detail solicited. However, most interviews will cover the same range of substantive areas in order to determine the degree of consensus or disjunctures in the impressions across groups. Individual perceptions, both negative and positive, need to be looked at and interpreted within the larger whole. In addition, although some questions are more appropriate to particular levels or groups within the organization, it is useful to determine the extent to which other groups have some basic familiarity with the issue. For example, in Sections D and E, since analysis and evaluation tend to be fairly technical, a shorter and more general set of questions would be appropriate for many groups.

Once a complete set of interviews is developed, it is important to note that these interviews will need to be field tested. It is also important to note that the comprehensive set of interviews is only one of several strategies required to thoroughly investigate the learning capacity of an organization. In addition, reviews of policy statements, strategic plans, technical operations, training programs, and any documents that bear on the learning steps and the capacity of the organization to learn, should be used to supplement the body of evidence obtained through the interviews.

A. Introduction: Overall Assessment of the Plant

Section Overview.

This section provides some general questions with which to begin the interview process. These questions address general perceptions of plant performance and culture. The culture items specifically focus on the general orientation toward learning and improving.

How is this plant as a place to work?

What are the plant's strongest points?

What are the plant's weakest points?

How has the plant been performing? Has plant performance been improving?

What factors have contributed to plant improvement?

What factors, if any, have prevented the plant from improving?

Do you think that enough emphasis is placed on safety improvement? How about economic improvement?

Is too much emphasis placed on safety improvement at times? How about economic improvement?

Do you think most management levels sufficiently stress the importance of learning and improvement? Can you give examples of how learning and improvement have been stressed by the following groups?

Utility management:

Upper plant management:

Operations department management:

Maintenance department management:

Engineering department management:

Management in other departments:

Do you think there is a strong learning and improvement orientation among most non-supervisory plant staff? Why do you think this?

B. Problem Identification/Performance Assessment

Section Overview.

This section focuses on:

- employee awareness and evaluation of problem identification activities;
- the degree to which this process is perceived to be proactive or reactive;
- whether problem identification efforts are perceived to be improving or declining;
- the range and scope of problems being investigated (problem space);
- the degree of organizational support for employee participation in problem recognition and performance improvement;
- the opportunities for and level of employee participation in problem identification and reporting;
- the ways in which the plant enhances employees aptitudes and abilities to identify performance issues; and
- employees ideas for improving this activity.

Although these questions tend to be worded for non-management interviewees, a subset of these questions (with some rewording) are appropriate for management. In addition, a more specific interview directed at persons responsible for performance assessment activities should supplement these general questions directed at plant employees. The interviews should also be supplemented with other types of investigatory strategies, as discussed in the introduction to this Appendix.

To what extent would you say this plant recognizes issues before they result in an obvious performance deficiency or are identified by NRC, INPO, or another external agency as a performance concern?

Probes:

Has this changed over the last 5 year period? If so, what has contributed to this change?

Can you give any examples of early problem detection?

Can you give recent examples when you think problems were recognized later than they should have been?

To what extent do you think upper plant management successfully anticipates and prepares for challenges (e.g., regulatory issues, labor force issues, economic issues)? Please explain.

Probes:

What challenges has management identified?

What plans have been made to address each of these challenges?

Can you think of any challenges that management failed to respond to in a timely manner? Please explain.

What activities are in place to help management identify future challenges?

To what extent do you think upper plant management promotes and supports thorough reviews of other plants' operating experience, industry communications, and NRC communications for performance issues that may have relevance to this plant?

Probes:

What systems are in place to assist in these searches?

How effective are these systems?

Does management encourage and support active internal searches for possible obstacles or barriers to error-free performance? Please explain.

Probes:

Are there any attempts to systematically solicit employees' perceptions of performance issues?

In what ways does **upper management** promote problem identification and input from employees? Can you give some examples?

In what ways does your **immediate supervisor** actively promote problem identification and input from employees? Can you give some examples?

What methods/procedures are used by individuals to bring problems to the attention of management? How well do they work?

Once a problem has been brought to management's attention, are there established policies or guidelines prescribing what actions should be taken? If yes, what are these actions? If no, what generally occurs?

Do employees readily bring plant performance issues to management attention? Why or why not?

Probes:

What kinds of issues have employees brought to management attention? Please be as specific as possible.

Would most employees feel comfortable reporting a problem even if it were caused by their personnel error? What, if anything, might happen to them? Can you give any examples of such cases?

Would most employees feel free to bring up problems involving their supervisors? Can you give any examples of such cases?

Are there procedures to allow employees to report anonymously? If not, is there a need for such procedures?

Do most employees feel responsible and accountable for identifying and bringing attention to problems? Why or why not? What aspects of the organization encourage workers to feel responsible and accountable?

Is there sufficient recognition of employee efforts to bring problems to management attention? Can you give any examples of specific employee efforts to improve plant performance that have been recognized by plant and/or utility management?

Does the performance evaluation and reward system promote employee participation in identifying and solving problems?

How does this organization enhance employees' abilities to identify potential performance problems?

Probes:

Is there sufficient training devoted to encouraging and facilitating employee problem identification and reporting? What kinds of training do employees receive to help them recognize potential problems?

Are there formal or informal programs to increase employees' awareness of problems experienced and addressed by other plants?

What practices exist to give employees exposure to performance issues experienced by different functional areas?

In your opinion, how effective is problem identification at this plant?

What could be done to improve problem identification?

C. Problem Diagnosis/Performance Analysis

Section Overview.

This section focuses on employee perceptions of:

- data collection, database management technology, and technical expertise (availability, depth, and breadth);
- the comprehensiveness of root-cause analysis;
- the level and scope of participation in root-cause analysis;
- the types of problems receiving attention;
- the level of organizational support and resources devoted to problem analysis; and
- the role and usefulness of performance oversight groups.

Many of these questions ask for fairly technical information. While the questions as written are appropriate for technical personnel, a shorter set of more general questions would be appropriate for most other groups. Also, more detailed information on the technical bases of problem analysis should be obtained using non-interview types of investigatory strategies.

Is there an effective system in place for inputing and analyzing this plant's operating experience?

Probes:

How easy is it to access all the information needed to do this effectively?

How useful is it to thoroughly review and analyze plant operational experience?

Is there an effective system in place for inputing and analyzing industry operating experience?

How useful is it to thoroughly review and analyze industry operating experience?
Do you think that the resources, time, and staff allocated to problem analysis are sufficient to do an effective job?

Probes:

How many staff members and how much staff time are dedicated to this activity?

Are performance assessment personnel of a high caliber?

Do you think that performance analysis involves a sufficiently diversified group of individuals to promote a thorough understanding of the potential causes and significance of performance problems? Do you usually agree with the interpretation of performance issues made at this plant?

What could be done to improve the abilities and skills of performance assessment and quality assurance personnel?

Is computerization and database management technology adequate? What improvements are needed?

How is performance assessment and analysis organized at this plant? What groups are involved? What is the role of each (division of labor), and what is their relationship to one another?

Probes:

How do QA, QC, or other performance assessment groups contribute to a continual improvement orientation at this plant? Do they ever get in the way of real improvement?

To what extent do any of these performance assessment groups function as a resource group providing performance analysis and improvement assistance to other functional groups, as opposed to or in addition to playing a quality control function? Please explain.

Has your department or group solicited assistance from any of these performance assessments groups in addressing problems? If yes, please explain. If no, why not?
How helpful have each of the performance assessment groups been in assisting your group or other functional groups to improve work processes?

Is the significance of performance assessment and analysis adequately related to your work processes or does it tend to be too removed from your work to be as useful as it might be? Please give some examples.

Do performance assessment groups have enough influence on top level decision-making? Please explain.

What methods are used at this plant to determine the factors (root causes) contributing to a problem or set of problems?

Do you think there is sufficient emphasis given to understanding and improving processes, as well as to obtaining specific performance outcomes?

Is there sufficient emphasis given to both technical performance and people performance?

Probes:

What techniques exist to elicit information on factors contributing to human performance issues?

What kinds of contributors to human performance issues are investigated?

Is sufficient attention paid to management causes of performance problems?

What techniques exist to elicit information on management contributors?

What kinds of management contributors to human performance issues are investigated?

Is sufficient attention paid to organizational causes of performance problems?

What techniques exist to elicit information on organizational contributors?

What kinds of organizational contributors to human performance issues are investigated?

Do all levels of staff fully cooperate with root-cause investigations?

Are employees sufficiently encouraged to volunteer root-cause information? Please explain.

To whom is root-cause training provided?

How could performance assessment and analysis be done better at this plant?

D. Solution Implementation/Improvement Innovation

Section Overview.

This section focuses on employee perceptions of:

- management efforts to search for concrete approaches and innovative ideas to improve performance;
- the extent to which functional groups are encouraged to formulate and implement improvements;
- how priorities are established and resources allocated;
- the quality of management improvement decisions;
- the level of acceptance and cooperation in implementing improvement initiatives; and
- the success of management strategies for effectively introducing and managing change.

How has upper management contributed to the search for new approaches to improve performance?

Probes:

Where does management search for new approaches to improve plant performance?

Does management keep actively informed about solutions and innovative approaches tried by other plants?

Does management search the management literature for new ideas?

Is management willing to be creative in its attempt to address issues? If so, please give some examples where management has proposed creative solutions.

Do you think management errs in being too unwilling to try new approaches or too uncritically receptive to new ideas?

Does management encourage innovation among the subunit groups? How?

Do employees have too much or not enough autonomy to formulate and implement solutions to problems affecting their immediate work situations? Please explain.

Are performance improvements directed more often at improving efficiency? Can you think of any instances where there was a potential conflict between these improvement goals?

What organizational processes have been established for developing solutions to problems?

Probes:

How systematic is the process?

How is the lead and team composition determined?

Do all relevant personnel have enough input to these decisions?

How could the approach to formulating solutions be made more systematic?

Does plant management tend to make sound improvement decisions?

Probes:

Are management decisions sufficiently guided by systematic performance assessment and problem analysis?

How well does upper plant management balance internal priorities and external pressures?

Does upper plant management have a clearly prioritized set of improvement objectives?

In your opinion are priorities too rigid, sufficiently flexible, or too frequently changed?

How are priorities established?

Probes:

Is there some established method or procedures for determining priorities and allocating resources between competing needs?

How collective is this decision-making process?

Do you think that decisions for establishing priorities and allocating resources are guided by a clear management strategy that benefits plant performance as a whole? Has this process improved over time and, if so, how?

Is there sufficient acceptance of these improvement priorities on the part of all groups? Why or why not?

Do you think priority setting and resource allocation could be done more effectively? Please explain.

Can you think of any barriers to more effective prioritization and resource allocation?

Are there clearly established improvement priorities in your functional work group? How are these established?

Once priorities are set, it is possible that too much attention can be directed away from other areas. Has this ever been a problem at this plant? What processes are in place to prevent this from happening?

Probes:

Is there an adequate budget reserve available for resolving unexpected problems?

Have large improvement initiatives sometimes taken too much attention away from formulating and implementing smaller corrective actions?

How well does management maintain the balance between promoting cooperation and loyalty to plant improvement decisions and the freedom to voice concerns about actual or potential problems regarding these decisions?

How successful has management been in introducing changes to improve plant performance? Could changes have been more positively introduced?

What areas have posed the greatest difficulties with respect to formulating and implementing solutions?

What barriers, if any, make it difficult to implement change?

Probes:

Are there tendencies among some groups to guard their turf or to be less than fully open and cooperative?

What groups still need to improve their level of cooperation and coordination?

What strategies has management developed, if any, to align the goals and interests of all groups?

Are there other strategies management has used to promote acceptance of and cooperation in implementing change?

Have there been any changes in organization or staff that have caused resentment?

How does management handle problems of individual opposition?

Does management adequately follow through with sufficient resources to implement improvement decisions?

Probes:

[Time] Are improvement objectives translated into a workable operational plan with a reasonable time table, or is there a tendency to attempt to do too much at once?

[Money/Staff] Have sufficient staff and other resources been allocated to improvement efforts? Why or why not?

[Involvement] Does management generally maintain interest and active promotion of improvement efforts?

E. Tracking and Evaluation

Section Overview.

This section focuses on:

- processes for tracking solution implementation;
- the amount of effort expended to evaluate solutions and improvement programs;
- communications and sharing lessons learned; and
- feedback processes.

More detailed information on the technical processes involved in tracking solutions and evaluating improvement programs will require in-depth interviewees with specialized personnel.

What is the backlog of corrective action items?

How is tracking of corrective actions conducted at this plant?

In addition to tracking corrective actions, have evaluations of the effectiveness of past corrective actions or improvement programs been conducted at this plant? Please provide examples.

How systematic and thorough are evaluation efforts?

Probes:

When are evaluations typically conducted?

What does the evaluation process consist of and how is information obtained?

What kinds of activities have been included in past evaluations?

Is there sufficient effort given to building-in evaluation strategies at the onset of implementing changes?

How worthwhile are current evaluation efforts?

Can you give any examples as to how evaluations have benefitted the plant?

Probes:

Have evaluations kept the plant from repeating similar mistakes?

Have evaluations helped redefine the nature of a problem?

What could be done to make evaluation efforts more useful?

Is there sufficient sharing and learning from problems and attempted solutions across different functional groups?

Probes:

How is learning from successes and failures communicated at this plant?

Are people ever afraid to admit that a solution hasn't really worked?

Are people sufficiently informed about how well solutions to problems are working in most areas of the plant to enable them to benefit from lessons learned?

Are positive results sufficiently communicated to all plant personnel?

Is the attention given to programs that do not live up to expectations informative and "positive" from a learning perspective?

In what ways, if any, could learning from past efforts be improved?

F. Implementation of Specific Improvement Programs

Section Overview.

This section contains specific questions to be asked of individuals with responsibility for the implementation of improvement programs. The specific programs to be addressed should be identified through an initial interview with plant management. The purpose of this section is to investigate how the learning steps were carried out in these particular case examples.

Are there any problem-solving programs you are responsible for or involved in?

Program 1:

Program 2:

Please describe each program. How and why was this program selected? How useful has the improvement program been to plant performance? What strategies have been used to make the program successful? What, if anything, has kept the program from being as successful as it possibly could be? Give examples.

Program 1

Description:

How and why selected:

Usefulness:

Strategies to enhance success:

Obstacles to success:

Program 2

Description:

How and why selected:

Usefulness:

Strategies to enhance success:

Obstacles to success:

How supportive has management been in these improvement efforts? Please give specific examples.

Have you had the budget and personnel you needed to get the job done?

How much cooperation have you received from QA and other departments in carrying out these programs? Please give specific examples.

Was there sufficient attention paid at the onset to building-in strategies for evaluating the performance of these programs?

Can you think of any major improvement program initiatives that haven't paid off? If so, what and why?

G. Summary

Section Overview.

This section provides some general questions with which to conclude the interview process. The questions focus on general perceptions of how learning and improvement processes have affected past performance and could influence future performance.

Have problem identification and problem-solving processes at this plant been sufficient to prevent performance declines? Why or why not?

Probes:

Based on your experience, what factors have contributed to past declines in plant performance? To what extent have these been eliminated?

In what areas, if any, does the plant still need to improve? What has kept the plant from improving in these areas?

Are learning and improvement processes and procedures sufficiently in place to promote systematic performance improvement, or do issues arise and get addressed in an ad hoc manner?

What factors, if any, make it difficult for a plant to sustain high performance over a long period of time? Please explain.

Probes:

To what extent do you think that a systematic performance assessment and evaluation process could help sustain high performance and prevent backsliding?

Would sustaining high performance require something beyond having a high quality learning process at this plant?