STAFF REPORT

DECEMBER 1979

MASTER

**ISSUES RELATED
TO THE
RELIABILITY OF
POWER PLANTS
IN CALIFORNIA**

DE-FCOI-MRA08137

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California Energy Commission

P700-79-016

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CALIFORNIA ENERGY COMMISSION

STAFF PAPER

ISSUES RELATED TO RELIABILITY
OF POWER PLANTS IN CALIFORNIA

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NOVEMBER 1979

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ISSUES RELATED TO RELIABILITY
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ABSTRACT

This paper reflects the concern that without reexamination on the part of the industry of its past policies, traditions and practices, the power plants yet to be licensed in the State of California may not fulfill their full productivity potential. Also, this document seeks a recognition of all parties participating in the regulatory processes, that unless appropriate and deliberate measures are applied, the reliability of the future power generating facilities may be inconsistent with the energy needs, and consequently the reliability deficiency may have to be compensated for by construction of additional generating units that otherwise should not be required. Accordingly, the causes and factors contributing to degradation of power plants reliability are identified, and various means of reduction (or elimination) of such causes, along with related economic aspects are discussed. Basic policies derived from the statutory requirements, the ensuing Commission's role, and the role of the Commission's staff relative to the reliability issues are identified. The contents of this document are applicable to any type of baseload power generating facility. The provided record, pointing to the need for reliability improvement covers the history of nuclear, geothermal, coal, gas, and oil-fired units. The record encompasses variables such as the generating unit size (MW) and the plant maturity (age). Also, certain facilities with exceptional productivity levels, which resulted from specific measures taken to achieve them, are identified. In addition to the specific measures that can be taken to increase the power plant's reliability, the paper includes the recommendation to study the merits of incentivising the power industry to improve the productivity levels of future power plants.

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I. INTRODUCTION:

This paper reflects the concern that without re-examination on the part of the industry of its past policies, traditions and practices, the power plants yet to be licensed in the State of California may not fulfill their full productivity potential. Also, this document seeks a recognition of all parties participating in the regulatory processes. Unless appropriate and deliberate measures are applied, the reliability of the future power generating facilities may be inconsistent with the energy needs, and consequently, the reliability deficiency may have to be compensated for by construction of additional generating units that otherwise should not be required. Accordingly, the causes and factors contributing to degradation of power plants reliability are identified, and various means of reduction (or elimination) of such causes, along with related economic aspects, are discussed. Basic policies derived from the statutory requirements, the ensuing Commission's role, and the role of the Commission's staff relative to the reliability issues are identified.

II. STATUTORY REQUIREMENTS

The California Legislature through AB 1575 (Warren-Alquist Act) amended the Public Resources Code 21000 with Division 15 commencing with Section 25000, as further amended by SB 1859. Section 25001 states "...that it is the responsibility of state government to ensure that a reliable supply of electrical energy is maintained for protection of public health and safety, for promotion of the general welfare, and for environmental quality protection".

To enable the state government to carry out this responsibility (among others), the Act created the California Energy Resources Conservation and Development Commission and mandated the Commission to take specific action in its deliberations of the Notice of Intention and the Application for Certification with regards to this responsibility.

Section 25511 of the Act requires the Commission to "...review the factors related to safety and reliability of the facilities at each of the proposed sites designated in the notice," and to require of the applicant "...to account for seismic and other potential hazards...and such other information as the Commission may determine to be relevant to the reliability and safety of the facility..."

Other sections of the Public Resources Code require the Commission to include material pertinent to safety and reliability of the proposed facility in reports (25514), approve or disapprove the notice (25516) based on findings on reliability-related matters (among others), empower the Commission to obtain supplementary safety and reliability information with the Application for Certification (25520), or condition the certification by such supplementary information (25528), and require the Commission to inform appropriate federal agencies of its findings pursuant to Section 25511.

The relationship of the above to the Commission's policies is given in the subsequent sections of this document.

III. DEFINITION OF RELIABILITY

- A. Funk & Wagnalls Dictionary, 1974 edition describes reliability as a characteristic of a system "exhibiting consistency of results obtained." The consistency of results obtained may be expressed statistically as a fraction of total events, or as a fraction of unit time a given event or characteristic of a system has occurred in the past. For example, during a lifetime of an automobile out of 10,000 attempts (events) to start the engine, the engine will start 9,215 times. Thus, the starting system reliability is 0.92 (rounded off). Similarly, if an automobile requires two days of maintenance work each month during a year its yearly service reliability (fraction of time) is $365 - (2 \times 12)/365 = .93$.
- B. Applying the definition of reliability to power plants, the characteristics, whose consistency is desired, are:
- o Low Forced Outage Rates
 - o Low Scheduled (Maintenance) Hours
 - o High Capacity Factors (baseload generating units), and,
 - o High Availability Factors.

These and other parameters are defined in Glossary, Section XI.

- C. The expressions of reliability illustrated in the given above examples reflect only a historical record, and as such they may be used as achievement targets, but they do not have a predictive potential. There are, however, analytical techniques which can predict the degree of consistency of given characteristics. Such predictive assessments may be expressed by a statistically derived statement of probability of occurrence (or nonoccurrence) of a given characteristic of a system. Supplementary information of such predictive procedures along with other analytical tools as provided in Appendix II.

IV. PURPOSE

In order to effectively and uniformly deal with the reliability issue during the NOI/AFC processes, it is necessary to establish certain "operating parameters" which will provide the basis for mutual understanding of the issue by interested parties.

Thus, this document has been prepared to establish and clarify the following aspects of power plants' reliability, as provided for by the Warren-Alquist Act and amendments thereto:

- o Reliability as a topic and its place within NOI and AFC processes.
- o Basic premises regarding attainability of safe and reliable generation of power.
- o Measures of reliability and applicability of common power plant reliability indicators.
- o Identification and control of factors contributing to loss of load or loss of generating capacity.
- o Method(s) that will be used by the CEC staff in evaluation of probability that safe and reliable generation of power will be achieved.
- o Policies on safety and reliability.
- o Rationale(s) for the adoption of the proposed policies.

It is expected that this document, in conjunction with NOI/AFC Regulations, will provide the necessary framework for generating, evaluating, and processing the NOI's and AFC's through the regulatory cycle with an appropriate perspective on the reliability issue.

V. SUMMARY

This document principally addresses the adequacy of reliability (productivity) of power generating units. Included are discussions on the need for reliability improvement and the means of attainment of higher reliability levels. The Commission's staff activities deemed necessary to fulfill the state's responsibility to ensure a safe and reliable supply of electrical power consistent with the need are also delineated. The highlights pertaining to these topics are given below:

- o The average reliability of power plants as measured by Capacity Factors is about 60 percent.
- o On the average, the availability for service as measured by Availability Factors is about 75 percent.
- o For comparable unit size and age, these factors may vary as much as 30 percent.
- o Some utilities have demonstrated that 80 percent Capacity Factor is consistently achievable during the first or second year of plant operation.
- o High power plant reliability (productivity) may result in construction of fewer generating units which otherwise would be required.
- o Attaining high Capacity Factors (70-80 percent range) as early as in the first or second year of operation, and maintaining this level of productivity, may be worth millions of dollars (depending on the unit size).
- o Small generating units require more capital investment per 1 KW of installed capacity compared with large (600 MW and greater) units, but are not necessarily more reliable. However, the impact of a small unit outage on the bulk generating system is less than that of a large unit.
- o The main contributors to degradation of power plant reliability or requiring long maturation periods (3 to 5 years of problem solving) are inadequate component redundancies and insufficient control of equipment quality.
- o The review of utility operating performance records has resulted in the staff position that only through deliberate actions and measures can a consistently safe and reliable generation of power be assured.
- o The staff takes the position that measures designed for reliability improvement are justifiable only in application to baseload units (see note)*.

*NOTE: Less than 15 percent of operating time of peaking units, and less than 50 percent of operating time of intermediate units provides ample opportunity for maintaining such units in operable condition.

- o Analytical tools (relating cost to productivity gain) for determination of appropriate level of redundancy and quality control are described. Utilizing such tools will provide increased assurance of improved reliability and plant performance.
- o An analytical method for selection of seismic design criteria by relating risk during plant life to recurrence intervals of seismic events of given magnitude is provided. Application of this method will eliminate industry practice of arbitrary selection of seismic design criteria.
- o Consistent with the above, the staff will propose, recommend or impose adoption of only those measures and reliability-related requirements for generating units which are consistent with cost/benefit considerations.
- o The staff will examine the adequacy of measures (proposed by the Applicant) designed for attainability of target reliability/productivity levels of generating units rather than set numerical performance or reliability standards which could be in conflict with cost/benefit balance.
- o For the bulk generating system reliability, the staff accepts the criterion of Loss of Load Probability of one day in ten years (currently adopted by the industry), unless a different criterion can be justified.
- o During the NOI proceedings, the staff will review as a minimum those design criteria, plans, and reliability programs which cannot be deferred to AFC proceedings without the risk of affecting the Applicant's design progress or other activities which will have been accomplished by the time of AFC filing, or the risk of affecting the scheduled plant availability.
- o During the AFC proceedings, the staff will review those plans and criteria which were not covered during the NOI, along with evaluations of the basis for the proposed criteria, including those proposed during NOI. In addition, to the extent possible, evidence of implementation of the Applicant's reliability program will be examined through review of sample documents containing a detailed description of reliability-related factors, including a review of adequacy of program(s) for verification of conformity to the stated requirements.
- o During the NOI and AFC, the staff will make findings and conclusions relative to adequacy of Applicant's plans for attainment of safety and reliability goals, but the staff will not design any systems or components of the proposed facility.
- o During the AFC, the staff will propose a compliance program that includes elements of reliability as the Commission's tool for monitoring conformity and adherence to conditions (if any) attached to AFC approval.

VI. SCOPE

Reliable generation of power is a complex issue. Reliability is a man-made characteristic, subject to control within economic constraints and it includes recognition of an accountability for natural phenomena. The reliability as a topic goes beyond the field of mathematical assessment of reliability. The issue encompasses consideration and mitigation of factors which tend to downgrade reliability, including mechanisms and strategies for increasing reliability, taking into account different missions of generating units such as peaking, intermediate and baseload. It is also within the scope of the issue to examine the potential reliability of small versus large generating units and the impact of such units on the bulk generating system.

This paper provides general discussions of all of the above aspects and detailed discussions appropriate to the following:

- o Reliability of the facility, its system and components with respect to their adequacy for environmental protection requirements.
- o Reliability of the facility as a power generating unit.
- o Reliability of the transmission system.
- o Reliability of the bulk power system as a function of the above, availability of reserve capacity, and adequacy of intertie system.
- o Reliability of fuel and water supply.
- o Reliability as a function of seismic characteristics of the facility site.

VII. RECOMMENDATIONS

Based on the material presented in Section VII, (Technical Discussion) and the rationales developed therein, the staff offers the following recommendations:

To further promote the improvement of generating units' performance and reliability, it is recommended that the Commission in cooperation with the California Public Utilities Commission undertake studies (or cause studies to be undertaken) to determine merits of:

1. Rate incentives, or other financial inducements compensating the utilities for improvements in performance and reliability of existing generating units;
2. Rate incentives or other inducements for:
 - a. Attainment of plant operating maturity in a time not exceeding x years (to be determined) of new generating units, and/or;
 - b. Attaining and maintaining productivity levels of new base-load units, as measured by Capacity Factor and combined Forced and Scheduled Outages not exceeding x days (to be determined), or as measured by equivalent Availability Factor and combined Forced and Scheduled Outages not exceeding x days (to be determined), and/or;
 - c. Surcharge to fully or partially cover the cost differential associated with implementation of reliability-related measures (subject to CEC approval). The surcharge would terminate upon completion of construction or when the unit becomes operational.

VIII. TECHNICAL DISCUSSION

This section provides bases, rationales and other materials that led to the evolution of elements given in the Summary Recommendations and the proposed Policies. For certain technical details and analyses, the reader will be referred to the Appendix.

A. Need for Reliability

Power plant reliability is characterized by consistent low Forced Outage Rate, low Scheduled Outage Hours, high Capacity Factor and high Availability Factor. Failure to achieve consistency of these parameters may carry (and usually does) significant economic penalties for the utility and the rate payer. These economic losses have increased during the last few years to the point where examination of past practices and policies which effect the reliability of power generation systems and elements therein is appropriate.

Some examples of the rising cost of outages are given below. For convenience, a 1,000 MW generating unit was chosen for illustration purposes. These examples refer to nuclear power plants; however, there is no reason to believe that the cost of outages of other types of generating units would be significantly different.

- o One 24 hour outage of a 1,000 MW nuclear generating unit which became operational during the 1973-1974 period represented a worth of \$250,000. (Ref. Philadelphia Electric, Peach Bottom 2).
- o Early in 1978 the cost of replacement of a 1,000 MW nuclear unit by power generated by high cost fuels runs as high as \$500,000 per day (Ref. Nuclear Engineering, April 1978).
- o Inflation in general and rising cost of fuels in particular will continue to be reflected in the cost of energy. A one-day outage of a similar unit scheduled to become operational in 1986-1988 may carry a price tag of \$750,000-1,000,000. (Ref. Dr. Barnath, SDG&E). The concern regarding these costs acquires additional proportions when one becomes aware that it is not unusual for a new generating unit to be forced out of service 120 days per year during the 4-5 year plant "maturation" period. The former Federal Energy Administration identified eight such generating units in California with a total generating capacity of about 5,300 MW (Ref. Summary Report FEA Regional Meetings on Improving Power Plant Productivity, August 1976).
- o Postulating that steps and measures (such as outlined in Part 4, of this Section, "Means of Reliability Achievement"), can be taken to achieve plant generating reliability in three years rather than four, and that the plant Capacity Factor will increase from 40 to 70 percent by the end of the third year, this improvement would be worth \$65,000,000 for a 1,000 MW generating

unit. Two times as much would be gained if the plant maturation was reduced by two years. For derivation of these assessments the reader is referred to Appendix I.

- o. Equally significant is the worth of additional energy that could be sold (or would not have to be replaced) if a 10 percentage point improvement (equivalent to 100 MW or 36 days of operation at full capacity) in Capacity Factor of a 1000 MW generating unit were achieved. The worth of such improvement is about \$40,000,000 per each year of operation for a unit which will become operational in the years 1986-1988. For derivation of this assessment, the reader is again referred to Appendix I.

Admittedly, the above examples reflect the worst case scenarios in that purchase of replacement power was assumed. It can be expected that during the off-peak demand hours there will be sufficient intermediate generating units to provide the needed energy. Should an outage occur during the peak demand periods, however, the purchase of replacement power can be totally or partially avoided only through reserve capacity available to the service area. Also, if there is a significant number of units in plant maturation stage (Low Availability Factor) and therefore unavailable for service during peak demand, the economic losses may approach the magnitude shown in the above examples.

Another example attesting to the need for increase in power plant reliability is the need for reserve capacity as a compensating vehicle for loss of service due to forced outage or down-time due to excessive need of maintenance.

The "Introduction to the Biennial Report of the California Energy Commission", Tables 19 through 23 (pages 76-83) shows peak demand forecasts ranging from 18,000 to 38,000 (approximately) of additional generating capacity that will be required by year 2000. In addition, unless a reduction in forced outage rates is realized, at least 15 percent reserve capacity, or about 10,000 MW more will be required. However, if through reduction in forced outage rates, the reserve capacity need could be limited to 10 percent or 5,000-7,000 MW, this reduction could represent a savings of several billion dollars of capital investment. In addition, it would conserve natural resources such as land and water and would reduce the degradation of the environment.

The foregoing demonstrates that there is a need for reliability improvement, that such improvement will be profitable, and therefore is worth striving for and investing in. Means for reliability improvement are discussed in Part 5 of this section.

B. Reliability/Performance Indicators

There are nine indicators listed below which depict various reliability-related or performance characteristics of a power plant. Of the nine, the Nuclear Regulatory Commission (NRC) monitors only

three, (Availability Factor, Capacity Factor, Forced Outage Rate).* The nonnuclear industry periodically computes, as often as daily, some of the parameters described below, but the most common practice is to monitor on monthly and yearly basis.

None of the parameters discussed herein singly or even collectively fully and truly define the reliability of a generating station. Nevertheless, they do constitute a set of indicators by which the reliability, productivity, or economic value of the unit can be measured and/or compared to other generating stations. Such information is used in making decisions for establishing order of economic dispatch, relegating generating units to peaking status, retirement, future planning, etc. Specifically, what information these and other indicators provide, and what are their shortcomings, is provided below.

1. Availability Factor

Provides:

Information of what percent of time during a specified period the unit was available for service. As long as the unit was available to generate some electricity, full credit is given for all such hours, including reserve shutdown.

Shortcoming:

This indicator would not reveal that a technical problem could have resulted in only a partial forced outage, but precluded generation of power at the full capacity of the unit. This indicator can be applied to peaking, intermediate and baseload units, but it can be misleading in application to the baseload units.

2. Equivalent Availability Factor

Provides:

Information of what percent of time during a specified period the unit was in service equivalent to full power. As an example, it gives only 24 hours credit for 48 hours operation at 50 percent capacity. This indicator eliminates credit for plant availability when the plant energy output is reduced by equipment failure. Therefore, more realistic characterization of availability of baseload units can be obtained.

Shortcoming:

This indicator is of little value in application to peaking or intermediate units. A low Equivalent Availability Factor may be

*Mathematical definitions of these and the parameters discussed below are given in Section X, Glossary.

of no consequence, as long as the unit is available for service during the relatively short periods when it is required.

3. Service Factor

Provides:

Information is analogous to that of availability factor, except that reserve shutdown is not included. However, as long as the unit breakers were connected to the bus a full "in service" credit is given. This indicator is of little value in application to peaking units.

Shortcoming:

A high service factor does not necessarily reveal that: (a) only a small fraction of the rated power was produced, or (b) whether economic or technical problems were the causes of low productivity.

4. Capacity Factor

Provides:

Information of what percent of the energy based on the unit rated power was generated during a period a time. As a reliability indicator, this parameter is of little value to peaking or intermediate units.

Shortcomings:

This is primarily a productivity indicator. A high capacity factor inherently implies a high unit reliability. On the other hand, a low capacity factor may or may not be indicative of low reliability.

5. Forced Outage Rate

Provides:

Information of what percentage of the time the unit was forced completely out of service (shutdown). This is a most widely used indicator of technical problems.

Shortcomings:

This indicator does not account for partial forced outages (derating).

6. Equivalent Forced Outage Rate

Provides:

Information includes partial outages [hours of operation (full power-generated power)] converted to full outage equivalency. As an example, operating at 50 percent power reduction for 48 hours would be equivalent to 100 percent outage for 24 hours.

Shortcomings:

Technically none. However, there is very little data of this kind available. Organizations such as EEI and EPRI, and NRC do not report it. It is not certain that all utilities practice computation or keep records of this indicator.

7. Forced Outage Ratio

Provides:

Information on the percent of time attributable to forced outages compared to the total hours the unit was unavailable for service.

Shortcomings:

The indicator, if used alone, may be misleading. A large forced outage ratio is not indicative of poor reliability if the total of unavailable hours is small.

8. Scheduled Outage Hours

Provides:

Information on how many hours the unit was planned to be out of service. This parameter may be indicative of excessive maintenance requirements.

Shortcomings:

A retroactive record does not reveal how much of the "planned" downtime was attributable to prolonged periods of inspection in maintenance beyond the originally scheduled downtime.

9. Heat Rate

Provides:

Information on efficiency of thermal to electric energy conversion. The parameter is indicative of proper selection and sizing of components and of optimization of systems design. This parameter is also indicative of penalties when the generating unit is not operating at the optimum design point (usually full power). Along with other considerations, heat rate provides a basis for deciding which units in the service area are most suitable for operating at partial power when the need arises for load following.

Shortcomings:

The parameter is not very useful when used as an indicator isolated from comparison to other units. Also, its significance tends to decrease with the decrease of the fuel cost.

C. Attainability

For illustration, given below is a historical record of Capacity Factors attained in nuclear and coal-fired power plants. Oil- or gas-fired units are not shown because the needed data was not readily available.

1. Nuclear Units

The tables below include only 800 MW and larger units, because only these appear attractive to the industry.* To minimize the effect of plant "maturation" period, only units with 3 or more years of operation are shown in Table I below and the data shows cumulative Capacity Factor attained through December, 1978. The data shown was extracted from NRC NUREG 002.00 monthly reports dated January, 1979.

TABLE I

	<u>No. of Units in Group</u>	<u>CAPACITY FACTOR</u>		
		<u>High*</u>	<u>Ave.</u>	<u>Low*</u>
PWR's	16	76.5	62.0	44.0
BWR's	6	74.6	60.0	38.8

*Highest and lowest observed.

The Tables IIA and IIB below show 1978 year average Capacity Factors (CF) and Forced Outage (FO) Rates of 800 MW and larger units. These Tables show the effect of the unit age.

2. Coal-Fired Units

Given below are life-time factors of coal-fired units (Ref. C. Komanoff, Council on Economic Priorities). The reference does not contain data on forced outages, thus only capacity factors are shown.

<u>INSTALLED CAPACITY MW</u>	<u>CAPACITY FACTOR</u>		
	<u>High</u>	<u>Ave.</u>	<u>Low</u>
400 and Less (157)*	96.7	68.0	41.1
400 - 800 (74)	81.8	57.6	42.2
800 and Larger (21)	79.8	57.9	43.0
800 - 1300 (17)**	84.0	66.0	58.0

*The numbers in parenthesis indicate number of units in the group.

**Operated by, (not included in Komanoff's Report) American Electric Power.

*See Item 5 of this Section, "Large Versus Small Generating Units."

TABLE II A

BWR

<u>No. of years in operation as of Dec. 31, 1978</u>	<u>No. of units in the group</u>	Jan. 1 - Dec. 31, 1978 Operating Data			
		<u>Rate</u>	<u>High</u>	<u>Ave.</u>	<u>Low</u>
1	2	F.O.	23.6	16.5	9.5
		C.F.	66.5	62.9	59.3
3	3	F.O.	45.8	23.9	15.1
		C.F.	56.0	46.8	38.8
4	3	F.O.	40.2	18.5	7.6
		C.F.	61.9	53.7	39.5

TABLE II B

PWR

<u>No. of years in operations as of Dec. 31, 1978</u>	<u>No. of units in the group</u>	Jan. 1 - Dec. 31, 1978 Operating Data			
		<u>Rate</u>	<u>High</u>	<u>Ave.</u>	<u>Low</u>
1	3	F.O.	36.8	16.5	5.9
		C.F.	75.3	61.8	45.8
2	6	F.O.	39.2	21.1	5.1
		C.F.	80.2	63.7	16.5
3	4	F.O.	38.5	19.2	6.2
		C.F.	71.9	61.4	48.3
4	5	F.O.	22.6	13.2	4.9
		C.F.	73.9	64.6	57.3
5	4	F.O.	21.4	14.8	8.9
		C.F.	58.6	56.5	54.7
6	2	F.O.	16.3	9.9	3.6
		C.F.	66.3	61.9	57.5
7	1	F.O.	—	38.9	—
		C.F.	—	37.4	—

The above data reveals a considerable randomness. High capacity factors and low forced outage rates, and low capacity factors and high forced outage rates are experienced in new and mature units. There appears to be even a lack of trend with respect to average values of these parameters.

It would not be practical to tabulate all coal-fired units (over 250) but the capacity factor as function of years of operation for 800 MW and larger units is shown below. This will allow a comparison to be drawn between the coal-fired and nuclear units.

No. of years in operation through 1973	No. of units in the group	Capacity factor		
		High	Ave.	Low
1	21	80.5	53.8	41.4
2	17	79.0	56.2	41.0
3	9	70.7	58.9	30.1
4	5	65.0	53.3	41.3
5	3	60.9	57.4	51.4
6	2	70.8	65.2	59.6

As was the case with the nuclear units, here too, a randomness of occurrence of low and high capacity factors is apparent. Interestingly enough, however, high and low performance are traceable through CEP Komanoff's data to a particular utility as shown below:

CAPACITY FACTORS IN YEARS OF OPERATION						
	1	2	3	4	5	6
Utility A, Unit 1	44.2	41.2	30.1	41.3	51.9	59.0
Unit 2	61.3	41.8	58.3	49.5	59.4	-
Utility B, Unit 1	41.4	41.0	46.0	-	-	-
Unit 2	49.1	55.6	-	-	-	-
Utility C (above Ave.)	66.6	49.7	65.7	60.6	60.9	70.8
Utility D (High) Unit 1	82.1	81.1	64.1	62.0	59.0	74.8
Unit 2	81.9	70.3	58.5	71.8	38.7	-

The above suggest that reputable performance of power plants can be consistently attained through some appropriate actions. Conversely, inadequate actions lead to consistently low performance through a significant number of years, as experienced by utility A above.

Thus the major premise evolving from the above, which should guide the Commission's efforts to ensure safe and reliable generation of power, is that:

Only through deliberate actions and specific measures can desired levels of reliability of power plants be attained, and without such actions reliability cannot be taken for granted.

There is no reason to believe, that utilization of other fuels (for which data is not available at this time) would lead to a different conclusion.

D. Means for Achievement of Reliable Generation of Power

This section presents a discussion of tools, means, and alternatives which are available for achieving the Target (proposed by the Applicant in the NOI) Capacity Factor, Loss of Load Probability, and desired levels of other reliability indicators.

1. System Reliability

a. Basic Factors

System reliability is characterized by Loss of Load Probability (LOLP), which is defined as probability of failure to provide energy for one day in x number of years.

The utilities have adopted, based on experience and economic factors, a LOLP of one day in ten years. The Staff of the California Energy Commission finds no reason at this time to question the appropriateness of this criterion.

Simplistically, the computation of LOLP is based on Availability Factor of all generating units within and out of the service area. The computation specifically takes into account: (1) the utility--suggested forced and scheduled outage rates, (2) contracted or otherwise available power transfers, (3) the reserve capacity, and (4) the adequacy of the transmission system with respect to the lines capability to carry the load and the adequacy of interconnections within the service area and to the adjacent service areas. The computation through iterations determines the reserve capacity which is needed to satisfy the LOLP criterion of one day in ten years. Assuming the transmission system to be adequate (without making a quantitative determination of its adequacy during the LOLP computation) does not result in overestimation of reserve margin requirements. Furthermore, it is not likely that any detected deficiencies should be compensated for by an increase in reserve capacity. However, excluding the effect of potential deficiencies in the reliability of the transmission system may result in a lower computed LOLP than the actual LOLP which in reality characterizes the system.

Thus, it becomes clear that the reliability of the system is a function of the reliability of the individual generating units, the reserve capacity within the system, and the flexibility of the transmission system to transfer or reroute power as required. The factors and means of control of the factors effecting the reliability of the transmission system and those effecting the reliability of individual generating units are discussed in subsequent sections.

b. Power Transmission System

Public sensitivity to inconveniences caused by power interruption is almost invariably directed at the elements of the utility distribution system rather than at the bulk power supply (generation system). This perception is correct in that "approximately 98 percent of all outages to the consumer are results of distribution failures, not generation failures". (Ref. Electrical World, January 15, 1975). The above statement leads to the following questions:

- (1) Should reliability requirements for power distribution system be more stringent than those consistent with LOLP of one day in 10 years?
- (2) Should the quality of service (reliability) be the same for hospitals, manufacturers, restaurants, and the residential segment?
- (3) Is the expense associated with the increase in the reliability of the distribution system justifiable?

To answer these questions, it is necessary to identify the causes of the transmission system failures, the type of major equipment (elements of the transmission system) that is given to failures or can be caused to fail.

The key elements which affect the reliability of the transmission system are: (1) transmission lines and their components such as towers, poles and pole-mounted transformers, and (2) substations, including transformers, breakers, switchgear, etc., and switching stations with switchgear only.

According to Beaty ("Switching: Key to Reliability", Electrical World, January 15, 1975), only 15 percent of all power interruptions are attributable to transmission system equipment failure. All other power distribution failures such as caused by ice, snow, falling trees, lightening, man-caused accidents, aircraft and acts of malice are beyond utility control. "Inside DOE", October 16, 1978, estimates that all of the above cause an average yearly outage of 2.4 hours per consumer, which is equivalent to one day outage in ten years.

It thus becomes obvious that improving the reliability of equipment under most optimistic conditions would reduce the outage rate only by 15 percent or about 22 minutes per year. Therefore, it does not appear that the transmission system equipment reliability is a viable target that could be attacked on cost/benefit basis. To appreciably reduce the accident- or weather-related outages would require almost a

total redundancy of all those items which are susceptible to such events, because it cannot be predicted which transformer may be struck by lightning, or which pole may be hit by a car. This approach (total redundancy), considering the low frequency of occurrence of such events, also could not be justified on cost/benefit basis.

Thus, it appears to the staff that the current LOLP criteria are reasonable and that more stringent criteria could be met only at an added expense (to the consumer) which is not readily justifiable.

Some establishments, such as hospitals, production-oriented facilities, and others to which uninterrupted availability of power is essential, do have or exercise an option to have emergency power generating equipment which guarantees the appropriate quality of service.

The residential segment on the other hand prefers* an occasional inconvenience to significantly higher payments for a greater degree of reliability, which still would not eliminate all the interruptions, some of which are beyond the utilities control.

The reliability of the system is controlled through adherence to California Utilities' criteria in conjunction with Western Systems' Coordinating Council criteria. Among these, the principal single contingency criterion governing the system reliability requires continuity of system performance with one intertie control line outage. This, in general, provides for system functionality, up to four hours with protected inter- and intra-service connections. Adherence to the above and the current LOLP criteria appears to be adequate, and the staff has no reason to recommend any specific measures designed for improvement of reliability of the transmission and power distribution system at this time. It appears to the staff that a higher system reliability could be achieved at an added expense (to the consumer) which is not readily justifiable.

c. Reliability of Individual Power Plants

For the purpose of this discussion, it will be stipulated that the technology of the generating unit requires a fuel to be consumed, water for generation of steam or for heat removal and discharge of certain effluents. In addition, the unit will consist of systems and components which are critical to reliable generation of power.

*"Switching: Key to Reliability", Electrical World, January 15, 1975.

Thus, the reliable generation of power by a unit requires:

- o Reliable fuel supply.
- o Reliable water supply.
- o Reliable generating unit.

The above elements are discussed below.

(1) Fuel Supply

It is recognized that the availability of a given fuel to a considerable degree, and in some instances entirely, is beyond the control of the user. It is also recognized that projecting availability of fuel for some distant future (40 years) may not always carry the desired degree of credibility. Nevertheless, the NOI must provide information as to the arrangements, contractual agreements, etc., the Applicant has made or will have made, that barring some unusual circumstances, will provide a reasonable assurance of fuel availability in the future. In addition, the Applicant should develop and describe his plans for making design provisions for plant alterations which would permit use of an alternate fuel should the initial type become unavailable or uneconomical to use.

(2) Water Supply

It is required that the Applicant demonstrate that the supply of necessary water be secured either through contracted purchasing or that the Applicant will develop his own resources.

d. Generating Unit

The role of the Commission staff in reviewing the factors effecting the reliability of power generating facilities as prescribed in PRC 25511 and as amended by SB 1859 is also outlined in this section.

Causes of Unreliable Performance.

An unreliable performance or loss of generating capacity may result (primarily) from the deficiencies listed below, which will be discussed in some detail in subsequent sections. The order of listing reflects the sequence of activities leading to the erection of a facility rather than the relative weight these factors may have on reliability.

- o Faulty plant design (inadequate or faulty design criteria).
- o Poor construction practices.

- o Equipment failures.
- o Faulty operation.
- o Inadequate maintenance.
- o Regulatory requirements.
- o Natural phenomena.
- o Economic factors.

Reducing the effects of each of these will result in shorter plant maturation period and higher reliability levels. As it will be discussed, it may be necessary to abandon some orthodox practices, time-established traditions and eliminate judgemental procedures whenever possible. Activities structured for reduction or elimination of the above causes will be known as Reliability Program.

(1) Designing for Reliability

This section will not dwell on activities pertaining to fluid flow, thermodynamics, heat transfer, circuitry calculations, equipment sizing, etc. Instead, the emphasis will be placed on approaches and methodology for enhancement of reliability of generating units.

Two methods are described below. The first, the Failure Cause and Effect Analysis Method, because of its relative simplicity will be recommended. This, however, does not preclude acceptability of other approaches the Applicant may propose. The second, Reliability Assessment Method, is provided for information only. Its merits and disadvantages are discussed, but the staff does not recommend its implementation.

Failure Mode Cause and Effect Analysis Method (FCEAM)

The method described below is an "in-process" plant design optimization tool taking into account economic considerations for decision making process, rather than relying on judgemental factors.

The process starts with the development of criteria. Owner's or industry experience is used to assign outage durations caused by given, or similar equipment failure. The outage duration is translated to its costs. These costs then are compared to the cost of measures that can be taken to prevent or reduce the frequency of such outages. This in turn is used to establish the following or similar design criteria:

- o Outage not in excess of x hours:

Need not be mitigated by design.

- o Outage of x number of hours.

- (a) If caused by off-design environment, provide for control of induced environment and protection from operator's error (if susceptible).
- (b) If caused by poor quality equipment, impose appropriate quality assurance/quality control requirements.

- o Outage in excess of Z number of hours:

Equipment redundancy may be required.

In the process of plant design development, through formal or informal procedures, the designer postulates a failure of each piece of equipment. He then identifies all causes of the postulated failures and the effects that may or would result. If the identified effects so warrant, the designer selects appropriate mitigating measures in accordance with one of the above criteria or combination thereof. He further determines (using economic trade-offs) the degree of necessary redundancy, such as two-100 percent capacity components, versus three-50 percent components. (See Appendix II for analytical method). Ultimately, other design consideration, such as accessibility, operating experience (feedback from plant operators) etc., are factored into the plant design. Subsequently, as discussed later, all components whose failure would result in an outage would be subject to appropriate Quality Assurance and Quality Control. Having taken or assigned all the measures that are necessary to prevent inordinate outages, there is little more--if anything--that can be done to assure that the system will perform as intended. In this case, a preassessment of plant availability is academic; all the necessary measures have already been taken. The resulting forced outage rates, availability and capacity factors will be in balance with the cost of their achievability.

The above is not to be construed as a substitution for requirements set forth in the Code of Federal Regulation Title 10, Part 50, Appendix A (10 CFR 50 App. A). It should be recognized, however, that 10 CFR 50 pertains only to safety-related items of nuclear plants and is designed to assure safety; it does not necessarily provide for reliable generation of power. However, there is no reason why the criteria proposed herein could not be used for determination of redundancy requirements over and above those covered by 10

CFR, whereby both safety and power generation reliability would be enhanced.

In addition to the above, 10 CFR 50, Appendix B defines a Quality Assurance program applicable to safety-related items. In many cases, the program applies only to the pressure retaining boundaries (prevention of release of radioactive matter) of components, but it does not necessarily control the quality of internal parts of such components. For further discussion on this subject, see Item C of this section.

Reliability Assessment Method

At the outset, this method requires that the target availability factor (see Glossary of definition) of the plant be established on the basis of cost of its achievability and the economic impact of any plant unavailability. Further, all equipment whose failure results in outage (Reliability Critical Items) must be identified and accounted for. In addition, failure rates and arrangement (series, parallel, redundancy) of all such equipment must be known. Then, through modeling of the plant (which usually requires the use of a computer), the plant Availability Factor (AF) is determined. If the obtained AF does not match the predetermined target AF, iterations with lower equipment failure rates and added redundancies are made until the computed and the target AF match.

A more detailed description, along with analytical tools pertaining to this method, are given in Appendix II.

The method described above is a complex one. It was used by Rasmussen group (Wash-1400) in determining the probability of nuclear plant core meltdown. It took the group several years to conduct the study restricted to safety-related items. A 30-40 member trained design group (because they are more intimately familiar with their own design drawings) might be able to model the tens of thousands of components and complete the assessment of the entire plant in one year. History has shown (Three Mile Island) that having made such an assessment does not provide assurance that the computed plant availability will materialize. The entire process can be invalidated if the purchased equipment will not exhibit the quantitative characteristics (such as Mean Time Between Failures, Failure rates, etc.) which were used in computations. Thus, it becomes essential that the necessary controls of the equipment manufacturing process, equipment quality requirements and verification of conformance to such requirements be established.

In conclusion, the above method could be used effectively by the designer as a reliability tool. However, the complexity involved and before hand knowledge requirements of all equipment and its reliability characteristics tend to reduce its efficiency.

Seismic Design Criteria

A special element of designing for reliability is consideration of adequacy of structures and equipment supports to withstand seismic events. The safety-related structures and components of nuclear power plants are designed in accordance with the requirements set forth in 10 CFR 100, Appendix A. These requirements provide safeguards against release of radioactive matter and provide for retention of functionality of safety-related components, at least to the extent necessary to shutdown the reactor and maintain it in shutdown conditions in the event of a maximum potential vibratory ground motion (Safe Shutdown Earthquake--SSE). In addition, such safety-related items are required to retain their functionality and the capability for restart following Operating Basis Earthquake (OBE) when vibratory ground acceleration is at least one half of SSE. The staff has no grounds for challenging the adequacy of the above design criteria for the safety-related structures and components.

On the other hand, the staff has found that the Uniform Building Code (UBC), if applied to the balance (non-safety-related) of nuclear power plants or to non-nuclear power plants, is not always consistent with the seismic characteristics of the candidate site(s). Considering that many of the California power plants already in existence which have been designed to UBC are susceptible to various degrees of damage and removal from service, it becomes very important that the generating units yet to be licensed by the Commission be designed to criteria which take into account Maximum Probable Earthquake, Maximum Credible Earthquake, probability of exceedence and cost/risk relationship (SB 1859, Sec. 25511). A typical process for selecting appropriate seismic design criteria and correlating the decision making parameters is given in Appendix III.

Unless the Applicant can show that consideration of design criteria can be deferred to AFC without a risk of affecting his design progress and the plant availability schedule, the adequacy, the design criteria, or plans to develop appropriate design criteria will be considered during the NOI proceedings.

During the AFC proceedings the staff will evaluate the basis for the proposed criteria and (on sample basis) documents providing for understanding of implementation of the proposed criteria.

(2) Construction Practices

The construction and installation practices which pertain to safety-related items of nuclear power plants are strictly controlled by the Nuclear Regulatory Commission. The control of construction of other elements of the nuclear power plant and nonnuclear power plants appears to be adequate.* The nature of work is such that occasional nonconformances are readily evident and therefore correctable in accordance with project management decisions. Similar occasional field modifications appear to be under control most of the time. There is no evidence indicating the need for concern on the part of the Commission staff in this area.

(3) Equipment Failures

It should be recognized that most forced outages result from equipment failures. Electric Power Research Institute (EPRI) assesses that 97 percent of all forced outages is caused by equipment failures. Furthermore, it is the internal parts and mechanisms of components, as opposed to the pressure retaining parts (pump housing, valve bodies, piping), that causes failures. And yet, currently, the most common orthodox approach to plant operability is to:

- o Procure "off the shelf" items;
- o Rely on a single acceptance test prior to shipment;
- o Control only pressure retaining parts as required by the Asme Code, NRC, or when permissible by other, less stringent acceptance standards;
- o For quality of internal parts or the entire assembly rely on manufacturers without verification of conformity to design documents;
- o Rely on manufacturer's inspection practices without examining or specifying inspection frequency or attributes for which the inspection of parts should be performed;

*Except where new and unaccounted for by design seismic hazards were discovered, there were no reported instances of plant outages attributable to poor construction practices.

- o Rely on manufacturers' warranty for replacement of faulty items, rather than taking measures that would provide for adequate quality to start with;
- o Rely on maintenance for restoration of components operability, rather than striving for appropriate equipment quality.
- o Procure the equipment on the basis of the lowest cost.

The above illustrates why the plant maturation may take 4-5 years to achieve.

It is recognized that it would not be appropriate to impose the same degree of requirements and controls on all components of the power plant. A balanced equipment quality control program would be one that weighs the cost of implementation of quality requirements against the consequences of outages, and cost of spare part provisioning, etc.

Accordingly, in order to assure the necessary quality of equipment, quantitative criteria reflecting cost/risk/benefits considerations can and should be developed. The effectiveness of application of appropriate criteria requires that all equipment whose failure would result in forced outage be recognized as reliability-critical. Subsequently, each Reliability Critical Item should be assigned an appropriate quality level ranging from no controls (procure "off the shelf") to strict controls including proof of conformance to all stated requirements, and a Certificate of Compliance furnished by the manufacturer.

The staff will evaluate during the NOI the proposed criteria or plans to develop such criteria using the Applicant's cost effectiveness approach as adequacy criteria.

During the AFC process, through examination of selected specifications and procurement documents, the Commission staff will determine the adequacy of implementation of the measures proposed in the NOI.

(4) Faulty Operation

Although not frequent (less than 3 percent), operator's errors are additional sources contributing to reduction of plant reliability. Reduction of forced outages caused by operator's error can be achieved through a number of administrative measures such as implementing more or better procedures, leaving less to operator's

judgement, providing more equipment status displays, more stringent training and periodic, or continuous, training, including periodic verification/certification of proficiency of all personnel involved in plant operation.

Not later than during the AFC proceeding, evidence of existence of a program, including reasons of Applicant's view, of its adequacy for reduction of operator's error will be required.

(5) Plant and Equipment Maintenance

Maintenance activities are necessary for keeping the facility in good working condition. Scheduled maintenance is designed to enhance plant reliability and reduce the potential for forced outages. However, a poor maintenance system can result in excessive outage durations and thereby reduce the plant availability for generation of power. Thus, it becomes important for the owner to have a plant maintenance system which is effective in enhancing the plant reliability without becoming a significant contribution to the down time, or one which substitutes planned maintenance for equipment quality or redundancy without due consideration of economic tradeoffs.

Not later than during the AFC proceedings evidence of existence of a maintenance program, including plans for generating maintenance procedures, providing and maintaining a systematic maintenance training consistent with assigned functions of the maintenance personnel, periodic testing and certifying proficiencies of the maintenance personnel. Criteria the Applicant will use in determining, ordering and maintaining spare parts (components) inventories will be required, including Applicant's rationale for adequacy of the proposed program.

(6) Regulatory Requirements

It is recognized that certain regulatory requirements pertaining to pollution control or other discharge limitations may be straining the limits of technological capabilities and reliability of equipment on the market. Other requirements adequately protect the safety, but in doing so may downgrade the reliability of the plant as a generating unit. In both cases, the reliability of the power plants with respect to safety and generation of power without sacrificing safety can be increased through:

- o Added redundancy.

- o Diversity of in-plant and outside power sources, and diversity of equipment control or operating devices, etc.

Unless the Applicant can show that consideration of measures, criteria or plans to develop these, can be deferred to AFC without risk of affecting the progress the Applicant will have made by the time of AFC filing, the staff will evaluate the proposed measures and criteria using cost effectiveness approach as adequacy criteria.

During the AFC process, the basis for the adopted measures and criteria and identification (specific examples) of implementation of measures adopted to reduce the probability of outages which otherwise would likely occur as a result of regulation requirements will be required.

(7) Natural Phenomena

In addition to inappropriate or inadequate human action which can adversely effect the power plant reliability or availability for service, certain natural phenomena which are discussed below may have a similar effect.

(a) Earthquake

Seismic design criteria for nuclear power plants' safety-related structures are defined in 10 CFR 100, and these criteria are subject to enforcement by NRC. The discussion here will be limited to nonnuclear power plants and to those structures of nuclear power plants which are not controlled by NRC.

It is expected that the Applicant in formulating his design criteria will take into consideration the seismic characteristics of the proposed sites, and that such criteria will reflect the Recommended Lateral Force Requirements and Commentary, Seismology committee, Structural Engineers Association of California, or other design parameters accounting for the encountered seismic risk. Specifically, Section 2313a alerts the designer that application of the Uniform Building Code to power plants, stacks, tanks, and water towers may not be adequate, and that development of more appropriate criteria may be required.

Failure to account for seismic risks associated with various Recurrence Intervals may result in plant damage which could have been mitigated by design.

Several approaches to choosing seismic design parameters are discussed in greater detail in Appendix III.

Other considerations should include structural adequacy of tanks and containers of toxic flammable or other hazardous materials. The Applicant is expected to examine adequacy of these items and, if not adequate in light of hazards and consequences associated with Maximum Credible Earthquake (no historical record of occurrence, but one which can be expected to occur), to identify criteria designed to preclude such consequences.

(b) Floods

The Applicant is expected to consider all conditions which could cause flood damage including Maximum Probable Flood (one occurrence in 100 years), and to identify the measures he proposes to implement to guard against damage which may result from such events.

(c) Tsunami and Tornado

It is recognized that these phenomena rarely occur in California. Designing nuclear power plants against hazards that may be generated by these events is governed by requirements set forth in 10 CFR. For nonnuclear generating stations, the Applicant is expected to identify the criteria that will be implemented to guard against damage that can be inflicted by these events.

Unless the Applicant can show that consideration of criteria for mitigating the phenomena identified above can be deferred to AFC proceedings without risk of affecting the design progress the Applicant will have made by the time of AFC filing, identification of these criteria and justification for the proposed criteria will be required to be included in the NOI.

(8) Economic Factors

The discussion here is limited to those measures, heretofore discussed, which can be implemented before or after plant construction. Specifically, the redundancy of systems and components and equipment quality will be covered.

It is recognized that an option exists to consider the need for redundancy during the plant design stage and to assure the quality of the reliability-critical equipment on delivery. Alternatively, the necessary plant modifications and maintaining the equipment in operable condition through a more extensive maintenance, more frequent and longer scheduled outages can also be achieved on the "as need arises" basis. Not infrequently, when the first option is being considered, the question arises how much would it cost without addressing the other side of the equation: how much is it going to cost when problems materialize later? The design and construction of a modern power plant requires hundreds of millions, or even billions of dollars. Thus, it is understandable, that utilities may be reluctant to take steps which further aggravate their financial burden. Even though the capital cost will be recovered later, such recovery takes years and the recovery process does not start until years later when the commercial operation takes place. On the other hand, if after the completion of construction, plant modifications are required, or forced outages caused by equipment failures occur, the utilities need not borrow to finance the expenses which may result. These are financed through rate making. This approach however, requires a greater availability of reserve capacity (also very costly), or the energy demand may not be satisfied.

It is not readily obvious which of the above options "before" or "after" effect the rate payer more adversely. But it appears that, the utilities would be more inclined to consider in greater depth the reliability-related measures and would be more inclined to implement these measures before plant construction, if the differential cost (fully or partially) could be offset through rate making before the plant became a commercial entity. It is also likely, that the cost to the rate payer after the plant began commercial operation would be less, because of lower forced outage rates.

Yet another way to make it more attractive to the utilities to invest in reliability, is to provide rate-making incentives. The incentive formula would provide for a greater rate of return on investment for forced outage rates below a certain base, and penalties for outages above such base. Such a formula has been adopted by the State of Michigan and it may be worthy of examination. Other reliability/performance parameters can also be factored into the incentive formula, or through lessening the utility financing burden through construction work in progress payments.

E. Large Versus Small Generating Units

There appears to be a consensus that small generating units (both nuclear and nonnuclear) in the 400 MW-600 MW range tend to be more reliable than large units of 800 MW and greater capacity.

Mere statistics, however, do not tell the whole story. Not accounted for in the generally available figures are the number of years in operation (plant maturity), and generally less stringent criteria such as regulatory requirements for design and operation which existed at the time when the state of technology dictated construction of power plants not exceeding 600 MW. It is not readily evident that a small power plant (400-600 MW capacity), if constructed today in accordance with the current standards covering pollution control, safety, etc., would be more reliable than a large unit. The Tables below (extracted from Appendix III to System Development Corporation report on "Power Plant Performance Analysis") will allow the reader to draw his own conclusions.

It is to be noted that in recent years some utilities, cognizant of potential economic burden associated with poorly performing units, have adopted new policies designed to protect their investment with a remarkable success. Availability Factors above 90 percent in the first year of operation have been consistently obtained on 800-1300 MW coal-fired units.

CAPACITY FACTORS AND AVAILABILITY FACTORS; OPERATING EXPERIENCE COAL-FIRED GENERATING UNITS

<u>Size (MW)</u>	<u>Unit-year</u>	<u>Average CF</u>	<u>Average AF</u>
200-389	402	66.0	82.5
390-599	201	60.5	75.8
600-699	50	60.6	75.8
700-799	36	60.8	72.8
800-899	21	56.4	70.8
900-1299	15	60.6	72.8
1300	17	66	80.1

NUCLEAR

<u>Size (MW)</u>	<u>Unit-year</u>	<u>Average CF</u>	<u>Average AF</u>
400-499	12	71.8	80.2
500-599	21	59.7	75.6
600-699	15	67.0	75.3
700-799	9	67.5	73.3
800-899	38	54.9	66.0
900-999	3	53.1*	68.9*
1000 and Larger	13	47.1*	58.4*

*Data includes first and second year of operation only.

GEOTHERMAL

<u>Size (MW)</u>	<u>Unit-year</u>	<u>Average CF</u>	<u>Average AF</u>
55	24	74.77	83.6
55	7*	83.4	89.2
110	1	68.5	75.6

*At maturity, in the fifth year of operation.

GAS TURBINES

No meaningful data is available.

COMBINED CYCLE

No meaningful data is available.

GAS FIRED GENERATING UNITS

<u>Size (MW)</u>	<u>Unit-year</u>	<u>Average CF</u>	<u>Average AF</u>
90-129	20	45.7	86.1
130-199	18	69.6	88.9
200-389	67	54.9	84.8
390-599	34	66.3	85.5
600 and Larger	9	60.9	74.5

OIL FIRED GENERATING UNITS

<u>Size (MW)</u>	<u>Unit-year</u>	<u>Average CF</u>	<u>Average AF</u>
90-129	52	66.4	88.9
130-199	28	40.5	72.8
200-389	23	58.2	70.2
390-599	44	59.7	81.1
600 and Larger	14	52.2	78.5

The reader should bear in mind that the capacity and availability factors shown above are life time averages. Thus, the values of these parameters for large units with relatively few unit-years of experience are more weighted with low performance commonly encountered during the first few years of commercial operation.

Another aspect of reliability is the relative affect on the system of an outage of a large capacity unit compared with the affect of an outage of a small unit.

Specifically, are four small units (for example) more likely to generate power equivalent to that which can be generated by one large unit?

The mathematical treatment of this problem is given in Appendix IV. It shows that a multi-unit generating station will generate the same energy as a single generating unit of equivalent capacity. However, the probability that a multi-unit complex will generate at least a fraction of the installed capacity over a period of time is greater than of single unit, assuming that the Availability Factor of each unit (small and large) is the same. Thus the effect of forced or scheduled outage on the generating system (service area) is not the same. The probability that all units in the complex will be out of service at the same time is small (0.0016 compared with 0.2 of a single unit assuming 0.8 capacity factor for all), thus at least a fraction of a multi-unit complex will be available to generate power, whereas an outage of a single large unit will deprive the system of its total capacity for the duration of outage.

Thus from the system reliability perspective, several small generating units are preferred to a single, large unit of equivalent capacity. However, several small units offer no advantage over several large units.

Another factor that should be taken into account by a decision-maker is the effect the unit size may have on the reserve margin requirements. A generally accepted industry criterion is to maintain a reserve margin equivalent to two times the largest capacity unit. Thus, if the largest unit in the system represents five percent of the total installed capacity in the system, a ten percent reserve capacity would be sufficient. Twenty percent margin would be required if the largest unit would be equivalent to ten percent of the system capacity. In the opinion of the writer a ten percent reserve margin represents a reliability risk, unless henceforth, measures are taken to achieve at least 0.8 Availability Factor of individual new baseload generating units.

Obviously, reliability is not the only, and certainly not the overriding consideration upon which the decision to construct a small, multi-unit complex or a single large generating unit is based.

Capital investment (\$/kW of installed capacity) requirement is another key factor that influences the choice between small and large units. The C. Komanoff Report, Council On Economic Priorities (Table 9.1) provides relative construction cost as a function of size for two basic fuel technologies as follows:

"Ratio of Per-kW Capital Cost to Cost of Hypothetical 600 MW Units:

<u>Unit Size</u>	<u>Nuclear</u>	<u>Coal</u>
400 MW	1.14	1.10
600 MW	1.00	1.00
800 MW	0.91	0.94
1000 MW	0.85	0.89
1200 MW	0.80	0.85

The above table explains why the Utilities are attracted to larger units, and compensate for the generally lower availability factor by installing twin units such as Fossil 1 & 2, Pittsburgh 8 & 9, Sundesert 1 & 2, etc.. The effect of this preference on the consumer is depicted below.

It would appear that, because of the lower capital investment requirements, the trend towards progressively larger generating units should benefit the consumer. This, however, may not necessarily be so because one of the elements of the rate structure is the ratio of the Capital Cost to Capacity Factor (CC/CF). Because the Capacity Factors tend to decrease with the size of the unit, the Capital Charges for the larger units are higher as shown below.

Ratio of Per-kWh Capital Charges to Hypothetical 600 MW Unit*

<u>Unit (MW)</u>	<u>Nuclear</u>		<u>Coal</u>
	<u>PWR's</u>	<u>BWR's</u>	
400	1.03	1.03	1.03
500	1.01	1.00	1.01
600	1.00	1.00	1.00
700	1.00	1.01	1.00
850	1.03	1.04	1.01
1000	1.07	1.09	1.03
1150	1.13	1.17	1.00
1300	1.21	1.27	1.11

*Council on Economic Priorities, Tables 9.2 and 9.3.

The table above illustrates that the advantages of lower construction costs of larger units are in part at least offset by higher capital charges associated with such units.

Thus it becomes obvious, that in order to reduce (if not completely eliminate) the detriment reflected in the capital charges, raising the reliability (Capacity Factor) of generating units yet to be certified by the Commission should be a legitimate goal.

F. Relationship of Reliability to Plant Efficiency

The plant efficiency is usually expressed in terms of thermal to electric energy conversion ratio, Btu/kWh (heat rate). The lower the heat rate (less Btu's required to generate one kWh), the more efficient is the generating unit. The longer a unit is on line, the greater are the savings realized from a lower heat rate. Conversely, if a unit is shut down for an appreciable portion of time the importance of low heat rate diminishes. Also, if a unit is operated at

off-design point (partial power) the heat rate increases. Thus, in order to realize the full benefits of an investment made in plant efficiency one must have a reliable unit which operates at its peak capacity most of the time. Improved plant efficiency and reliability are effective alternatives to new generating units.

IX. TARGET RELIABILITY

To aid the reader in his efforts to follow the discussion below, Figure 1 is provided. Also, for definition of the technical terms used, the reader is referred to the Glossary provided in Section XI. It will be shown that some of the parameters which characterize power plant reliability, individually or collectively, can be applied to some types of generating units, but not to others. Examination of Figure 1 reveals each of the events designated by an unshaded area is detrimental to energy production which most commonly is expressed as Capacity Factor. A unit which produces the amount of energy (kWh) equal to the unit rating will have a Capacity Factor of unity. This implies there were no Forced or Partial Outages, no maintenance was required (Scheduled, Partial or Total Outages), and there was a need for the energy (no reserve or economy shutdown).

For some periods of time, a Capacity Factor of one can be expected. Ultimately, however, Forced Outage will occur and prudence dictates a necessity to schedule periods of inspection, maintenance, refueling (if nuclear) etc. In addition, as Figure 2 indicates, the demand for power during a 24-hour period is not constant. The demand varies with the time of the day as shown in Figure 3, and it varies seasonally. Thus, it is unavoidable that when the period of peak demand is over, some units will be totally removed from service, or they will operate at a reduced load, as dictated by operation economics.

For peaking units it is obvious then that Capacity Factor ~~would not~~ be a reasonable indicator of the unit reliability. The units totally removed from service can be rotated to provide an opportunity for limited maintenance. However, it is important that these units be not forced out of service by equipment failure when they are needed, especially during the peak demand period. Thus the reliability indicators for such peaking units, or for those units whose full generating capacity is needed only during the peak demand periods are the Forced Outage Rates and the Availability Factors.

Some units, however, especially those which are most economical to operate within the service area (geographic area served) and/or those which require several hours to bring to full capacity are expected to operate at Maximum Capacity Factor at all times. For these baseload units Forced Outage Rates and Capacity Factors are good indicators of their reliability. It is recognized that, except for periods of drought, hydro-electric power will displace some of the least efficient baseload units. The economy involved indicates, that the last units to be displaced by hydro-electric power would be the coal-fired and nuclear generating stations.

Considering all of the above, plus the economic losses which may result from under achievement, as discussed in the preceding sections, the Commission will strive collectively and in cooperation with the industry for the lower limits of Forced Outage Rates and upper limits of the Capacity Factors shown in Figure 4, unless other values can be justified. Figure 4 was extracted from the ERCDC Order No. 76-123-13.

It is recommended that these targets be adopted for future generating units, and incorporated in the EFPR, Biennial Report (as appropriate),

PFO – Partial Forced Outage (Operating problems force load reduction)
 PSO – Partial Scheduled Outage (Load reduction to permit maintenance, and so on)
 ESD – Economy Shutdown (Not economical to generate)
 FO – Forced Outages (Equipment failures, accidents, environmental factors)
 SO – Scheduled Outages (Routine or planned maintenance, inspection, and so on)

Figure 1 Factors affecting productivity of power plants

ACTUAL DEMAND VS. HOURLY PERIODS

1977

Day of Annual Maximum

Day of Annual Minimum

FIGURE 2

ACTUAL DEMAND VS. TIME OF DAY

1977

Day of Annual Maximum

Day of Annual Minimum

FIGURE 3

ASSUMPTIONS REGARDING THE TYPE OF FUTURE GENERATING FACILITIES
(continued)

Type of Generating Resource	(8) Estimated Nuclear Refueling Schedule <hr/> (Days/Year)	(9) Estimated Forced Outage* Rate at Maturity <hr/> (% of Year)	(10) Maximum Estimated Capacity Factor at Maturity <hr/> (% of Max. Dependable) Capacity
Nuclear - LWR	30-45	5-15	50-75
Conventional Coal	Not Applicable	5-15	50-75
Conventional Oil	Not Applicable	3-11	60-80
Combined Cycle	Not Applicable	4-10	60-80
Combustion Turbine	Not Applicable	4-23	N/A
Conventional Hydro.	Not Applicable	0.5-5	N/A
Pumped Storage Hydro.	Not Applicable	2-5	N/A
Geothermal Steam	Not Applicable	6-12	70-80

*Immature forced outage rates are higher and gradually decline to maturity rates.

FIGURE 4

along with other requirements of a generic nature discussed in this document.

The question arises why these parameters should not be set and adopted as reliability/performance standards. There are several reasons why standards for these parameters are not proposed to be set at this time.

One reason is that, it will be ten years or longer (regulatory certification process, several years of construction and up to four years of plant "maturation" period) before it will be known whether or not these standards have been met.

Another reason is that it is uncertain what actions and with what authority could the Commission take to enforce the compliance with such standards, if they were not met.

Further, any compliance enforcement action that could be taken would only make sense if it were in balance with any potential impact on cost and benefits. It does not appear that the revocation or suspension of license is one of them.

Any other course of action would not likely be effective, unless the power plant productivity is tied through the rate making process to some incentive or penalty formulae.

X. EXCEPTIONS AND LIMITATIONS

- A. Except for target reliability indicators, the contents of this document pertain primarily to baseload thermal generating units. Generating units which are planned for use as baseload units during the first several years of operation before they are reduced to a peaking or intermediate role will be treated as baseload units.
- B. Peaking units provide ample time and opportunity to be maintained in a state of operational readiness to provide the needed power. Thus, such units will not be subject to policies and requirements outlined in this document, except as required for reasons of health and safety.
- C. Geothermal units have consistently demonstrated the capability to operate at 80 percent and higher Capacity Factors. Thus considerations of reliability will be limited to aspects of health and safety except when an Applicant has not demonstrated prior experience. In those cases, the reliability-related aspects will be treated in accordance with the preceding discussions.

XI. POLICIES AND PRACTICES

Pursuant to the AB 1575 and SB 1859, and consistent with the NOI and AFC siting regulations, enumerated in this section are key CEC policies and policy-derived staff practices. These policies and staff practices summarize the current basis of the review process of reliability-related factors during the NOI and AFC proceedings. They evolved from the Commission's cognizance of its role as an instrument of the state government in ensuring safe and reliable generation of the needed power. (PRC 25001).

- A. The Commission, through increase in reliability/productivity of power plants endeavors to reduce the need for additional generating capacity, reduce the need for capital investment, conserve land, water, and preserve the quality of the environment.
- B. The Commission deems unacceptable any productivity or reliability improvement program which would compromise the health and safety of the public or that of plant personnel.
- C. The Commission takes the position that the reliability/productivity-related policies shall be made applicable only to baseload generating units. The reliability of peaking, intermediate and geothermal units shall be reviewed only to the extent of health and safety, unless otherwise warranted.
- D. The Commission staff takes the position that only through deliberate actions and measures safe and reliable generation of power can be assured.
- E. The Commission staff will strive for implementation of measures designed for reliability improvement which can be justified on cost/benefit basis rather than to set numerical reliability standards (which may or may not be in cost/benefit balance).
- F. The Commission staff will not design any components, systems or facilities, however, the Applicant's approach to ensuring the adequacy of such items will be examined by the staff.
- G. The Commission staff will challenge any arbitrary structural design criteria which do not account on cost/benefit basis for seismic risks associated with the site seismic characteristics.
- H. The Commission staff, in addition to consideration of site-related factors presented in the NOI, will evaluate the Reliability Program by the Applicant for its potential effectiveness and adequacy for achievement of safe and reliable generation of power. The evaluation will be limited to the review of those criteria and reliability/safety-related factors which cannot be deferred to AFC proceedings without risk of adversely affecting the progress the Applicant will have made at the time of AFC filing.

- I. The Commission staff will perform, in detail, an evaluation of all safety/reliability-related aspects presented in the AFC, including review of justifications and rationales for all design criteria, adequacy of implementation of safety/reliability-related measures and resolution of prior Commission's findings.
- J. The Commission staff will challenge any reliability program, which in its view is inadequate or leaves the attainability of safe and reliable generation of power indeterminate.
- K. The Commission staff, if appropriate, will identify compliance monitoring requirements and means for enforcement.

XII. GLOSSARY

A. Availability (Available Hours)

The total clock hours the unit was in service or was available for service during the report period.

B. Availability Factor*

$$\frac{\text{Availability Hours}}{\text{Period Hours}} \times 100$$

C. Equivalent Availability Factor

$$\frac{\text{Service Hours} - (\text{Equivalent Forced Outage Hours} + \text{Equivalent Scheduled Outage Hours})}{\text{Period Hours}}$$

D. Equivalent Forced Outage Hours

$$\frac{\text{Forced Partial Outage Hours} \times (\text{Reduction From Rated MW})}{\text{Rated MW}}$$

E. Equivalent Scheduled Outage Hours

$$\frac{\text{Scheduled Partial Outage Hours} \times (\text{Reduction From Rated MW})}{\text{Rated MW}}$$

F. Service Hours

The clock hours the unit generator was on line with breakers closed to bus during the period.

G. Service Factor

$$\frac{\text{Service Hours}}{\text{Period Hours}} \times 100$$

H. Capacity

1. Maximum Dependable Capacity (MDC), MW, Gross Unit Capacity, Winter or Summer whichever is smaller.
2. Design Electrical Rating, MW, Nominal Net Electrical Unit Output.

I. Capacity factor

$$\frac{\text{Total Electric Generation (MWH)}}{\text{Period Hours} \times \text{Capacity (MW)**}} \times 100$$

*Availability Factor which the owner has adopted as a goal to which the facility will be designed will be known as "Target Availability Factor.

**As defined in H1 or H2.

J. Forced Outage

An outage required to be initiated no later than the weekend following discovery of an abnormal condition.

K. Forced Outage Hours

The clock hours in the period the unit did not produce electricity due to forced outages.

L. Forced Outage Rate

$$\frac{\text{Forced Outage Hours}}{\text{Forced Outage Hours} + \text{service Hours}} \times 100$$

M. Equivalent Forced Outage Rate

$$\frac{\text{Total Full-forced Outage Hours} + \text{Equivalent Forced Outage Hours}}{\text{Total Time at 100 percent Power} + \text{Total Full-forced Outage Hours}} \times 100$$

N. Forced Outage Ratio

$$\frac{\text{Forced Outage Hours}}{\text{Total Unavailable Hours}} \times 100$$

O. Scheduled Outage

P. Planned removal of unit from service.

Q. Scheduled Outage Hours

The clock hours in the period the unit did not produce electricity due to planned removal from service.

R. Scheduled Outage Rate

$$\frac{\text{Scheduled Outage Hours}}{\text{Scheduled Outage Hours} + \text{Service Hours}} \times 100$$

S. Heat Rate

$$\frac{\text{Btu's Used}}{1 \text{ kWh Generated}}$$

T. Certificate of Conformance

A written statement, signed by a qualified party, certifying that items or services comply with specific requirements.

U. Certificate of Compliance

A written statement signed by a qualified party, attesting that the items or services are in accordance with specified requirements and accompanied by additional information to substantiate the statement.

APPENDICES

APPENDIX I
DOLLARS WORTH OF POWER PLANT MATURATION PERIOD REDUCTION
AND PRODUCTIVITY INCREASE

This Appendix provides derivation of assessments of potential commercial worth of acceleration of power plant maturation, and productivity increase each of which can be attained through implementation of certain measures designed for improvement in plant reliability.

For the purpose of illustration it was assumed that the hypothetical facility is 1,000 MW rated capacity, and one kWh will be worth \$0.05 in 1986 and beyond. It is not important how accurate the assumption is regarding the projected cost of energy. More likely than not it is understated. What is important, however, is the conclusion that the projected benefits are not insignificant. The computed worth reflects an assumption that there will be a need for the extra energy that can be realized, and if it was not generated it would have to be purchased.

Admittedly, this is the worst case scenario, because some utilities, especially the large ones may have sufficient reserve margin to supply at least part of the need, for part of the time. However, the additional energy, if not needed by the owner could be sold to another service area.

Figure 1 graphically depicts a potential commercial worth of reduction of plant operational maturity period by one year. The estimated worth is a "one time" benefit as opposed to any repetitive yearly benefit.

Figure 2 shows dollar worth as function of percent productivity (Capacity Factor) increase. The estimates shown represent yearly dollars worth, or benefits which can be expected through the most of the plant life.

The potential worth shown should be used as a tradeoff parameter against the level of investment that can be made in the plant reliability.

DOLLAR WORTH OF REDUCTION OF PLANT MATURATION PERIOD

- Assume 1. 1000 MW power plant
2. \$0.05 per kilowatthour (KWH) (1986 dollars). 1979 oil price increases by OPEC are not included.

Calculations:

(A) Area Under Curve 1

$$A_1 = 300,000 \text{ KW} \times 2 \text{ yr} \times 8760 \text{ hr/yr} + 2 + 300,000 \text{ KW} \times 1 \text{ yr} \times 8760 \text{ hr/yr} = 5,256,000,000 \text{ KWH}$$

(B) Area Under Curve 2

$$A_2 = 300,000 \text{ KW} \times 3 \text{ yr} \times 8760 \text{ hr/yr} + 2 = 3,942,000,000 \text{ KWH}$$

Area Between Curves (Shaded Area)

$$A_1 - A_2 = 1,314,000,000 \text{ KWH}$$

(C) Dollar Worth

$$1,314,000,000 \text{ KWH} \times \$0.05/\text{KWH} = \$65,700,000$$

DOLLAR WORTH OF INCREASE IN CAPACITY FACTOR

- Assume 1. 1000 MW power plant
2. \$0.05 per kilowatthour (KWH) (1984 dollars) *

1 year = 8760 hours

Percent x 8760 hours x 1,000,000 KW x \$0.05/KWH = \$

5% Yields \$21,900,000

10% Yields \$43,800,000

15% Yields \$65,700,000

20% Yields \$87,600,000

* 1979 oil price increases by OPEC are not included.

APPENDIX II

RELIABILITY - ASSESSMENT METHOD

The intent of this Appendix is to outline the prerequisites for application of this method, give key computational steps and methodologies involved, discuss limitations and conditions which have to be met in order to achieve a pre-determined reliability goal. Within this context, the material presented will appraise the reader of the complexity and the magnitude of the effort, its approximate cost and of those advantages that other, simpler methods cannot offer. The material presented herein is not intended as a mathematical model, or a guide ready for use by those who may be inclined to use this method.

The method described herein is of particular value to the designer or the owner as a check whether or not a preselected Target Availability Factor (TAF) will be met, or what design modifications are required in order to meet such preselected value. It is also likely that the owner would revise the TAF upward or downward depending on whether or not the attaining of the original TAF exceeds or falls below the resources allocated for this purpose.

Prerequisites:

To make an assessment of the potential Availability Factor of a generating unit all of the following must be known to the designer:

- o All equipment whose failure would result in forced outage (Reliability Critical Items) must be identified.
- o Equipment arrangement, the relationships among the systems and equipment therein (series, parallel, redundancy).
- o Mean Time Between Failures of all equipment (MTBF)
- o Mean Time to Repair (MTTR).

The MTBF's and MTTR's are usually those provided by the selected suppliers. If in the early stages of the project, the suppliers have not been yet selected, and the needed supplier's information is not available, the designer may have to resort to some general data bank. Such data may reflect some average values for the type of equipment, but not necessarily represent the equipment of a particular supplier which ultimately will be selected.

Assessment Process:

The analyst allocates preliminary Availability Factors to each of the plant systems.

$$AF_{(system)} = \frac{N}{\sqrt{TAF_{(plant)}}}$$

where N is number of systems

The availability of components within each system is either initially allocated per

$$AF_{(comp)} = \frac{M}{\sqrt{AF_{(system)}}}$$

where M is number of components, and tradeoffs of AF's of components are made thereafter, or AF's are computed using the following formula:

$$A_1 = \frac{1}{1 + \text{MTTR}/\text{MTBF}}$$

Parallel with or without redundant arrangements of like components and subsystems are computed per the following:

$$A_2 = \sum_{K=0}^N \frac{N!}{K! (N-K)!} A_1^K (1-A_1)^{N-K}$$

where A_2 is the fraction of time the subsystem is expected to be available for service with N components assigned the same function and K the minimum components out of N which must be functional in order to fulfill the mission.

The Availability of the entire system is the product of all A_1 's and A_2 's. The Availability of the plant is the product of Availability of all systems.

If the computed number does not equal or exceed the Target Availability Factor, the designer might add redundant components, or assign higher MTTR to some components, and repeat the computing process. The cutoff point of such iterations is when:

1. The TAF is met, or
2. The cost of added redundancies and other measures cause the cost of the project to match the allocated resources.

In addition to the computing effort, the analyst may need to structure fault trees and event trees for selected systems or subsystems as aides to plant modeling by a computer program.

Condition of Effectiveness:

It should be recognized that using the method described above does not assure that the computed Target Availability Factor will be met. The computed value of TAF will be met only if appropriate steps are taken to ensure that the used values of MTBF and MTTR will materialize. By definition--"Mean Time"--50 percent of components of a production line will fail before the MTBF. The analyst should bear in mind that the actual time to failure may vary by as much as a factor of four with respect to MTBF. The components of longer than postulated MTBF do not always compensate for those which fail prematurely because (as an example) $.90 \times .99 < .95 \times .95$, if two like components have a postulated MTBF of 0.95.

Thus, unless appropriate controls on materials, parts and manufacturing processes are imposed the chances are very good that some of the delivered "off the shelf" equipment without such controls will have a shorter than MTBF, which would invalidate the entire assessment process.

Cost:

Although some utilities have undertaken to design some of their generating facilities on probabilistic basis (method described above), none of them have progressed enough to allow making cost projection with any degree of certainty. The available information, although recent, is fragmentary and spans a wide range of estimates. These are shown below:

Case 1:

7,500,000 engineering hours were contracted to design a twin unit, 1,000 MW each, nuclear generating station. A similar facility design without probabilistic analysis requires 5,000,000 to 5,500,000 eng. hours. Thus by inference the probabilistic design effort requires about 2,000,000 engineering hours.

Case 2:

100,000 engineering hours were budgeted for probabilistic design of a twin unit, 1,350 MW each, nuclear generating station.

Case 3:

50,000 engineering hours were budgeted for probabilistic design of a twin unit, 600 MW each, coal-fired facility.

With regards to Case 1 above, it is not certain that the engineering effort included writing many specifications for Reliability Critical Equipment and formulation of the necessary quality assurance and quality control requirements. Other services also might have been included. Cases 2 and 3 on the other hand include only effort related to the design. The work is still in progress, therefore the actual cost of this effort cannot be ascertained.

Case 4:

A probability of core meltdown was assessed for one existing PWR and one existing BWR facility. The study was conducted by the Rasmussen Group. There was no need for iterative process, because "as build" drawings were available for all safety-related system. It took the group several years to conduct the study, however, the effort included a preparation, revision (based on comments received) and issuance of the final 11-Volume report (Wash-1400).

In conclusion it can be said that there is no clear cut historical record of a well defined scope and associated incurred cost that can be quoted as reasonable indicator of the total magnitude and cost. The most credible estimate appears to be reflected in Cases 2 and 3.

APPENDIX III

SEISMIC DESIGN CRITERIA

Discussed here are the options the Applicant's may have in choosing seismic design criteria for power plants. Excluded from the discussion are criteria applicable to the safety-related structures and components of nuclear power plants set forth by the Code of Federal Regulation (CFR).

Specifically, the discussion will deal with the level of peak bedrock acceleration (g) that should be considered as the basic design parameter applied to nonsafety related items of nuclear power plants and to all other types of nonnuclear generating facilities.

Option 1--Application of the Uniform Building Code (UBC)

The UBC in general provides for safety to those inside the structure in that it guards against the structural collapse. It does not provide, however, for prevention of damage. Thus in the event of an earthquake of some magnitude the resulting damage may range for minor (readily repairable) to extensive. The risk probability is not taken into account, neither are the economic tradeoffs between the cost of mitigation or prevention and the consequences of underdesign. Thus it becomes difficult under these conditions to establish a defensible position whether or not the design criteria as provided by the UBC are appropriate. The example provided below will illustrate the point.

Consider a hypothetical case where 0.2g ground peak acceleration is proposed as a design criteria on a site where the postulated Maximum Probable Earthquake (MPE) (100 year event) and the Maximum Credible Earthquake (MCE) will result in 0.4 and 0.5g respectively. It is obvious that any earthquake resulting in ground acceleration in excess of 0.2g is likely to result in some damage. What is not known are the chances of exceedence of any level of ground acceleration above 0.2g, and therefore neither the extent of a likely damage resulting from such events, nor the appropriateness of the chosen design criteria can be assessed. Consequently, the economic risk cannot be established.

Option 2--Design to MPE or MCE

Obviously designing to either MPE or MCE is a better criterion than any other level below MPE. The rationale for each is that the facility is expected to remain operational following any earthquake of a magnitude lesser than the chosen design criterion.

The probability of exceedence can be computed by:

$$\text{Prob. of exceedence} = 1 - e^{-(1/RI) T}$$

Where: RI is occurrence interval
T is mission time (Plant Life)

Thus, if the plant life is 40 years, and MPE (RI=100), the probability of exceedence is 33 percent. Now the question is, is the risk too high? Can it be significantly reduced by allocating additional, but moderate resources? Or are the resources necessary to satisfy this criterion already too excessive? The

same questions arise if the design criterion was to be MCE, with 250 years (assumed) of occurrence frequency. In this case the risk of exceedence is 15 percent. In neither case it is obvious which of the criteria is more appropriate, or even whether any of the two is appropriate.

Some analysts prefer to compute the probability of exceedence of a given ground-shaking intensity during the plant life using the following relationship:

$$P = 1 - \left(1 - \frac{1}{RI}\right)^T$$

Where: P is percent probability of exceedence
 RI is Recurrence Interval
 T is mission time (plant life)

Over the time range of interest, the two relationships approximate each other very closely. Considering the inherent uncertainties in recurrence intervals, it would not be fruitful to discuss which of these two relationships is more accurate.

If applicable, the computed probability of exceedence should be further modified (reduced) by locational analysis taking into account the location of the site in relationship to the fault length.

Option 3--Risk Versus Resource Balance

The method described below (although not the only one that can be used) disassociates the process of selection of appropriate seismic design criteria from arbitrary parameters such as MPE or MCE.

The decision maker examines the history of seismicity of a given site and establishes a frequency of occurrence of peak bedrock accelerations at a given site as function of earthquake magnitudes caused by all potential sources (faults). Only as points of reference he may also identify accelerations associated with MPE and MCE. The typical results of the generated relationship between peak accelerations and frequency is presented graphically in Figure 1. Next by considering the frequency of occurrence of each accelerations he computes the probability of exceedence of each of these accelerations during the life of the plant. These computations will produce a series of points defined as percent g versus probability of exceedence. Again, as a reference one can locate MPE and MCE on the abscissa. In addition, if each of the g's represents a candidate design criterion, one can establish a relationship between the candidate g and the associated cost of construction and place these costs on the abscissa. A typical representation of these relationships is shown in Figure 2. Writing an equation for such a curve (a translated and rotated hyperbola) and taking the second derivative of risk with respect to g and plotting these as a function of g will identify the maximum rate of change of slope a point of optimum relationship between investiture and residual seismic risk. Considering the low level of accuracy of the geotechnical historical data it may suffice to locate the optimum point of the risk/cost/g relationship visually, as indicated in Figure 2. Examination of this figure shows that the optimum design point (g) is located where a small increment in g (also cost) results in a large reduction in risk while only a small additional reduction in risk would be realized through additional investitures.

g = ground acceleration (bedrock)

MPE - g corresponds to Maximum Probable Earthquake

MCE - g corresponds to Maximum Credible Earthquake

RI - Recurrence Interval

g = ground acceleration (bedrock)

MPE - g = corresponds to Maximum Probable Earthquake

MCE - g = corresponds to Maximum Credible Earthquake

g = Ground Peak Acceleration

P = Probability of Exceedance of g during plant life

Where the MPE or MCE may lie with respect to the optimum point is now immaterial, because the risk, cost and benefits are in a proper relation of one to another. Thus, unless some other considerations are brought forth, Option three (the method described above) appears to be most reasonable.

Taking into Account Risks Associated with More Than One Earthquake Source

When a site is being considered where ground-shaking can result from seismic events which can occur along more than one active geologic fault, the potential contribution to the frequency of occurrence of ground-shaking attributable to each must be accounted for. A histogram similar to the one shown in Figure 1 for each fault has to be constructed.

Then, the probability of exceedence of a given, but the same intensity of groundshaking (g) is computed as follows:

$$P = 1 - e^{-T\left(\frac{1}{RI_1} + \frac{1}{RI_2} + \frac{1}{RI_3} + \frac{1}{RI_x}\right)}$$

where: RI_1, RI_2, RI_3, RI_x are Recurrence Intervals of the same g attributable to faults 1, 2, 3, and x, respectively. Other symbols are as previously defined.

Making such computations for series of g's, one can construct a composite curve, similar to Figure 2, which would account for all known contributions.

Alternatively, if the probability of exceedence of ground-shaking (g) attributable to each fault has been established, as shown in Figure 3, the combined effect, or the resultant probability that a given g will be exceeded at the site during the plant life can be computed as follows:

$$P_{\text{Combined}} = [1 - (1 - P_1)(1 - P_2)(1 - P_x)]$$

where: P_1, P_2 and P_x are the probabilities of exceedence attributable to faults 1, 2, and x, respectively.

In summary, the analytical procedures, as outlined above, eliminates the dependence on arbitrary selection of design criteria which may be difficult to justify.

The methodology shown identifies the risk associated with the seismic design/performance criteria under consideration and it provides for selection of such criteria for which the residual risk becomes justifiable.

APPENDIX IV
 IMPACT ON SYSTEM RELIABILITY OF
 LARGE AND SMALL EQUIVALENT CAPACITY
 GENERATING STATIONS

This Appendix provides quantitative evaluation of the impact large and small capacity units may have on availability of power in the service area. Also, it will be shown that higher capital requirements for construction of small units cannot be compensated for by multi-unit arrangements if the Availability Factors of such units is low. Thus the importance of achieving Availability Factors as high as cost/benefit analysis may justify, will become evident.

The examples provided below will illustrate all of the above. To avoid clouding the issue, consideration of partial outage has not been included.

Case 1:

Consider addition to the service area of a single, 1,200 MW capacity baseload unit.

It is understandable that 20 percent and more savings in capital costs constitutes enough of an incentive to make it a preferred choice over two-equivalent capacity smaller units. However, unless the Availability Factor of this unit is 0.8 or higher (Capacity Factor of about 0.7), the advantage of the lower capital cost may be offset by low productivity (see Appendix I). In addition, the service area will be required to make up 1,200 MW of generating capacity 20 percent of the time. Note: The energy expected to be produced by this unit will be $0.8T \times 1,200 \text{ MW} = 960 \text{ MWT}$, where T is usually one year (8,760 hrs.)

Case 2:

Consider addition to the service area of a generating station consisting of two 600 MW baseload units.

Assuming that each unit has Availability Factor of 0.8 the following questions should be asked:

1. What percent (P) of time (T) both units are expected to be in service?
2. What percent (P) of time (T) one unit is expected to be in service?
3. What percent (P) of time (T) at least one unit is expected to be in service?

Using the following equation:

$$P = \sum_{K=0}^N \frac{N!}{K! (N-K)!} (A)^K (1-A)^{N-K}$$

Where N = Number of units in the generating station

K = Number of units in service

A = Availability Factor of each unit

P = Percent of time the generating stations will operate with K units in service

the availability for service and the energy that may be generated is computed as follows:

$$N = 2; K = 2; P = 0.64T \times 1200 \text{ MW} = 768 \text{ MWT}$$

$$K = 1; P = 0.32T \times 600 \text{ MW} = \underline{192 \text{ MWT}}$$

$$K \geq 1^*; P = 0.96 \quad 960 \text{ MWT}$$

*Denotes that at least one unit will be in service.

It is to be noted that the percentage of time two units are expected to be out of service is $(1-0.96)$ or 0.04, and that a two-unit generating station is expected to generate no more energy than a single unit of equivalent capacity and the same Availability Factor.

However, while a single large unit may generate no energy 20 percent of the time, two-half size units are expected to produce full power 64 percent of the time, and one of the units is expected to produce power about 1/3 of the time. Similar calculations show that a generating station consisting of four-300 MW capacity units of 0.8 Availability Factor each, will be also generating an average of only 960 MW over the same period of time. In this case higher construction costs have been incurred without any increase in the amount of energy produced. However, the percent time that at least K number of units will be in service is as follows:

$$N = 4; K \geq 1; P = .9984T$$

$$K \geq 2; P = .9728T$$

$$K \geq 3; P = .8192T$$

$$K = 4; P = .4096T$$

It is interesting to note that a multi-unit generating station arrangement does not compensate for low Availability Factor of such units, because the energy produced by such a station will be less than that which may be produced by a single unit of equivalent rated capacity, but of higher Availability Factor. For example, if the unit Availability Factor in a twin unit station is 0.6, the energy produced by such station will be:

$$N = 2; K = 2; P = 0.36T \times 1200 = 432 \text{ MWT}$$

$$K = 1; P = 0.48T \times 600 = \underline{288 \text{ MWT}}$$

$$K \geq 1; P = 0.84 \quad 720 \text{ MWT or } 0.6 \times 1200 = 720$$

Sometimes it is convenient to analyze problems of this nature from the perspective of probable time that 1, 2, 3 ... K units will be out of service rather than in service. The mathematical tool for this approach is shown below:

$$P = \frac{N!}{K! (N-K)!} (A)^{N-K} (A)^K$$

Where N = Number of units in the system

K = Number of units not in service ($K \leq N$)

A = Availability Factor of each unit

P = Expected percent of time T that K number of units will be out of service

In conclusion, the overall availability of the station for generating energy is no greater than the average availability of the generating unit(s) within the station. However, while a single unit generating station will produce no energy part of the time, a multi-unit station will produce at least some energy over a greater portion of time than a single unit may.

Therefore, it makes sense for generating stations to consist of more than one unit. In addition, coupling a multi-unit arrangement with reasonable Availability and Capacity Factors, and lower construction cost makes large units more desirable than small generating units.