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ABSTRACT

This report is a record of the proceedings of the EPRI Availability Engineering Workshop, held in Albuquerque, New Mexico, October 17-19, 1977. The workshop evolved out of an EPRI-sponsored, eight-month study by Holmes & Narver, Inc., titled, "Assessment of Methods for Implementing Availability Engineering in Electric Power Plants," EPRI Report NP-493, May, 1977.

FOREWORD

AVAILABILITY ENGINEERING WORKSHOP PROCEEDINGS

This report is a record of the proceedings of the EPRI Availability Engineering Workshop, held in Albuquerque, New Mexico, October 17-19, 1977. The workshop evolved out of an EPRI-sponsored eight-month study by Holmes & Narver, Inc., titled, "Assessment of Methods for Implementing Availability Engineering in Electric Power Plants," EPRI Report NP-493, May, 1977.

The 101 participants represented 32 utilities, 14 architect-engineers/consultants, 5 equipment manufacturers, and 6 other organizations. Covering a wide geographic distribution, the participants divided into small working groups to address the various issues and concerns involved with increased application of availability engineering methods in the utilities and related industries. Summaries of the working groups' recommendations and conclusions are included in the report.

Conducting a successful workshop requires the combined efforts of many individuals. As coordinator, I would like to acknowledge the preparation and fine presentations by each of the speakers. The working group chairmen and reporters worked hard to focus the discussions and prepare drafts of their reports, which were distributed at the final reporting session. Mr. E. B. Cleveland of Holmes & Narver very effectively organized the working group sessions and coordinated the preparation of these proceedings. Finally, Ann Long, the Workshop Secretary, kept the registration correspondence flowing smoothly, prepared programs and participants lists, typed the working group draft reports, and generally assured a successful workshop.

It is clear from the response of the participants and the evaluation of an _ad hoc_ review committee that availability engineering can be effectively applied in the industry. This report concludes with recommendations for a continuing effort to expand the activities, ultimately leading to significant cost-effective improvements in power plant generation productivity.

Robert L. Long
Project Manager
University of New Mexico*

*On sabbatical leave to EPRI, 1976-1977

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INTRODUCTION AND EXECUTIVE SUMMARY

EPRI Technology Planning Study, TPS76-662,* entitled "Assessment of Methods for Implementing Availability Engineering in Electrical Power Plants," was conducted to define and assess availability engineering, its practice, its possible rewards, and its limitations as a means of increasing productivity in existing and new electric power plants. The study concluded that availability engineering can be a worthwhile supplement to the traditional engineering process and should be used by the industry. The principal recommendation of the study was that EPRI should take additional steps to communicate throughout the industry the potential benefits of availability engineering and to discuss methods of implementation.

This Workshop was conducted in response to that recommendation and a general industry-wide need to improve communications among those organizations that can impact power plant productivity.** The objectives of the Workshop were:

- To present the methods of availability engineering
- To discuss their application within the electric utility industry
- To formulate positions on a number of key implementation issues

Management and engineering personnel from utilities, architect-engineers, consultants, equipment manufacturers, universities, and government agencies were invited to the Workshop and encouraged to participate in its activities.

This book of proceedings contains the text of presentations made during the first half of the meeting on availability engineering methodology and its implementation in the power industry. Records of working group topics, membership, and conclusions are also included. In addition, supplemental material has been provided in the appendices to help the attendees and others to gain a fuller understanding of availability engineering technology. Appendix B is an annotated bibliography which is an expansion of the one contained in EPRI NP-493. It also

*The results of this study are documented in EPRI Report NP-493. A copy of this report was provided for each attendee of the Workshop.

**See EPRI NP-543, "Optimization of Reliability Data Systems" EPRI Study RR826 Phase 1 report.

contains a subject matter cross-index. During the course of the meeting several extemporaneous talks were given on various facets of availability engineering; Appendix C contains material provided by some of these participants to document their remarks.

TUESDAY LUNCHEON ADDRESS

Ross Mullins
Vice President
Public Service Company of New Mexico

I appreciate this opportunity, on behalf of the Public Service Company of New Mexico, to share a few thoughts with you. I congratulate the EPRI organization for scheduling a workshop such as this, and I hope this is just a beginning, because these are the kinds of workshops that are really needed to get to the roots of our problems. I want to personally thank Bob Long for getting this program scheduled here in Albuquerque. I would like to share a few thoughts with you, first about our company. Then I have some observations and questions related to the workshop. These are questions which I don't have the answers to, so I'll just throw them out. Maybe they will stimulate your thinking.

Let me take a few minutes of your time to share with you some of the activities in which my company has been and is now involved. In New Mexico, we are fortunate to have a variety of energy resources which can be converted to electricity. We have oil, natural gas, coal, uranium, geothermal in the offing, and lots of sunshine, as you have noticed today. PNM is involved in either using or trying to learn how to use each of these resources.

The first resource I'll mention is natural gas. This was the backbone of our system until the past decade. The reasons are good ones. It is easily the cleanest and most conveniently used boiler fuel. As you know, a large percent of the electricity in this country is produced by boiler driven steam cycle generating stations where water is converted to steam to drive turbine generators. The other types are gas turbine generators and nonsteam cycle generation such as hydroelectric, and New Mexico obviously isn't well suited for hydro. There is one small hydro unit at Truth or Consequences.

Back to natural gas. The artificial price ceiling put on this fuel by the government in 1954 stimulated the use of a resource which was largely being wasted or left undeveloped. Gas boilers are much less expensive to build than other types and while the fuel price remained constant it was our best alternative. However, the artificiality of the price stimulated use beyond supply and now, in less than 20 years, we find demand far outrunning production. Something had to give and it did. The price we pay has risen by almost 500% in just the past four years. We saw this trend some time ago and by the early 1960's we were buying coal leases and planning for conversion to coal-fired generation.

Our first use of coal was through our participation in the two large units at the Four Corners power plant. Then we joined with Tucson Gas and Electric, to build the San Juan generating station (1700 MW gross) which is 9 miles north of Four Corners. Recently, we announced our participation with two other parties within the state, in the New Mexico station about 35 miles south of Farmington, 2000 MWe. This has brought us quickly into the position of a coal dominated system and last year about 65 percent of our energy was generated by coal-fired plants. Gas on our system is currently over four times as expensive as coal and this trend will no doubt continue. Although the coal-fired stations are much more complex and costly, the lifetime operating costs are significantly lower because of the lower fuel cost. Our rates are well below the national average. And much of these savings being enjoyed by New Mexico consumers is due to our shift to coal. By 1980, we hope to have a system which relies for 80 percent of its generation capacity on coal. Environmental protection requirements are boosting the cost of building coal stations by almost 50 percent, the ultimate energy production costs are still well below gas-fired operations and, with the probability of gas being banned for boiler use in the future. This brings an old economic law into play which says that price does not make any difference if there isn't any to buy. In other words, "Nobody gets any if there ain't none."

This brings us to our involvement in nuclear power. In an effort to have a generation base that can rely on a variety of resources, we joined with four other utilities in the planning and construction of the Palo Verde Nuclear Station south and west of Phoenix. The power from the first of these units is scheduled to begin flowing into our system in 1982. The other two units are scheduled for service in 1984 and 1986.

It is possible that we will be a partner in a nuclear unit in New Mexico before the turn of the century, but no firm plans have been made. We have long said that there is no single answer to our energy problems and that all resources will be needed in the future. This is why we are involved in solar studies and geothermal activities.

As for solar power, we believe that the greatest short-run application is in direct home heating and water heating. We are trying to determine how feasible the use of sunshine is for use in electric generation, and we have asked ERDA to support a project here that would add a solar mirror field and tower-mounted boiler to a conventional gas-fired unit. This would eliminate the need for expensive heat storage systems, new generators and auxiliary equipment. Although we haven't had a positive confirmation, we understand that ERDA is quite interested in this proposal. It would allow the use of sunlight during the day and provide the gas boiler for possible nighttime use.

With regard to geothermal energy, we are working with Union Oil, which has been investigating the geothermal potential in the Jemez Mountains north and west of Albuquerque. Again, we are asking ERDA for funding assistance for this project simply because at this point in time, based on our analysis, the electricity produced by geothermal would not be competitive with our coal-fired units. Since we do not think that we could burden our customers with additional costs right now, we are asking ERDA to help us in the R&D area with the geothermal project.

With all this frantic planning and varying of power production facilities, you might ask why are we doing it. The reason is that the population growth of New Mexico and the economic improvement in our state, combined with greatly increased mining, commercial, and industrial needs, have made us the fastest growing utility of our size in the country. Our major concern is not with selling energy, but with producing it fast enough to meet the growing needs of our state. A recent issue of Power magazine stated that it has been estimated that 60 percent of all unplanned power outages--and you notice they don't call them forced outages--are caused by rotating machinery failures. (These empty statements bother me but they do get published and out before the general public.) I think that this is the kind of thing this workshop is addressing.

Now I would like to share with you some of my observations about this Workshop and how I see some of the things related to it. I am not going to get involved in the definition of availability. I am even going to choose another word, "performance." To me you can use your own definition for performance, crank in cost, the capacity factor, availability, whatever you like. There is a commercial on TV that has stimulated my thinking in this area of power plant maintenance, design, and operation. The commercial I'm talking about has a mechanic standing there looking at this oil filter in his hand, explaining everything the oil filter would do for your car. Then as he looks over his shoulder at a mechanic overhauling an engine, he tells you the price of the filter and says, "You can pay me now or you can pay me later." I believe there is a message in this TV commercial for us who design, engineer, operate, and maintain power plants.

The relationship between capital outlay and operating costs is the next area which I would like to focus on for a few minutes. The electric utility industry is a capital intensive industry and it is becoming more so with escalating costs and pollution control requirements. Let us assume that the rate making commissions respond favorably to these increased capital outlays. That's a big assumption. Then we come to the items on the operating statement that we can do something about. That is the operating and maintenance expense. Electric utility O&M expenses are made up of various major items. We include fuel cost, scheduled overhauling of generating units, forced outage repairs, and expenses of normal operation and maintenance. In our company about two-thirds, or 66 percent, of our total O&M costs are in the power production area when you include fuel. If we can increase the time between the scheduled overhauls; if we can reduce the duration of forced outages; then we are moving in the right direction to reduce the O&M costs. I don't have the answers, so I hope you'll start working on them here and now.

There are countless decisions that are made during the design, engineering, and procurement phase of a new power plant which could improve the performance. In making these decisions, I think we should focus on the message of the TV commercial: Pay me now or pay me later.

Many of these decisions were based on cost benefit studies. These studies are needed to guide us in making our decision. The cost of a piece of equipment can be determined within limits. Include the escalation, and even if you are off one percentage point or so, you are not going to be too far off the final price of a piece of equipment. Where I have a hang-up is in the values assigned to the benefits. In my opinion, we are understating certain cases and possibly overstating others. Take the case of fuel, for example. Do we really have a good handle on the cost of fuel ten, fifteen, twenty years down the road? Many studies that I have seen show savings benefits based on these differentials by comparing the cost of your fuel with someone else's. What happens to the analysis if some of the high-cost fuels simply become unavailable in the future? It comes back to what I said earlier: "nobody gets any if there ain't none". What I'm saying is let's look at an alternative, or what would be the answer if we did not have these fuels available.

I believe that at our present-day plastic money (credit card) thinking has crept into the economic analysis that we use in our decision-making. We have become too accustomed to paying for things on the installment plan, and paying later. What is really being said is, "I'll pay for it later on the installment plan." Another thing we must look at when we analyze whether we pay now or pay later is what is the best for our customers, our investors, and the utility.

Another thought goes back to availability, performance, capacity factors and what I have been a proponent of for a long time. Perhaps we should judge a unit against what it was designed to do and only that. It is great to compare it with the national average EEI statistics and what not, but I think that before we can really find out what that unit is doing, we must determine what it was designed to do and how it is measuring up to that standard. In establishing a performance goal for a unit, as stated here this morning, you must start with the owner. He must take the steps to see that he gets that performance designed into the unit.

The majority of power plants are designed and engineered by A-E firms. I know that some large utilities have their own engineering staffs that do the engineering and procurement for major power plants. I think that A-E's are doing a great job of putting the major components together and furnishing the client with an operating unit. I'm sorry to say, however, that in most cases that is where A-E involvement stops. It is my feeling that the A-E's must continue to be involved after the unit goes operational if there is to be any hope of getting improvement in the next unit that an A-E designs for you. We must close that loop and get A-E's the feedback. There must be continued input to the A-E from the owner. How else will an A-E know that a certain motor, fan, or system is not performing up to par? I'd also like to throw in this big category, materials, and inspection of materials that go into power plants. The major pieces of equipment in the power plant are important, but it is these small pieces--nuts and bolts--that will break the backs and morale of your maintenance people. There is a move underway through the EEI prime movers to try to help close the design and materials loop between the A-E's and equipment manufacturers on equipment performance and failures.

I would like to leave you with one final thought. This complex society--its ideas, people, technology, and money--when all these are wrapped up into the concept of energy in this country, it presents a mystifying picture to the average citizen. It is even mystifying to most of us in this room, although we are working with it on a day-to-day basis. So I think it is up to us who are more interested in energy and involved in energy-related activities to explain this situation to the general public. When it comes down to some issues like the environment or nuclear power, we must be sure that people are properly informed. We must keep in mind what I said about the TV ad: you pay now or pay later. But remember, you must pay if we are going to continue to have energy.

SESSION 1
AVAILABILITY ENGINEERING

Chairman: J. E. Prestele

INTRODUCTION TO AVAILABILITY ENGINEERING

R. L. Long

METHODS OF AVAILABILITY ENGINEERING

E. B. Cleveland

IMPLEMENTING AVAILABILITY ENGINEERING
R. H. Gauger

EXPERIENCE IN AVAILABILITY DATA GATHERING

Mrs. R. K. O'Hara

INTRODUCTION TO AVAILABILITY ENGINEERING

R. L. Long
University of New Mexico

Joe Prestele's opening comments and the workshop booklet[1] make it quite clear that utilities have recognized the need for improved reliability and productivity of power generation facilities. When you can begin to look into the subject, you find that one of the reasons that people are obviously interested is that an increase in capacity factors to 65 percent for nuclear and large coal-fired units by 1980 could result in consumer savings of several billion dollars in fuel costs. A further increase to 70 percent by 1985 could save several billion dollars per year, leading to cumulative fuel cost savings of $10 to $15 billion in a ten-year period.[2] One reference in a 1976 American Power Conference paper suggested levelized power generation costs savings of two and a half mills per kilowatt hour could be achieved.[3]

Likewise, if we could decrease the forced outage rate of nuclear and coal-fired units from the current level of 15 percent to 10 percent by 1985, we could reduce our reserve margin requirements by as much as 5 percentage points, which amounts to more than 40,000 megawatts. New capital requirements could be reduced by as much as $20 billion (1975 dollars). Another advantage would be that of reduced oil and gas consumption. It is estimated that if we could increase the average capacity factor level to 70 percent by 1985, we could reduce our dependence on oil and gas consumption for power generation by more than one million barrels of oil per day. So these are the fundamental reasons why we need to be interested in improving availability.

There have been many papers in the proceedings of the American Power Conference, EPRI reports, the IEEE Annual Reliability Conference, and the ANS Executive Conference on Improvement of Power Plant Reliability a year ago calling for more up-to-date and accurate information pertaining to generating unit availability and equipment reliability. This need for data, as Joe has mentioned already, will, I suspect, be a recurring theme of the Workshop in the sense that many of the activities of reliability/availability engineers require better data than we sometimes have available. Joe mentioned that there is an Industry-Government Steering Committee that operated for a year and was my first contact with a number of you that has surveyed the industry, by talking to equipment manufacturers, A-E's, consultants, and government agencies, regarding their needs for reliability data. That committee's report has come out in draft form and will be in final form very shortly.

Joe also mentioned some EPRI activities, including a Holmes & Narver study, which have been looking at reliability data needs and how we might improve the existing systems. There are also a number of other projects at EPRI in this area. However, even with good data, there is a need for more wide-spread application of this systematic, disciplined approach to the improvement of power plant availability.

One of the fellows in our planning session this morning mentioned that, in his particular company, there really was not any systematic approach to specifying availability criteria for new plant orders. I believe this situation is changing very rapidly. But it is pretty apparent that when you begin to do a project like H&N did to prepare its report, examples of utilization of reliability engineering techniques in the utility industry are not easily found. You are not overwhelmed with references, nor are you overwhelmed with volunteers to speak on the subject. It is an area that needs work, and that is the basic motivation for this workshop.

There are a number of reliability engineering techniques that have been developed primarily for the aerospace and manufacturing industries and that may be applicable to our industry. I think this is evident, particularly from some of the surveys we did while I was with EPRI, that some utilities and A-E's are already developing fairly sophisticated systems and have expertise in the applications of reliability/availability engineering. Many papers (e.g., Reference 4) have appeared that advocate using some of these analytical tools listed in Table 1. Ed Cleveland will talk about this.

I am sure that there are many other things that could be listed, but these are just a few that I identified looking at current papers, of things that utilities' people said they were or ought to be using. I emphasize that these were utility

Table 1
AVAILABILITY ENGINEERING TOOLS

1. RISK ANALYSIS
2. LINEAR PROGRAMMING ANALYSIS
3. DECISION TREE ANALYSIS
4. DESIGN REVIEW
5. FAILURE MODE ANALYSIS
6. REDUNDANCY IN DESIGN
7. CRITICAL COMPONENT IDENTIFICATION
8. PROOF TESTING

papers in the American Power Conferences suggesting that we could improve the availability of power plants by applying risk analysis, linear programming analysis, decision tree analysis, formalized design review, etc. When I look at this list I immediately say, "But we (the utility industry) are doing that." When I was with ConEd in '70/'71, we did many of those things. But we did not do them in a very disciplined or formalized way and I think many times we missed some very great benefits. Having been trained as good engineers, we instinctively think along a lot of these lines. If you had been trained as a nuclear engineer, as I have, you would think "risk analysis" because it is drilled into you, just as we drill it into our students at UNM from the time they arrive on campus. But we haven't really learned, in many ways, the formal procedures for accomplishing these tasks.

This leads me to restate the basic objectives of the Workshop. First, we want to present the concepts and methods of availability engineering. Second, we want to elicit from this audience the possible applications within the electric utility industry and identify the possible problems. Many times, people who get very enthusiastic about a particular discipline, like the applications of availability engineering, do not recognize some of the problems faced by the people who have to do the job. That is why we think the working groups are very important. We want you to point out to us where some of the problems are. You may suggest that a power plant is a more difficult system to analyze than those operated by the aerospace industry. Utilities are a bit amorphous in that they do not all do things alike. They do not all have the same problems; e.g., distribution systems may be quite different. Thus, our third objective is to formulate through the working group sessions positions and recommendations on a number of key implementation issues. So that you will know what we have accomplished, we have asked our working chairmen and reporters to sit down at the end of the afternoon tomorrow (before they have their dinner) and prepare a first-draft summary of their groups' outputs. Tomorrow evening these will be typed and reproduced for distribution on Wednesday at our concluding session. We believe that is going to be a very important part of the process. EPRI is going to produce the proceedings, but it will take some time. Finally, the fourth objective is to stimulate and encourage more effective communications among utilities, equipment manufacturers, A-E's, and consultants. This was a recurring theme of the Power Plant Data Systems Steering Committee meetings. Group after group would come and say, "We just do not get the information we need when we need it." We must find better ways of communicating and we hope the Workshop will stimulate effective exchange of ideas among various groups.

To give you an idea of the makeup of our audience, I did a quick count of the preregistration list and the results are shown in Table 2. Of the thirty-two different utilities represented here, several have sent more than one person, as have the fourteen architectural-engineering or consultant companies.

I would like to turn now to defining a couple of terms, and these are basically the definitions from the H&N report.[1] Ed Cleveland and I found that we had a lot of difficulty talking with utility people about reliability engineering when the EPRI project began. One of the problems was the vocabulary. Reliability engineering for many utility people immediately translates "transmission and distribution system reliabiltiy," and that was not what we were talking about. We were more interested in power plant reliability. So we had to try to find some other vocabulary that we could start out with, and that is how the term "availability engineering" got on the cover of the H&N report. We were looking for a term which, although it might confuse people, it would not at the same time close their minds.

"Reliability" is defined in many textbooks, and I looked through a number of them just to confirm that they were reasonably unanimous. "Reliability" is, basically, the probability that an item will perform the required functions under specified conditions for a specific period of time. I am going to give you a rather mundane example a little later. The next term, "availability," is expressed as the probability that an item will be operational at a randomly selected future instant in time. I think that this is reasonably consistent with the way that term is used within the utility industry. When you try to put it into numbers then, people use different equations and we have some confusion. But it is the definition in the report that you all have. "Maintainability" is defined as the probability that an item will be restored to a specified condition within a specified period of time when maintenance is performed in accordance with prescribed procedures and resources. That seems to me to be a mouthful, and yet if we are going to do some quantitative analysis we need to specify these terms rather precisely so that we can attach numbers to them and use those numbers to guide our activities. Finally, "availability engineering" is defined in the report as an engineering activity that uses the proven methods and probabilistic data of past performance to set and achieve a specific level of availability at a

Table 2

WORKSHOP PARTICIPATING ORGANIZATIONS

UTILITIES	32
AE/CONSULTANTS	14
MANUFACTURERS	5
UNIVERSITIES	2
OTHER	4

minimum cost. Again, as we talked this morning in the preliminary planning session, this concept of availability engineering being an activity in which most engineers are involved is a very important one. We are not trying to do something that we do not ordinarily do; we are trying to organize and get a systematic approach, to use the data available, so we can be more effective at the job that we have tried to do over the years.

As one extreme situation, I would like you to consider the one-of-a-kind design typified in history by a particular individual. This, by the way, is from a delightful book which I recommend to you. It is a book called Reliability Concepts in Engineering Manufacturing by a British professor named Brook.[5] It's a little thin one that I got out of the UNM library. The author is a professor who is an engineer. He is very practical. He uses the example shown in Figure 1. He says, basically, that Noah had one chance to produce a reliable vehicle for a specific task: to produce an ark which would ride out a storm lasting 150 days. Now Professor Brook points out that the design specifications were correct, that is, "Make me an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch." Those were the specifications given to Noah. It seems likely that the designer of that ark had made an inspired guess that pitch within and without was sufficient to ensure that the ark would achieve its one-of-a-kind requirement. The type of mission and the mission time were known in advance. But there was no opportunity for testing the design, materials, or components. Actually, that might sound like some modern day project. The penalties for manufacturing such a reliable product under those circumstances were basically that the ark was probably over-weight, it was most likely incredibly expensive, and it would probably not have sold at an economic price. Nevertheless, the ark was unquestionably a vehicle with 100 percent reliability. The design was reliable due to simple construction, suitable material (gopher wood), minimum cutouts (there was only allowed to be one door and one window), and suitable finishing treatment (pitch). So there is an example of one-of-a-kind design.

At the other extreme, of course, we have the modern-day power generating station which is designed to operate for a lifetime of thirty to forty years. In some of the conversations I have heard recently, utilities are hoping that some of the stations that have already operated thirty years will operate another thirty years. We would like to have a lifetime availability of at least 80 percent or better. The plant design is complex and certainly dominated by economic concerns.

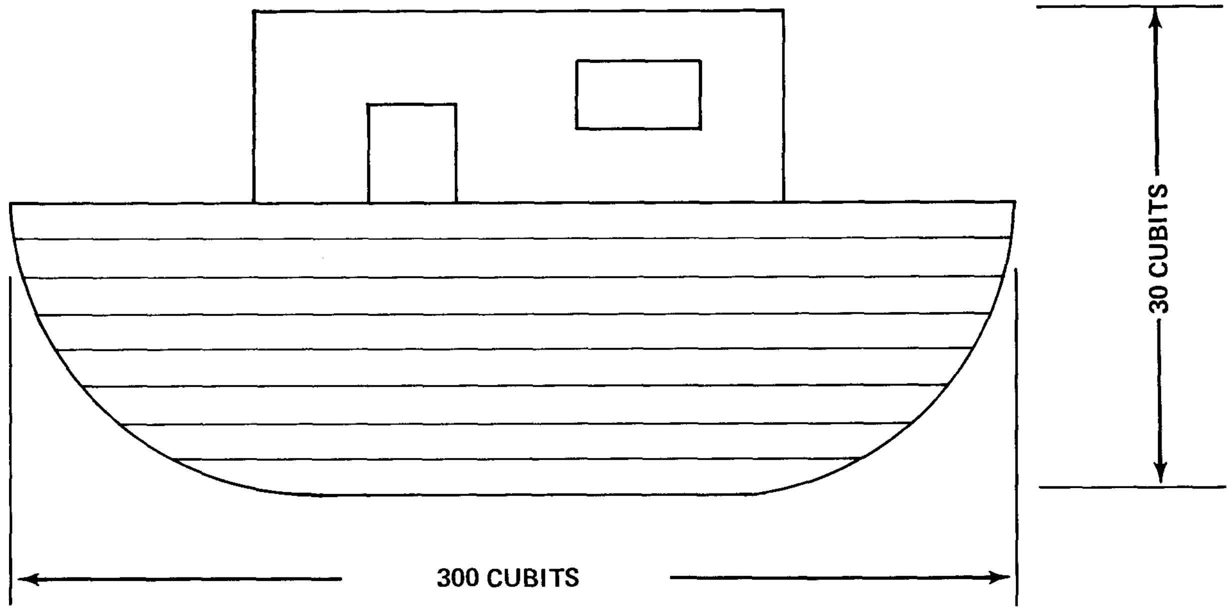

Figure 1. Example of Reliable Vehicle Design

There are all sorts of pressures from many different directions, e.g., regulators, environmentalists, company vice presidents.

The Holmes & Narver report suggests the need to consider a variety of ways to improve power plant availability. I would like to review those ways quickly. There are two alternatives. One is to reduce the frequency of outages (Table 3) and the other is to reduce the length (Table 4).

Now I want to mention one other item, not to spend time on it, but simply to point out that there are techniques that reliability engineers have developed that allow you to begin to translate from general criteria (that say that I want 80 percent availability in my plant) to something that the design engineer can work with. The example in the H&N report that we distributed shows that (1) if you have the goal of wanting an outage rate or unavailable hours to be a maximum of 10 per year per particular item, and (2) if either by gut feeling, by talking to the maintenance people, or by hard data, you found that the average time to repair that particular pump or valve or component of whatever type is about 20 hours, you could translate very readily (using Figure 2) to an allowable failure rate of .5 failures per year. That is something that you can give to the designers and say, "Look, I have to have an item that is only going to fail once in two years." Then the design engineer has a number that he can work with and begin to meet that specification. You also have a measure for determining the success of the deisgn. The purpose of showing Figure 2 is just to emphasize this orderly progression. We must get away from general goals to rather specific ones if we are going to achieve real improvements.

Now I suspect all of you have already seen the KISS and P^6 principles, but the last things I want to cover are some general approaches to reliability. I know all of you are familiar with the KISS (Keep it Simple, Stupid). But I thought some of you might have missed the P to the sixth power principle, which was one I learned in a military tactics course. It is: "Prior Planning Prevents P Poor Performance."

Professor Brook has other suggestions to add to these. In his chapter on an approach to a reliable design, he suggests, first, that there needs to be a practice both in the users' and in the designers' groups of cataloging design experience. Many times people try something and reject it, but do not leave a record behind. So somebody tries the same thing again. Second, keep a good

Table 3
WAYS TO REDUCE FREQUENCY OF OUTAGES

SCHEDULED OUTAGES

1. LENGTHEN THE PERIOD BETWEEN REQUIRED SERVICING AND OVERHAUL BY USING BETTER EQUIPMENT.
2. EXPAND ON LINE MAINTENANCE CAPABILITY.

NONSCHEDULED OUTAGES

1. USE EQUIPMENT AT DERATED LEVELS.
2. USE INSTALLED SPARES.
3. EMPLOY REDUNDANCY WHERE FEASIBLE.
4. REDESIGN TO SIMPLIFY SYSTEMS AND ELIMINATE WEAK POINTS.
5. IMPROVE PREVENTIVE MAINTENANCE BASED ON FAILURE TREND DATA.
6. USE TREND DIAGNOSTICS TO ANTICIPATE REQUIRED MAITNENANCE.

Table 4
WAYS TO REDUCE DURATION OF OUTAGES

1. REDESIGN TO IMPROVE ACCESSIBILITY.

2. PROVIDE FEATURES TO INCREASE EASE OF EQUIPMENT MAINTENANCE.

    - WORK PLATFORMS
    - LIFT LUGS/DEVICES
    - HOIST POINTS
    - PROPER TOOLS

3. IMPROVE RADIATION CONTROL TECHNIQUES (NUCLEAR).

4. EXPAND INGRESS AND EGRESS PROVISIONS.

5. CREATE MORE TOLERABLE WORK ENVIRONMENT.

    - LIGHTING
    - TEMPERATURE
    - ODOR AND SOUND CONTROL
    - CLEANLINESS

6. REDEFINE TASKS FOR PRECISION AND SCHEDULE.

7. INCREASE PROBABILITY THAT SPARES WILL BE AVAILABLE WHEN NEEDED.

8. ASSURE PROPER MAINTENANCE PROCEDURES ARE ON FILE.

9. ASSURE THAT WORK FORCE IS PROPERLY TRAINED, MOTIVATED AND SUPERVISED.

10. ASSURE THAT ALL REQUIRED TOOLS AND EQUIPMENT ARE ON HAND.

11. INCREASE DURABILITY OF EQUIPMENT USED IN INSPECTION, TEST, MAINTENANCE AND OVERHAUL.

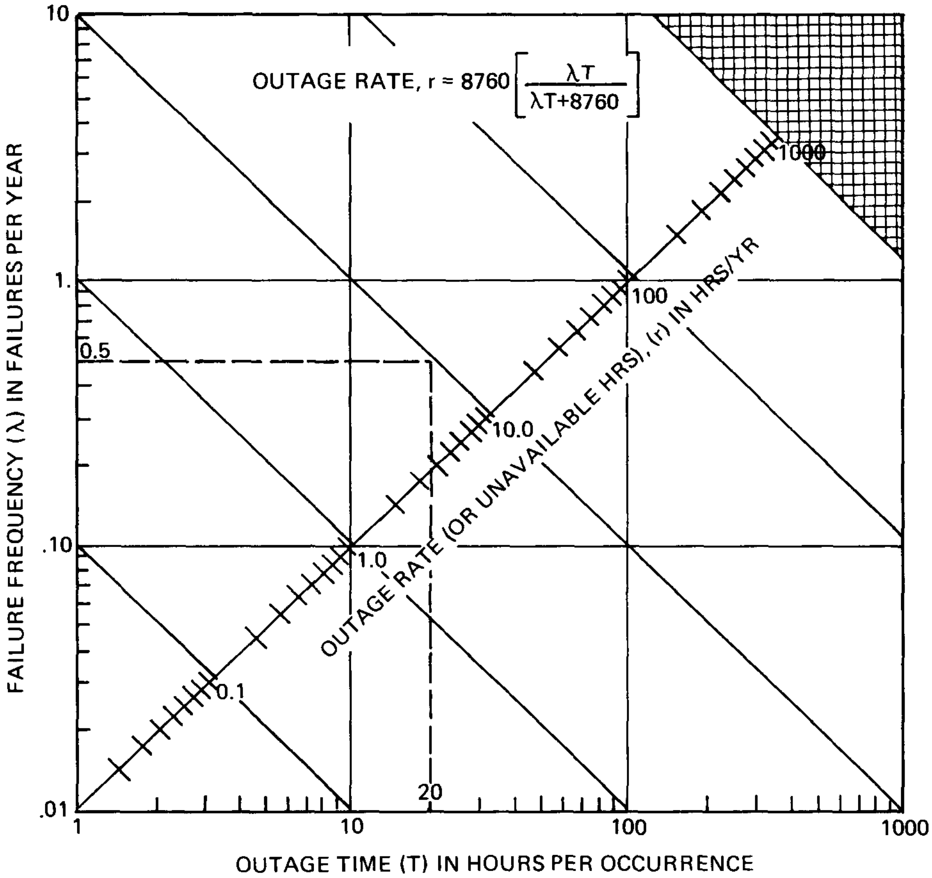

Figure 2. Average Outage Rate Conversions

service history record. This is one of those communication problems, because sometimes utilities, like the users, may not have a good record and the manufacturers do not learn of either the bad or good performance of components. His third suggestion was to swallow your pride and start walking. He is now talking to a reliability (availability) engineer and he says that this is the busy engineer's approach to failure analysis and design review meetings. Instead of going to design review meetings, start walking and go to the people who are going to give you trouble. Forget that you are the most brilliant person in the business and go to the person whom you believe is least likely to approve the design solution that you have and get his opinion. This idea is very basic, and I think there is value in it. We sometimes do not test our ideas on other people, particularly if we think they might be critical. It is safer to go to the person we know, maybe our subordinate, or maybe our best friend. They are not likely to say anything unkind. So, Brook says, swallow your pride, forget you are the smartest one, and go after the people who can help you. Then his fourth item is the desirability of having reliability/maintainability checklists. The most credible checklist he suggests is one that lists both all the failure modes that have occurred on previous occasions and those due to an in-service failure. He is suggesting that there is a need to be systematic. Where you can get data, get it; where you can't, use good judgment. Don't say you can't do the job. His fifth point in this particular chapter is the often-heard quotation, "You had a failure, so you'd better design a new one." His immediate response was, "That's absolute nonsense." Yet I have known and worked with groups where that has been the response. It fails; therefore, it is no good. Professor Brook suggests that there needs to be quantitative evidence that a new design has a chance of being better. If you don't have that kind of evidence, perhaps it is better to stick with the design with which you are already familiar. If your people are familiar with it, they know how to maintain it. They know its quirks. Finally, he addresses the question, "Why change a known reliable design?" He uses an example from the aerospace design industry and gives data on a number of airplane designs. The early failure rate (shown in Figure 3) was not due to break-in failures, that is things that were fixed and never failed again. As a result of studies, it was found that certain design changes had to be implemented. They were able to reduce failure rates very significantly over a period of a couple of years. I think, the message is simply that there is a great deal that those of us who are practicing engineers can learn from the discipline of availability engineering and it can benefit not only us but the nation as a whole as we systematically achieve increases in power plant productivity.

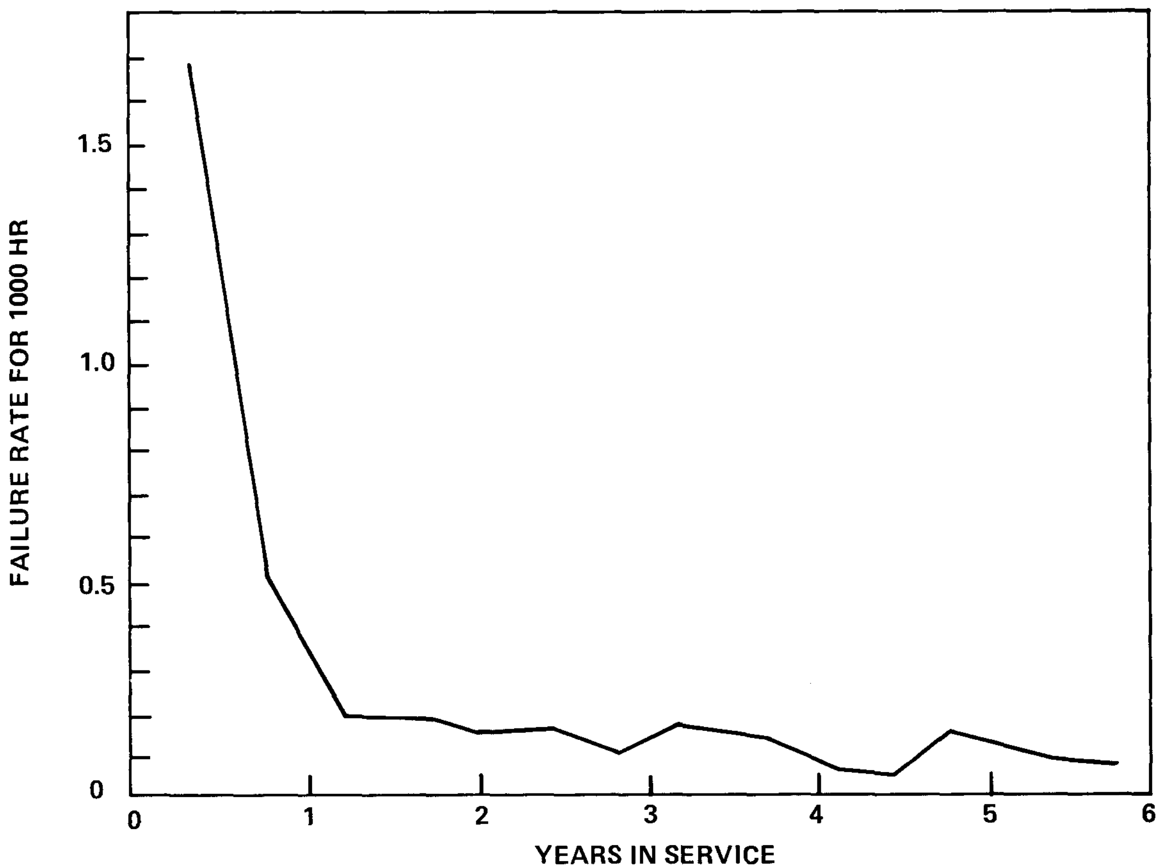

Figure 3. Why Change a Known Reliable Design?

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4. P. J. Kolesar, "Linear Programming and the Reliability of Multicomponent Systems," Naval Res. Log. Quart., 14, pp 317-326 (September, 1967).

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DISCUSSION

PARASCOS:* We should recognize the type of skills that we have and design for those skills. If you do have new stuff then you go into training.

LONG: I think that is a good comment and I will repeat it to make sure everybody heard. When I say, "Train your people to do the job," Ed is suggesting another approach which says, "We have in our utility this kind of capability. These are the skill levels of our technicians and our mechanics. We need your equipment designed so that kind of person can handle the job."

BARCELO: You showed a slide that had a list of analysis techniques. One of the techniques you referred to is linear programming analysis. I wonder if you could give an example of how you would use linear programming.

LONG: I can't give you a specific example. The context, basically, was in the use of a linear programming for cost benefit analysis of changes that you might want to make. The reference to use was in a paper in the 1976 American Power Conference. It was a paper by the staff of Detroit Edison (see Reference 3).

ANSON: In your definition of availability, you referred to the probability that the unit was operational. I am not sure whether I am nitpicking or we have a different understanding of "operational." I understand that "operational" means "in-service." I think that what you really mean is that it should be <u>operable</u>.

*People are fully identified in Appendix A, List of Attendees

LONG: Operable, yes. Capable. It will be able to operate at some given point in the future.

ANSON: Not necessarily at its full capacity?

LONG: Not necessarily at full capacity. There is an EEI committee working on a very carefully specified definition of "availability."

METHODS OF AVAILABILITY ENGINEERING

E. B. Cleveland
Holmes & Narver, Inc.

In May, 1977, Holmes & Narver completed a 9-month study for the Electric Power Research Institute (EPRI) on the subject of engineering electric power plants for greater availability. Final report EPRI NP-493, which was distributed to workshop attendees, is the result.

The methods to engineer for availability described in NP-493 derive from proven reliability and maintainability methods but emphasize power plant problems and take into account the way plants are ordered, engineered, constructed, and operated. The methods are basically aimed at engineering personnel. Although it was recognized that availability improvements could be made in operating plants through increased motivation, better planning, and greater maintenance, it was felt that a more fundamental and systematic method was needed. Availability engineering is the result.

ENGINEERING FOR AVAILABILITY

Engineering can be characterized by its measurement approach to the creation of machine and structure design. While it is true that successful machines and structures can be devised by others through trial and error methods, engineers are expected to do it right the first time at minimum cost - they must do for 50¢ what anyone else can do for $1.00. Engineers are trained to follow proven methods which rely on measured values and proven relationships and reactions. Requirements are quantified: horsepower, fuel consumption, heat rate, voltage, etc. Parameters affecting output requirements are quantified. Values of volume, weight, pressure, diameter, etc. are selected to indicate, when entered in suitable equations, whether or not requirements will be met. Then suitable documents are prepared to control manufacture and operation.

The same methods can be followed when availability is the requirement. The fundamental differences are simply that values may be known with less certainty and there are few engineers who have been trained to use the specialized methods. The methods of availability engineering can, however, be readily learned and successfully applied. Data that are currently available can be used if their limitations are recognized. Efforts now underway by the EPRI should eventually result in accurate up-to-date data, and educational programs such as this Workshop will serve to acquaint more engineers with the methods and their application.

THE METHOD

It is not intended that this presentation repeat the contents of NP-493, but rather to highlight the significant points and some of the problems. In developing the methodology we chose to define availability engineering as:

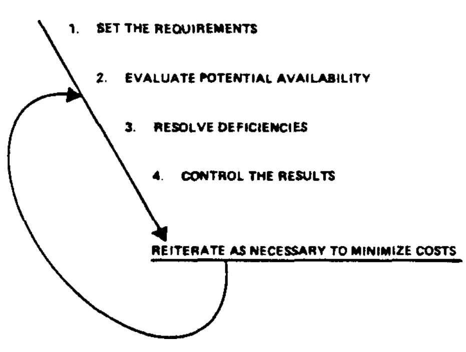
> *A SYSTEMATIC ENGINEERING METHOD USED TO SET AND ACHIEVE A NUMERICAL AVAILABILITY GOAL (FOR SYSTEMS OR EQUIPMENT) WITH MINIMUM (LIFE-CYCLE) COST.*

The term "availability" is to be interpreted as "energy or equivalent availability." It must be a measure of the actual or expected fraction of design energy output possible during a period of time.

The method is an engineering method used by engineers when plants are to be modified or new ones designed. The method must not only set an availability goal but must also show that the final design has a very good chance of achieving that goal. The method is concerned with the overall generating unit availability and with its systems and equipment. To ensure achievement of these goals, suitable controls must be instituted and these will reach into procurement orders, operating and maintenance procedures, QA activities, and management policies. Finally minimum bus-bar costs must guide each availability engineering decision.

Starting with the definition, four fundamental phases were identified for the methodology.

THE PROCESS



Fifteen steps have been defined for these four phases. They can be summarized thus:

STEPS		SUMMARY*
Requirements:		
1.	Define policies and constraints	Specify periods when unit must be available, maintenance plans, accessibility.
2.	Set availability goal and worth factor	Relate capacity factor to availability. Define value of availability.
Evaluations:		
3.	Allocate availability goal	Give each engineer outage limits for his equipment.
4.	Obtain and review system definitions and past performance	Perform qualitative design reviews -- start early!
5.	Prepare system failure analyses	Use FMEA's, fault trees, or common mode failure analyses as appropriate to find problems.
6.	Prepare system availability model	
7.	Obtain failure frequency data	During design, combine expected failure rates and repair times to obtain an estimate of unit availability -- if too low plan to make changes
8.	Develop maintenance and outage time estimates	
9.	Determine expected system availability	
Problem Resolution:		
10.	Identify problem areas and prepare critical items list	Highlight: data uncertainties, maintenance problems, operating difficulties.
11.	Conduct critical item review	Management to review problems.
12.	Develop and implement corrective action	Assign responsibity for resolving problems.
Control:		
13.	Establish inspection, tests, and preventive maintenance requirements	As design develops, write O&M procedures and prepare schedules.
14.	Develop availability-related requirements for specifications	Tell manufacturer what reliability and maintenance is required of equipment.

*See NP-493 p. 2-12 to 2-31 for detailed description of each step.

15. Review and evaluate changes	Review design and field changes <u>before</u> they are made.

THE COST

One of the first questions asked following any presentation on the availability engineering method is, "What will it cost?" This is not an unreasonable question. Unfortunately, there is no definite answer. One must believe that any additional engineering and capital costs will be more than compensated for by superior plant availability. The key to making this happen is to insist that each design or procurement decision be based on cost-benefit analyses that take the value of increased availability into account. Each investment for increased availability must show an early payback.

There is a tendency to presume that increased availability implies more costly equipment and installations. This view probably comes from the practice of adding redundant equipment (installed spares or duplicates) to increase reliability. But there are many other less costly ways to achieve greater reliability (and availability). Simplification is one traditional way to achieve greater reliability while lowering cost at the same time. Making maintenance tasks easier to perform is another. Easier maintenance can both increase reliability through fewer mistakes and shorten outage time.

To control the cost of availability engineering, a utility must take an active role with its A-E in engineering new units or modifications for existing units. All aspects of a functioning unit, hardware, systems, O&M procedures, spare parts, QA, training, outage, scheduling, etc., must be started with conceptual design and be developed through the engineering, construction, and start-up periods. This has not been common practice in the past. But to be cost effective, availability engineering must have an input into all of these areas.

CURRENT PROBLEMS

Problems associated with implementing availability engineering are related to current educational and resource deficiencies and to the need for new policies and practices. Resources in short supply include data on equipment reliability and maintainability. The data problem is being addressed by several EPRI programs (including the Workshop Session #5 discussion). The educational problems related to training of engineers and management updates are being addressed through studies by the FEA and EPRI, this Workshop, and papers and articles.

These efforts may have to be accelerated as system reserve margins shrink and increase the need for ways to increase the availability of existing generating units.

The numerical goals approach advocated by NP-493 introduces the additional problem of verification: how does one prove that his design will meet (or has met) its availability requirement? This question will be discussed during this Workshop. It applies to the availability of a generating unit and to the reliability and maintainability of its equipment. It is a question of the extent to which an A-E or manufacturer should be responsible for the performance of his product. The assignment of responsibility and the methods of proof must be defined in a way acceptable to all parties but with primary concern for generation costs. An industry-wide policy is needed on this subject, and it is hoped that the proceedings from this Workshop will serve as a starting point for a policy on setting and achieving availability, reliability, and maintainability goals.

A final problem is the prevailing attitude among seasoned engineers and managers that they already pay adequate attention to reliability and maintainability. While it is true that considerable thought may be given to these subjects, few people know just how reliable and maintainabile their portion of design must be. The methods of availability engineering give each engineer target values which, if met, will insure that the plant will have a suitably high inherent availability. But to gain acceptance, current engineering practice must change. And that is a problem which will take time to resolve.

SUMMARY

This presentation has introduced a suggested methodology for engineering greater inherent availability into systems and equipment. Other speakers will explain what they are doing to implement these or similar methods.

The electric power industry has an excellent record of providing reliable electric service. That record is now threatened by future blackouts and curtailments according to recent predictions by the NERC and the EEI. Not enough new units are being built to meet load projections; therefore, existing ones must be modified to work better. Declining fuel quantity and environmental restrictions are counter to this objective. Availability engineering applied to plant betterment projects offers a way to get the needed better performance.

At the present time there is no agreed-on availability engineering methodology. EPRI report NP-493 is intended as a starting point. The results of this Workshop will help to develop a methodology that is effective but is not an added burden to the industry.

DISCUSSION

PARASCOS: Should we have a range in the availability number like between 80 and 85% where the contractor can, with the utility, pick the number that is most cost effective?

CLEVELAND: No. We must specify the availability number as the minimum number required. Take, for instance, an availability minimum of 85%. If this is exceeded, then the excess availability may not be cost effective.

PARASCOS: Has there been any consideration given to failure analysis of equipment similar to that done in aerospace? Many vendors have said that the failure rate figure their equipment has exhibited is not enough for them to design out.

CLEVELAND: We in the power industry think that vendors have the ability to analyze failure of their equipment. This is not always so. Many vendors have said that if we identify failure modes they will design them out. The failure modes identification should be down to the material level if necessary.

SHOR: How does one include requirements in design specifications to improve equipment?

CLEVELAND: By requiring failure modes and effects analysis based on known or expected problems in equipment and asking the designer to identify the design features, manufacturing, construction, or preoperational testing requirements that will prevent the failure mode from occurring. Then specifing the use of quality assurance to verify that the designer's requirements are implemented.

SHOR: The process described in your talk and EPRI NP-493 contains provisions for describing the effects of each failure mode, but it is not obvious where investigation, identification, quantification and display of the root causes of each failure mode should be covered. Where are these activities best fitted into the process?

CLEVELAND: Traditional failure modes and effects analysis techniques require that the possible "mechanisms" of failure be listed for each failure mode. These can be used, along with detailed investigation of actual failures, to find ways to eliminate or reduce failures which have undesirable effects.

SAS: Other factors affecting availability goals are heat rate gains, load management, etc. The assessment report is silent on these subjects. Is there a reason for this?

CLEVELAND: The scope of the assessment report did not include these, but they are worthy of consideration.

BEAKES: Isn't it possible that the "inherent" availability of presently operating plants is quite high and that availability problems are mostly <u>operational</u> in nature?

CLEVELAND: Yes. We don't know enough about what is causing unavailability.

ALBRECHT: You pointed out that the worth of availability should be specified in addition to the availability goal. I agree that knowledge of the worth of availability is very important. However, if both a quantitative goal and a worth are set, it will not be possible for the designer to make any use of the worth criteria.

Suppose, for example, that the availability goal for a power plant is 85% and the worth of availability is specified as $12 million for 1% change in availability. The designer will design for exactly 85% at minimum cost. If he finds that it will cost $20 million more to achieve 85% over 84%, he must still meet the 85% requirement even though this exceeds the stated worth of $12 million.

An alternate procedure would be to state a range of acceptable availability, together with the worth of availability. The utility could then require that the designer perform a study to determine the most cost effective availability within this range. This would permit an evaluation of various plant configurations and alternate features, such as redundancy, on a cost versus worth basis.

MUSKA: Should we not measure the difference between actual and inherent reliability?

CLEVELAND: Yes. I should have explained that inherent availability, an aerospace idea, is what we think a design possesses without subsequent degradation due to manufacturing and operation. Actual availability is what is measured after a period of operation.

MUSKA: Should it not be listed as one item of outage hours as "operator and/or maintenance and other operating errors"?

CLEVELAND: Operator or maintenance error designations are for noting the causes of failure and only incidentally related to actual availability.

JENSEN: How do we prepare an equipment procurement specification with specific reliability/availability requirements? Should we include anticipated MTTF and MTTR? Are good examples of reliability and availability specification requirements available?

CLEVELAND: Check with Jan Krasnodebski of Ontario Hydro. I would say they have the most experience in this area.

BACHOFER: Classic reliability engineering deals with inherent failures. There are other elements, such as "operator/maintenance error" and function design specifications, which also need to be included. Fundamentally, O&M errors can be minimized by adequate identification of applicable limits on systems and equipment so that these can be written into system descriptions and operations/maintenance procedures. Functional design requirements need to be identified to designers so that all operating modes and requirements are understood and provided for in system and component designs.

IMPLEMENTING AVAILABILITY ENGINEERING

R. H. Gauger
Holmes & Narver, Inc.

Both the presentation by Mr. Cleveland and the EPRI Report he referenced have provided us the basic methods of implementing availability engineering. We have found, however, that putting this into practice is not as easy as describing how to do it. I would like to share with you our experience in implementing availability engineering on several programs, including the design of an advanced nuclear plant.

The first step is the decision itself: to use availability engineering as a discipline incorporating availability considerations into new design decisions and to use availability data as the basis for modifying existing design or modes of operation. Several factors are likely to be involved in making these decisions. One is political. Federal pressure, particularly from the former Federal Power Commission and the Federal Energy Administration, have been applied to upgrade both the fossil and nuclear plant performance. Public opinion, directed towards nuclear plants, has tended to imply that when a plant is shut down because of failures, that is an indication that the plant is unsafe.

The overwhelming factor, however, has been the financial consideration. During this past week, one utility announced that an outage of one of their larger nuclear plants represents a loss of about $300,000 per day. For another utility, the figure was nearly half a million dollars a day. The loss here is not just the need to purchase makeup power, but that a plant that is out of service means a loss of reserves, reducing the utility's ability to meet peak demand.

Having made the decision to proceed with an availability program, we're going to need top management's support to properly apply the availability technology. Their support will be needed in:

- Establishing the availability engineering policy
- Assigning responsibility to the participating organizations

- Issuing procedures to implement the policy
- Indoctrinating all departments and ensuring their support

Though the basic availability policy will be essentially the same, the policy statement will differ from organization to organization, depending on whether we represent a utility, an architect-engineer, or a supplier. Several sources, including EPRI Report NP-493, cover the basics of such a policy statement.

We recently helped an architectural-engineering organization prepare a rather detailed 3-page statement for a new plant design. Figure 1 shows the outline of both the qualitative and quantitative requirements included.

The policy statement required that with the exception of certain designated items, all equipment in functional systems would be accessible for inspection of their essential features, for replacement of worn-out or defective parts, or for complete replacement of the item itself. The policy also required that numerical availability goals be set for all functional systems which were essential for the production of electric power. These goals, of course, were to be commensurate with the overall plant availability goal. To ensure maintainability and accessibility, the design of all functional systems were to be checked for maintainability and accessibility prior to release for construction. A documented, controlled inspection was to be used to ensure compliance with both the qualitative and quantitative requirements of this policy. As a part of this check, the equipment system and plant availability were to be estimated based on a failure frequency and repair time assigned to each piece of equipment necessary for plant operation. These availability goals were to be reflected in the procurement documents,both in terms of qualitative availability requirements and appropriate requirements concerning the manufacture and handling of equipment. In addition, the manufacturer of these kinds of equipment was required to supply prediction or test data on similar equipment showing the estimated frequency of failure and repair time for the systems.

The second point that we mentioned for management action was the need to identify the groups and assign the responsibility in order to put the availability policy into effect. Engineering, of course, has a prime responsibility for design, including designing for availability. This is just one of their many responsibilities during design and an area where they clearly need outside support. Other groups, such as procurement and quality assurance, are also involved in implementing the availability engineering program and had to have their responsibilities

QUALITATIVE	–	REQUIRE EQUIPMENT TO BE ACCESSIBLE FOR INSPECTION AND REPLACEMENT
QUANTITATIVE	–	ASSIGN NUMERICAL AVAILABILITY GOALS FOR THE PLANT & ESSENTIAL FUNCTIONAL SYSTEMS
MAINTAINABILITY & ACCESSIBILITY	–	REVIEW & DOCUMENT SYSTEMS BEFORE RELEASE
AVAILABILITY	–	ESTIMATE/ASSIGN FAILURE FREQUENCY AND REPAIR TIMES TO EQUIPMENT
PROCUREMENT	–	ASSIGN QUALITATIVE REQUIREMENTS
	–	REQUIRE MANUFACTURE DATA OR ESTIMATE

Figure 1. Availability Assurance Policy

assigned. What appears to be an ideal organizational structure is indicated in Figure 2. This was adapted from an organizational chart given in Reliability Engineering by Arinc.* This kind of organization ensures availability considerations by placing availability engineering equal to design/procurement operations and the other organizations with which they must interact. In practice, several other organizational structures are also used. For example, availability may be a part of the engineering department, usually as part of an engineering support organization. Some groups operate very effectively as part of a quality assurance or quality engineering organization. In other cases, the organization responsible for availability may be in a staff position, reporting to the project or division manager.

The choice of an organization name is also of some concern. Some of you are identified as being part of an availability engineering group. More common, however is the inclusion of availability with other functions such as "reliability assurance" or "RAM" (Reliability, Availability, Maintainability). Since the inclusion of the term "reliability" sometimes implies cost and NRC compliance, some organizations have found that cost-saving titles such as "produceability engineering" or "productivity" are more saleable.

It is likely that a certain amount of trauma or concern will develop over the introduction of a new function and a new group into an existing organization. Procedures defining both this group and its function can serve to minimize this concern and anxiety. In the case of the new plant design, we used two such procedures. The procedures clarified both the responsibilities and techniques in these ways:

- Requiring the application of availability engineering in the design of those systems essential for plant operation
- Defining the responsibility for the cognizant design engineer, the availability engineer, and others having a responsibility for achieving plant availability
- Providing the instructions for including availability requirements in the design descriptions and the procurement specifications
- Providing typical reliability requirements for both the design descriptions and the procurement documents
- Providing a checklist for assurance that the procedures and design requirements were met

In addition, a number of existing procedures and procedures of other organizations required changes in order to implement the availability engineering. These included

*Arinc Research Corp., Reliability Engineering, Prentice-Hall, 1964.

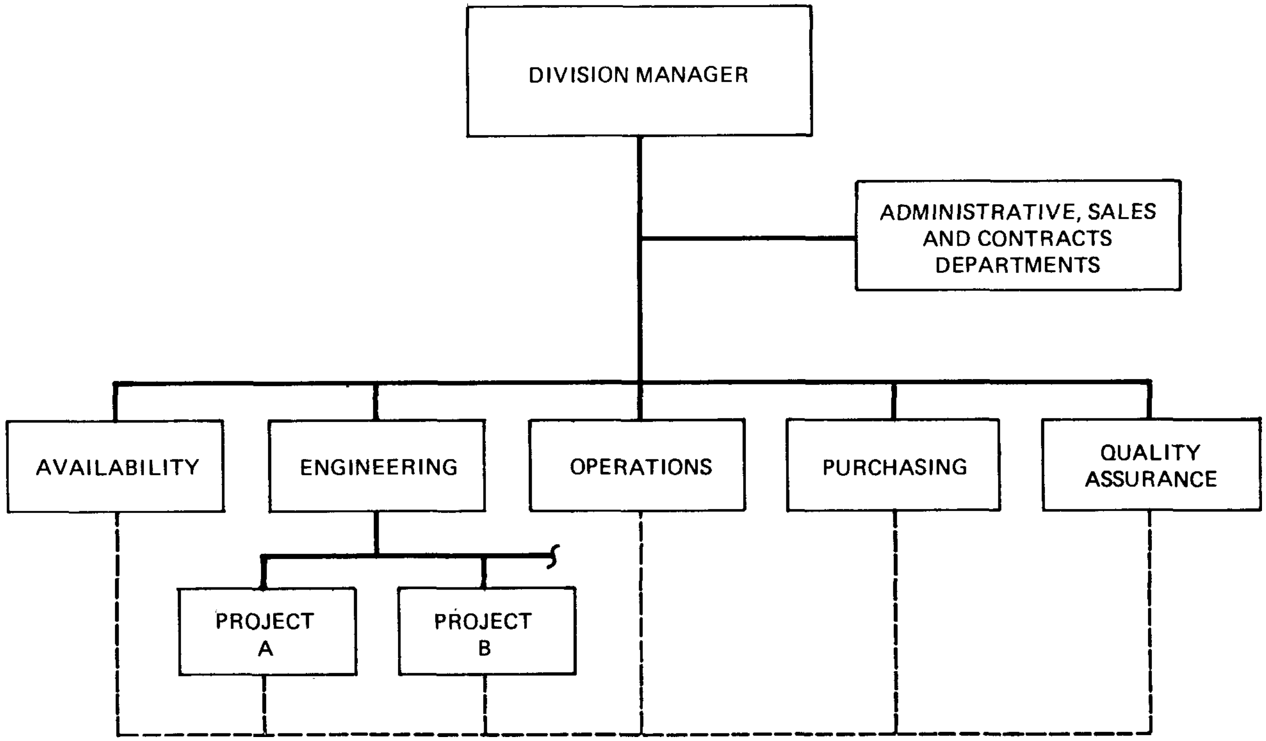

DIVISION MANAGER
ADMINISTRATIVE, SALES AND CONTRACTS DEPARTMENTS
AVAILABILITY
ENGINEERING
OPERATIONS
PURCHASING
QUALITY ASSURANCE
PROJECT A
PROJECT B

Figure 2

procedures for documentation, design review and sign-off, procurement, vendor selection, data, and quality assurance.

Since this qualitative and quantitative concern for availability represented a different way of doing business, we introduced it into the organization with a series of training sessions.

The establishment of the overall plant availability goal is probably one of the most important and certainly one of the most challenging assignments in availability engineering. In the simplest case a single goal will be assigned. It represents the overall average availability to be achieved by the plant throughout its operating life. As an alternate, we may choose to establish only an interim or short-term goal, as for example if a series or sequence of changes is being introduced into an operating plant.

The major factors to consider in establishing the plant availability goal are:

- Own experience
- Industry data
- Worth of availability
- Incremental cost of increasing availability
- Outside influences

Where a utility has experience with plants of a similar type and size, it is its own availability operating experience that is likely to be the major consideration in establishing the goals for improvement of a new design. A-E's and other utilities have to depend more heavily on the broader-based industry data in establishing their plant goals. These data may be the general fossil or nuclear data, such as are available from the Edison Electric Institute. Much more useful, however, are the special runs and special reports that are available from the EEI, since these can be selected for plants of similar type, similar size, or age. In either case, it must be realized that this is historical data and the availability goals need to be scaled up to account for the past and projected availability growth.

Another technique is to use industry data that show the cause of failure. These detailed data, available from EPRI and other industry sources, show the failures down to the system and component level. From these data, the degree of improvement can be estimated and realistic and achievable availability goals established at the system level. Unfortunately, there is far less of this kind of data available for the fossil plants than there is for the nuclear plants.

As noted before, the worth of availability in terms of dollars per day or dollars per hour for a full outage and the equivalent cost of a partial outage is needed both for goal setting and for trade-off analyses. From a return on investment viewpoint it would be profitable to increase our plant availability by making changes in all areas where the present worth of availability exceeds the cost of the change or design improvement. In other words, a utility can decide whether it is more profitable to achieve the required power output by increasing plant availability, buying power elsewhere or by building new plants. In reality, there are other outside influences, such as public opinion or government intervention, which may make this more than an ROI (Return On Investment) consideration.

Taken by itself, the establishment of an overall plant availability goal is likely to have only a limited influence on the plant design. Setting an availability goal that is higher than the present industry average indicates that the designers must do more than normal design practice, but this is hard for each cognizant design engineer to translate into practice when he defines his system or specifies his equipment. In order to achieve the plant goal and to achieve it in the most cost effective manner, it is necessary to allocate or assign the overall plant goal down to the system and equipment levels. This is most easily understood if we make this assignment in terms of frequency of failure and repair time rather than of a numerical availability. An example of a possible allocation is shown in Table 1. In this case, a relatively complicated system of a new design was being considered. Because of the new design, a plant goal in the .80 to .85 range was selected. You will note that an improved refueling system design is anticipated, with the plant completing both the refueling and scheduled maintenance outages in a 20-day annual period. This is a particular challenge, as it represents less than one third of the time currently being used for the annual refueling and maintenance outage in present-day LWR plants.

You will note that the availability goal for the Balance of Plant is 0.96. This goal is easier to interpret if we consider it in terms of the average allocated outage time per year, in this case 332 hours per year. The Balance of Plant was made up of some 17 systems, of which only these 8 were considered to be both essential for continued plant operation and likely to make a significant contribution to the overall plant outage time. Taking a more detailed look at the first

Table 1
ALLOCATION OF AVAILABILITY GOALS

SYSTEM	AVAILABILITY GOALS	AVERAGE OUTAGE TIME/YEAR
PLANT	.82	67 DAYS
SCHEDULED OUTAGE (REFUELING)		20 DAYS
UNSCHEDULE OUTAGE		47 DAYS
NUCLEAR ISLAND SYSTEMS	.85	53 DAYS (1)
BALANCE OF PLANT (2)	.96	14 DAYS
• ELECTRICAL TRANSMISSION		11 HRS/YR
• IN-PLANT ELECTRICAL		13 HRS/YR
• COMPRESSED GAS SYSTEM		2 HRS/YR
• FEEDWATER AND CONDENSATE		21 HRS/YR
• MAIN AND AUXILIARY STEAM		259 HRS/YR
• HEAT REJECTION		20 HRS/YR
• RIVER WATER SERVICE		2 HRS/YR
• TREATED WATER		1 HR/YR

(1) INCLUDES 20 DAYS REFUELING
PLUS 33 DAYS FORCED OUTAGE

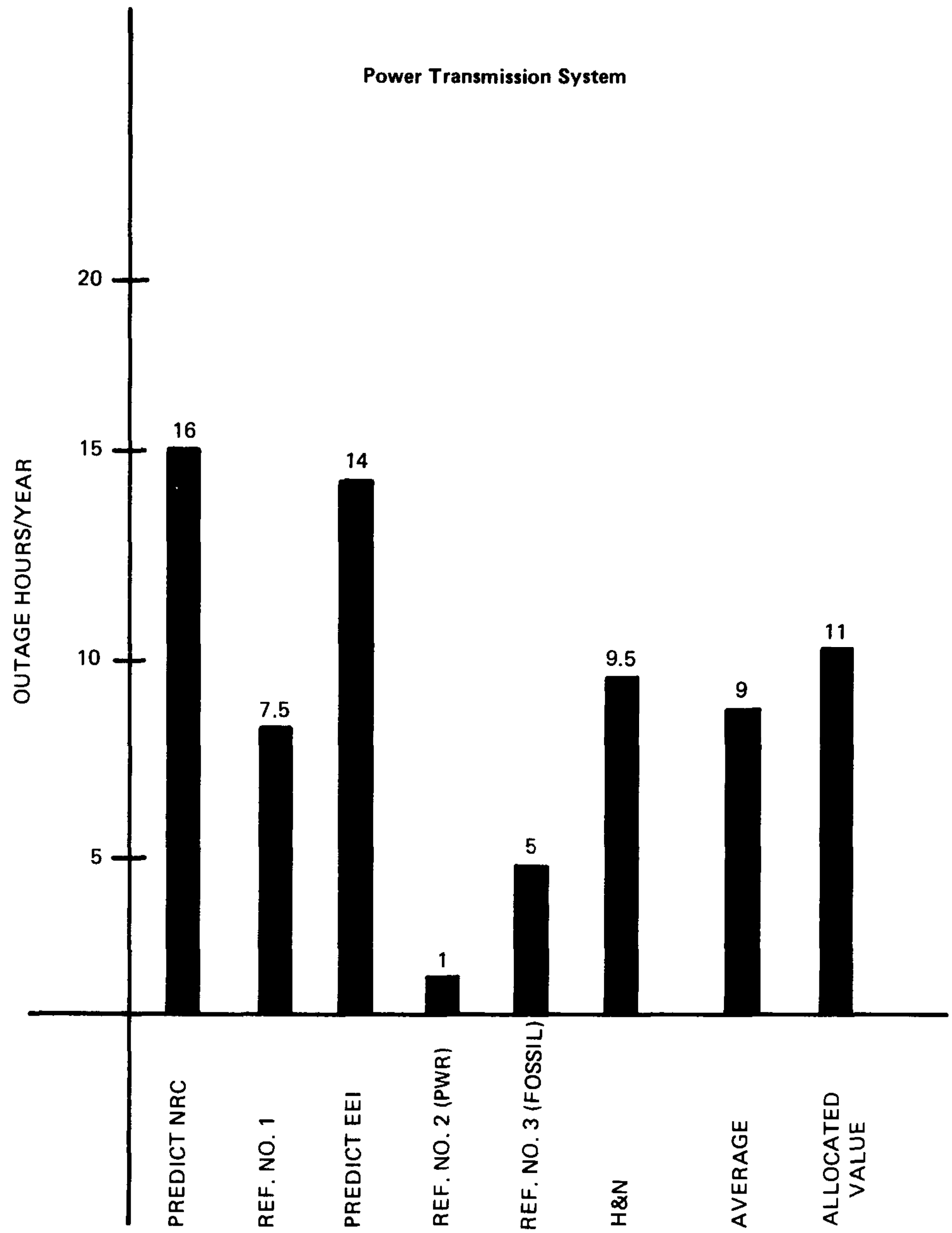
(2) INCLUDES ALL RELATED
INSTRUMENTATION AND CONTROLS

system, the electrical transmission system with its allocation of 11 hours per year, will give an indication of the method used. Data from both the NRC and EEI failure data systems were used as well as expert opinion from other allocations. The data were first assembled and calculated in tabular form, then a bar graph for visual display of the data was used in evaluating the results and applying the engineering judgement. Figure 3 shows these allocations. For this power transmission system, the weighted average based on all sources cited would have been 9 hours per year. Examination of the bar graph and the application of engineering judgement placed greater weight on the NRC and EEI data, raising the allocated value to 11 hours per year. This is the third estimate or allocation that we made for this system, and is not expected to be the last.

Another application of availability engineering is in assessment or prediction. This is essentially the inverse of the allocation technique. An estimate or prediction of the probable frequency of failure and the availability of an individual system or component is combined with similar estimates for other components in order to predict the availability of the whole plant. These are assembled using a mathematical model that shows all the essential functional systems and identifies redundancy and operational restrictions. In practice, this prediction will also be updated several times during the system design.

Probably one of the areas in which the availability engineer can make the greatest contribution to the design of the plant is availability studies or trade-off analyses. In most cases, the company policy will (or should) require availability considerations to be a factor in each major design decision. Thus, availability will be considered and availability trade-off analyses made along with each of the major design decisions by cognizant engineers. Typically, the difference in availability of each alternative will be included in these analyses in terms of present worth of the future plant availability. Such studies and analyses may be either brief and informal or formal and documented. We made a formal availability trade-off for boiler feedpumps and a series of revisions which considered such factors as reserve capacity, motor versus turbine drive, and hydraulic versus fixed coupling.

The evaluation of two station service transformer schemes, Figure 4, is an example of one of the shorter studies. Originally, a single station service transformer, T_1 was used; when switchgear arrangements made it desirable to use two 50% capacity transformers, the impact on plant availability was considered before the decision was made. While repair of T_1 or T_2 would introduce more failures than the original



Power Transmission System
OUTAGE HOURS/YEAR
20
15
10
5
16
7.5
14
1
5
9.5
9
11
PREDICT NRC
REF. NO. 1
PREDICT EEI
REF. NO. 2 (PWR)
REF. NO. 3 (FOSSIL)
H&N
AVERAGE
ALLOCATED VALUE

Figure 3.

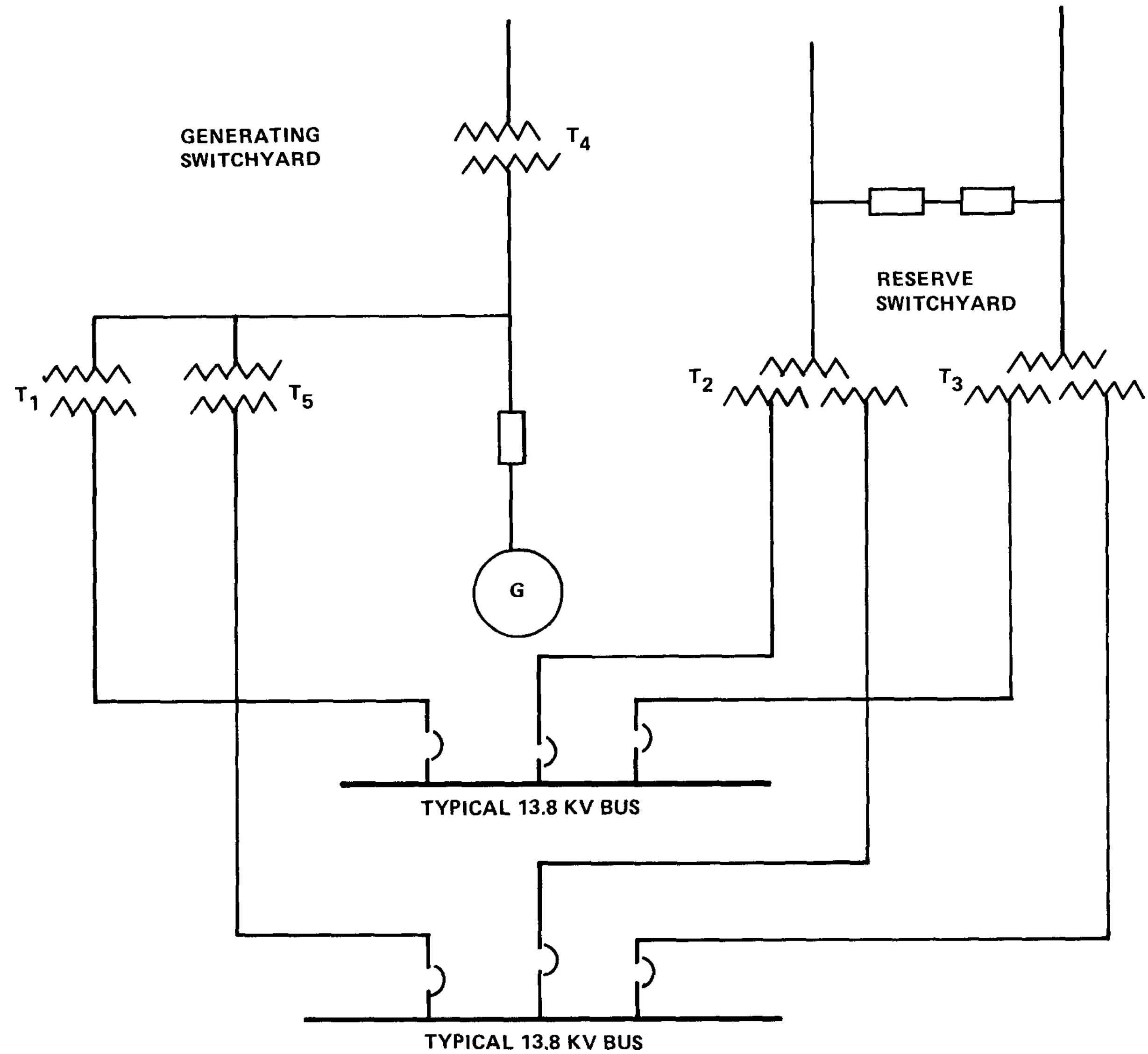


Figure 4. Evaluation of the Scheme with Two 50% Station Service Transformers and Two 100% Reserve Transformers

design with a single transformer, the increase in plant unavailability was found to be acceptable. This was based on use of one of the reserve switchyard transformers while repair of T_1 or T_2 was being completed. Safety requirements were met by the testing or use of the emergency diesel generators.

Another significant contribution can be made by the availability engineer in the design review process. His independent review and sign-off verifying the adequacy of the design from the availability viewpoint frequently take several forms. There is the review scheduled at several design checkpoints that includes not only the availability engineer but also experienced personnel from all other disciplines. In addition to this formal scheduled review which occurs only at a few checkpoints during the design, much can also be accomplished by a continuous review performed by a group of experienced experts such as might be set up in an engineering support group.

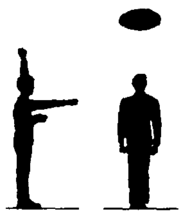
There are two particularly effective stages for reviewing the access and the remove-and-replace routes. The first is in the review of the general arrangements drawings and the second is a three-dimensional review on the model when it is assembled. For the access review of the drawings, plastic overlays (Figures 5 and 6) have proved to be very useful. Similarly, three-dimension figures are used for the model revisions.

Availability considerations in procurement are relatively new and offer some unusual challenges, including the specification and procurement of the total power plant. Our recent experience has been in working with specification at the component or system level. For safety-related components, particularly in the electrical systems, we can require testing and qualification. The new diesel generator requirements, for example, provide for 300 starts of the diesel generator to demonstrate a 99% probability of starting and taking load. If, however, we were to include similar quantitative availability requirements in nonsafety-related components, we would be likely to get an unrealistic price from most vendors, reflecting their apprehension and unwillingness to conduct such a test. Besides, in the case of particularly stringent or life-test requirements, we could not wait for the test results. Some utilities have been maintaining good performance data records and are able to prepare and negotiate quantitative procurement requirements. Our own experience has been more like that of the small utility having very limited specific data available. As a result, we have found it necessary to restrict availability requirements to those of a more qualitative nature, specifying requirements such as a thirty-year life, identification of wear-out items that are not

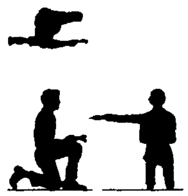
CLINCH RIVER BREEDER REACTOR PLANT

CLEARANCE DIMENSIONS–ALL WORKSPACES

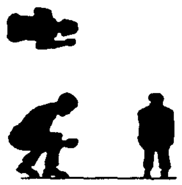
SCALE	DATE	REV.	SECTION	SHEET
1/8" =1'-0"	11-30-75	0	HUMAN FACTORS	2.7



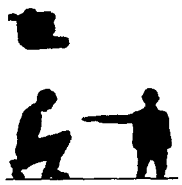
STANDING WORKSPACE



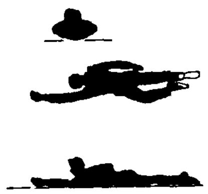
KNEELING WORKSPACE



STOOPING WORKSPACE



SQUATTING WORKSPACE



PRONE WORKSPACE

Figure 5

SCALE	DATE	REV.	SECTION	SHEET
1/8" = 1'-0"	11-30-75	0	HANDLING AND LIFTING EQUIPMENT	7.2

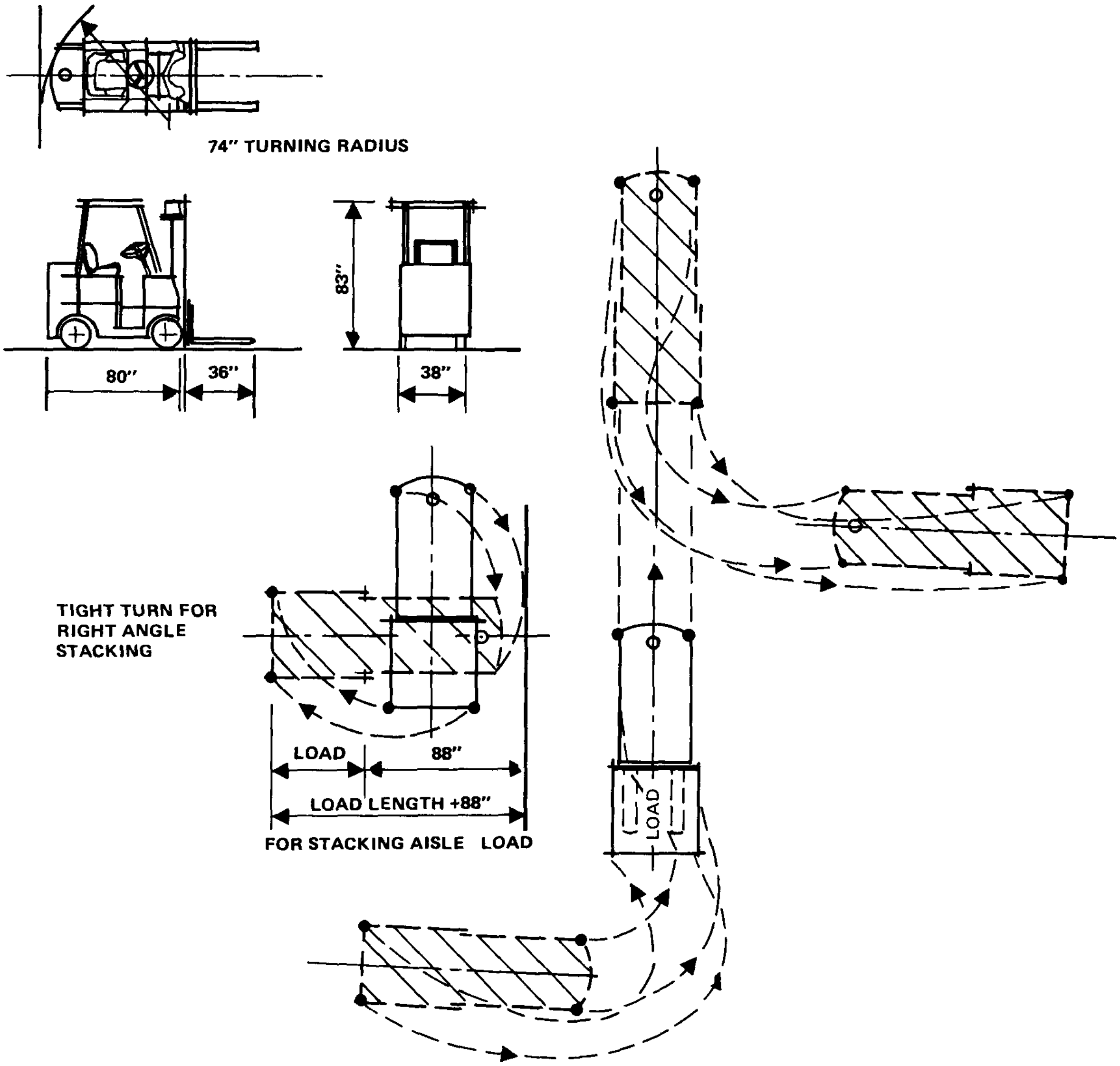


Figure 6

likely to meet the thirty-year life, and identification of failure impact and spares required. To support these requirements, we typically demand that a design margin be used, that the design consider repair and replacement, that the manuals support this design, and that provisions for failure detection be included. In most cases, we also require that the successful bidder provide his experience or test data in terms of frequency of failure, failure modes, and repair times. In some cases, we even require such experience data before including the vendor on the bidders list. Depending only on qualitative data, the importance of bidder selection and a qualified bidders list is even more important. Utilities with a good data collection system and years of experience have the means to evaluate vendors performance and can weight bids accordingly. Since we didn't have that private data source available, we have used EEI data for evaluation and weighting of the bidders for some of our Balance of Plant components. This is probably the first time that EEI data have been used in such a manner for bidder selection. It is neither as complete nor as exact as we would like, but it does contribute significantly to the amount of information we have available on which to make our decisions.

Our potential bidders gave us permission to obtain the data and EEI cooperated in helping us obtain special 10-year data runs for each of the bidder's equipment when used in the type and size of plant we selected. The data output obtained was similar to that in the annual Equipment Availability Fossil and Nuclear Component Cause Code Summary Reports. As a result, we were able to select the Cause Codes of interest and to evaluate the bidders following the steps shown in Figure 7.

The last topic might be entitled "Feedback and Corrective Action." We have shared with you some of our concerns for feedback of more experience data in the Balance of Plant and fossil areas. We are pleased to see the results of the IEEE Std. 500 with electrical data and to see a similar project for mechanical data currently under way. We all need a much closer interface among the utility, the A-E, and the designer. The kind of interface and feedback we're getting from workshops such as this results in a better understanding of operating conditions.

We have been working with American National Standards Institute Subcommittee to increase this feedback and to solve problems in several related areas. First is a recommendation for a Design Guide and Checklist that will aid in assuring that those factors affecting operation, use, and plant availability are considered in the design of the equipment. A second concern, also affecting availability, is

- OBTAIN BIDDER PERMISSION
- REQUEST SPECIAL EEI RUN
- CALCULATE FORCED OUTAGES (HOURS/YEAR) FOR EACH MANUFACTURER
- ESTIMATE FRACTION OF EACH CAUSE CODE ATTRIBUTABLE TO A MANUFACTURER
- ESTABLISH A BASE
- CALCULATE THE DIFFERENTIAL FOR EACH MANUFACTURER
- ASSIGN A PENALTY OR BONUS

Figure 7. Use of EEI Data for Bid Evaluation

the allocation of spares. Today these are too often allocated by rule of thumb rather than by a cost-effective consideration for plant availability. A third problem we have treated in the ANSI Subcommittee has been the question of repair manuals. Many instances have been cited where a repair has been delayed because a manual was not complete or was not written at a level that could be interpreted clearly by the repairmen. A fourth area treated by our committee has been the concern for the annual outage for refueling and maintenance of nuclear plants. We have found that these outages have been running about three times the duration that was anticipated when the plant was designed. In many cases, the actual refueling outage could be decreased, but the plant would still be down in order to complete the associated scheduled maintenance. Designing a plant with the accessibility and capability to also accomplish the scheduled maintenance in one third the present time will undoubtedly offer one of the greatest availability design challenges we have today. Our combined efforts will be required to meet these challenges and increase the availability of power plants.

DISCUSSION

ALBRECHT: You mentioned a proposed availability goal of 82% for a new nuclear plant design. Since this would be the first reactor of this design to be built, it might be asked whether this goal is intended to apply to the first year of operation or to some future year. More generally, I would like to suggest that it would be more natural to view availability as a growth function instead of a single number, especially in such a prototype situation. In the aerospace industry, reliability growth is a recognized concept, especially during the development and prototype phases. Thus, there could be a series of time-phased availability goals for such a prototype, one for each year of operation. This series of (increasing) goals would emphasize the need and commitment to continuing effort and improvement after the initial year of operation.

I would appreciate your comments on this approach.

GAUGER: I agree that availability is a growth function, certainly for the first few years of operation. In the case I cited, a single goal was proposed but it did not apply to the period in which testing and related changes were being made.

MUSKA: You have indicated using the estimates of several experts in allocation work. Have you used the Delphi Technique in conducting these allocations studies?

GAUGER: No, it was not used for the estimate I cited. As you probably know, we did use it in estimating the failure frequencies for the IEEE Project 500 for electrical components and it will probably be used again for a similar project estimating mechanical failure rates and repair times.

SHERLOCK: What is the approximate ratio of availability engineering personnel to other engineering personnel in such a program, both for safety-related and availability-related analyses?

GAUGER: This will be dependent on the plant type and similarity to past designs. In the case of the A-E's program for a nuclear design, I have estimated that the availability-related effort will be about equal to the safety-related reliability effort. Each might be in the range of 2-4% of the design engineers on the staff.

ANSON: Comment - Reliability engineering was described as having very great scope - too great to be easily encompassed in an educational program. However, the real subject with which we are concerned is even broader. We are concerned with finding the most economic ways of meeting a continuous but variable demand from a source with inherent unavailability and negligible storage capacity.

EXPERIENCE IN AVAILABILITY DATA GATHERING*

Mrs. R. K. O'Hara
The Detroit Edison Company

Data gathering for all utilities has been a problem. At Detroit Edison, the gathering of data to meet the annual request of EEI and the need management had for monthly availability numbers was a tedious, time-consuming, after-the-fact job. I will attempt here to discuss with you some of the problems with our old system and the four steps we took to get to the Generation Outage Equipment Status (GOES) computerized system we now have at Detroit Edison.

In the old system, the recording of outage data was not consistent at all plants. Part of the inconsistency was due to the fact the recording was done by a variety of power plant operators, engineering technicians, and engineers. Some plants recorded the data daily, others after the end of the month, and still others only when they were reminded to supply the data. The plants mailed the completed forms to a central location where they were visually checked for gross errors. Then the information had to be transferred to key punch cards and processed. The complexity of the data required several computer runs and manual correction of the data to obtain error-free information. Once the data in the old system were considered error free, the total megawatt weeks of unavailability were used to calculate manually a company percent of availability. When all of the above was completed in three months, we were thrilled. But, in 1973, the company was working on a method of evaluating performance. "Management by objectives" was introduced and power plant availability was one of the measures chosen. With this new requirement for management to have timely availability numbers, we put a concentrated effort to reduce the time lapse from the end of a given month to when the availability numbers would be available to management. We were able to reduce the three months to six weeks with concentrated follow-up efforts. Also, in 1973, we began to take a serious look at our system to determine if we could convert it to an on-line computer terminal system. Our investigation of the

*Originally prepared for and presented at The EEI Prime Movers Committee Meeting, Kansas City, MO, September 26-28, 1977.

total power plant activity of how megawatt reporting was done indicated we were not coordinating the estimated daily capability for customer load and the megawatt loss being recorded as outage data. The estimated capability was phoned each morning to a central location by all power plants with an explanation of what problems were causing each unit to carry less than its net demonstrated capability. The phoned-in data were not the same as the data recorded at the month end in many instances. Therefore, it was obvious a change had to take place, which leads us to phase one of the new system. This phase took place in mid-1973, when the programming and using departments came to the joint agreement that in order to provide timely and accurate data, the recording of all megawatt changes would have to take place as the change occurred rather than after the fact.

With this decision, it was decided that the plant operator would record the megawatt losses. A form was designed for the operators to record all outages and estimated capability for daily peak load. In addition, a "Standard Job Breakdown," a tool that we use at Detroit Edison, was written to provide detailed steps and definitions necessary to ensure uniform recording at all plants. The operators would not only record time and quantity of megawatt losses, but would record the EEI code that best described the problem. This eliminated other plant nomenclature being used to describe equipment problems and was a first at Detroit Edison. The operators recorded all megawatt changes for the twenty-four hour period along with estimated capability for the peak hours. The data from the forms were called in each morning to a recording tape at our central office where it was transcribed by plant to the identical form used at the plants. Having the data entered by terminal into the GOES system from a central location, we were able to test the program and audit accuracy of the plant data each day. The programs were designed to permit central staff to perform all functions, such as add, delete, and completion of outages for the purpose of controlling accuracy. The plants could only perform the one function of completing a given outage. The reason for plants performing this function was to assure department management that the plant staffs were reviewing their outages. As the reliability of the system developed sessions were held and a manual prepared for the purpose of training the plant clerical staff to perform the terminal operation of the GOES system. Each working day all new outages were added by central staff to the individual plant outage file. However, the plants were instructed to complete outages at least twice a week.

January of 1974 was the first month we had the new system in operation and the availability percentages were ready for management the fourth working day of February. (Quite an improvement from three months.) The timeliness and accuracy of the system made GOES a household word and requests by management for data poured in. Examples of some special requests were:

- An availability percentage to be provided for any number of specified months or years
- Outage losses accumulated by individual EEI cause code numbers
- Percentages by designated equipment groups

Samples of these reports are attached.

Phase two of the new system began in mid-1975, when programming was under way, to prepare reports needed by the Michigan Electric Power Coordination Center for capability estimates for peak loads. This new program would scan yesterday's outage data to determine the megawatts of capability that would be available at peak tomorrow. Two changes were necessary when we implemented the program for peak capability estimates:

- The form used to record outage data would have to cover twenty-four hours starting at 0700 hours each day instead of midnight. This was necessary so all outage return times that were known would be available when the plant clerks completed outages at 0730 hours each day.
- The plant clerks would have to complete outages each working day instead of twice a week.

We discovered a few gross errors in the data while in this testing stage. The amount of outage when compared to what the unit was producing indicated that some plants were not checking their data. Directions were issued to the operators to compare the megawatt loss with the generation by unit each and every hour. This resolved the errors found in testing.

Phase three of the new system was to eliminate the call to the tape recorder at the central office. The company System Operation Center would record all outage information as the operators were calling them with load changes. The System Operation Center is manned twenty-four hours a day, seven days a week; therefore, this change required little modification to complete. One major problem occurred with this phase. The data at the plant and that recorded at the System Operation Center often did not agree. This problem occurred because of the miss-communications between the groups which resulted in many unnecessary changes of input to the system.

By the end of 1976, it was evident through audits that the plants were doing an excellent job of recording data and were aware of the impact it had on management decisions.

Phase four, the last phase of our new system, was to eliminate the telephone calls. The plants now have full responsibility for recording and operating the computer terminal system. Central staff's only function is to enter estimated future outages and audit the plant operation.

Now that we have covered the system changes, I would like to mention some of the characteristics and benefits of the present-day GOES system.

- The base used to calculate all percentages is megawatt weeks. Megawatt weeks are used so we can put all partial and full outages on a uniform basis.
- Each plant has a unique control file containing individual boiler and turbine information for outage validation. This means each instance of outage is checked against previously established limits.
- A separate validation program checks for megawatt overlaps by unit, minute by minute.
- All plants can use the system for input simultaneously.
- The plants receive as little or as much information as they need to run their plants.
- Engineers and technicians at the plants have been relieved of work that can be done by clerks.
- The available capability of each unit at peak is matched with capability losses and capability losses are recorded for history.
- The phoned-in estimate of capabilities was eliminated.
- The GOES system provides uniform data on equipment problems to be used for discussion by operations, equipment and maintenance engineers.
- The current months availability is known through the month to allow for corrective action before the month end.
- Statistics are now available four working days after the month end.
- The use of Mark IV computer language in GOES permits ease of retrieval for reports or special studies.
- The flexibility of the GOES system permits us to meet the requirements of outside requests such as EEI, ECAR, and the Michigan Public Service Commission.
- Having the plant personnel intimately involved has made them think of availability as their number.

In conclusion, GOES provides Detroit Edison with a good availability system. But, looking ahead, this is where we now see a need to expand the data gathering.

In order to do reliability studies and problem solving, the power plant staff, design engineer, architect-engineer, and equipment manufacturer need additional information. As we see it, a complete data base must contain manufacture and model number along with provisions to supply individual component records of categorized repair done on each component. For instance, a unit has spare mills, gas recirculating fans, drain pumps, or condenser pumps and work may be performed to maintain them, but a record is not retained because the capability of the unit was not affected. Only when a partial outage takes place do we have a record.

Two examples of expansion to be investigated are:

Example #1. (121) Pulverizers (Megawatt derate may or may not be present.) Items listed below would not be recorded:

- Main bearing
- Feeder motors
- Mill motor failure
- Broken ball
- Broken ring
- Broken spring
- Spring set
- Plugged feeder
- Burner line shutoff

Example #2. (630) Vibration of turbine generator unit (Full megawatts of unit would be recorded.) Items listed below would not be recorded:

- Last stage blade tie wire repair
- Generator inspection
- Control valves inspection and replacement
- Exciter diode fuse inspection and replacement

The more timely and reliable data become from a system, the greater use management can make of the information. This requires on-going studies to improve or expand existing systems.

Detroit Edison is in the study phase to enhance GOES or build a coordinated system to meet the needs I mentioned above.*

*The following reports were illustrated by R.K. O'Hara: Daily Capability Report, Standard Job Breakdown -- Data Collection for Generation Outages and Equipment Status, Hit Parade -- Totals by Individual EEI Category Code Forced and Unforeseen Outages, Summary of Generating Equipment MW-Weeks of Outage, GOES August Results.

DISCUSSION

PARASCOS: Didn't the Michigan Power Commission apply a penalty or a bonus to your rate structure based on availability?

O'HARA: Yes. The equity return is:

Annual Average System Availability	Equity Return Incentive Adjustment
0 - 70%	- .25%
70.1 - 80%	- 0 %
80.1 - 85%	+ .25%
85.1 - 100%	+ .50%

MUSKA: Do you think that tieing a utility computer into a national computer system is feasible and advisable?

O'HARA: I feel it is feasible. However, the only way it is advisable is if the turnaround is real time. In other words, we now have our reports four days after a month end and expect to maintain the same results if the system were a national one. The utilities must be able to search the data base and extract data as they see necessary.

SESSION 2
EXAMPLES OF APPLICATIONS

Chairman: R. L. Long

RELIABILITY AND MAINTAINABILITY IN DESIGN OF POWER STATIONS

J. Krasnodebski

J. Christians

SUNDESERT RELIABILITY ENGINEERING PROGRAM

D. W. Latham

USING EEI DATA TO IDENTIFY IMPROVEMENTS IN NUCLEAR PLANT PRODUCTIVITY

R. J. Squires

RESULTS OF ADVANCE MAINTENANCE PLANNING SERVICE

R. Butrovich

E. Hummel

RELIABILITY/AVAILABILITY ANALYSES AT DUKE POWER

B. W. Logan

RELIABILITY AND MAINTAINABILITY IN DESIGN OF POWER STATIONS

J. Krasnodebski
J. Christians
Ontario Hydro

SUMMARY

This paper describes the development of a reliability and maintainability (R&M) engineering program and its application to the design of Ontario Hydro thermal power stations. The effects of unavailability of these stations on the reliability of the power system and resulting cost of unavailability are described. The R&M program and application of the various R&M tasks in design are outlined. Allocation of availability goals, application of reliability analysis, design reviews, maintainability program, data collection, R&M activities in equipment procurement and R&M training are discussed.

INTRODUCTION

Ontario Hydro designs, constructs and operates power stations and supplies electrical energy to the Province of Ontario. Ontario Hydro is a member of the Northeast Power Coordinating Council and it is tied to and exchanges energy with New York and Michigan utilities. Installed capacity of Ontario Hydro System is 21,900 MW, of which 11,700 MW (53%) is fossil, 6,400 MW (29%) is hydraulic, and 3,800 MW (18%) is nuclear. An additional 9,900 MW of nuclear and 2,700 MW of fossil generation are in various stages of design and construction.

The reliability of electrical power supplies at the customer level depends on the reliability of power stations, transmission and distribution systems. The reliability of generation depends on the forced outage rates of the generating units in the system and size of reserves.

Increase in forced outage rates and decrease in availability of new thermal power stations in Ontario Hydro and on the North American continent became apparent in the late sixties. This was due largely to the rapid increase in size, and in steam conditions, of fossil units resulting in a number of prototype designs. The forced outage rates of thermal units now in service proved to be higher than originally expected. Ontario Hydro, in common with most other North American utilities, expected forced outage rates to be near those predicted by the Federal Power Commission (FPC).[1] Figure 1 shows that the equivalent forced outage rates (EFOR) of fossil fired units, as reported by the Edison Electric Institute (EEI) in the Annual Report on Equipment Availability,[2] and those experienced by Ontario Hydro are both higher than those predicted by the FPC. Data contained in the EEI Annual Reports on Availability shows a trend of increasing forced outage rates and declining availability in the past few years.

COST OF POWER STATION UNAVAILABILITY

Most economic analyses for nuclear units in Canada and the US were based on 80% capacity factor:[3] a forced outage rate of 2% and availability in excess of 90% were expected from some units in the US.[4] The operating statistics for nuclear

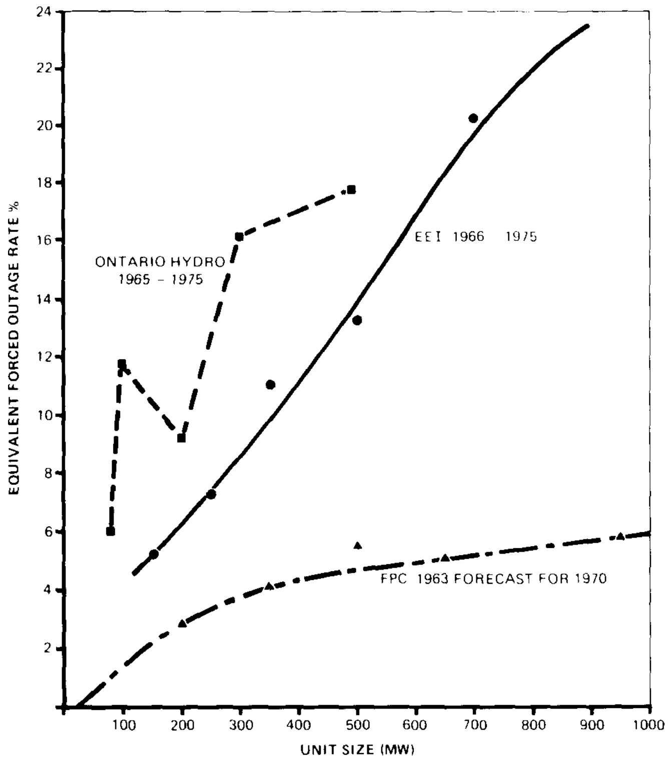


Figure 1. Equivalent Forced Outage Rate vs. Unit Size—Fossil Units

units (see Table 1) shows higher forced outage rates and lower availabilities and capacity factors than the expectations quoted above. The unavailability of a generating unit contributes to system costs which in turn dictates the price per kilowatt-hour, delivered to a customer, as follows:

- Cost of increased generating reserves to maintain the required reliability level of service to customers. Because of the higher forced outage rates of the units in a system, higher reserves are required to satisfy the system reliability criterion.
- Replacement energy costs. The fueling cost of the CANDU type nuclear power station is at present about 1.5 mills $/kWh, but coal cost (in Ontario Hydro fossil-fired stations which are used to replace power from nuclear stations) is 12 mills $/kWh and higher.
- Additional cost of maintenance manpower, man-rem in nuclear stations, spare parts, etc.

These costs resulting from power station unavailability were recognized by the management of Ontario Hydro and were assigned specific dollar value in 1970. Since 1970 estimates of these costs have increased by about a factor of five. These values are used in decision making processes both in design of future plants and operation and improvements of existing plants. These costs are expressed as net present value of costs resulting from reduced availability over the lifetime of a station, typically 30 years. Table 2 summarizes these costs for Ontario Hydro units which are in various phases of planning and design and construction, expressed in dollars of a year in which unit is to be declared in-service.[5]

DESIGN ORGANIZATION AND R&M PROGRAM

The Design and Construction Branch of Ontario Hydro is responsible for design and construction of nuclear, fossil and hydraulic generating stations. Most design

Table 1
NUCLEAR UNITS OPERATING STATISTICS

No. of Units		49
No. of Unit Years		168
Forced Outage Rate	%	12.6
Equivalent Outage Rate	%	17.3
Scheduled Outage Rate	%	15.1
Operating Availability	%	74.3
Capacity Factor	%	59.5

Source: EEI Report on Equipment Availability for the Ten-Year Period, 1966-75

Table 2
NET PRESENT VALUE OF COSTS RESULTING FROM UNAVAILABILITY EXPRESSED IN $/kW FOR VARIOUS TYPES AND SIZES OF UNITS

Unit Size [MW] and Fuel	In-Service Date	System Reserve Cost/1% EFOR [$/kW]	Energy Replacement Cost/1% Equivalent Availability [$/kW]
200* Coal	1982	10.4	1.2
500 Coal	1987	8.0	0
516 Nuclear	1987	8.0	22.3
750 Coal	1987	8.6	0
850 Nuclear	1987	8.9	21.7
1250 Nuclear	1987	9.4	21.5

*These units are part of the North West System capacity of approx. 700 MW.

is done in-house, but some hydraulic and fossil stations are designed by consultants. The client of the Design and Construction Branch is the Operations Division of Ontario Hydro, which requires an assured level of availability to achieve its objective of generating electrical power at the lowest cost. The objective of Design and Construction Branch is to build the required level of availability into new generating stations.

The design and construction of new stations is divided between two divisions. One of them, Generation Projects Division, is responsible for the detailed design and construction of the complete project. Project managers administer the project and are responsible for its final design, cost, and schedule.

The other division, Design and Development, consists of functionally oriented departments in various engineering disciplines, e.g., mechanical, nuclear, civil, electrical, instrumentation and control, etc., and fulfills the following functions:

- Supplies central technical expertise and supplies design personnel to the projects
- Carries out conceptual and preliminary engineering for new generating stations before responsibility is transferred to the Generation Projects Division for the detailed engineering, procurement and construction
- Is responsible for the quality of design which includes R&M

Development of R&M Program is the responsibility of the Engineering Quality Section in the Design and Development Division. The basic R&M Program was formulated and approved by management in 1971 and is being progressively incorporated in the new projects. The objective of the R&M Program is to design to specified reliability requirements by elimination or reduction of risks and attention to detailed engineering. The following main tasks have been identified as integral parts of the program:

- Preparation of an R&M program plan
- Training of personnel in the application of basic R&M tasks
- Collection, analysis and utilization of operational experience from both internal and external sources
- Integration of R&M tasks with the design process
- Acquisition of equipment with required level of R&M

Recently, a more extensive approach called the Quality Engineering (QE) Program was established. The QE Program combines elements of R&M Engineering and Quality Assurance in Design and other aspects of system design which affect its quality. The Engineering Quality Section (EQS) is responsible for planning and coordinating quality engineering activities with the Design and Development and Generation Projects Divisions, maintaining the Quality Engineering Manual, performing engineering audits and providing R&M support functions.

Reliability and Maintainability groups have been formed in the following departments: Instrumentation and Control, Power Equipment, and Mechanical Design. They are primarily responsible for obtaining and analyzing operating data of equipment and for providing feedback to the designers and suppliers, as well as analysis of the systems.

An extensive R&M Program also exists in the operational phase of Ontario Hydro thermal stations. Operational reliability goals are established, performance is monitored, reasons for deviation recorded and analyzed, and corrective actions taken where they are economically justified. Other elements of this program encompass staff training (use of simulator in training of nuclear operators) and preparation, and maintenance (preventive and breakdown) which is well planned and carried around the clock.[6]

R&M TASKS IN DESIGN

The word "design" is defined in Webster's dictionary as something skillfully and methodically planned that requires time and study. The ability to develop a quality design is conditional on the availability of time and engineering skills to perform the design tasks with which selected elements of R&M engineering are integrated. Output of these R&M activities must provide useful inputs into the design decision-making process. Design is planned to start well ahead of the time when procurement and construction schedules dictate its progress.

Designing the appropriate R&M level for a system or a product is the designer's responsibility. R&M tasks (operational feedback, quantitative availability goals, R&M analyses, design reviews) provide the designer with tools to evaluate his process and product relative to the end need. The designers and those who provide guidance to the design process must exercise judgment on the degree of R&M assessment required and the timing of application. The R&M Program in design consists of several interrelated tasks and is an integral part of design activity, as shown in Figure 2. It accomplishes a great deal by just bringing to the attention of each designer the fact that the R&M of his system is important to the success of the power station. Simple design, use of reliable equipment, and use of redundancy when necessary form the basis of a reliable system.

Station R&M Targets

The R&M targets for a station are specified in a R&M report which is prepared in the preliminary engineering phase of the design. These targets provide the basis for R&M activities in the station design. The R&M targets are given for each generating unit and are allocated to all major systems and equipment as shown in Tables 3 and 4. The bases for allocation of R&M targets are:

- Operating experience with similar systems
- Maturity of design (i.e., state of the art)
- Desire for improvement
- Subjective judgment

The R&M targets are expressed in terms of forced maintenance and planned outage rates and their duration and frequency. The established quantitative R&M targets are challenging but realistic and can be attained with concerted effort. These targets are necessary to communicate to system and equipment designers the required R&M at the system and equipment levels in quantitative terms. The

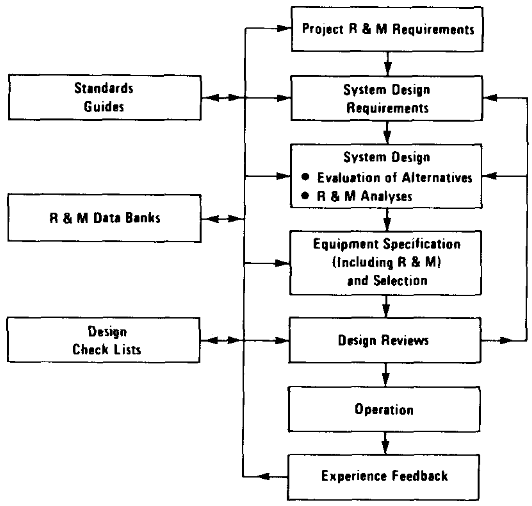


Figure 2. R & M Tasks in Design

Table 3
850 MW NUCLEAR UNIT—AVAILABILITY TARGETS

Type of Outage	Rate (R), %	Hours (H), Per Yr.	No. of Occurrences/Yr. Total	Sudden
Forced	4.5	363	8	2
Equivalent Forced	6.0	484		
Maintenance	2.0	175	4	–
Planned	6.0	526	1	–
Total Unavailability	12.1	1063	13	2

Table 4
850 MW NUCLEAR UNIT—TARGETS FOR FORCED OUTAGE
DURATION, RATE, AND FREQUENCY

System	Forced Outage		
	Duration Hours/Yr.	Rate %	Frequency No./Yr.
General Causes	3.2	0.04	0.06
Buildings and Structures	7.3	0.09	0.09
Reactor – Boiler and Auxiliaries	189.4	2.35	2.43
Turbine – Generator & Auxiliaries	111.2	1.38	1.56
Electric Power Systems	15.3	0.19	0.30
Instrumentation and Control	28.2	0.35	3.32
Auxiliary Processes & Services (Water & Comp. Air)	8.1	0.10	0.21
Unit Total	363	4.5	8

requirements force adoption of a disciplined approach in design to achieve the specified goals. The report also gives the costs for various types of outages. These costs allow a proper economic evaluation of R&M and other performance characteristics for trade-off studies. The R&M report also outlines in a general way the tasks and analyses that are necessary to ensure that R&M targets will be met in operation.

In the design of the Nuclear Steam Supply Systems (NSSS), a radiation dose (man-rem) management program has been established in Ontario Hydro to minimize external and internal doses received by operation and maintenance staff. This program consists of the following tasks:

- Establishment of man-rem targets
- Establishment of economic worth of man-rem to guide the design decisions
- Training the designers in the basics of radiation protection and performance of man-rem design audits

The radioactive dose accounting system in the nuclear generating stations identifies critical systems and equipment and provides designers with the necessary information for corrective action.

Design Requirements

The requirements and criteria which design must satisfy are documented. It is only with firm objectives and targets and with a realistic description of system's functions under normal and abnormal operating conditions and physical parameters and constraints that the designer of a system can achieve the desired level of R&M. "Normally, poor specifications will result in redesign or patch-up of subsystems, a less than optimum design configuration, probable over-complexity and subsystems interfaces that are inconsistent."[7] These requirements are prepared during preliminary engineering and consist of the following:

- Functional requirements
- Performance requirements
- Interfacing systems
- Design limits and strength requirements
- Design constraints
- Environmental, reliability, and maintainability requirements
- In-service inspection
- Safety requirements, standards, and codes (nuclear, radiation, industrial)

Proper and timely documentation of the design requirements, including all relevant bases for revisions, enables the orderly progress of the design effort and provides valuable information for future designs.

Reliability Analysis

The main objective of reliability analysis at Ontario Hydro is to support the design decisions by providing necessary and timely inputs. The scope of analysis must be carefully specified, assumptions must be clearly stated, the sources of assumptions and data identified, and the methods of analysis documented. Reliability evaluations are carried out on a variety of systems in order to compare alternative configurations, evaluate effect of equipment R&M on availability of a unit and its life cycle costs,[8] and evaluate cost benefits associated with spares. Detailed quantitative reliability analyses and predictions are generally limited to the safety systems.

The techniques used in evaluation range from combinatorial analysis, minimal cutset technique, failure mode and effect analysis (FMEA), and Markov models to extensive fault tree analysis (FTA). Effort is made to keep techniques used as simple as possible and still adequately solve the problem. Reliability models are constructed using realistic assumptions and explicitly considering the effects of interfaces with other systems. This requires that the system designer and analyst work together in the R&M evaluation process.

When necessary, Ontario Hydro requires its suppliers to perform FMEA or some other relatively simple analysis on some of the critical equipment to identify weak areas and make improvements. Fault tree analysis requires a considerable amount of time and effort, both by the system designer(s) and the reliability analyst(s). Such analyses are generally undertaken infrequently and only for the complex systems.[10] When there are no available data or there is a lack of sufficient data, sensitivity analyses are performed. Such analyses are found to be very useful in the decision making process.

Maintainability

Maintainability is defined as the quality of equipment design and installation which facilitates the accomplishment of inspection, testing, servicing, repairing, and overhaul needed to meet such operational objectives as availability, with a minimum of time, skills, and resources. Maintainability assumes increased importance in continuously operated systems, such as those of a nuclear generating unit. These systems are generally designed for a minimum lifetime of 30 years. The generating unit has to be shut down before any maintenance can be carried out on most items of equipment in the Nuclear Steam Supply Systems. Maintainability of these systems and equipment should be high enough to keep to an allowable minimum the man-rem doses received by maintenance and operation personnel.

Maintainability of systems is influenced by inherent maintainability of their equipment and factors such as accessibility (affected by layout, lifting facilities, etc.), availability of spares, technical information, maintenance and test procedures and facilities, and personnel training. The inherent maintainability of any piece of equipment depends on its arrangement and complexity.

In planning for the maintainability of a nuclear generating unit, its critical systems and equipment are identified. The maintenance approach is determined and maintenance activities are planned. Some major maintenance tasks and equipment which are considered are:

- Reactor coolant tube inspection and replacement
- Boiler tube leak detection and plugging
- Heat transport pump-motor set repair and replacement
- Fueling machine repair and maintenance

Design requirements for all systems include maintainability requirements.

During the detailed engineering phase of some piece of major or critical equipment, maintainability analyses are coordinated with other design activities to ensure that the specified maintainability characteristics are met. Maintainability analysis also provides an input to the maintenance planning activities in order to determine requirements for special maintenance facilities, equipment and tools, spares, and types of skills required. The concept of "on-condition maintenance" is applied to detect deterioration in performance and to shut down and repair pieces of equipment only when necessary but before serious damage occurs. For example, major pumps are fitted with vibration monitors.

Design Reviews[11, 12, 13]

Design review is probably the most important activity in the R&M Program, as it brings into focus all other R&M activities. It provides the project or supplier management with a means to review and control the quality of design. It is a complete survey of all aspects of design that affect its quality and to ensure that it meets the requirements. It consists of the preparation of a data package documenting the design, a review of the data package prior to the meeting, the design review meeting, and documentation of its findings and recommendations. It permits a systematic and disciplined application of the broad knowledge and experience of engineering, manufacturing, operation and construction personnel to the design of systems or equipment. Members of a design review team must possess a high degree of competence and should be independent of the team which produced the design under review. This is necessary to the objectivity of its findings and to the authority of its recommendations.

In Ontario Hydro, this activity has been found to be very useful. It promotes understanding amongst the designers, operators and construction personnel, and an opportunity for them to express their views, thus providing for direct feedback, and improvement in the design. This program has the full support of Ontario Hydro management expressed in a formal design review policy.

DATA COLLECTION[14, 15]

The success of any enterprise depends, to a large degree, upon its ability to effectively apply past experience towards improving future products.

Ontario Hydro's information feedback from nuclear plants to design has been evolving since the early sixties. The feedback is in a written form and on a personal basis. The main objective of this feedback has been to transmit information regarding the unsatisfactory performance of plant systems to designers of new stations. Feedback of operating experience begins with the start-up of the plant systems in the commissioning stage. The following reports are produced from commissioning throughout plant operation to satisfy various operational requirements, as well as to provide feedback to design:

- Non-Computerized Reports: Commissioning Reports, Station Technical Reports, In-Service Reports, Significant Events Reports, Operations Requirements Document
- Computerized Reporting Systems: The Unit and Major Equipment Reporting Systems reports availability of generating units and their major equipment and is similar to the EEI Equipment Availability Report. The reports produced by this system give durations and frequencies of full and partial outages (forced, maintenance, planned). In addition to measuring unit unavailability, Ontario Hydro also measures production lost in MWh and assigns it to the systems, equipment or conditions

which were responsible for this loss. "Incapability factor" is defined as production lost in MWh divided by the maximum output which a unit could have delivered in a given period of time. This index provides clear identification of the system(s) and equipment responsible for production losses, and provides management with a single most important productivity index.

- Data collection system reporting on a component level provides information on the R&M performance of selected items of equipment. For a successful computerized system with good retrieval capabilities, it is essential that the means of equipment identification, failure event information recording, and equipment engineering data cataloguing be developed. In Ontario Hydro, a method combining the System Classification Index (SCI) with the equipment device code has been developed to identify uniquely all items of equipment. Deficiency Reports (DR), shown in Figure 3, are used to report on faulty equipment and to record repair work in the stations and provide input to the data collection system. The DR's are stored in a computer file, updated as new information related to a repair becomes available, and the file is used for the preparation of reports on a component basis. The component data library is needed to provide engineering data such as generic name, type, size, rating, material, and other information on components. This, in turn, allows estimation of generic component population, manufacturer, size, etc., and preparation of reports in formats suitable for system design, equipment selection, and feedback to manufacturers.

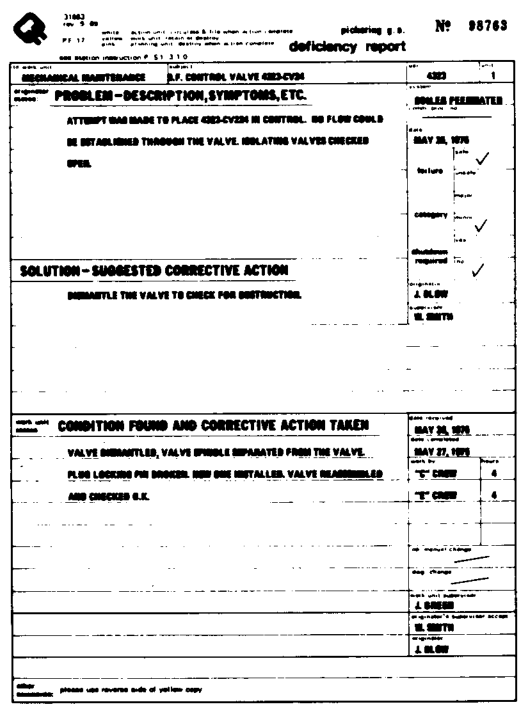


Figure 3. Deficiency Report

- Direct feedback of information to suppliers of major equipment was introduced recently. It takes the form of a meeting between Ontario Hydro operations management and design engineers and supplier management and engineering staff. Actual performance is compared to requirements and reasons for unsatisfactory performance are reviewed. Areas for improvement and proposals for corrective actions requested are thus identified.

RELIABILITY AND MAINTAINABILITY OF EQUIPMENT[16]

To meet the R&M targets for a unit and its system, the equipment purchased must have a corresponding level of reliability and maintainability built into it. It is the station designer's responsibility to establish and communicate these requirements to the suppliers. When establishing and specifying R&M requirements for equipment, it is important to consider such aspects as practicality and cost effectiveness. Technical specifications for major or critical equipment contain the following R&M requirements:

- Quantitative requirements in terms of allowable frequency and duration of forced and/or scheduled outages, starting reliability, operating reliability in terms of mean time to failure (MTTF), and maintainability in terms of mean time to repair (MTTR)
- Qualitative requirements such as those for redundancy, provisions for (periodic) testing, on-condition maintenance, etc.
- The means, such as operating experience, data, tests, and R&M analyses, by which specified levels of R&M will be insured.

Ontario Hydro requires high reliability and maintainability levels for critical equipment which cannot be made redundant or whose failure can result in a loss of unit output or a prolonged outage. Included in this category of equipment are turbine-generators, main transformers, steam generators and many other similar items. In these cases, a supplier will be required to have a formal R&M program which will ensure achievement of the R&M requirements specified for the equipment and system. For equipment of lower criticality, a less formal R&M program will be acceptable.

Ontario Hydro prepared and is using a comprehensive standard for R&M programs and activities which are required from manufacturers of selected major and critical equipment. These programs are intended to ensure that the delivered product will meet R&M targets set by Ontario Hydro. The R&M requirements are flexible and are to be compatible with the product and supplier organization. Detailed requirements as to the required R&M activities will be included in the specification for a particular item of equipment.

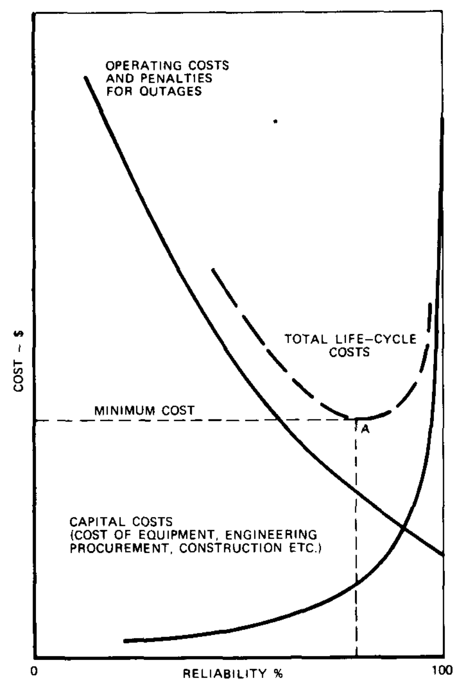
The technical evaluation of equipment is made on the basis of:

- Performance capability and efficiency
- Reliability and maintainability

Expected R&M of equipment are estimated and penalties assigned for performance below that of a leader. These penalties are explicitly considered in evaluations of equipment which are performed on the basis of the total life cycle costs and not just the first costs as shown in Figure 4.

Ontario Hydro has been specifying R&M requirements for selected equipment since 1974. The response of the suppliers, in general, has been encouraging. We have found that some suppliers had existing formal R&M programs, or at least that some R&M tasks were integrated in their design process. As a result of our R&M requirements, a number of suppliers introduced R&M programs into their own organizations.

The main problem of suppliers in developing an effective R&M program is establishing a proper mix and timing of R&M tasks to support and improve design decisions.



RELATIONSHIP OF RELIABILITY TO COSTS IS SHOWN BY THESE CURVES.
POINT A SHOWS THE LOWEST TOTAL COST AND THE CORRESPONDING RELIABILITY.

Figure 4. Reliability Against Life Cycle Cost Trade-off

Some mistakenly consider the R&M program to be a numbers game. The major complaint is inadequacy of feedback from most of their customers. Ontario Hydro provides operational feedback to suppliers who ask for it and frequently works with them in development of cost effective R&M programs.

STANDARDIZATION OF DESIGN

Reliability and maintainability of systems and equipment can be considerably increased and maintained at a high level when design, manufacture, and construction are performed according to a well-documented and implemented system of standards. Standards help to eliminate a number of problems because "standardization is the activity which relegates problems that have been already solved to their proper place, namely, to the field of routine and leaves the creative facilities for the problems which are still unsolved."

The Pickering B and Bruce B nuclear stations are nominally repeats of existing Pickering A stations or Bruce A stations under construction. Although each differs in some degree from previous stations, we are repeating as much of the existing design and equipment as is feasible for reasons of capital savings and operating economies. Review of Pickering A and Bruce A performance has identified a number of systems and components which are or are expected to be responsible for a major share of unit unavailability. In such cases, design reviews and R&M analyses were planned so that systems were reviewed to forestall similar problems in the future.

TRAINING OF PERSONNEL

The majority of engineers employed in Ontario Hydro station design were not familiar with practical and analytical R&M tasks; therefore, training of engineering personnel was required to introduce them to this subject and show them how R&M techniques can be applied effectively in their work areas and what their potential benefits are. It was also necessary to motivate designers to think of R&M constantly during their work.

The training required to support the practical application of a R&M program in Ontario Hydro falls into three broad classifications:

- Selected engineers are trained in the required R&M analytical techniques and are expected to perform some analyses in their disciplines.

- Most other engineers are trained in the basics of R&M. They learn to recognize the potential benefits of application of R&M techniques to the project.
- All engineering project personnel are motivated into designing and building R&M into the equipment and therefore into the system. They are also acquainted with means of measuring R&M performance (data collection) and important R&M activities (design reviews).

The training was one of the first tasks in development of the R&M program and is an ongoing activity.

CONCLUSIONS

The R&M program in design of Ontario Hydro generating stations started in 1970 and is being progressively introduced into new projects. The program has the full support of management of the Design and Construction and Operations Branches.

More people are becoming convinced that R&M programs and tasks, if applied properly, make a positive contribution to the development of reliable generating stations and are not a numbers game. The approach to R&M adopted by Ontario Hydro is practical and flexible. We firmly believe that it will contribute significantly to achievement of the twin goals of reliability and safety of our nuclear generating stations.

ACKNOWLEDGEMENT

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THE SUNDESERT AVAILABILITY IMPROVEMENT PROGRAM

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San Diego Gas and Electric has established an availability goal of 90% for the two units of its Sundesert Nuclear Plant. It is an ambitious goal but one that we feel is possible. The purpose of this paper is to describe why San Diego Gas and Electric established such a goal and, more importantly, how it is proceeding to attain this goal.

There are basically two reasons for improving availability: politics and economics. In California both are perhaps more important than in many other parts of the country.

First, since pressurized water reactors have historically averaged only about 72.5%[1] availability, the regulatory agencies, both state and federal, are concerned about and are pushing for improved availability. A concerted effort on the part of SDG&E to improve plant availability, as well as other measures of plant performance, is expected to aid in the licensing processes.

Second, and more important, replacement power for each 950 MWe unit is expected to cost $800,000 to $1,000,000 per day, depending on the projected cost of oil in 1986. For those of us who must rely on oil-fired generation for replacement power, this economic incentive provides reason enough to undertake a significant effort to improve the availability of any nuclear plant being planned today.

The specific goal of 90% availability was established early by the Sundesert Project management after reviewing historical nuclear plant availability figures and after examining the impact of large blocks of nuclear generation on SDG&E system reliability. To the historical availability figures, we added the projected effects of state of the art plant improvements and the anticipated improvements due to staffing, training, and plant design features specifically aimed at maximizing plant reliability and maintainability. It should be noted that this 90% goal applies to each unit after it has reached maturity, that is, after it has completed its initial three years of operation, since we, too, expect to have to go through a shakedown period prior to achieving our goal. San Diego Gas and Electric is convinced that the 90% availability goal is reasonable for Sundesert, given its location and scheduled operating date. Given other locations and commercial operation dates with different mixes of electric generation alternatives available, political considerations, capital costs and replacement power costs, different availability goals would be appropriate.

Organizing the efforts to achieve this 90% availability goal involve the same basic steps required in organizing or planning the activities for any task. First, the goal or objective must be reasonable and clearly stated; second, there must be a plan for achieving that goal; and, third, there must be an organization with the authority and resources to implement the plan. Since the goal has already been appropriately established, let's examine the major concern of this paper: the reliability plan and its implementation.

San Diego Gas and Electric could find no documentation of any such reliability effort by a utility building any type of generating facility. Nor could we find any such plan proposed in the literature. We did, however, find and retain as a consultant a man familiar both with nuclear power and with formal reliability techniques and who has been a leading proponent of increasing power plant availability. This individual, John Garrick of Pickard, Lowe and Garrick, was asked to formulate, with Sundesert management, the basic plan for achieving our 90% availability goal. The Sundesert Reliability Engineering Guide[2] was the resulting document. It details the steps to be taken to subdivide the 90% availability goal into pieces small enough to be managed. The objective is to identify in as much detail as possible those systems and components that cause unit outages and to quantize those outages so that priorities can be established for the redesign efforts.

Basically, the approach recommended and being used involves converting the availability goal of 90% to an unavailability goal of 10%, or 876 hours of unit unavailability each year, and then allocating portions of unavailability to the critical systems and components. These 876 hours were then allocated, roughly in proportion to experience as follows:

Nuclear steam supply system	175 hours
Turbine - generator	88 hours

Balance of plant	175 hours
Refueling/scheduled maintenance	438 hours

Each contractor organization was then asked to further subdivide its basic allocations to the system level and then to the component level as studies of failure rate data and reliability analyses were completed. As a first cut, the Reliability Engineering Guide provided a rough breakdown of each organization's unavailability allocation. These initial allocations are undergoing continual modification, with revised allocations being published periodically for project guidance. These reallocations are not limited to the systems and components within one contractor's scope of supply, but have changed and are expected to change at the contractor level.

Reliability analyses, performed for each system, using mean-time-between-failure and mean-time-to-repair data collected from government and industry sources, provide estimates of unit unavailability due to the failure and repair times involved with each system. If a system reliability analysis indicates that it will cause unit unavailability in excess of the allocation, the system (or components therein) is either redesigned or its unavailability allocation is increased. This means, of course, that the unavailability allocation of another system or systems must be decreased commensurately.

Further, as an aid to focusing attention on components and systems whose reliability is critical in achieving the 90% availability goal, a Reliability Critical Items List (RCIL) was established. Items on this list normally coincide with those components and systems reflecting the highest unavailability. In fact, as the Sundesert reliability effort has matured, the RCIL has grown to include mean-time-between-failure and mean-time-to-repair data and the status of the reliability effort for each item. This is in addition to the information initially included, which consisted of the system and component name, criticality ranking (i.e., ranking of the item according to its relative impact on unit availability), and commentary on the reason for inclusion and possible improvement procedures.

Items on the RCIL, as with items designated in the unavailability allocations, include activities as well as physical components. Any of these items that keep a high criticality ranking after attempted redesign are given special attention. This attention includes special quality assurance, approaching that of a Q.A. Category I item, special clearance and accessibility considerations for maintenance purposes, special spares considerations, special tooling, special handling, special operating procedures, and special training for the maintenance crew.

The RCIL has also provided a priority listing of equipment to be instrumented in our diagnostic instrumentation program. In fact, the RCIL has prompted SDG&E to look for means of detecting and predicting some failure modes that were not initially included in the program. The diagnostic instrumentation prompted by the RCIL, added to the standard instrumentation provided on such equipment as the reactor coolant pump, the turbine and the generator, has resulted in an extensive total plant diagnostic instrumentation system.

This diagnostic instrumentation system is being designed to inform the operating staff of component problems prior to, during, and following a component failure. This information, properly interpreted, may:

- Prevent a failure through preventive maintenance of a problem component
- Prevent a unit shutdown by providing time to bypass the problem component
- Minimize the damage to a component through early recognition and shutdown
- Minimize the unit downtime by providing the maintenance crew with specific information on needed tools and spare parts
- Minimize unit downtime required for technical specification inspections if the on-line diagnostics can substitute for some of the otherwise required inspections

Sequential neutronic, process, and diagnostic signals and alarms will be analyzed by computer with instructions or conclusions provided to the reactor operator. It was felt that the analysis capability of the computer could be used to relieve the operator of some of his analysis responsibilities. The instructions may be as simple as a warning to watch a certain parameter all the way to advising an immediate shutdown to avoid severe damage to a major component.

Following a cost-benefit analysis, a nuclear power plant training simulator has been recommended to SDG&E management. With the very high cost of replacement power, sufficient time should be saved in the fuel loading to commercial operation schedules to almost pay for the simulator. Also, the increased quality of the training using a plant specific simulator should make a considerable improvement in plant availability, but one that is not feasible to document. The savings in usual staff training costs turn out to be minor in comparison to the value of the increased availability.

To this point, the discussion has concentrated on the engineering design. Those who recognize the importance of the operation and maintenance activities in achieving high availability may be questioning the emphasis. The reason for the emphasis on engineering results from the fact that that's where the Sundesert Project is at this time. In engineering the design we are attempting to provide a plant that will have the capability of achieving a high availability. Studies of general operation and maintenance requirements resulted in design criteria for accessibility, clearance, laydown space, hoisting and transport mechanisms, spare parts storage space and for standardization of components wherever possible. The selection, training, and organization of the staff, the detailed lists of spares and tools, and the detailed operations and maintenance plans and procedures are recognized as essential to achieving a high availability. They are just not as pressing as the current engineering concerns.

The Sundesert Availability Improvement Program is an evolving program. Even this first phase, associated with the engineering design, is evolving as we explore and find more effective ways of accomplishing the various tasks. This, of course, should not be unexpected, since no one has used a similar program before. As the project progresses, the program plan will be expanded to include the construction, startup and operation of the plant. Thus, the nature of the activities involved in implementing this program are expected to change significantly during the approximate fifty-year life of the project.

The authority and resources required to implement the program are provided through the Sundesert Availability Committee chaired by the SDG&E Nuclear Department Manager. Each contractor organization is represented on this committee by at least one member of project management, as well as one designated reliability engineer. SDG&E is further represented by John Garrick, our reliability consultant, and by several SDG&E engineers, with the reliability engineer generally coordinating the program.

SDG&E management, from the president down, are cognizant of the program. The responsible vice president and the Sundesert project manager have supported the program and have participated in committee meetings. This type of management support has provided the impetus for the program and maintained its momentum.

With this support and the support of the contractor organizations, the 90% availability goal is, we believe, within reach.

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DISCUSSION

BARCELO: A goal of 90% availability was stated. In setting this goal, were forced partial outages and scheduled partial outages treated as available hours? Also, in determining if this goal is met, how will forced and scheduled partial outages be treated?

LATHAM: Keep in mind that availability is only one of the productivity parameters that we're trying to maximize. The 90% availability goal considers a unit available even when it is experiencing a partial outage. We do, however, expect our capacity factor to be in the neighborhood of 84 to 86%, even though we have stated in our Reliability Engineering Guide that our capacity factor goal is 80%. We anticipate operating Sundesert as a base loaded plant which should help us keep our capacity factor very close to our availability.

BARCELO: How was the availability goal of 90% established? Was a formal procedure used to establish the optimum cost benefit point and if so, how was the cost of improving power plant availability obtained?

LATHAM: The 90% availability goal was established considering the historical availability of Stone and Webster plants, and the historical availability of plants utilizing Westinghouse NSSS. We added to this expected state of the art effects and the effects of specific improvement aimed at increasing Sundesert availability. Some of these latter improvements were prompted by a desire to minimize the effects of unit outage on the SDG&E Grid.

The costs of all the design changes necessary to meet the 90% availability goal were not known at the time the goal was established so, necessarily, from the cost/benefit standpoint, the decision was somewhat subjective.

TOMMOR: To what extent has the reliability program formulated for SDG&E's Sundesert Station been applied to conventional fossil-fired designs?

LATHAM: It has not been applied to our fossil-fired designs. The Engineering Department responsible for fossil station design is now in the process of developing a reliability program similar to the Sundesert Reliability Program.

SHIAU: What are the items used for your cost-benefit evaluation of steam turbogenerator bids? Why did you select Westinghouse? Are your low-pressure turbine rotors interchangeable? Do you have any spare rotors? How many? What is the economical justification?

LATHAM: The deciding factor in the evaluation of steam generator bids was the willingness of our supplier to include in the contract a reliability program which involved a willingness to redesign, to perform reliability analyses, and to institute a test program. The low-pressure turbine rotors are interchangeable and we will have one spare rotor, essentially on loan from the manufacturer, stored at our site. This rotor will be kept on-site until SDG&E is assured through operational experience, that the risks involved with needing this rotor and not having it is of less consequence than the cost of "renewing" the loan or rental agreement.

BUTROVICH: Have you placed reliability guarantee requirements on your component suppliers?

LATHAM: No, we have not asked for guarantees. We have, however, asked for objective reliability data in our bid specs. In these specs we also ask the supplier to provide information on his reliability improvement program and to provide a list of current users of the specific component we're planning to purchase.

HAUETER: The EEI data show an effect on productivity of 78% from forced partial outages. Have partial outages been included in the allocation of unavailability to the various systems?

LATHAM: In establishing priorities for redesign efforts, we consider "equivalent" unavailability hours, not just full outage hours. For example, we consider ten hours at 50% power as seriously as five hours of full outage.

BACHOFER: Can you identify the incremental costs of the Sundesert Reliability Program in terms of (1) additional engineering costs? (2) additional plant capital costs?

LATHAM: We have identified improvements primarily resulting from reliability/availability considerations costing more than $50 million. I don't know what the additional engineering costs are relative to implementing the reliability program.

PRESTELE: Provide examples of design features comprising the $50 million already identified for Sundesert.

LATHAM: Some examples of improvements made in the initial design primarily to improve availability are:

1. Enclosed turbine hall
2. Model "F" steam generator
3. Improved reactor coolant pump
4. Titanium tubing in the condenser
5. Upgraded refueling system
6. An extensive diagnostic instrumentation system
7. The use of a high alloy steel in the impellers of the condensate pumps (as an example of a less expensive improvement)

BEAKES: Your current availability goal incudes 438 hrs/year (less than 20 days/year) for planned outage. What are you incorporating into the design that will help you to achieve this challenging goal?

LATHAM: It is a challenging goal. First, we have purchased the Westinghouse Upgraded Refueling System, which should keep the refueling activities off the critical path. Second, we have contracted with Westinghouse to provide us with a detailed maintenance and inspection plan which will provide us with details on staffing, tooling, spares, and skills required to meet our goal. It's going to be tight, but we believe that, on the average, we can make it.

USING EEI DATA TO IDENTIFY IMPROVEMENTS IN NUCLEAR POWER PLANTS

R. J. Squires
Commonwealth Edison Company

INTRODUCTION

Commonwealth Edison appreciates the opportunity to appear at this Availability Engineering Workshop to relate our experience with using Edison Electric Institute (EEI) data to identify improvements in nuclear power plants. When we hear the words "improvements in nuclear power plants," we first think of increases in equipment and component availability and increases in plant productivity. At Commonwealth Edison when we use the words "improvements in nuclear power plants," we also think of the decreases in component unavailability and decreases in plant nonproductivity.

This paper covers three items: (1) a method of using existing EEI outage data as a yardstick to numerically measure component unavailability and nonproductivity, (2) a way of economically measuring the cost of component nonproductivity to identify where improvements are needed in nuclear power plants, and (3) the major results from an investigation of the nonproductivity caused by the Zion Station reactor coolant pump seals. We hope that sharing our experience with you will provide you another method of using EEI data to identify where improvements are needed in nuclear power plants.

EEI EQUIPMENT AVAILABILITY DATA SYSTEM

Members of the EEI Prime Movers Committee recognized many years ago that information was needed on equipment and power plant outages. It was necessary to make meaningful design, procurement, operation and maintenance decisions to improve plant equipment availability. In the early 1960's the EEI Equipment Availability Data System (EADS) was put on computer (Figure 1). The Data System was also significantly expanded in scope by adding nuclear power plants. EEI publishes annual reports of equipment availability to program participants, and also publishes annually a general report to the public. The data used for these annual reports can be analyzed in a variety of ways. Special studies can be

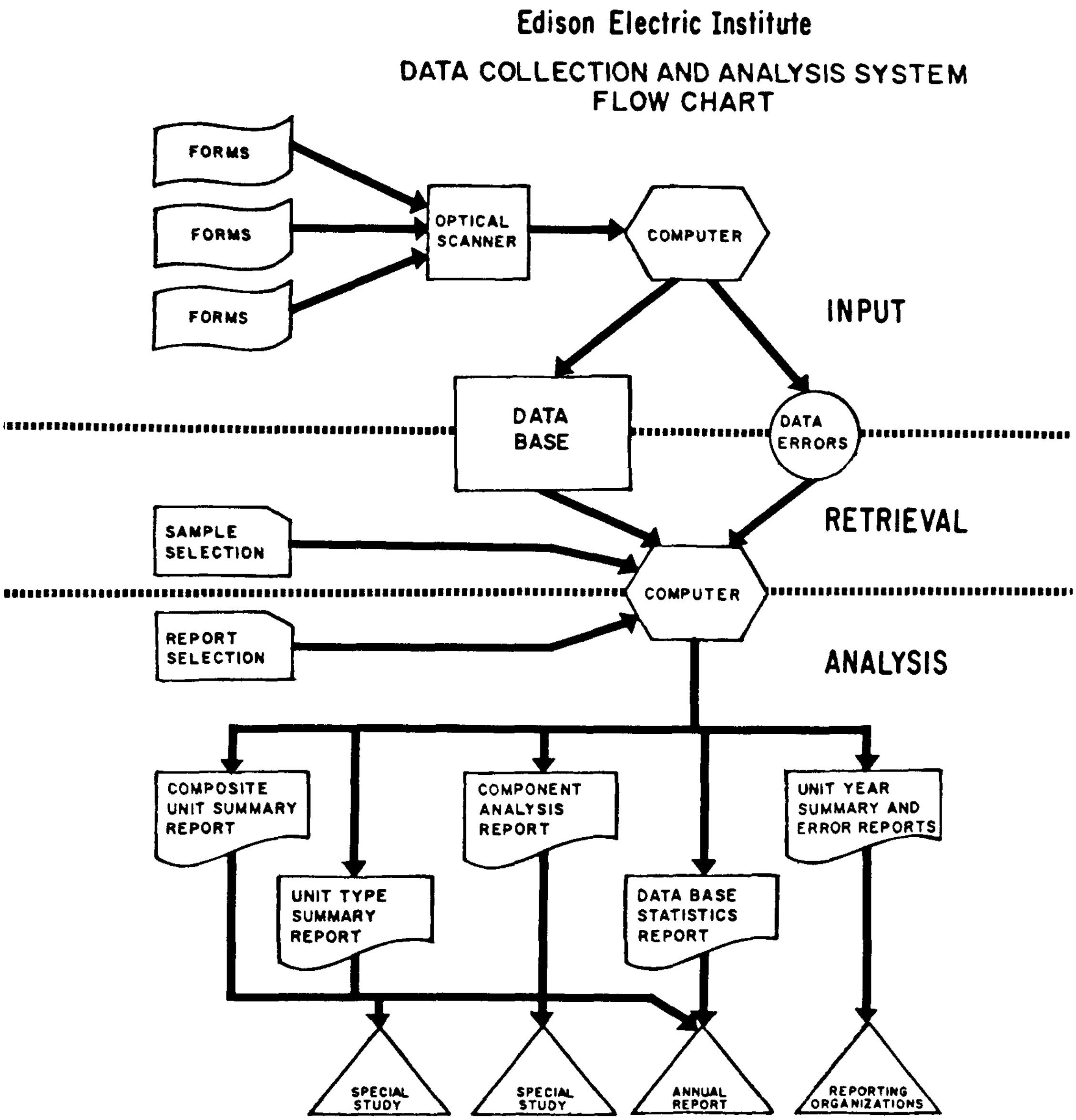

Edison Electric Institute
DATA COLLECTION AND ANALYSIS SYSTEM
FLOW CHART
FORMS
FORMS
FORMS
OPTICAL SCANNER
COMPUTER
INPUT
DATA BASE
DATA ERRORS
RETRIEVAL
SAMPLE SELECTION
COMPUTER
REPORT SELECTION
ANALYSIS
COMPOSITE UNIT SUMMARY REPORT
COMPONENT ANALYSIS REPORT
UNIT YEAR SUMMARY AND ERROR REPORTS
UNIT TYPE SUMMARY REPORT
DATA BASE STATISTICS REPORT
SPECIAL STUDY
SPECIAL STUDY
ANNUAL REPORT
REPORTING ORGANIZATIONS

Figure 1

requested by any utility, manufacturer, architect-engineer or other interested party through EEI, subject to certain requirements and restrictions.

It is important to understand that the EADS was designed to document the effect of components and plant activities on the availability of equipment and on the productivity of power plants for eight types of outages. Therefore, the output of the Data System identifies which component or activity is responsible for unavailability and nonproductivity within each type of outage.

CECo. EEI OUTAGE DATA

The Commonwealth Edison Company started submitting outage data to EEI for Dresden Unit 1 in 1960. Since that time outage data for Dresden Units 2 and 3, Quad Cities Units 1 and 2, and Zion Units 1 and 2 have been added to our EEI nuclear data submittal. The outage data submitted to EEI are also stored on company computer tapes and used to calculate unit availability and capacity factors. These factors are used to monitor equipment availability improvement and unit productivity improvement. As mentioned earlier, we are also interested in using the existing EEI outage data to numerically measure component nonproductivity and unavailability.

Our outage data are submitted to the EEI as an event. Each event is identified with the name of one of the 129 components and activities defined in the data system for a nuclear power plant. To measure outage duration the events are submitted with a start and completion date and time. The outage events are also classified as one of eight outage types for the data submittal. This means there are approximately 1000 data inputs to the EEI Data System for each generating unit. At the risk of oversimplification, let us look at a method of combining the 1000 data inputs to provide two data outputs for each generating unit.

The outage types range in scope from a forced outage, which requires a unit to be removed from service immediately, to a nonoperating system test, which requires the reporting of component failures during unsuccessful tests while the unit is shutdown. These outage types are arranged into two groups (Figure 2). The outage duration of each event in the nonproductivity group is used to measure the amount of nonproductive outage hours each component and each activity contributed to the unit outages and deratings. These outage hours were named unit nonoperating hours. The outage duration of each event in the unavailability group is used to measure the unavailability of each component caused by the out of service time for maintenance. This second group of hours was named component nonoperating hours.

OUTAGE GROUPS

Outage Types	Nonproductivity Group	Unavailability Group
	Unit Nonoperating Hrs.	Component Nonoperating Hrs.
FORCED	X	X
MAINTENANCE	X	X
PLANNED	X	X
RESERVE SHUTDOWN	X	
FORCED PARTIAL	X	X
SCHEDULED PARTIAL	X	X
NONCURTAILING EQUIPMENT		X
NONOPERATING SYSTEM TEST		X

Figure 2

UNIT NONOPERATING HOURS

The unit nonoperating hours occur whenever the unit is shut down during forced, maintenance, planned and reserved shutdown types of outages. Also, the gross megawatt hour energy not produced during deratings, of a forced partial outage or a scheduled partial outage, is converted to unit nonoperating hours. Each unit nonoperating hour is assigned the amount of energy equal to the summer gross maximum dependable capacity.

The unit nonoperating hour concept is based upon the principal that each component, such as a steam generator, a pump, and a valve, and each activity, such as refueling and turbine inspection, share the unit's nonproductive hours during the maintenance or planned outage. A new method was developed to assign the unit's nonproductive hours from maintenance and planned outages to the maintenance of each component and activity that required the unit to be shut down. This means that components, which are not part of the critical path of the outage, share the burden of the outage nonproductivity and are charged with unit nonoperating hours.

IDENTIFYING IMPROVEMENTS IN NUCLEAR POWER PLANTS

An economic measurement of component nonproductivity is used to identify where improvements are needed in nuclear power plants. The basis of this economic measurement is the annual average fuel replacement cost. Since 1971, the annual average fuel replacement cost at Commonwealth Edison for a nuclear power plant has steadily increased from $5.94 per net megawatt hour to a value of $11.99 per net megawatt hour in 1976 (Figure 3). This means that a unit at the Zion Station, which is rated at 1040 net megawatts per hour, requires an average annual fuel replacement cost of approximately $12,500 for each unit nonoperating hour in 1976.

To identify where improvements are needed in components at the Zion Station, the 1975 report of unit and component nonoperating hours and the annual average fuel replacement cost were reviewed with Zion Station personnel. A review of the listings of the ten components and activities with the highest unit and component nonoperating hours identified the reactor coolant pumps as a major contributor to nonproductivity and unavailability. The reactor coolant pumps were charged with 910 unit nonoperating hours and 2616 component nonoperating hours during 1975. These unit nonoperating hours required an average fuel replacement cost of $10 million. The majority of this cost was due to reactor coolant pump seals. This identification of the cost of nonproductivity resulted in an investigation

AVERAGE NET FUEL REPLACEMENT COST

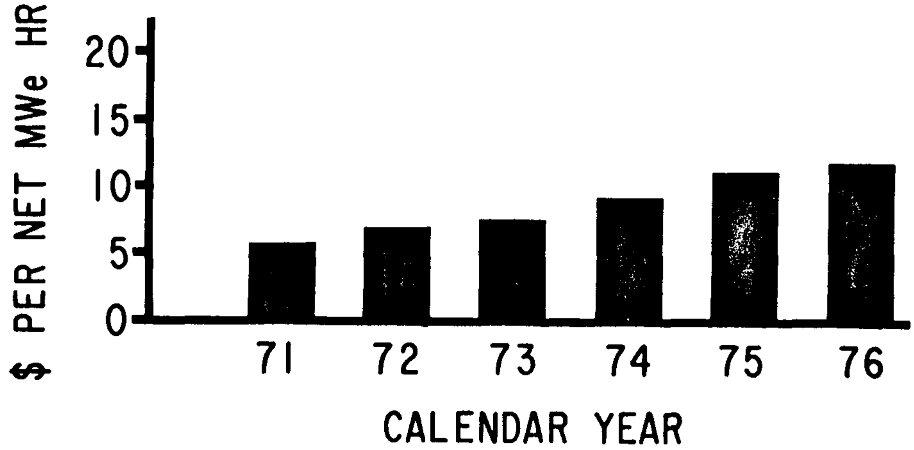


Figure 3

of the reactor coolant pump seals as a joint effort of the Zion Station and the Station Nuclear Engineering Department personnel.

REACTOR COOLANT PUMP SEAL INVESTIGATION

An investigation team with experience in understanding the relationship between reactor coolant pump seal design and plant operation was needed. The team also needed to be free of the daily pressures of operating the reactor coolant pumps at the Zion Station in order to provide an independent investigation. A two-man investigative team was selected from the Reliability and Design Specialist Group (R&DS) of the Station Nuclear Engineering Department. One of the design specialists had previous pump design experience and the other had previous shift foreman experience at the Zion Station. The Zion Station Technical Staff Engineer for reactor coolant pumps was added to the team to verify that the data collected from the station was accurate.

A systematic collection and analysis of data was documented on an Equipment Failure and Maintenance Investigation Report Form (Figure 4). The format of the form provided for documenting in chronological order the when, what, where, and extent of each seal failure, maintenance problem, and existing solution. Each problem and existing solution was analyzed for its basic causes. The form also provided for documenting comments and recommendations by the R&DS when the existing solution to a problem did not appear to prevent the basic causes of the problem from recurring.

Nine man-months were spent investigating outage, maintenance, and inspection data of the reactor coolant pump seals and preparing a report. The report identified the basic causes of the seal failures and maintenance which were responsible for $17,500,000 of fuel replacement cost during 1975 and 1976. The major point of the report was that the basic causes of nonproductivity still existed and could recur unless the corrective action recommended in the report was taken.

A computer program was developed to search the company computer tapes for data submitted to EEI and to calculate the unit nonoperating hours. The program tabulates each year the total amount of unit nonoperating hours from six of the outage types for each of the 129 components and activities.

EQUIPMENT FAILURE & MAINTENANCE INVESTIGATION REPORT

FORMAT	DOCUMENTATION
Date Nonoperating hrs Equipment hrs Operating experience and cause Additional information (Zion station & Westinghouse reports)	PROBLEM • WHEN • WHAT • WHERE • EXTENT
▼	▼
Immediate resolution & corrective action by maintenance	SOLUTION
▼	▼
Reliability & design specialists comments / recommendations	ANALYSIS OF PROBLEM & SOLUTION

Figure 4

COMPONENT NONOPERATING HOURS

The computer program used to tabulate the unit nonoperating hours is also used to tabulate the component nonoperating hours. The component nonoperating hours occur whenever a component is taken out of service for corrective or preventive maintenance. The component nonoperating hours occur for certain components while the unit is shut down, derated, or at full power. Therefore, component and unit nonoperating hours do not always occur for the same events. For example, (1) an operating feedwater pump fails, causes a unit trip that results in unit shutdown, or (2) one of two operating feedwater pumps fails, causes the unit to be derated, and (3) the feedwater pump is shutdown as a spare and needs maintenance while the unit is at full power. In each example the feedwater pump is taken out of service for maintenance, considered unavailable, and charged with component nonoperating hours. In the first two examples the feedwater pump is responsible for the shutdown and derating of the unit and is charged with unit nonoperating hours.

UNIT AND COMPONENT NONOPERATING HOUR REPORTING

The unit and component nonoperating hours from the computer printout are reported for each of the 129 components and activities according to an equipment functional arrangement tree. At the top of the tree is the generating unit. At the next level are three groups, nuclear equipment, secondary equipment, and unit operations. The nuclear and secondary equipment groups contain components and activities that are related to component corrective and preventive maintenance. The unit operations group contains the activities such as training and operating license limitations that are related to the administrative operation of the unit. The components and activities are divided among the three groups as follows: the nuclear equipment group has 37 components and activities, the secondary equipment group has 79 components and activities, and the unit operations group has 13 activities. A partial arrangement of the secondary equipment group is shown in Figure 5.

The functional arrangement method of reporting provides for the addition of nonoperating hours from the lower groups to the next higher group. This additive method provides two data outputs from the EEI data for each generating unit, one total for unit nonoperating hours and the second total for component nonoperating hours. The functional arrangement of reporting permits a comparative analysis between similar components and activities of different units. The functional arrangement method also provides visibility as to how the nonoperating hours of each component and activity contribute to the overall total of nonoperating

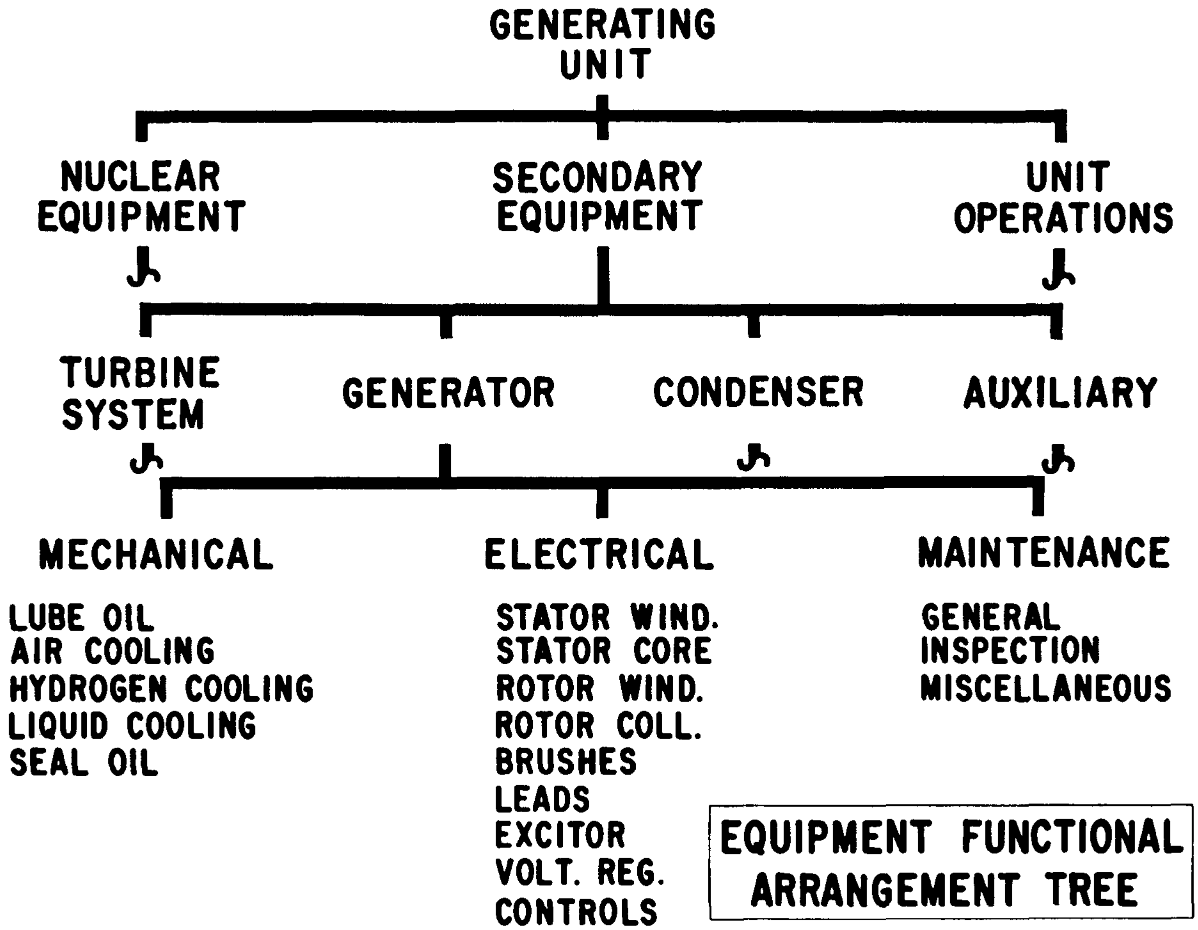

GENERATING UNIT
NUCLEAR EQUIPMENT
SECONDARY EQUIPMENT
UNIT OPERATIONS
TURBINE SYSTEM
GENERATOR
CONDENSER
AUXILIARY
MECHANICAL
LUBE OIL
AIR COOLING
HYDROGEN COOLING
LIQUID COOLING
SEAL OIL
ELECTRICAL
STATOR WIND.
STATOR CORE
ROTOR WIND.
ROTOR COLL.
BRUSHES
LEADS
EXCITOR
VOLT. REG.
CONTROLS
MAINTENANCE
GENERAL
INSPECTION
MISCELLANEOUS
EQUIPMENT FUNCTIONAL ARRANGEMENT TREE

Figure 5

hours for the generating unit. The report also contains listings of the ten components and activities with the highest unit nonoperating hours and the highest component nonoperating hours to identify the major contributors to nonproductivity and unavailability.

Forty-two recommendations were made by the Reliability and Design Specialist to the Zion Station and the Westinghouse Electric Corporation. These recommendations, along with supporting technical information, were presented to reduce the occurrences of No. 1 seal failures and reduce the nonproductivity of the basic causes of the problems identified. The recommendations were jointly reviewed with Westinghouse and Zion Station personnel and action items resulted. The major recommendations covered the following:

- Revising station procedures to eliminate seal failures caused by depressurization of the RCS system at cold shutdown conditions with pressurizer full
- Reducing outage time associated with draining, filling, and venting RCS loops during seal maintenance and inspection.
- Decreasing frequency of scheduled seal inspections
- Expediting procurement and installation of ultrasonic flowmeters for measuring seal leakoff flow and reducing startup delays
- Reducing introduction of crud to the seal faces during RCS level changes
- Reviewing with Westinghouse selected seal design features and inspection procedures and criteria to improve station procedures

ECONOMIC ASSESSMENT

Implementation of the action items resulting from the recommendations is being assessed by the Reliability and Design Specialist. The recommendation for reviewing the criteria for the present inspection interval of the reactor coolant pump No. 1 seal is partially completed. The results of the review showed that Westinghouse recommended inspection of the No. 1 seals after every two refueling cycles because of wear of the No. 1 seal insert with 18,000 operating hours. Since the Zion Units refuel each year, two refueling cycles are only 12,000 operating hours. The Zion Station has extended its inspection of reactor coolant pump seals to 18,000 operating hours, which is 3 years.

A ten-year present-value analysis was performed for changing the No. 1 seal inspection interval from a two-year cycle to a three-year cycle, starting with the September, 1977, refueling outage at the Zion Station. An average outage time of 200 unit nonoperating hours was used and an average fuel replacement cost of $12,500 per unit nonoperating hour was used throughout the analysis.

The present value analysis in 1977 dollars showed a savings of $3,470,000 over a ten-year period for Unit 1 (Figure 6). A ten-year savings of $3,300,000 was also obtained for changing the seal inspection cycle of Unit 2. The company is receiving additional benefits from the seal investigation at the Zion Station. This comes from applying the reactor coolant pump seal recommendations to the Byron and Braidwood Stations now under construction.

SUMMARY

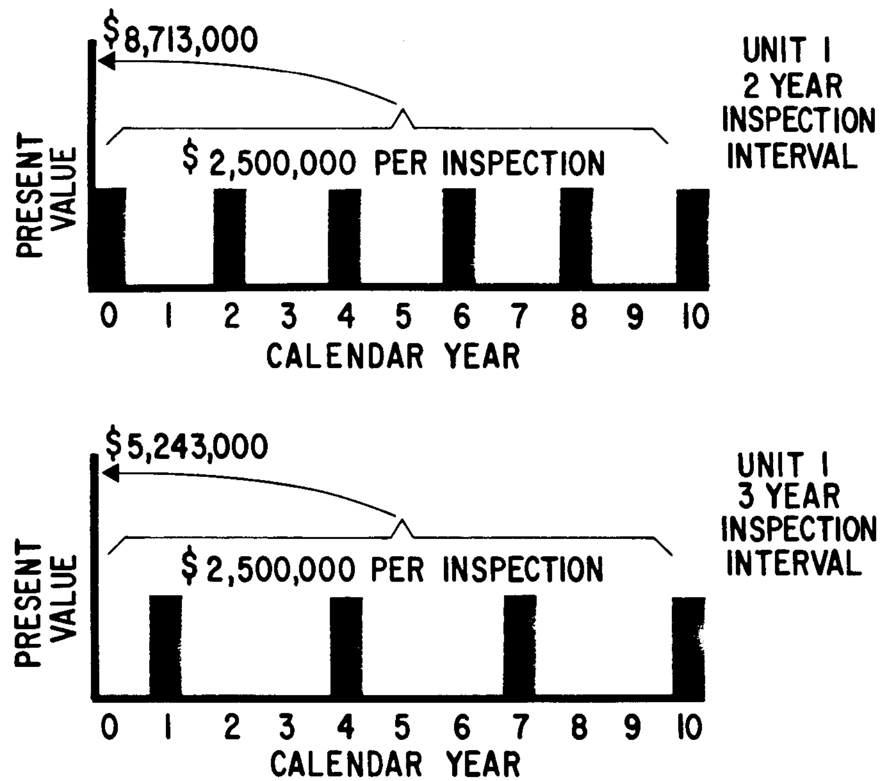
There is an underlying theme to what has been said in this paper. The Commonwealth Edison Company has formalized the methods of using existing EEI data and performing an analytical investigation of equipment problems into a Generating Stations Productivity Improvement Program. We hope that sharing our experience has provided you with another method for identifying where improvements are needed in nuclear power plants and with a means for estimating the economic benefits of these improvements.

REFERENCES

1. R. J. Squires, "A Method for Increasing Nuclear Generating Station Component Availability and Generating Unit Productivity," September 3, 1976.
2. R. J. Squires, "Unit and Component Nonoperating Hours - Zion Station 1975," September 10, 1976.
3. R. S. Kolflat and R. J. Squires, "Zion Station Reactor Coolant Pump Seals Failure and Maintenance Investigation Report," June 10, 1977.
4. R. S. Kolflat and R. J. Squires, "Action Status - Zion Station RCP Seal Report Review, July 14, 1977," August 31, 1977.

TEN YEAR PRESENT VALUE ANALSIS

RCP NO. I SEAL INSPECTION



UNIT I SAVING $PV_{10} = \$8{,}713{,}000 - \$5{,}243{,}000$

$= \$3{,}470{,}000$

Figure 6

DISCUSSION

O'HARA: What level of employee is used to record outage data? What method is used to gather data (if forms, how often)? Do you have a validation or audit to ensure that all data are recorded?

SQUIRES: An engineering assistant at each station is used to record the outage data. The current Edison Electric Institute System forms are used. This is gathered monthly on the EEI forms and transmitted to Production. Production uses a validation program to verify that the data are accurate. We do not audit the data to verify that all data are recorded. After validation, Production sends the data quarterly to EEI.

PILGRIM: In working with EEI data to identify problems, who in Commonwealth Edison initiates a recommendation to management that a problem should be investigated and who is responsible for allocating outage time between equipment design and operation and maintenance of the equipment?

SQUIRES: The Reliability and Design Specialists Group of the Station Nuclear Engineering Department recommends that a problem be investigated. During the investigation of a problem, the investigative team members determine if the outage time was caused by design, operation, or maintenance and allocate the outage time to the cause as part of the investigation.

PASSAMONTE: Do you find EEI data adequate to properly classify component failures to allocate component outage hours?

SQUIRES: Yes.

PASSAMONTE: Do you find the log time in EEI reporting a problem or acceptable for your needs? Since "RMA" (Relative Mechanical Availability) is not reported by most utilities, how, if at all, do you account for operations unavailability due to lack of planning - lack of priority to get machine back on line - operator or maintenance staff "goofs" - spare parts not available, etc.?

SQUIRES: No. The company uses its own computer programs to report the data. We do not attempt to identify unavailability to this level. The purpose of using EEI data is to identify major problems of nonproductivity and investigate the causes of failures and maintenance and to provide recommendations to reduce the problem from recurring.

RESULTS OF ADVANCE MAINTENANCE PLANNING SERVICE

R. M. Butrovich
E. Hummel
General Electric Company

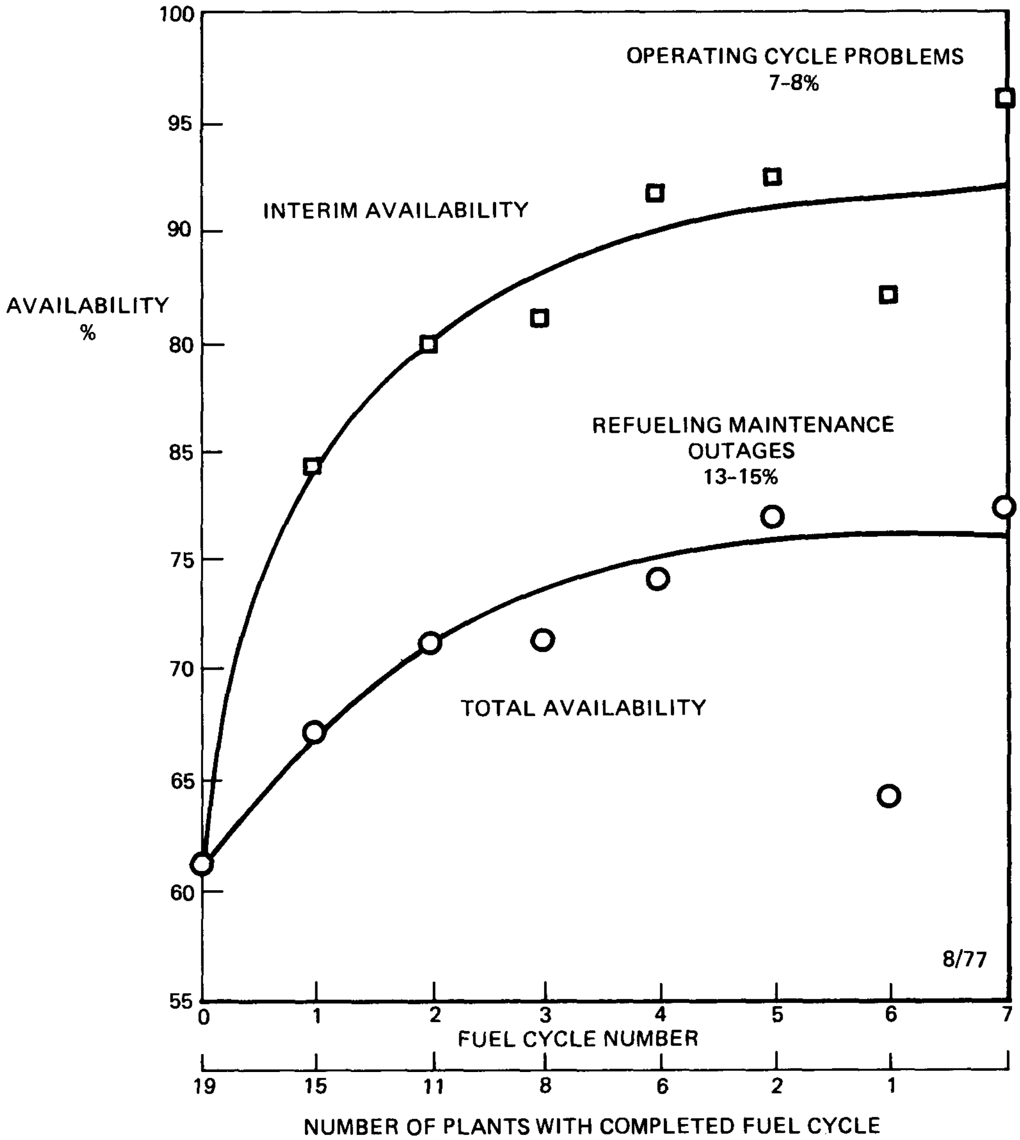
INTRODUCTION

Planned refueling maintenance outages have historically had an adverse annual availability impact of 13 to 15 percent. Operating cycle problems add 7 to 8 percent to those figures. Figure 1 shows plant availability as a function of plant age. To reduce this impact on availability, General Electric has placed concentrated effort on helping utilities optimize outage planning by continually improving techniques as more experience is gained. Because of outage complexities and the requirement to direct the work of large numbers of specialists within a short time, it is apparent that a well-planned and systematic approach is necessary. Not only must every aspect of plant maintenance be examined closely, but shared experience is also a key factor in reducing outage length. The reactor supplier must be open. He must share operating experience - good and bad - with all operating plant owners to maximize unit reliability.

THE AMPS SYSTEM

To help utilities share this wealth of experience, General Electric has developed its Advanced Maintenance Planning Service (AMPS) for operating BWR power plants. This service is similar to our Steam Turbine-Generator Division's AMPS Program, which was implemented in 1970. By 1975, Steam Turbine-Generators had accumulated data on 50,000 maintenance events, with which it is possible to anticipate the need for service with 80 percent accuracy. Knowing what service will be required and when it will be required has significantly contributed to optimizing the performance of Steam Turbine-Generators.

In 1975, General Electric issued its first Advance Maintenance Planning Service to an operating nuclear plant. Since that time 22 AMPS have been given to



OPERATING CYCLE PROBLEMS
7-8%
INTERIM AVAILABILITY
AVAILABILITY
%
REFUELING MAINTENANCE
OUTAGES
13-15%
TOTAL AVAILABILITY
8/77
100
95
90
80
85
75
70
65
60
55
0
1
2
3
4
5
6
7
FUEL CYCLE NUMBER
19
15
11
8
6
2
1
NUMBER OF PLANTS WITH COMPLETED FUEL CYCLE

Figure 1

utilities: two in 1975, eight in 1976, and twelve in 1977. Five more are scheduled to be completed by the end of 1977 (Figure 2). The ultimate goal is to provide an AMPS package for each refueling-maintenance outage.

The purpose of AMPS is straightforward: to help reduce planned outage duration and minimize forced outage rates in the future. To accomplish this, AMPS provides (six to eight months in advance of a planned major outage) a summary and analysis of the plant's last operating cycle, plus recommendations on all known and likely nuclear steam supply system maintenance requirements. Included in these recommendations are the resources required to perform the maintenance, precautions to be taken, special procedures, manpower needs, radiation exposure, contingency plans, and spare parts. This information is accumulated from utility reports and reports prepared by General Electric's field service personnel. It is then stored in General Electric's computerized Component Information Retrieval System, CIRS (Figure 3).

CIRS is a computerized maintenance reporting technique that is used to identify trends in personnel and equipment performance. As the CIRS data base expands, each BWR owner will benefit from the operating and maintenance experience of all others. The success of AMPS is keyed to CIRS and is therefore keyed to the cooperation and joint participation of each BWR owner in establishing the necessary broad data base.

THE AMPS MANUAL

AMPS is presented to the BWR owner as a manual which is composed of five major sections:

- Introduction
- BWR/Plant Experience
- Recommendations
- Outage Services
- Appendices

The sections of greatest interest to BWR owners and operators are the BWR/Plant Experience section and the Recommendations section. The remainder of this presentation will highlight the content of these two sections.

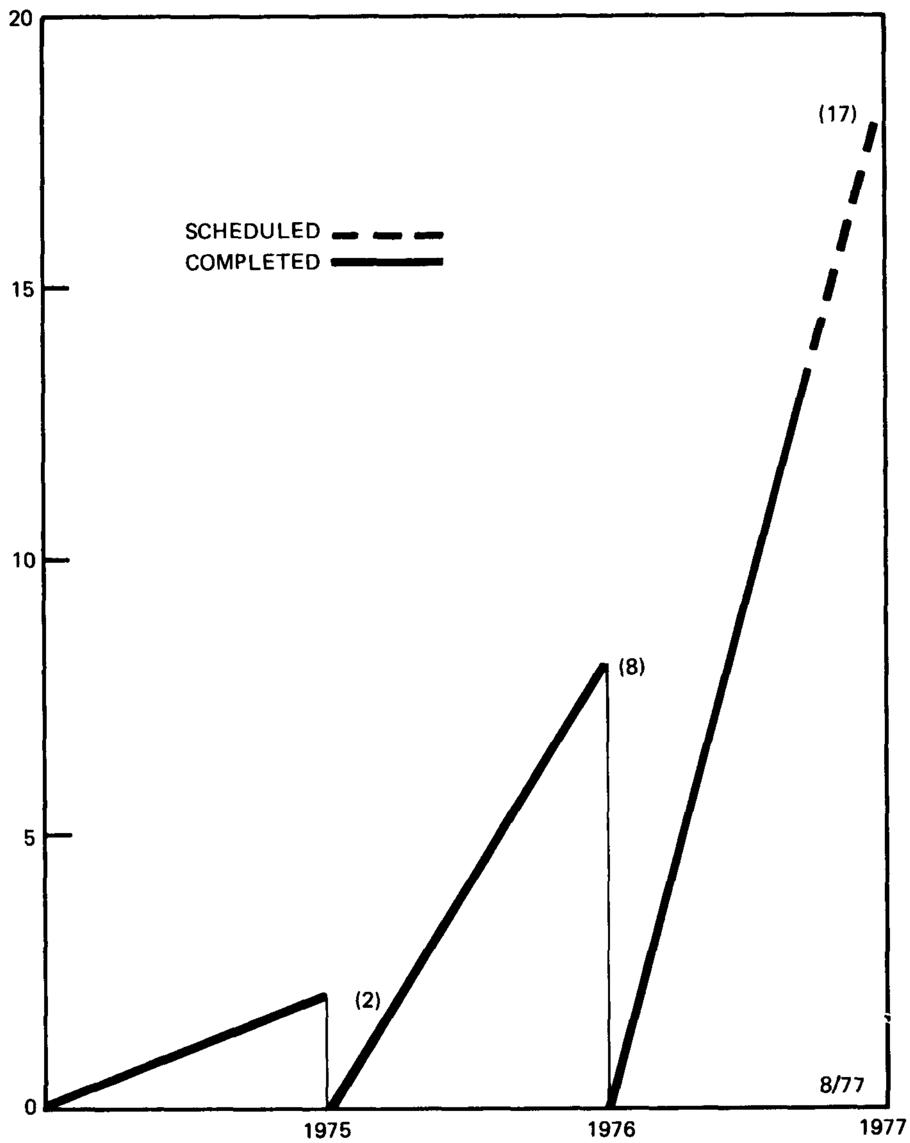


Figure 2. AMPS Program Progress

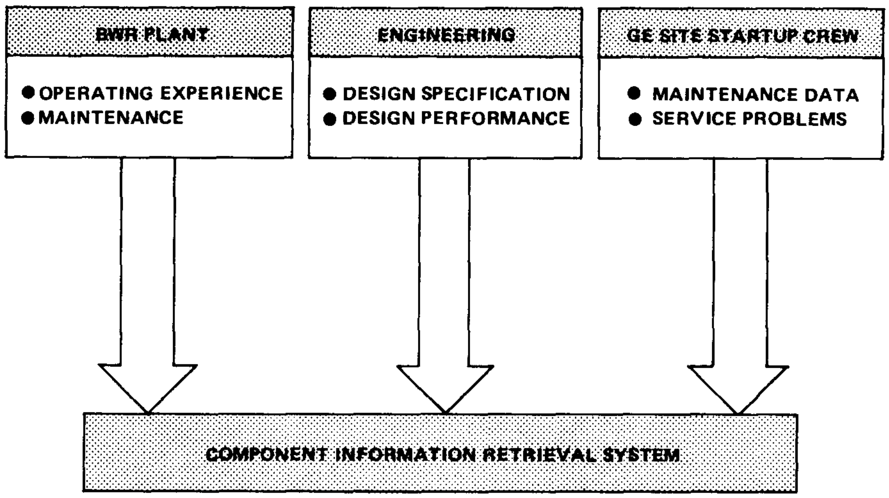

BWR PLANT
● OPERATING EXPERIENCE
● MAINTENANCE
ENGINEERING
● DESIGN SPECIFICATION
● DESIGN PERFORMANCE
GE SITE STARTUP CREW
● MAINTENANCE DATA
● SERVICE PROBLEMS
COMPONENT INFORMATION RETRIEVAL SYSTEM

Figure 3

BWR INDUSTRY/PLANT EXPERIENCE

This section compares the operating experience of the specific utility to that of the BWR industry. The three major topics covered are:

- Performance rate comparison
- Forced outage Experience
- Refueling maintenance outage

Also included in this section is a summary of current BWR problems.

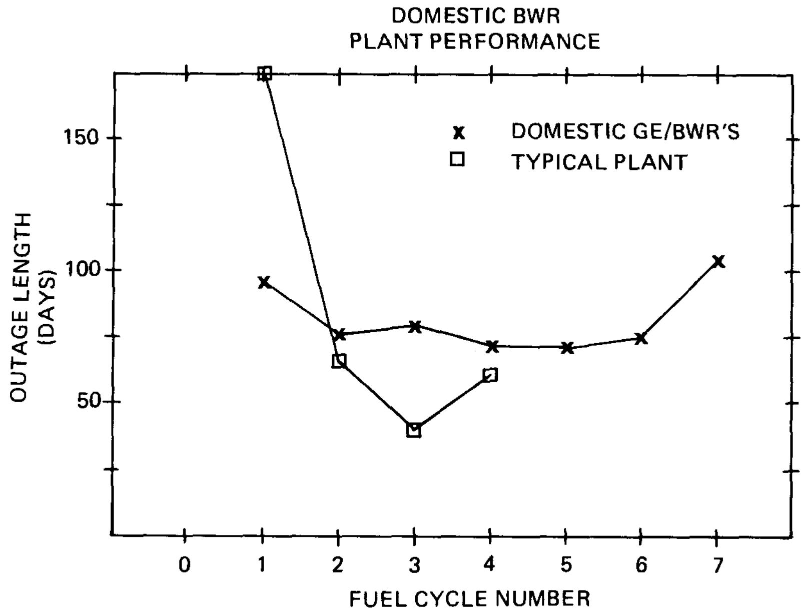
Performance Rate Comparison

Typical of AMPS tables is the following comparison of the specific plant's performance rate to other BWR plants and the light water reactor industry:

Total Plant Performance Rates During First 28 Months of Operation

LWR Groups	Number of Plants	Availability (%)	Forced Outage Rate (%)	Capacity Factor (%)
Specific Plant	1	79	12.2	57.5
All GE BWR/4 Plants	13	64	21	45
U.S. GE BWR/2 & Later Plants	22	66	20	49
All GE BWR/2 & Later Plants	27	66	17	50
All LWR Plants > 300 MWe	63	66	-	50
All LWR Plants	75	65	-	50

The timespan taken above was chosen to directly relate the specific plant performance to that of other LWR's. A similar comparison is also made on a cycle basis; however, this time the industry data base is limited to United States BWR 2 and later plants. Cyclic data are presented in AMPS in three areas: cycle duration data (Figure 4) and interim cycle performance and total cycle performance (Figures 5 & 6). A cycle is defined as the time period commencing at the end of the following refueling. The advantage of this type of analysis is that it readily identifies trends in operating performance. The latest cycle can easily be compared with previous cycles. The particular plant's performance depicted compares favorably with the rest of the industry, with the exception of the second cycle interim availability. The plant's outage length data shows that its first refueling outage was extremely long, but after the first one, it has dropped down or below the industry average for outage length. Also depicted is that off-line days during the second operating cycle were considerably above industry average.



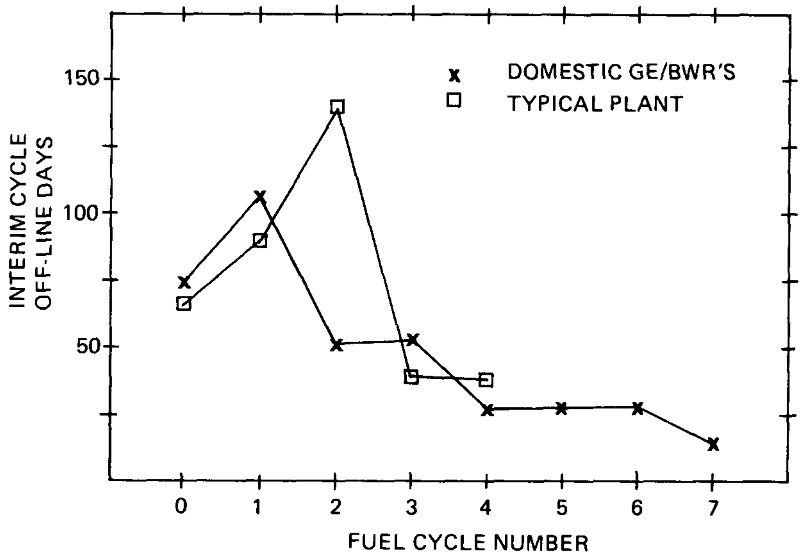


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Figure 4

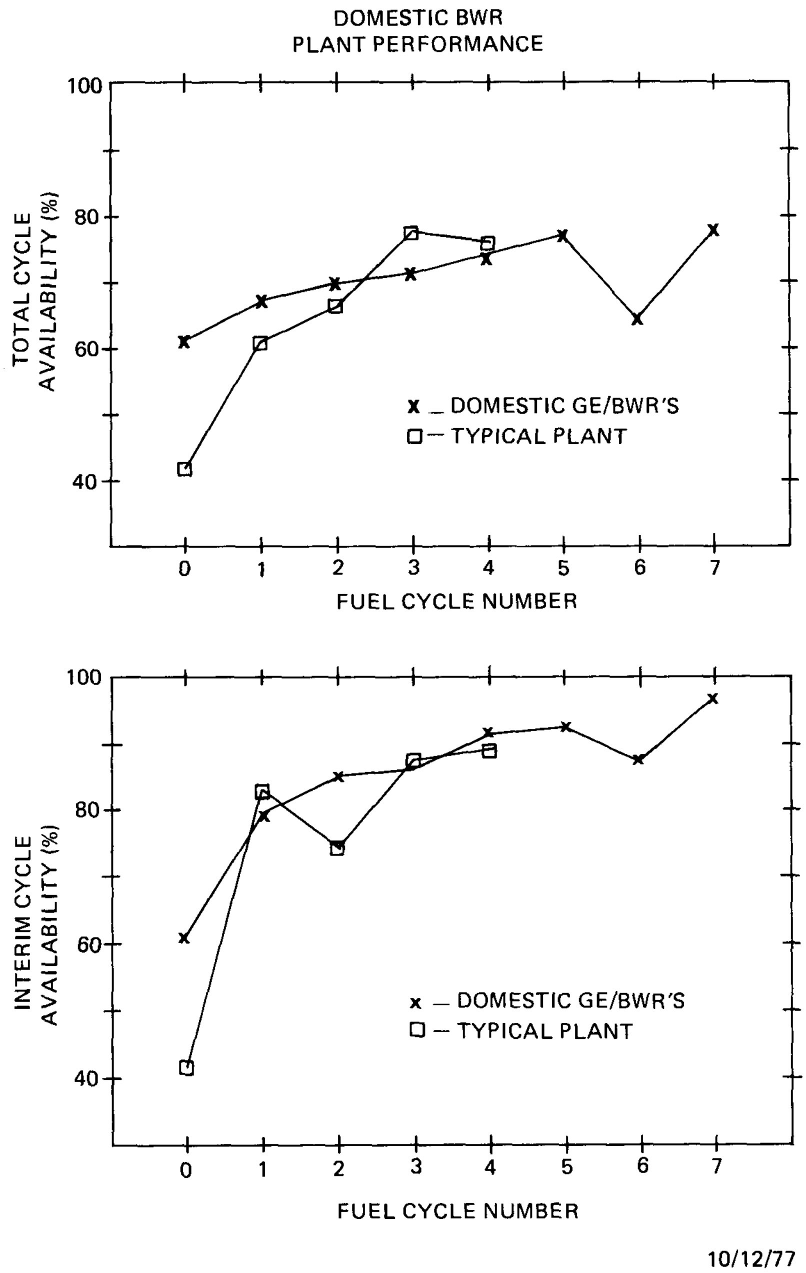
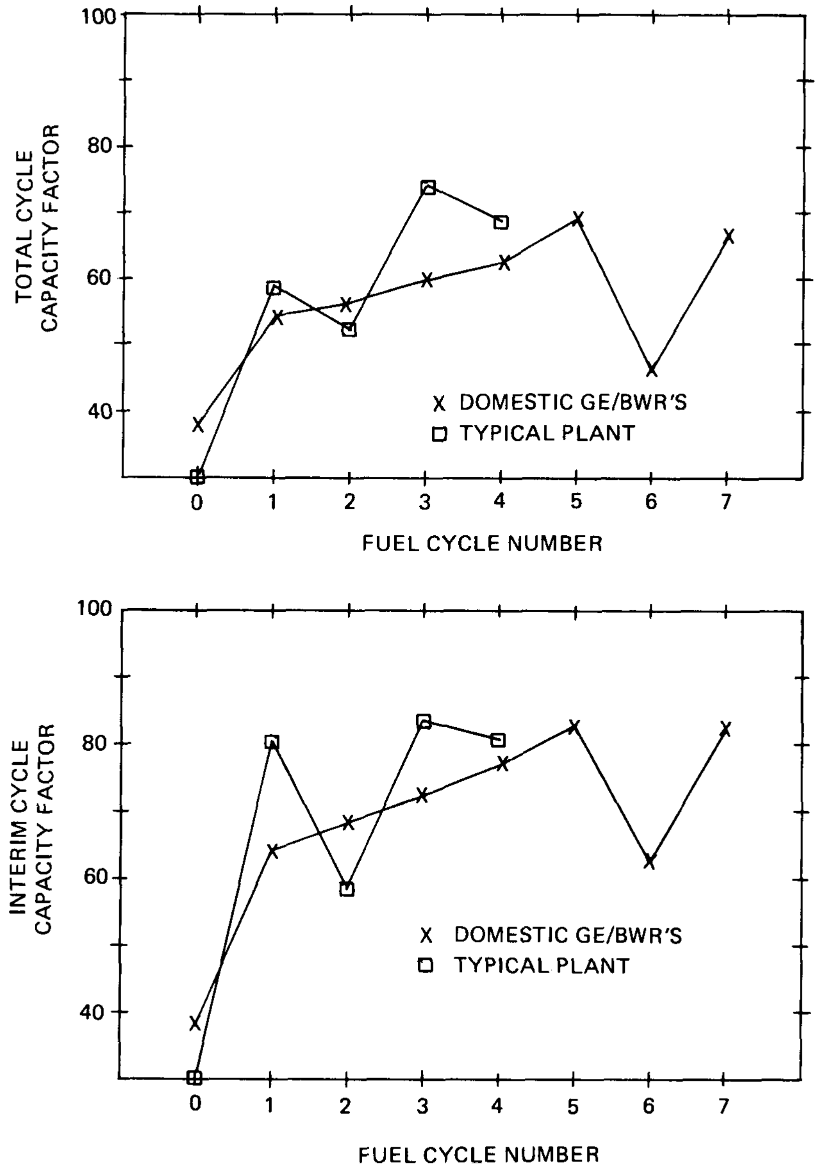

DOMESTIC BWR
PLANT PERFORMANCE
TOTAL CYCLE AVAILABILITY (%)
100
80
60
40
x _ DOMESTIC GE/BWR'S
□ — TYPICAL PLANT
0
1
2
3
4
5
6
7
FUEL CYCLE NUMBER
INTERIM CYCLE AVAILABILITY (%)
100
80
60
40
x — DOMESTIC GE/BWR'S
□ — TYPICAL PLANT
0
1
2
3
4
5
6
7
FUEL CYCLE NUMBER
10/12/77

Figure 5

DOMESTIC BWR
PLANT PERFORMANCE



10/12/77

Figure 6

Forced Outage Experience

Forced outage history provides a comparison of a specific plant's forced outage experience with that of the industry in general. This information is helpful in identifying areas of potential improvement. The data tabulated come from the CIRS detailed report of component performance (Figure 7). This report is included as an appendix to the AMPS Manual. The report contains additional specific information on the maintenance performed and its contribution to plant unavailability.

Refueling Maintenance Outage Experience

This section summarizes the plant's refueling/maintenance experience and compares it to similar industry outage experience. Data for this comparison are taken from CIRS detailed outage reports. Because information in this report is also contained in the detailed report of component performance it is not included in the manual, although data from the report are summarized for the plant and included as an appendix.

Review of Current Problems

This section is included to keep BWR owners advised of current problems being experienced by BWR plants and the progress being made in solving them. Typical topics which have been included in this section are:

- Intergranular stress corrosion cracking
- In-core vibration problems
- Collet retainer tube cracking

Recommendations

In this section recommendations are presented to the BWR owner that are intended to provide information to assist utility management in making decisions leading to increased availability and to reduce outage time. These recommendations are divided into four subsections:

- Routine outage tasks: Includes those tasks that are repetitive in nature and that can be expected to be performed every major outage.
- Specific outage tasks: Tasks that are specifically recommended for the upcoming outage.

MARCH 7, 1977

COMPONENT INFORMATION RETRIEVAL SYSTEM
DETAILED REPORT OF COMPONENT PERFORMANCE

PLANT(S) SELECTED: OPERATING PLANT DATA THRU: 1977 (BEGINNING IN 1974)

Functional Group / System / Component Type / Component Application	Outage Date / Plant Name / Outage Type/Prox Cause / Reason/Type Work	Contribution (Days)	Unavailable (Days)	Description of Activity
Nuclear Steam Supply Sys				
Stm & Clnt Invt & Reg Sys / Recirculating Water Sys / Pump / Seal	12-06-74 / F / Equipment / No / Cor Actn	1974- .0	3.0	Replaced 2nd stage. Seal recirc Pump "B". S Time is estimated.
Pump / Seal	01-17-75 / F / Equipment / Yes / Cor Actn	1975- 11.0	11.0	Rx manual scram when 2-stage seal on b recirc pump failed causing DW pressure to exceed 1.0 psig. Due to improper installation seal damaged by interference with seal cooling water impeller. Lower coupling half installed using revised procedure.
Pump / Seal	01-17-75 / M / Equipment / Yes / Cor Actn	1975- 4.0	4.0	While heating up, recirc pump B indicated improper functioning of first stage. Replaced seal.
Pump / Seal	09-17-75 / M / Equipment / Yes / Cor Actn	1975- 6.5	6.5	Replace recirc pump seal.
Valve	09-18-74 / M / Equipment / No / Cor Actn	1974- .0	1.2	Repaired clutch and adjusted torque switch on VLV MO-66B. Time is estimated.
Valve	12-06-74 / F / Equipment / No / Cor Actn	1974- .0	.2	VLV MO-65B would not fully close. Adjusted torque switch. Time is estimated.

Legend:
Outage type: F=forced, M=sched maintenance, R=sched refueling. Type work: Type of activity performed on the component.
Reason: Was work on component one of the reasons for outage. Unavailable: No. of days component was unavailable.
Prox Cause: The proximate cause of the work (not root cause). Contribution: No. of days this component contrib to plant

Figure 7

- General plant performance: Recommendations that may not be directly related to outage maintenance but can help to improve plant availability.
- Long range planning: Tasks that cannot be completed in the upcoming outage for various reasons - usually long lead times for material - but which should be considered for future outages.

As much as possible, the following kinds of information are included in each recommendation:

- The reason for the recommendation
- Manpower estimates
- Time estimates
- Radiation exposure estimates
- Precautions
- Licensing requirement
- Hardware requirement
- Special procedure requirements
- Special tools required
- Spare parts required

Typical of the information included in AMPS recommendations are the following resource estimates taken from control rod drive (CRD) maintenance recommendations:

Radiation Exposure Per Man	60 - 80 MR/12 Hour Shift
Crew Size (Without Rebuilding)	8 Technicians/Shift 2 Engineers/Shift
Remove TIP System Tubing Install Platform Leaves Perform Timing Tests	1 Day
Remove Shoot-Out Steel	1/2 Day
Uncouple and Valve Out	1/2 Day
Remove and Replace CRD	4-1/2 Days
Install Shoot-Out Steel	1/2 Day
Install TIP Tubing	1/2 Day
Cleanup	1/2 Day
	8 Days (Two 12-Hour Shifts/Day)

Also included with the recommendations is a list of the spare parts normally required to repair the component. Spare parts recommendations are included in the last appendix of the manual.

Assessment of AMPS

The NSSS AMPS Program has been in effect for approximately two years. Although it is premature to make long-range predictions on the value of AMPS, the results through June, 1977, have been encouraging. Since the first AMPS was issued in 1975, plants receiving AMPS have conducted shorter refueling outages. The average length of all refueling outages through June, 1977, has been 87 days, whereas the average length of all AMPS outages has been 72 days (Figure 8). General Electric anticipates that as more plants participate in the AMPS Program this record will continue and improve.

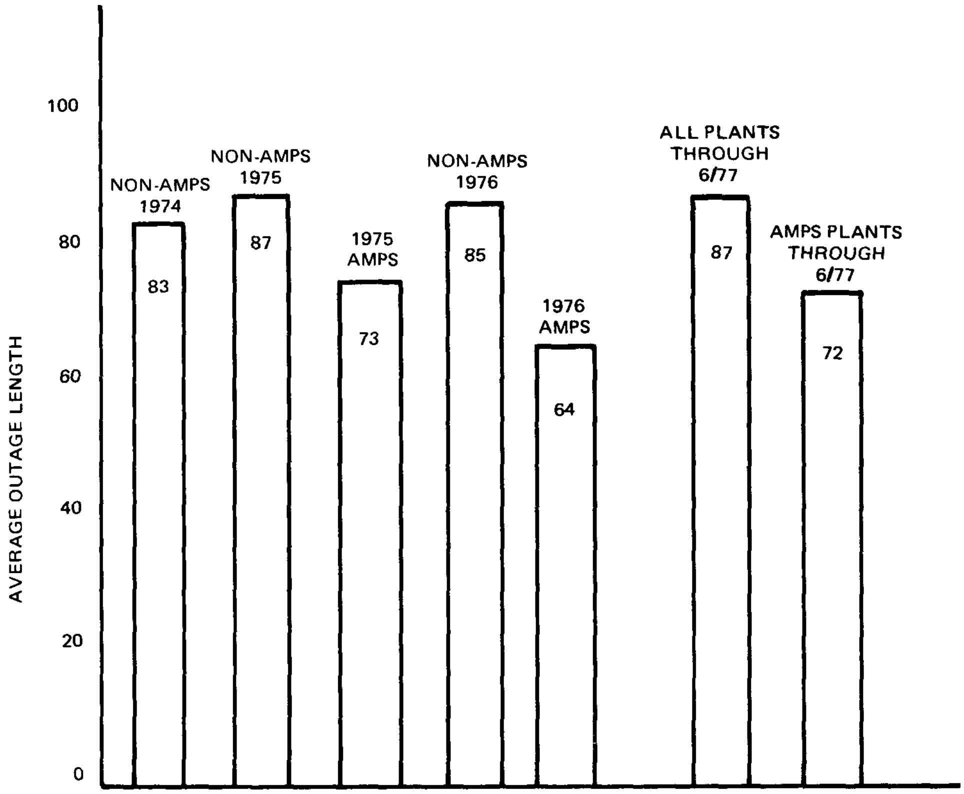


Figure 8. Assessment of AMPS through June of 1977

RELIABILITY/AVAILABILITY ANALYSIS AT DUKE POWER COMPANY

Bruce W. Logan
Assistant Design Engineer
Duke Power Company

ABSTRACT

Reliability/availability analysis techniques are engineering tools which, applied to a wide variety of problems, can give some insights into the expected behavior of components and systems. This paper will present, as examples, summaries of two analyses performed by reliability engineers at Duke Power Company. The examples will demonstrate two completely different applications of reliability/availability techniques. The first example will involve a determination of the economic feasibility of purchasing a mobile, spare step-up transformer. The second example will demonstrate a comparative analysis where auxiliary power system reliability for two alternative generator step-up designs is evaluated.

INTRODUCTION

The use of reliability/availability techniques in power plant design is slowly but surely gaining acceptance in the power industry. Three IEEE standards concerning the subject have been published.[1,2,3] Articles about reliability and/or availability are appearing with increasing frequency in the power industry's trade journals. Organizations throughout the industry have developed, or are developing, the capability to apply reliability/availability techniques to a broad spectrum of engineering problems. Recently, the Nuclear Regulatory Commission has funded a study which will investigate possible uses of reliability technology within the licensing process.[4]

This activity is due largely to two reasons. The first is the power industry's general acceptance of WASH-1400 and its methodology. The second reason is a growing realization on the part of engineering management that the application of reliability/availability techniques to certain classes of problems can provide them with another source of information upon which they can base their engineering decisions. The methodology provides a systematic approach to probabilistic problems that were previously left to judgment alone. This should not be interpreted as saying reliability analysis has replaced good engineering judgment, but rather that this sort of analysis can provide additional information which is useful when making decisions.

Two completely different applications of reliability/availability techniques are shown in this paper. In the first example, a Markov availability model is joined with economics to investigate the feasibility of purchasing a mobile, spare step-up transformer. Fault trees are used in the second example to compare auxiliary power system reliability for two alternative generator step-up designs.

EXAMPLE 1: SPARE TRANSFORMER ECONOMICS

The economics of operating a power station have changed considerably over the past few years. Modest increases in unit availability have become very desirable, especially for large, efficient units. Availability can be increased in two ways: one can increase the "up-time" by designing more reliable systems and purchasing more reliable components, or one can decrease the "down-time" by better planning for outages and having necessary parts available for repair or replacement in the case of failure. The latter choice is, of course, the most practical method for units which are already operating.

Step-up transformers have a direct effect on unit availability since a transformer failure can cause a total or partial outage depending upon the design used in a unit. Furthermore, major failures lead to long (about nine months) repair times. These facts led us, at Duke, to investigate the economic feasibility of purchasing a spare, mobile step-up transformer which could be used at any of our existing or planned steam stations using a 230kV switchyard. By having such a spare, the "down-time" associated with a major failure could be drastically reduced, thereby saving millions of dollars.

To assess the feasibility of purchasing a transformer, three cases were evaluated: (1) a system with no spare, (2) a system with a spare, but without a dedicated Schnabel railroad car for transportation, and (3) a system with both a spare and a dedicated Schnabel car. The initial investigation was an annual cost assessment based on expected yearly outages, which were predicted by using a

Markov availability model, and system economics as were predicted by our System Planning Department's production, costing and security assessment program. Later, an attempt was made to select the optimum time for purchasing the transformer.

Factors considered in the evaluations were:

- Historical step-up transformer failure rates (from Duke records)
- Generic transformer failure rates
- Differences in repair/replacement times for the three cases
- Possible use of transformers from plants under construction as spares
- Planned outage times at the plants being spared
- Realistic production costing
- Variations in interest rates

Each factor had a definite impact on the analyses.

Availability Model

A two-state Markov model with repair was used to predict the transformers' unavailability. The model, with its associated state transitions, is shown in Figure 1.

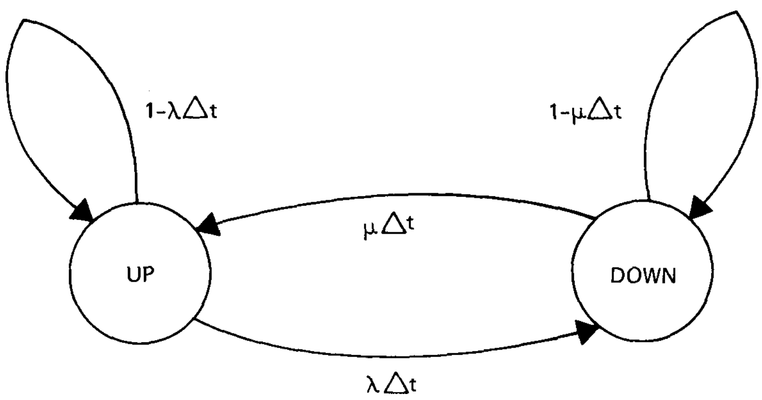


Figure 1. Two State Markov Model With Repair

A pair of simultaneous, first order differential equations were derived from the model. The equations described the probability of being either in the "up" state or the "down" state at any moment in time, or the availability and unavailability, respectively. The time-dependent solution for the unavailability could be closely approximated by its steady state term. This equation is

$$U_{ss} = \frac{\lambda}{\lambda + \mu} \qquad \text{(Eq. 1)}$$

Where U_{ss} = steady state unavailability, λ = failure rate, and μ = repair rate.

Failure Rates. The failure rates used in the study were derived by selectively grouping data from the company's historical records. The failure rates were found to lie within a range (.003 failures/unit-year $\leq \lambda \geq$ .013 failures/unit-year) that could be established using data from the 1974 IEEE Industrial Reliability Survey.[5]

Repair/Replacement Rates. The average times for the repair or replacement of a transformer were derived from conversations with major transformer manufacturers. The repair/replacement times are shown in Table 1A. It was necessary to modify these repair/replacement times to account for a possible overlap with normal planned unit outages. The equation used to make the modification is

$$\bar{R} = R(1 - \emptyset/365) \qquad \text{(Eq. 2)}$$

Where $\bar{R}$ = the modified repair/replacement time, R = the manufacturers' original estimates, and $\emptyset$ = the length in days of an annual unit outage. The results of the modification are shown in Table 1B. The difference in the fossil and nuclear units is due to the difference in the length of their annual outages. The repair/replacement rate, μ, was calculated by dividing 365 by $\bar{R}$.

Economics

An expected annual cost assessment was used to compare the three cases. Costs were calculated for each case using a number of failure rates which fell within the range established by the 1974 IEEE Industrial Survey, as mentioned above.

TABLE 1A

REPAIR/REPLACEMENT TIMES[6]

Case 1:	No Spare	R = 270 days
Case 2:	Spare without Schnabel car	R = 45 days
Case 3:	Spare with Schnabel car	R = 24 days

TABLE 1B

MODIFIED REPAIR/REPLACEMENT TIMES[6]

Case 1:	R = 270 days, $\bar{R}_{n1}$ = 244 days, $\bar{R}_{f1}$ = 262 days
Case 2:	R = 45 days, $\bar{R}_{n2}$ = 41 days, $\bar{R}_{f2}$ = 44 days
Case 3:	R = 24 days, $\bar{R}_{n3}$ = 22 days, $\bar{R}_{f3}$ = 23 da

The expected annual cost of Case 1 (no spare) was due solely to the cost of replacement energy. This cost was computed using the following equation:

$$\text{Expected Annual Replacement Energy Cost} = \sum_{\substack{\text{all} \\ \text{units}}} LC \cdot REC \cdot U \qquad \text{(Eq. 3)}$$

where LC = lost capacity in MW due to a transformer failing, REC = replacement energy cost in \$/MW-year as calculated by our System Planning Department's production, costing, and security assessment program, and U = unavailability calculated in Equation 1 above.

The expected annual costs of Cases 2 and 3 (spare without Schnabel car and spare with Schnabel car, respectively) were computed by adding the fixed charge cost of the spare equipment and the associated operation and maintenance costs to the expected annual replacement energy cost for each of these cases. The results of the three computations were then plotted. See Figure 2.

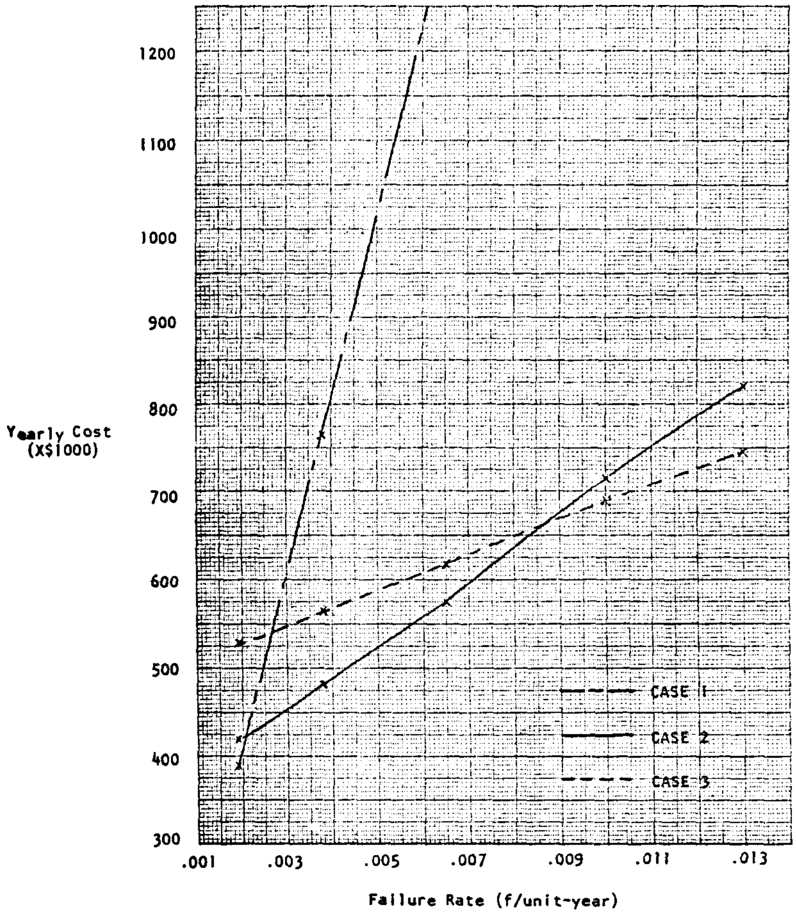


Figure 2. Initial Study Results

Initial Study Results. As can be seen from Figure 2, there was a significant reduction in the expected annual cost of those cases where a spare was used. The cost difference between a spare with a Schnabel car and a spare without a Schnabel car is not as significant. Two further analyses were run to determine if the study results were sensitive to variations in either replacement energy cost or interest rate. Figures 3 and 4 show the outcomes of these analyses, respectively, and indicate that the overall study results are rather insensitive to variations in these parameters.

Optimization of Purchase Time

After showing that the purchase of a spare transformer was advantageous, the next step centered around determining the best time to purchase the spare. The

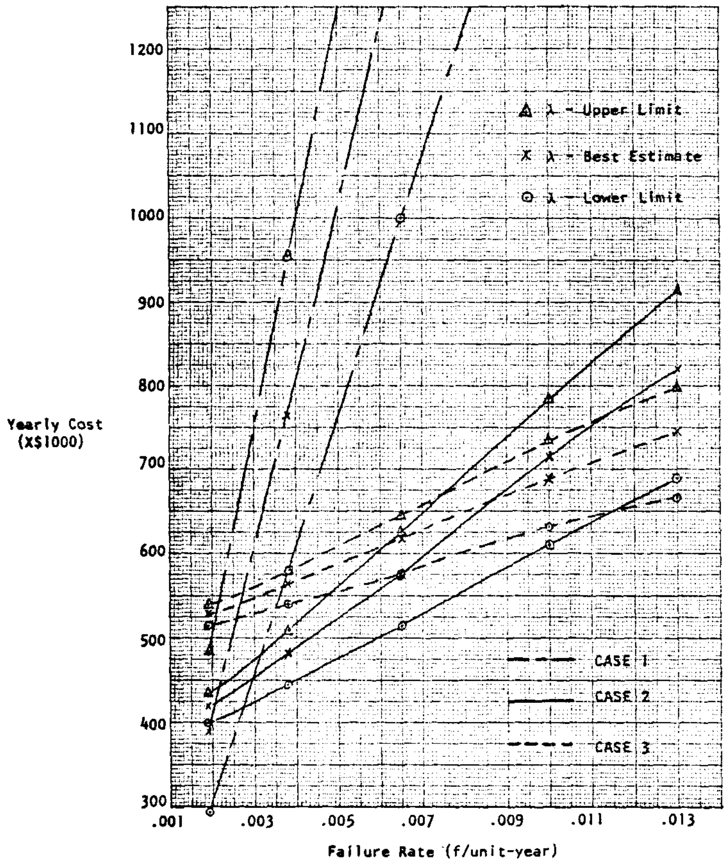


Figure 3. Sensitivity of Initial Results to Variations in Replacement Energy Costs

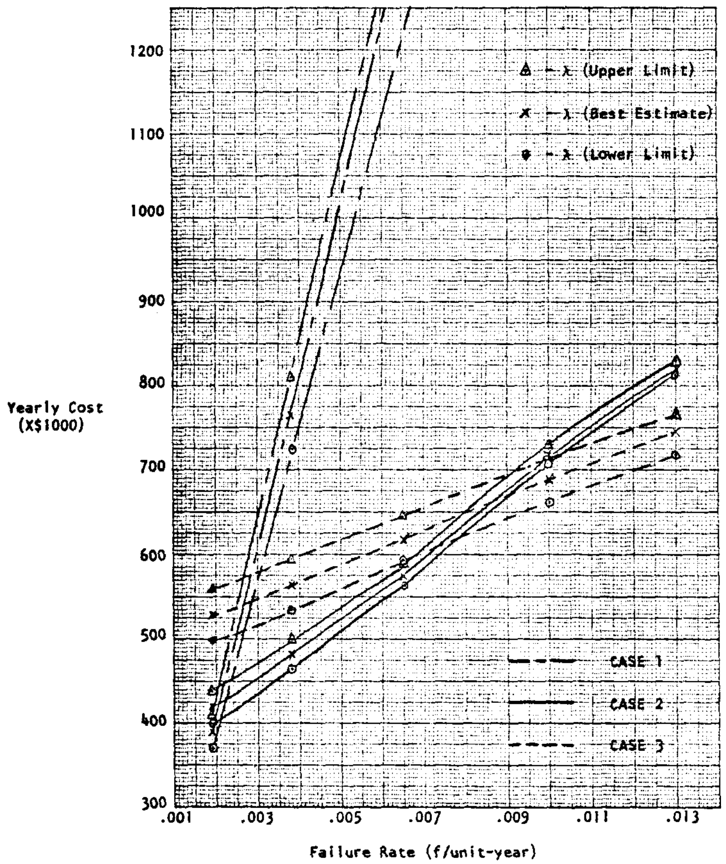


Figure 4. Sensitivity of Initial Results to Variations in Interest Rate

optimum time to have the spare available for service would be the point at which the cumulative annual monetary risk assumed by not having the spare transformer was equal to its cost. The cumulative annual failure probability was computed by

$$F_s(T) = \sum_{i=1}^{T} (1 - e^{-n_i \lambda i}) \qquad \text{(Eq. 4)}$$

where $F_s(T)$ = the probability of the system having experienced a failure after T years of exposure, T = the number of years of exposure, and n_i = the number of transformers having i years of exposure. The cumulative failure probability for our study is shown in Figure 5.

The average cost of an outage on the system was computed using the following equation

$$C(T) = \frac{\sum_{j=1}^{n} (LC)_j \cdot (REC)_j}{n} \qquad \text{(Eq. 5)}$$

where n = the number of transformers being spared during year T, $(LC)_j$ = lost capacity due to a failure of the jth transformer and $(REC)_j$ = replacement energy cost of the jth transformer. The cumulative annual monetary risk was then computed using

$$\text{Cumulative monetary risk} = F_s(T) \cdot C(T) \qquad \text{(Eq. 6)}$$

This result for our study is shown in Figure 6.

Conclusions

The initial study showed that it was, indeed, advantageous to have a spare transformer which could be used as a system spare. The economics of the Schnabel car were not clear cut and could be influenced by other factors such as the spare's storage site and the general availability of Schnabel cars within the industry. The later work was able to identify the time period in which the spare transformer should be purchased.

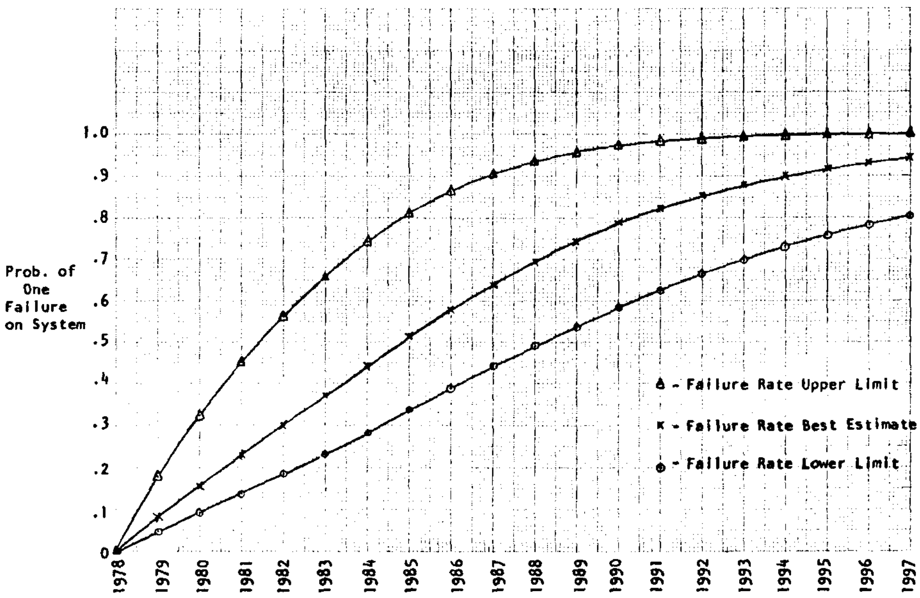


Figure 5. Cumulative Failure Probability for System

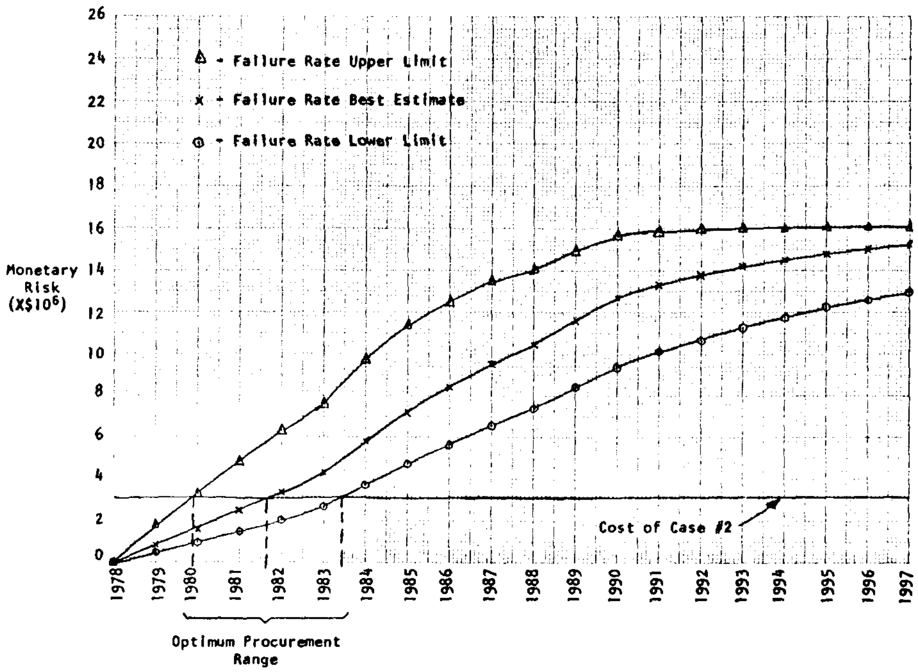


Figure 6. Cumulative Monetary Risk for System

EXAMPLE 2: A COMPARATIVE ANALYSIS

Comparative analysis is a very useful reliability technique. As the name implies, it allows a comparison, either quantitative or qualitative, or both, between two or more designs. In this example the relative reliabilities of two generator stepup/auxiliary power system designs will be investigated. The designs are a startup transformer scheme and a generator breaker scheme which are typical of designs found in the Duke system or being planned for it.

The major advantage of comparative analyses is that they can be used early in the design process to gain insights into the relative strengths and weaknesses of competing designs. This is because the technique makes relative comparisons, which allow the use of generic failure data rather than data which are specific to a particular type of equipment or model. The study illustrated by this example was done to confirm our choice of design, but the study could just as easily have been done to provide information for the initial decision.

Startup Transformer Scheme

A typical startup transformer scheme is shown in Figure 7. In this design, generator voltage is stepped up to transmission voltage by a main stepup transformer (1). Plant auxiliary power is received by stepping down generator voltage through an auxiliary, three winding transformer (1T). When the generator must be taken off the line, primary feeder breakers (1TA-1, etc.) are opened and secondary feeder breakers (1TA-2, etc.) are closed, automatically, allowing power flow from the switchyard through a startup transformer (CT1). When the generator is placed back on line, the reverse procedure is followed. Interconnections between buses 1TA and 1TC and between 1TB and 1TD have been provided in the event that one of the two loses power. In this case, the interties are made by manually closing breakers 1TA-3 and 1TC-3 or 1TB-3 and 1TD-3.

Generator Breaker Scheme

The generator breaker scheme is shown in Figure 8. Here generator voltage is stepped up to transmission voltage by two three-quarter sized transformers (1A and 1B). Two generator breakers (GB1A and GB1B) have been provided to isolate the generator when it is not operating. Plant auxiliary power is received by stepping down generator voltage through two auxiliary transformers (1ATA and 1ATB). During shutdown operation, transmission voltage is stepped down through transformers 1A and 1B, and is stepped down again through transformers 1ATA and 1ATB to provide

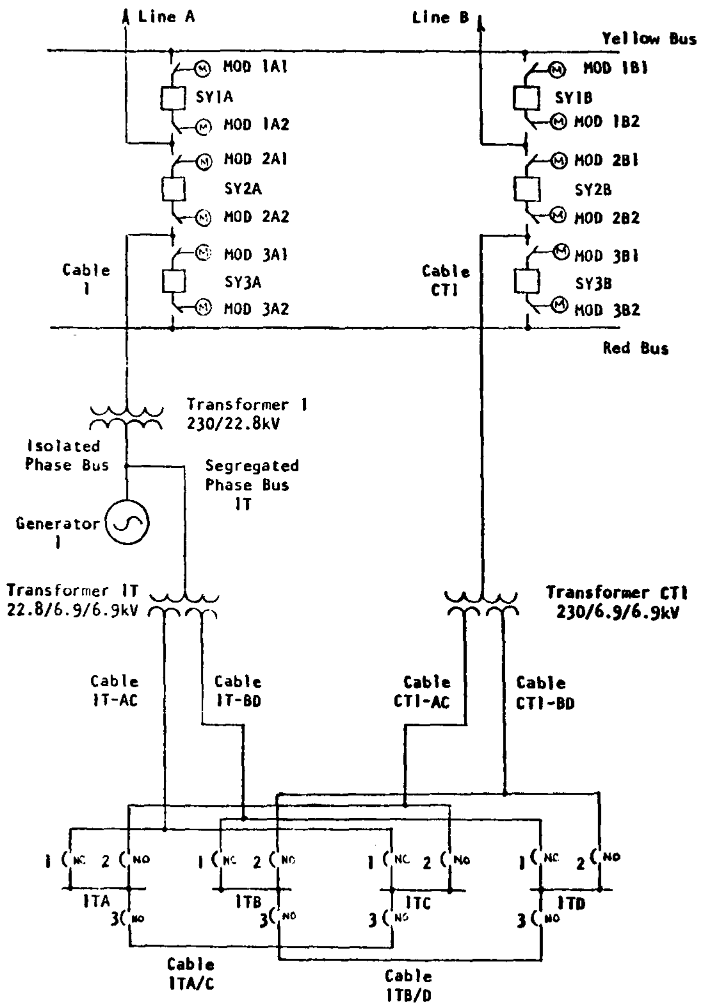


Figure 7. Startup Transformer Scheme

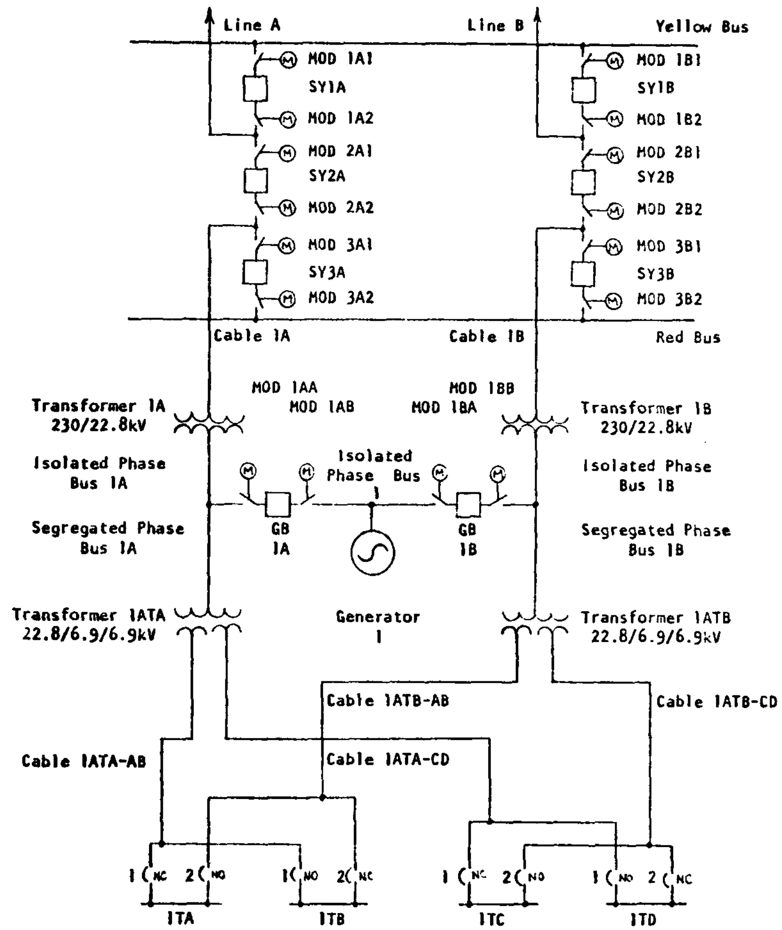


Figure 8. Generator Breaker Scheme

plant auxiliary power. This design avoids a momentary power loss in the case of a generator trip which is inherent in the startup transformer design. In the event that a bus loses power it is automatically tied through its secondary feeder to an alternate power source.

Reliability Comparison and Results

The two designs have been modeled using fault trees to determine their probabilities of losing power to all four 6.9kV buses. (Since the connections below the 6.9kV level are identical in both designs, they have been eliminated in this study.) The fault trees for the startup transformer design and the generator breaker design are shown in Figures 9 and 10, respectively. Failure data from IEEE Standard 500[3], the 1974 IEEE Industrial Survey[5], and Duke historical records have been used in computing the failure probabilities. The results of these two calculations are shown in Figure 11.

Conclusions

For this particular case, the generator breaker scheme is substantially better than the startup transformer scheme. Although the more rapid increase in failure probability for the generator breaker scheme is somewhat disturbing, an outage exceeding the design life of a plant would be required for the failure probability to equal that of the startup transformer scheme.

REFERENCES

1. IEEE Standard 352-1975, "IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems."
2. IEEE Standard 577-1976, "IEEE Standard Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations."
3. IEEE Standard 500-1977, "IEEE Guide to the Collection and Presentation of Electrical, Electronic, and Sensing Component Reliability Data for Nuclear-Power Generating Stations."
4. Federal Register, Vol. 42, No. 130, July 7, 1977, p. 34955.
5. "Report on Reliability Survey of Industrial Plants, Part 1: Reliability of Electrical Equipment," IEEE Transactions on Industrial Applications, Vol. 1A-70, No. 2, March/April 1974, p. 220.
6. "Economic Assessment of a Spare Step-up Transformer for a System of Generating Stations," Third Annual Reliability Engineering Conference for the Electric Power Industry, B. Logan and W. Riggs, September 1976, pp. 135-138.

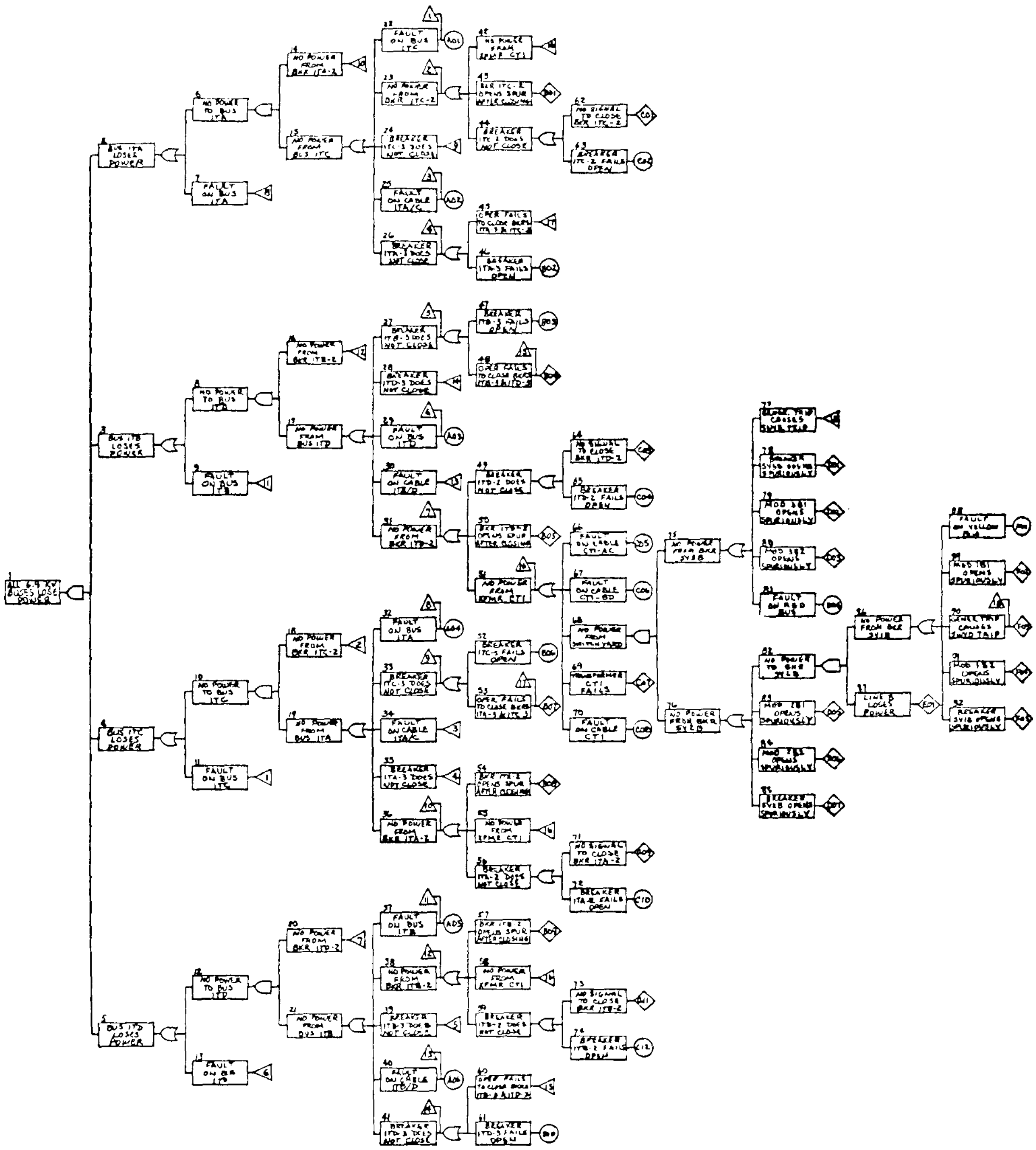


Figure 9. Startup Transformer Scheme—Fault Tree for Loss of all 6.9 KV Buses When Unit is in the Shutdown State

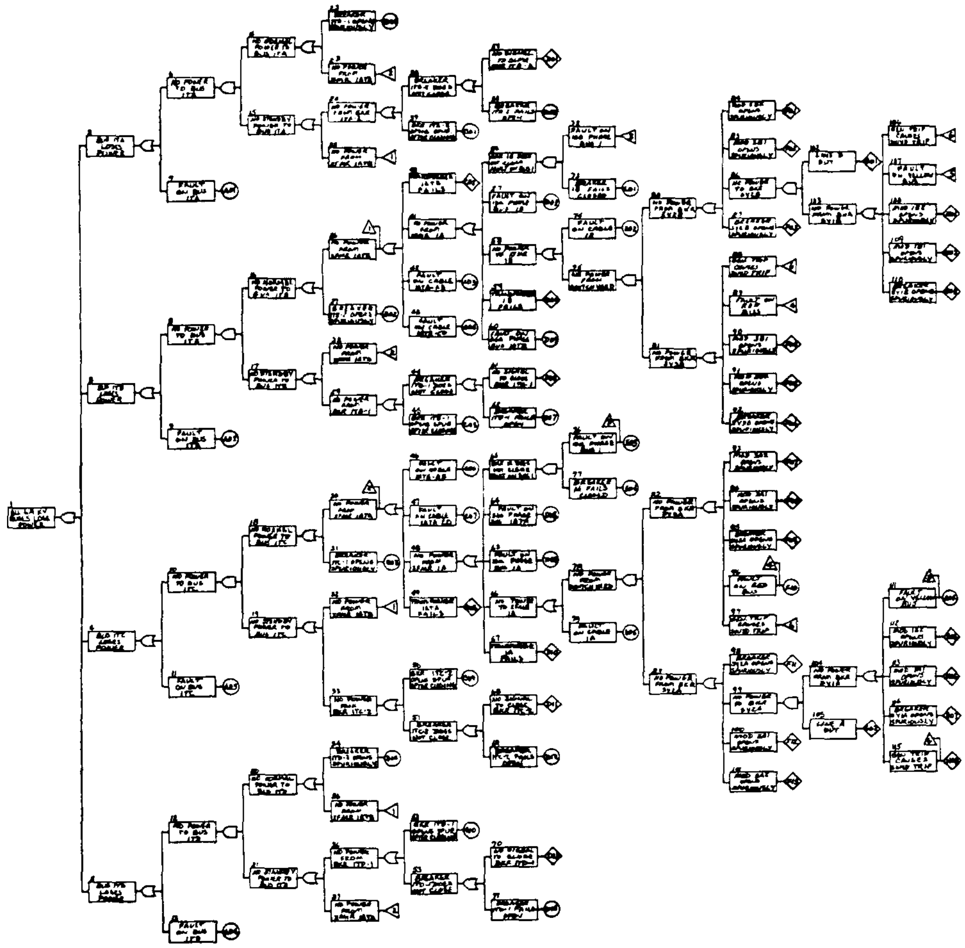


Figure 10. Generator Breaker Scheme—Fault Tree for Loss of all 6.9 KV Buses When Unit is in the Shutdown State

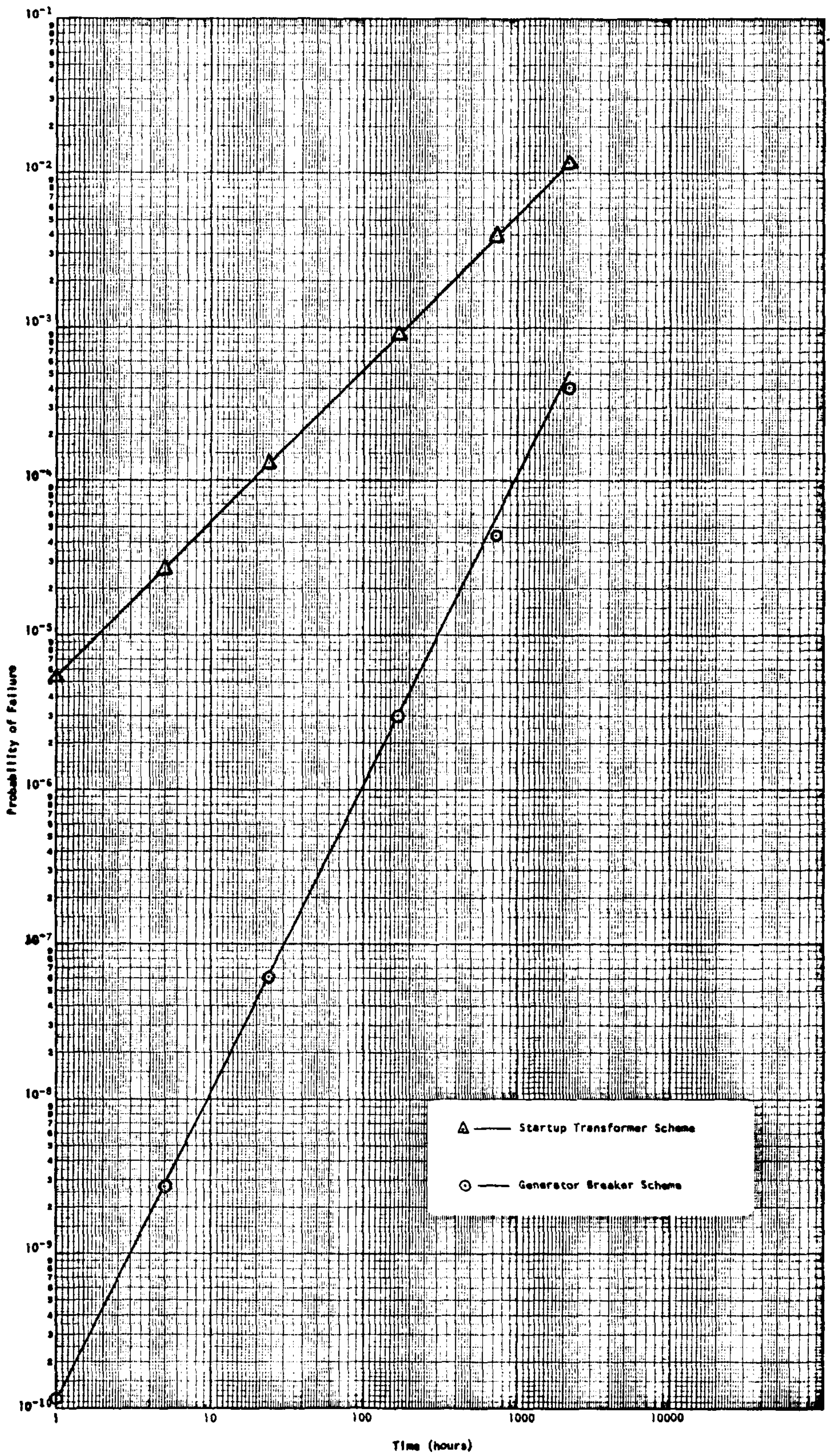


Figure 11. Comparative Analysis Results

DISCUSSION

SWANSON: In connection with the transformer study, did you consider the economics of purchasing future unit transformers early to serve as the spare?

LOGAN: The use of future unit transformers as spares was considered in the study. Early delivery was not considered since there were a number of transformers already in the pipeline.

SWANSON: Is the spare transformer considered to be in the rate insofar as economic analysis is concerned? If not, how are the fixed charges handled?

LOGAN: As soon as a work order for the spare transformer is closed out and the transformer becomes operable it will be incorporated into the rate base. The fixed charge is accounted for in the rate base.

SCHOEN: Have you found difficulty in getting engineers or management in your company to accept problem solutions of this type, which are based on the higher mathematics rather than past practices?

LOGAN: As in any organization, there are individuals who readily accept the results of new methodologies, and there are those who must be convinced.

CORT: I know that Duke Power has a substantial engineering staff. Many engineers are dedicated to a formalized reliability program and what are your projected manpower needs?

LOGAN: At the present there are two engineers who are doing reliability work. I expect that by the early 1980's the number will be four or five.

WORKING GROUP DISCUSSIONS AND REPORTS

GROUP 1. ESTABLISHMENT OF UNIT AVAILABILITY GOALS

CHAIRMAN: V. Throckmorton, Dallas Power & Light Co.

REPORTER: D. I. Morris, Black & Veatch

GROUP 2. ASSIGNMENT OF AVAILABILITY GOALS TO A-E's AND MANUFACTURERS

CHAIRMAN: J. Stewart, Public Service Co. of New Mexico

REPORTER: L. Booth, Bechtel Power Corp.

GROUP 3. RELIABILITY AND MAINTAINABILITY REQUIREMENTS IN PROCUREMENT SPECIFICATIONS

CHAIRMAN: E. T. Parascos, Consolidated Edison Co. of New York

REPORTER: F. Beininger, Burns & Roe

GROUP 4. PROOF OF COMPLIANCE - A SET OF GUIDELINES

CHAIRMAN: R. M. Ohlenkamp, Atomics International

REPORTER: E. B. Cleveland, Holmes & Narver, Inc.

GROUP 5. COMPLETING THE EXPERIENCE FEEDBACK LOOP

CHAIRMAN: D. Anson, Tennessee Valley Authority

REPORTER: D. Pratzon, PJM Interconnection

GROUP 6. EDUCATION AND TRAINING

CHAIRMAN: B. J. Garrick, Pickard, Love, & Garrick

REPORTER: J. L. Weiser, Edison Electric Institute

WORKING GROUP #1

TOPIC: Establishment of Unit Availability Goals

PREMISE: There should be an availability goal for each generating unit.

GROUP OBJECTIVE: Determine the advisability and possible methods to establish unit availability goals.

CHAIRMAN: V. Throckmorton

REPORTER: D. I. Morris

GROUP MEMBERS*:

Abraham
Beaubouef
Biggerstaff
Cort
Hui
Kohansedgh
Krall
Lightner
Murray
Passamonte
Rittenhouse
Sas
Thompson
Whitcomb
Woodson, R. D.

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*These persons were present when the group was first convened. It should be noted that many people participated in several groups during the afternoon.

CONCLUSIONS AND RECOMMENDATIONS

The group agreed by a substantial majority that an availability goal should be established for each generating unit.

It was also generally agreed that a range of goals, ranging from optimistically high for base load class units on the one hand to realistically low and in keeping with the relative economics for peaking units on the other hand, would be more appropriate than a single numerical goal for all units. Other factors influencing the magnitude of the goal were fuel base, fuel cost, fuel availability, unit size, system load shape, system reserve, system power sales/purchase agreements, and other unique requirements of a given utility's system.

It was felt that availability goals would serve several purposes:

- As a bench mark for determining success toward improved availability
- As a system planning parameter
- As a fuels planning parameter
- As a generation reserve (LOLP) parameter
- As a system expansion/capital requirements planning parameter

It was recommended that each utility establish an availability goal for each unit, individually basing the value on reasonably predictable criteria which are expected to continue over the life of the unit. The goal should not be influenced by unit maturity alone, but by anticipated changes in the operating regimen of the unit, i.e., progression from base to intermediate to peaking modes. An alternative, and probably a more realistic one, would be to reestablish goals annually. Measured, or achieved, availability would be that averaged over the course of a complete maintenance cycle for the unit.

The group considered the advisability of having a national standard goal for availability. The concensus was that national, state, or system-wide goals were inappropriate. There was considerable discussion on the topic of imposed availability goals and on the difficulties in measuring the actual availability on a consistent basis. Perhaps a precise, industry-wide definition of unit availability would resolve this problem.

The general feeling of the group was that unless formal programs aimed at improving power plant availability are instituted by the utilities, some system of goal setting and mandatory improvement programs may be imposed by regulatory agencies. Such programs could very well relate plant availability/productivity to capital requirements and directly impact rate setting. If voluntary programs are initiated by utilities in a timely fashion, the utilities will be in a stronger position to justify and defend the goals they, themselves, have established for their individual units.

QUESTIONS USED TO STIMULATE GROUP DISCUSSION

1. How would the types of generating units in a system (hydro, nuclear, geothermal, etc.) effect unit goals?
2. Should goals vary with unit age?
3. Over what period of time should a goal apply?
4. Should there be a national standard method to arrive at unit goals?
5. How would mode of operation (baseload, intermediate, peaking) affect unit goal?
6. Should there be an allowance for future regulatory restrictions?

WORKING GROUP #2

TOPIC: Assignment of Availability Goals to A-E's and Manufacturers

PREMISE: The utility should make availability a contractual requirement.

GROUP OBJECTIVE: Identify problems and possible solutions associated with assigning availability requirements.

CHAIRMAN: J. Stewart

REPORTER: L. Booth

GROUP MEMBERS:
Barcelo
Derdiger
Heller
Holmes
Jarrett
Larson
Ledford
Logan
McCrohan
Muska
Schnelle
Starr
Sullivan
Sykes
Visweswaran
Wisniewski

CONCLUSIONS AND RECOMMENDATIONS

The premise addressed by this group was changed slightly to: "The utility should make an availability goal a contractural requirement. (The goal may not necessarily be numerical, but should be a requirement to perform specific tasks which will enhance or promote increased availability.)"

The group discussed communication problems caused by not having a uniform set of definitions and it was noted that there is an ad hoc committee on power plant productivity definitions operating under an EEI steering committee on power plant data systems. They have a set of definitions out for review.

After much discussion, the group agreed that the assignment of availability requirements must be the utilities' responsibility. The general consensus was that the utility must take the lead role in setting availability priorities.

The discussion then turned to provide evidence that availability requirements have been accounted for in the design process, and the group concluded that a contractual commitment shall require the A-E and/or manufacturer to provide a detailed statement that the availability goals for each system or component have been achieved. The utility must be involved in the early stages of the design review process. The contractual requirements are not limited to full forced and partial forced outages, but must include scheduled and planned outages. Scheduled and planned outages are handled as part of detailed descriptions which show that availability goals have been achieved. (PERT charts and Critical Path methods are examples of how to demonstrate compliance during design.)

Other conclusions were that: (1) although a factor can be developed to trade off availability and life cycle costs, the payback period would be up to the utility and the Public Service Commissions, and (2) there should be a factor to trade off availability and unit efficiency. (It was noted that several papers have addressed this question. Reference "Operating Economics and Unit Availability," by R. W. Saran, Joint Power Generation Conference, Long Beach, CA, 1977.)

It was also noted that, in general, economic analysis must be employed in all phases of availability engineering, such as:

- When establishing and apportioning overall goals and when making decisions among design alternatives
- When evaluating the effect of partial forced outages (including decisions among design alternatives proposed to reduce such outages)
- When evaluating methods proposed to increase plant efficiency (such proposals should be weighed against any potential increases in failure rates or repair times for potential increased downtime cost over the life of the unit)

Finally, it is noted that in recognition of the diversity of the industry, the application of these basic principles must be plant specific, that is, dependent upon the particular utility, contract, and project.

QUESTIONS USED TO STIMULATE GROUP DISCUSSION

1. Should the A-E have prime responsibility for showing compliance?
2. Should the utility divide the goal among A-E, steam system supplier and T-G manufacturer?
3. What commitments should be made by A-E's and manufacturers to provide evidence that availability requirements have been accounted for in the design process?
4. How would scheduled and planned outages be taken into account?
5. Can a factor be developed to trade off availability and capital investment? If so, what should the payback period be?
6. Should there be a factor to trade availability and unit efficiency?

WORKING GROUP #3

TOPIC:	RAM Requirements in Procurement Specifications
PREMISE:	All specifications for equipment related to power generation should contain reliability and maintainability requirements.
GROUP OBJECTIVE:	Identify advantages and disadvantages and suggest the most practical approach.
CHAIRMAN:	E. T. Parascos
REPORTER:	F. Deininger
GROUP MEMEBERS	Colvin Comer Derrick Fowler Gauger Hughes Kelly Lescisin Rose Sherlock Sherman Squires Stevens Weiss Woodson, J. H.

CONCLUSIONS AND RECOMMENDATIONS

Should there be reliability, availability, and maintainability (RAM) requirements in procurement specifications? The consensus of the group was that there should be such requirements. Most members of the group felt, however, that suppliers were not yet able to respond to such requirements and that their first response would be to no-bid them.

Suppliers should not be allowed to refuse to conform to RAM requirements. They must be made aware that the utility industry will no longer award contracts for large systems and equipment without incorporating RAM requirements. The basic reason for the reluctance of suppliers to respond to these requirements is their fear of the unknown. They must be educated to accept RAM methods and techniques as part of their design process. RAM methods and techniques are cradle to grave technologies.

The level of RAM requirements incorporated into a system or equipment depends on life cycle analyses of costs involved. Prudent adaptation of the RAM philosophy will drive life cycle costs down, though it may drive initial costs up. RAM requirements could be applied as incentives to be used in the evaluation of procurement bids. This would require extensive record keeping by supplier and user. In addition, RAM requirements could initially be stated as options, with costs separated for evaluation purposes.

To stimulate RAM improvements by suppliers, utilities can provide financial incentives by teaming up with other utilities to provide volume purchase of equipment with RAM requirements. A negative stimulus might be to publicize or alert other utilities of manufacturers whose equipment is performing poorly and who will not adapt to reliability improvements.

Suppliers of off-the-shelf items may also be reluctant to incorporate RAM requirements in their equipment design. If the equipment involved is very reliable (more than specified), these suppliers need not conform to the RAM requirements, but if the equipment is unreliable, we must find either another vendor who will conform to the RAM requirements or one who will modify the off-the-shelf items or qualify them to meet the specified RAM requirements.

"Reliability improvement warantees" (extended warrantees) may be the way of inducing suppliers by financial incentives to supply equipment to RAM requirements. The supplier warrants an equipment or system to meet the specified reliability for a period of more than five years. If he exceeds the specified reliability in operations during this period, he receives a bonus. But if he does not meet the specified reliability, he is penalized to the level of the cost for the equipment's unreliability. In this type of contract all failures are considered "no-fault" in nature.

To reduce the unreliability of the human element in the man-machine interface, several things must be controlled:

- Recording and analyzing all failures to determine cause
- Specifying shipping, storage, and installation constraints by the user
- Training of personnel
- Providing operation and maintenance manuals

Finally the RAM requirements specified should have some quantitative form. The following RAM characteristics should be specified as a minimum:

- Reliability - MTBF (Mean time between failures)
- Maintainability - MTTR (Mean time to repair)
- Availability - MTBF/MTBF + MTTR

QUESTIONS USED TO STIMULATE GROUP DISCUSSION:

1. Can the supplier protect himself from misapplications and misuse? If so, how?
2. Should the supplier specify shipping, storage, and installation constraints?
3. Should RAM requirements be a warranty item?
4. What incentives, if any, are needed to stimulate reliability/ maintainability improvements?
5. Would the life-cycle cost of equipment go up or down?

WORKING GROUP #4

TOPIC:	Proof of Compliance - A Set of Guidelines
PREMISE:	If unit availability goals and equipment reliability/ maintainability requirements are specified, the method of compliance should also be specified.
GROUP OBJECTIVE:	Identify what should be done by A-E's and manufacturers to prove that their designs can meet the RAM requirements and availability goals.
CHAIRMAN:	R. M. Ohlenkamp
REPORTER:	E. B. Cleveland
GROUP MEMBERS:	Albrecht Butrovich Christensen Jaquith Johnson Krasnodebski Latham Pabst Parr Pilgrim Robinson Schiau Shor Tommer

CONCLUSIONS AND RECOMMENDATIONS

The starting point for this discussion was the premise that if unit availability goals and equipment reliability and maintainability requirements are specified, the method (or methods) of compliance to those requirements should also be specified. The objective of the group discussion was to determine or provide guidance on the method (or proof) of compliance.

The group decided that as a starting point there should be a written plan (probably several utility/A-E/manufacturer plans) which specified beforehand how acceptable levels of reliability, maintainability, and availability would be decided. This plan would define design review procedures to be used for review of known past problems. It would be the responsibility of manufacturers and the A-E's to negotiate with (and prove to) the utility (or A-E or first level supplier) that these problems had been sufficiently overcome to permit attainment of the requirements. Proof of compliance would then consist of making formal assessments of availability (or reliability or maintainability) at several predetermined times using appropriate historical data or judgments.

It was stressed that availability should be reviewed as a growth parameter and, although it is the responsibility of the utility, it should be addressed by the utilities, A-E's and manufacturers as a team. This team responsibility for availability must continue for several years of operation. Although it was thought that incentives for increased availability are advisable, none were suggested. The use of warranties was ruled out as a way to encourage high reliability because they are difficult to enforce and are penalties rather than incentives.

It was suggested that specifications should define:

- The times during a program (from conceptual engineering to 5 to 10 years into commercial operation) when formal assessments of reliability or maintainability are to be performed
- The methods which will be acceptable for these assessments
- Acceptable kinds of data (historical, test, engineering estimates, or judgment) as a function of the review times
- The value of desired availability at each review point (the desired growth rate)

Rather than prove compliance to some static set of values, it was emphasized that from the beginning the utility with an availability goal should demand that his

A-E (and others) convince him that allocated requirements will be met. When it is practical (cost-effective) to test, this should be done as one good way to show that requirements will be met in service.

It was conceded that the group had probably not completely answered the question. However, it was felt that cooperation in the resolution of availability limiting problems was of paramount importance in achieving high unit availability.

QUESTIONS USED TO STIMULATE GROUP DISCUSSION

1. To what extent would analyses using available data or demonstration tests be acceptable?
2. Over what period of time should performance be judged?
3. What would be the relationship to warranties?
4. What kind of evidence would be acceptable proof that equipment can be expected to meet goals and requirements during actual operation?
5. Should acceptance testing be performed at the unit and the equipment levels?

DISCUSSION

JENSEN: How do we prepare an Equipment Procurement Specification with specific Reliability-Availability Requirements? Should we include anticipated MTTF and MTTR? Are good examples of Reliability-Availability Specification Requirements available?

CLEVELAND: This is a very important question which needs an answer acceptable to all of the parties involved. The utility or A-E must tell the supplier what is needed, but the supplier must also be able to state what he expects that the equipment can do if operated and maintained according to his specifications. I don't think imposing MTBF and MTTR requirements is the right way to go at this time. I suggest you talk to Jan Krasnodebski of Ontario Hydro or Don Latham of SDG&E. They have recent experience in this area. Eventually we should have a U.S. standard on this subject.

WORKING GROUP #5

TOPIC: Completing the Experience Feedback Loop.

PREMISE: Utilities should assume responsibility for informing A-E's and manufacturers of problems, reliability, and maintainability of their designs and products.

GROUP OBJECTIVE: Define areas of responsibility for utility, A-E and manufacturer.

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REPORTER: D. Pratzon

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Bosen
Brailey
Gilchrist
Hord
Jensen
McGrath
Peebles
Scagalia
Schmid
Schoen
Sigler
Swanson

CONCLUSIONS AND RECOMMENDATIONS

When discussing methods to assess and improve the performance of electric generating units, it quickly becomes evident that there is no single experience feedback loop. Rather, several interconnected loops are required to serve the needs of individual utilities, vendors, A-E's, and other interested parties. As part of the background to this discussion, R. L. Haueter, Chairman of the EEI Prime Movers Reliability Subcommittee, described ongoing efforts to consolidate a national plant reliability data collection system. EPRI and EEI are considering alternatives to the present situation in which utilities, especially those operating nuclear plants, must report data to several different bodies. Acceptance of a single national data reporting requirement by all concerned parties would lead to the availability of a more uniform and complete data base for nationwide applications.

Although creation of a nationwide data base could serve as part of one experience feedback loop, others must also be considered, namely, those occurring completely within a utility and the ones between a utility and its suppliers and A-E's. These loops will require more in-depth data than is reported on a national basis so that detailed information will be available during analysis of specific problems.

In order to satisfy these informational needs, the first requirement of an experience feedback system is complete, systematic recording of data. This should include identification of individual plant items (by code description and serial number) and clear descriptions of the relevant fault, the remedial work, and the effects. Minimization of feedback delay is an important concept and prompt reporting of failure data (ideally daily, certainly no less than monthly) is of greater importance than awaiting completion of a detailed root-cause diagnosis, which could be added later as it became available. For completeness, it is essential to record all failures (including faults causing no loss of output), repairs and maintenance to prevent outages or to restore performance, and "nuisance factors." Nuisance factors are conditions, including system problems, which may not require specific actions in the above categories but which prevent the plant from operating up to expectations or require frequent special attention for satisfactory performance.

Much of the required information, including repair time, method, and materials, can be abstracted from a well-designed maintenance/repair work order, but such records are difficult to analyze. There seems to be no alternative to a local computer to provide adequate data storage and access in an acceptable time frame. Prompt availability of outage and repair information is essential for effective planning and for achieving rapid feedback of information to relevant technical and management personnel. It is recognized that rapid turnaround of data precludes thorough technical analysis before reporting, but it should alert people to the need for further investigation before the evidence is lost.

Two kinds of feedback can be distinguished: positive and responsive. Positive feedback, the regular reporting of failure or other events to utility management and manufacturers, needs to be brief and factual. Responsive feedback concerns the supply of data in response to the needs of particular individuals, for example, data on materials used or labor expended on particular tasks. Once a computer storage system is adopted, both kinds of information can be provided and the problem of deciding the frequency and extent of reporting are largely irrelevant. The different requirements of local maintenance, management, vendors, A-E's, etc., can be met on demand provided that the input is properly encoded. However, it must be noted that the encoding of data describing nuisance factors presents a difficulty because of the lack of "hard" failures in such cases.

Feedback loops within individual utilities are of primary importance since they provide the fastest means of dealing with problems, especially if operational modifications can provide a remedy or if logistics are involved. Positive feedback via daily, weekly, or monthly reporting procedures is required so that management can assign priorities to remedial efforts. The provision of data to regular staff meetings is a good feedback mechanism and provides a forum for discussion of nuisance factors which may escape the formal reporting system. Vendors should receive feedback on their products on a similar, routine basis.

Implementation of an effective two-way utility/vendor interface is no problem for major suppliers, most of whom maintain data recording, data reduction, and service engineering capabilities. Vendors generally appear willing to supply data on fault experiences and the related corrective actions. However, the system of issuing repair or service bulletins is frequently too slow and there has been a reluctance to report on problems before the solution is known. The situation may also be complicated by concerns about product liability litigation. Informal (or unofficial) information disseminated by service engineers does not always reach all concerned parties. There is a need to accelerate the feedback of information from vendors to customers in a frank and factual way. Where service or maintenance manuals are provided, they must be complete and promptly and continuously updated.

Ontario Hydro has instituted annual performance reviews with major suppliers and applies a two-level approach: working level feedback to provide input for technical improvement programs on a rapid frequency basis, supplemented by the annual management level meetings which provide corporate support for effective action. While this approach shows great promise in promoting reliability improvement, such an arrangement may not be practicable for every utility, nor would it be possible to include all secondary suppliers.

The feedback loop between the utility and its A-E should be firmly established before the design is set and maintained throughout the design, construction, and early operational phases. The process is initiated by the utility, which has the responsibility to define its design objectives and operational, reliability, and maintainability requirements. To assist in the design process, the utility must feed in the whole of its relevant experience. The A-E will feed in its own experience and knowledge. This completes the feedback loop in the design process.

Confidentiality is not a significant problem in feeding data back between a utility and its supplier, so long as information on competitive products is safeguarded. The sensitivity of vendors and utilities to the publication of specific data on a national basis appears to be declining and the acceptance of "open access" data systems such as the NPRDS data bank is likely to set a precedent for the future.

As noted previously, national data bases do not require the same amount of detail as is needed for applications within individual utilities, and it would be counterproductive to report all available detail on a national basis. The current EPRI/EEI effort will define the extent and nature of the records required to serve national needs.

QUESTIONS USED TO STIMULATE GROUP DISCUSSION

1. To what extent should A-E's and manufacturers be involved in failure analyses?

2. To what extent should a manufacturer's reliability equipment be made public?

3. Should manufacturers play a more active role in the designs of systems, plant layouts, site storage and installation, operating procedures, and maintenance planning?

4. How long should problems and information continue to be sent to A-E's and manufacturers by a utility?

DISCUSSION

DERDIGER: Is the concern for confidentiality (a) due to a desire to protect competitive positions or (b) to prevent investors, the government, and the general public from gaining access to the data?

EDITOR: Actually neither. The primary reason data collecting organizations have restricted the access to their files is to minimize their risk of being subjected to legal actions for damage or libel. The need for greater exchange of information and improved communication in the power industry seems to be causing a relaxation of these restrictions. The EEI Prime Movers Committee has, during the past few years, made the equipment availability task force data much more accessible to organizations who are not members of EEI. We should also note, however, that an increasing number of legal actions are being taken to prevent the federal government from releasing allegedly damaging information under the Freedom of Information Act. The legal risk is still present.

WORKING GROUP #6

TOPIC: Education and Training - What and Where

PREMISE: There should be more courses on availability engineering as applied to the electric power industry.

GROUP OBJECTIVE: Identify objectives, methods, required subjects and levels (undergraduate, graduate, practicing engineer, etc.).

CHAIRMAN: B. J. Garrick

REPORTER: J. L. Weiser

GROUP MEMBERS:

Beakes
Ector
Federighe
Keller
Long
Manning
O'Hara
Shook
Vicchiarelli
Wakabayashi

CONCLUSIONS AND RECOMMENDATIONS

There is a clear need for more trained power plant reliability/availability engineers to serve the electric power industry. Availability engineering covers a broad spectrum of activities, including operations, design, and research and analysis. It is convenient to address availability engineering training at these three levels.

Operations

The role of availability engineering at the operations level is twofold. First, if there is an on-going reliability program in the plant, it is the task of the availability engineer to be the technician for that program. Second, the operations availability engineer must be trained to solve in-plant operational problems. His training should include a fundamental grasp of reliability terminology, a knowledge of outage planning and maintenance practices, and an understanding of the requirements and applications of relevant data and information systems and the practices and principles of failure and reliability analysis.

Generally, the training takes the form of a basic engineering education (e.g., mechanical, electrical, chemical, nuclear) supplemented by specific reliability engineering courses. For the operations level of availability engineering there is a strong dependence on supplemental training to provide the necessary practical knowhow. Such supplemental training sources include industry seminars, workshops, visiting instructors, and university short courses.

Design

The role of the availability engineer at the design level is to complement the design engineer in designing the availability goals into the plant. His training may be slightly more formal than for the operations level engineer, but not necessarily so. He should probably be a degreed engineer in one of the above-mentioned disciplines with additional formal reliability training. The training requirements include considerable emphasis on reliability analysis techniques and a knowledge of plant systems, together with those items listed for the operations level engineer.

Supplemental educational resources for the design level availability engineer should include regular university courses and university short courses, in-plant training, and industry training programs such as seminars and workshops.

Research and Analysis

The research and analysis availability engineer conceives and develops methods, procedures, and programs. He is analytically oriented with graduate training in such disciplines as probability, statistics, and decision theory. Clearly, his training must come principally from the university and take the form of advanced courses in reliability technology. His effectiveness is enhanced, however, through exposure to industry and in-plant training programs.

Conclusions and Observations

Highlights of the observations and conclusions rising from the discussion are as follows:

- Availability engineering is too broad in scope and needs definition of different levels.
- The university has a major training role for the research and analysis level.
- The industry should pick up the slack in design and operations training.
- Integration of formal training and experience is required for availability engineering.
- Utilities should take the lead in making availability engineering requirements known to the academic community.
- Government and industry must work closer together to provide grants and financial assistance.

QUESTIONS USED TO STIMULATE GROUP DISCUSSION

1. Is this a university or industry responsibility?
2. How useful are short courses?
3. What is a proper mix of theoretical and practical subjects or topics?
4. What should be the nature and content of practical reliability, availability and maintainability course for electric power plants?

DISCUSSION

SHOR: Are there any books on failure analysis?

SQUIRES: Commonwealth Edison has used an analytical problem-solving technique described in the book, The Rational Manager (Kepner Tregoe, McGraw Hill, 1965) to solve its reactor coolant pump seal problems.

GARRICK: I do not know of a book on that specific subject. It is discussed in a number of the basic textbooks on reliability.

LOGAN: Should there be some sort of educational process for high level management, acquainting these individuals with the capabilities, costs, and benefits of R/M engineering?

GARRICK: Yes. I participated in a conference for that purpose in September of 1976. It was co-sponsored by ANS, EEI, and EPRI. I understand that EPRI intends to plan additional programs involving top utility management.

ANSON: Reliability engineering was described as having very great scope--too great to be easily encompassed in an educational program. However, the real subject with which we are concerned is even broader. We are concerned with finding the most economic ways of meeting a continuous but variable demand from a source with inherent unavailability and negligible storage capacity.

APPENDIX A

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2. Organizational Representation

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1. Arizona Public Service
2. Arkansas Power & Light
3. Boston Edison
4. Carolina Power & Light
5. Commonwealth Edison
6. Consolidated Edison of New York
7. Consumers Power
8. Dallas Power & Light
9. Dayton Power & Light
10. Detroit Edison
11. Duke Power
12. Florida Power & Light
13. Georgia Power
14. GPU Service
15. Houston Lighting & Power
16. Middle South Services
17. Montana Power
18. New England Power Service
19. Northern Indiana Public Service
20. Northern States Power
21. Ontario Hydro
22. Pacific Gas & Electric
23. Pennsylvania Electric
24. Pennsylvania Power & Light
25. PJM Interconnection Office
26. Public Service of Indiana
27. Public Service of New Mexico
28. Salt River Project - Arizona
29. San Diego Gas & Electric
30. Tennessee Valley Authority

31. Toledo Edison
32. Utah Power & Light

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1. Bechtel Power
2. Black & Veatch
3. Burns and Roe
4. Commonwealth Associates
5. Ebasco Services
6. Fluor Pioneer
7. General Physics
8. Gilbert Commonwealth
9. Holmes & Narver
10. NUS
11. Pickard, Lowe & Garrick
12. Stearns-Roger
13. Stone & Webster Engineering
14. Southwest Research Institute

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1. Atomics International
2. Babcock & Wilcox
3. Combustion Engineering
4. General Electric
5. Westinghouse Electric

OTHERS

1. California State University - Fullerton
2. Edison Electric Institute
3. Electric Light & Power Magazine
4. Electric Power Research Institute
5. U.S. Department of Energy
6. University of New Mexico

Appendix B

BIBLIOGRAPHY

PERIODICAL RESOURCES

Publication: EEI Report on Equipment Availability.

Content: This report is issued annually and contains summary performance data on all types of electric power generating equipment. Principal statistics concern the outage, availability, and maintenance data by unit type and size.

Availability: These reports are published by the Edison Electric Institute, 90 Park Ave., New York, NY 10016.

Publication: EPRI Journal.

Content: General review articles describing various research programs of the Electric Power Research Institute. Each issue also contains lists of projects initiated and reports issued during the previous month.

Availability: Published monthly by the Electric Power Research Institute, P.O. Box 10412, 3412 Hillview Ave, Palo Alto, CA 94303.

Publication: IAEA, Operating Experience with Nuclear Power Stations in Member States.

Content: Data on nuclear power stations, highlights of operation, significant outages, thermal and electrical capacity, availability data, and average power level on a yearly basis.

Availability: Published by the International Atomic Energy Agency. IAEA documents may be purchased from UNIPUB, P.O. Box 433, Murray Hill Station, New York, NY 10016.

Publication: IEEE Spectrum.

Content: Spectrum is the monthly news magazine of the IEEE. It frequently contains articles on the power industry.

Availability: IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

Publication: IEEE Transactions on Reliability.

Content: These transactions are published five times a year by the IEEE Reliability Group. Each issue contains about 20 technical papers on reliability, maintainability, availability, and specific analytical techniques related to these subjects. Each issue also contains book review of new publications in the field and other general information of interest to readers. Special issues devoted to specific subjects are produced frequently. These issues contain mostly papers prepared by recognized specialists who have been invited to prepare material for that particular issue. The special issue on nuclear plant reliability published in the fall of 1975 would be of particular interest to the power industry.

Availability: For information on orders or subscriptions, contact the IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854. Back issues and paper are also available in microfiche or microfilm.

Publication: Journal of Quality Technology.

Content: Although primarily devoted to papers on quality assurance techniques most issues contain at least one article dealing with reliability technology.

Availability: Published quarterly by The American Society for Quality Control, 161 W. Wisconsin Ave., Milwaukee, WI 53203.

Publication: <u>NPRDS Newsletter</u>.

Content: Provides special instruction and advance revisions for Nuclear Plant Reliability Data System forms and reports, as well as general news on systems operations.

Availability: Published quarterly by Southwest Research Institute, Departments of Quality Systems Engineering, Building 88, 6220 Culibra Rd. San Antonio, TX 78284. Mailing address, P.O. Drawer 28510, San Antonio, TX 78284.

Publication: <u>NRC Operation Units Status Report</u> (Gray Book)

Contents: These reports provide, on a monthly basis, a single source of data on all operating commercial nuclear power plants in the United States. They include summaries of data, by reactor, for power generations history, outages and shutdowns, availability, schedules, and power forecasts.

Availability: These reports are published by the Nuclear Regulatory Commission and may be purchased from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Regal Rd. Springfield, VA 22151.

Publication: <u>Nuclear Safety</u>.

Content: Although primarily devoted to Nuclear Safety topics, this publication frequently contains discussions of plant operating experience as well. It is an excellent source of reference to publications and conferences in the general area of reliability, which is not always exclusively nuclear.

Availability: Published by the ERDA Technical Information Center and may be purchased from the Superintendent of Documents, U.S. Government Printing Office.

Publication: <u>Power Apparatus and Systems</u>.

Content: This bimonthly publication of the IEEE Power Engineering Society contains all papers which have been approved for publication by one of the PES committees. Most issues contain one or more papers on the subject of reliability, availability, or maintainability. Frequently, these transactions provide abstracts of papers presented at various technical meetings sponsored by the PES and give information on the availability of reprints.

Availability: Published bimonthly by the IEEE Power Engineering Society and available from the IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

Publication: <u>Power Engineering</u>

Content: In recent years, this magazine has carried an increasing number of articles on the subjects of power plant availability and equipment reliability.

Availability: Technical Publishing Co., 1301 S. Gurc Ave., Burrington, IL 60010.

Publication: <u>Proceedings of the Annual Reliability Engineering Conference for the Electric Power Industry</u>.

Content: These proceedings contain the texts of papers presented at this annual ASQC, IEEE, and EEI co-sponsored meeting. The fourth conference of the series was held in New York on June 16 & 17, 1977.

Availability: These proceedings are available from the IEEE Service Center, 445 Hoes Lane Piscataway, NJ 08854.

Publication: Proceedings - Annual Reliability and Maintainability Symposium.

Content: These proceedings contain the complete text of all papers presented at this annual symposium. These symposia began in 1954. A cumulative index for the 15-year period 1954 - 1969 was published in the 1970 proceedings. The 1977 proceedings contains a cumulative seven-year index (1970-1976) and a three-year (1975-1977) cumulative key word index. The following samples of papers of interest to the power industry were taken from the contents of recent symposia:

- 1977 Symposium, Nuclear Power Systems.
  - Moderator: J. S. Bozek, Westinghouse Electric Division
  - System Probabilistic Studies at the Nuclear Regulatory Commission, William E. Vesely, James W. Pittman.
  - Solving Reliability Models of Nuclear Systems, Leonard R. Doyon.
  - A Probabilistic Approach to Design for the ECCS of a PWR, B. Gachot.
  - Nuclear Power Plant Reliability Audits, Theodore Essinger.
  - Reliability Assessment for Heavy Machinery by HI-FMECA Method, Katsushige Onodera, Minoru Miki, Keizo Nukada.
- 1976 Symposium.
  - Moderator: J.M. CoVan, Ph.D., Texas A & M University
  - On Optimization of SCRAM Systems, Igor Bazovsky, Jr.

- IEEE Project 500 - Reliability Data Manual for Nuclear Power Generating Stations, A. J. McElroy.

- Nuclear Industry - Approach to Performance Assurance, Alan E. Siebe.

● 1975 Symposium.

  - Moderator: Dr. G. L. Steihl, Jr., Nuclear Systems Reliability.

  - Nuclear Plant Reliability Data Program, R. D. Johnson and M. J. Wise.

  - A Time Dependent Model of a SCRAM System, K. A. Solomon and I. Bazovsky, Jr.

  - Reliability Evaluation of a Containment Fan Cooler System, S. J. Sarver.

  - Reliability of Nuclear Mechanical Systems, Dr. J. J. Burns, Jr.

  - Moderator: Professor R. Billinton, Power Systems Reliability-R.

  - Maintenance Reserve Evaluation for Large Systems, L. G. Leffler, et al.

  - Montecarlo Methods for Power System Reliability Evaluations in Transmission and Generation Planning, Dr. L. Paris, P.L. Noferi and L. Salvaderi.

  - A Sequential Method for Reliability Analysis of Distribution and Transmission Systems, M. S. Grover and Professor R. Billinton.

  - The Reliability Assessment of Emergency Electrical Supplies, A. E. Green.

Availability: Copies of past proceedings still in print are available at each year's symposium or by mail. Contact the Symposium Proceedings Chairman, Dr. Ralph A. Evans, 804 Vickers Ave., Durham, NC 27701 for information on obtaining copies.

Publication: Quality Progress.

Content: Quality Progress is the monthly news magazine of the American Society for Quality Control and frequently contains articles on the subject of reliability. It also provides reviews of various meetings, symposia, standards activities, and similar functions in which the ASQC is involved.

Availability: American Society for Quality Control 161 West Wisconsin Ave., Milwaukee, WI 53203.

EPRI REPORTS

EPRI Reports on plant availability, equipment reliability, and related subjects have been tabulated in this section of Appendix B.

Each issue of the EPRI JOURNAL includes summaries of EPRI's recently published reports.

Requests for copies of specific reports should be directed to Research Reports Center, P. O. Box 10090, Palo Alto, California 94030; (415) 366-5432. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others pay a small charge. Research Reports Center will send a catalog and price list on request.

Standing orders for free copies of reports in EPRI program areas may be placed by EPRI member utilities, libraries of U.S. national, state, and local government agencies, and the official representative of each foreign organization with which EPRI has an information exchange agreement. For details, write to EPRI Communications, P. O. Box 10412, Palo Alto, California 94303.

Microfiche copies are available from National Technical Information Service, P. O. Box 1553, Springfield, Virginia 22151.

EPRI FP-422-SR. Availability of Fossil-Fired Steam Power Plants. D. Anson. September 1977.

> This report summarizes recent experience regarding availability and reliability of fossil-fired steam generating units of 600 MW or more capacity. To define problem areas and develop a strategy for improving availability, the statistics compiled by EEI have been analyzed. Conclusions were supplemented by meetings with utilities that operate power plants in that category.

EPRI NP-241. Assessment of Industry Valve Problems. MPR Associates, Inc.

> The failure of valves to function as designed has had a significant impact on nuclear plant availability. This report recommends course of action to be taken to correct specific problems identified in an engineering review of

valves and associated equipment currently installed in commercially operating nuclear generating stations.

EPRI NP-263. A Summary of Nuclear Power Plant Operating Experience for 1975. Science Applications, Inc. October 1976.

This report provides a summary of operating experience of 56 nuclear plants licensed to operate in 1975. The analysis is based on information and data contained in the 1975 series of Operating Units Status Reports. Additional information was derived from a special survey conducted by EPRI.

EPRI NP-280. Failure Analysis and Failure Prevention in Electric Power Systems. Failure Analysis Associates. November 1976.

This report describes new methods developed to better quantify and increase the reliability, safety, and availability of electric power plants. An improved computerized data base of malfunctions in nuclear power plants combined with detailed metallurgical and mechanical failure analyses has enabled identification of present and potential problem areas.

EPRI NP-280. A Computer-Oriented Approach to Fault Tree Construction. University of California at Los Angeles. November 1976.

This report describes a methodology for systematically constructing fault trees for general complex systems via the computer program CAT. The report describes a procedure for constructing and editing fault trees, either manually or by computer.

EPRI NP-290. Documentation of Utility Experience with Process Computer in Power Plants, Vol. 7. Macro Corp.

This report provides a compilation of power plant process computer types and applications to facilitate communication among utilities. It documents utility experience with procurement, operation, and maintenance of these systems. It also formulates and evaluates future R&D efforts relating to process computer applications in power plants.

EPRI NP-309. Human Factors Review of Nuclear Power Plant Control Room Design. Lockheed Missile & Space Co., Inc. March 1977.

Human factors engineering is an interdisciplinary specialty concerned with influencing the design of equipment, systems, facilities, and operational environments to promote safe, efficient, and reliable operator performance. The human factors aspects of five representative nuclear power plant control rooms were evaluated by such methods as a checklist-guided observation system that included structured interviews with operators and trainers, direct observations of operator behavior, task analysis and procedure evaluation, and historical error analysis. The human factors aspects of design practices are illustrated and many improvements in current practices are suggested.

EPRI NP-309-SY. Human Factors Review of Nuclear Power Plant Control Room Design. Lockheed Missile & Space Co., Inc. November 1976.

This report is a summary edition of EPRI NP-309. The full report (approximately 500 pages) provides a description of all the procedures and data used to reach the conclusions described in the summary.

EPRI NP-326-SR. Modeling and Estimating System Availability. D. P. Gaver and B. B. Chu. November 1976.

This report reviews several models that directly consider the random nature of malfunction and repair. Its principal purpose is to show how estimates of system availability may be constructed from component data and how the statistical stability of these estimates may be assessed directly from the data. This report is basically mathematical in nature but not so much so that the dedicated engineer cannot make use of it.

EPRI NP-443. Characteristics of Instrumentation and Control System Failures in LWR's. Science Applications, Inc.

Characteristics of instrumentation and control (I&C) system failures, including set-point drift problems, are discussed in this report. Specific topics included in the discussion are general trends in the occurrence of I&C failures, principal reactor systems affected, variation in I&C failure rate overtime, and the impact of I&C problems on plant availability.

EPRI NP-481. Steam Plant Surface Condenser Leakage Study. Bechtel Power Corp. March 1977.

This report presents the results of a study to determine factors that affect the deterioration and subsequent leakage of main surface condenser tubes in electric power plants. Several areas related to condenser tube leakage, including design, materials, chemistry, operation, and maintenance, were studied.

EPRI NP-493. Assessment of Methods for Implementing Availability Engineering in Electrical Power Plants. Holmes & Narver, Inc. July 1977.

This report is the result of an EPRI-sponsored study to define and assess availability engineering, its practice, its possible rewards, and its limitations as a means of increasing productivity in existing and new electric power plants. The study identified several key requirements for the successful implementation of availability engineering in the power industry. The study concludes that availability engineering can be a worthwhile supplement to the traditional engineering process and should be used by the industry.

EPRI NP-438. Characteristics of Pipe System Failures in LWR's. Science Applications, Inc.

This report, one of a series on nuclear power plant availability and reliability, presents a statistical description of pipe system failures as derived from reports submitted by the utilities to the Nuclear Regulatory Commission.

EPRI NP-559-SR. Nuclear Unit Productivity Analysis 1976 Update. M. E. Lapides. October 1977.

This report is a continuation of earlier work which extends operating experience assessments through January 1, 1977, and which provides further elaboration on the components of performance data.

EPRI SR-26-R. Use of Nuclear Plant Operating Experience to Guide Productivity Improvement Programs. M. E. Lapides and E. Zebroski. November 1975.

Examines the productivity of existing light water reactor (LWR) capacity and identifies how this productivity can most effectively be increased.

EPRI SR-46. Nuclear Unit Productivity Analysis. M. E. Lapides. August 1976.

An updated version of SR-26 with an extensive discrimination analysis to properly account for now-modified design features as well as changes in operational and regulatory climates.

EPRI NP-xxx. Optimization of Reliability Data Systems. (Final Report, EPRI Study RP-826. Holmes & Narver, Inc. To be published.

Through a variety of survey methods, it was learned that none of the existing reliability data systems completely satisfy industry needs. This report describes the features needed to make a data system more responsive to the industry and describes modifications to the existing data system, where practical. The report provides a plan for the development of a single national data system which would meet recognized needs and significantly reduce industry reporting requirements.

EPRI NP-543. Optimization of Reliability Data Systems. (Phase I Report, EPRI Study RP-826.) Holmes & Narver, Inc., October 1977.

This report provides a summary of the activities and results from investigative efforts during the first phase of the study. The objective of this first phase was to determine the current and planned uses of reliability data by the various segments of the electric power industry. The report contains the results of personal interviews and a mailed questionnaire. It also contains a summary of the results of 1976-1977 meetings of the Industry/Government Power Plant Data Systems Steering Committee.

EPRI FB-583-SR. Availability Patterns in Fossil-Fired Steam Power Plants. D. Anson. November 1977.

In an earlier report the main causes of outage in fossil-fired steam power plants over 600 MW were examined. This report compares the availability of units over 600 MW with that of units of 200-389 MW and 390-599 MW during the five years 1970 through 1974. Baseload cyclic, coal, oil, mixed-fuel, once-through boiler, drum-type boiler, mature, and immature units are examined separately to show the effects of design and operating variables. The reasons for the observed differences are discussed. The conclusions lead to recommendations for collecting and utilizing outage data and for research to improve availability.

EPRI RESEARCH AND DEVELOPMENT PROJECTS

The following is a tabulation of current EPRI research and development projects in the general area of availability and reliability. Proposed titles and content of planned reports are included where possible. Project titles have been enclosed in quotation marks to distinguish them from underlined report titles.

FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

EPRI RP-372. "Structural Design Concepts for Increased Reliability and Safety in Power Plant Condensing Systems." University of Pennsylvania.

> The objective of this 2-year program is to reevaluate traditional condenser structural design methods by: (1) establishing rational design criteria for tube support plates, (2) establishing design rules relating to deformation of condenser flatplate sections stayed by discrete pipes, and (3) performing theoretical analyses and scale-model tests to determine the stress distributions in built-up pressure vessels such as condenser meter boxes.

EPRI RP-559. "Elimination of Impurity-Induced Embrittlement in Steels." University of Pennsylvania.

> This 2-year project is designed to provide the technology required to minimize the risk of failures of steel components resulting from metal grain boundary embrittlement phenomena associated with impurity segregations. This project is jointly funded by the Fossil Fuel Advanced Systems, Fossil Plant Performance and Reliability Program and the Clean Solid and Liquid Fuels Program, and by the Nuclear Power, Plant Materials and Processes Subprogram.

EPRI RP-637. "Detection of Water Induction - Steam Turbines." Westinghouse Electric Corporation.

> Unpredicted water flow into steam turbines is the cause of forced outages, due to turbine blading damage, rotor distortion, and other thermally induced stress conditions. The objective of this 2-year project is to quantitatively characterize the profile of conditions that have a high probability of producing water carryover from the boiler and to utilize computer processing techniques to provide early warning.

EPRI RP-641. "Boiler Feed Pump Outage Survey." Energy Research and Consultants Corporation.

The failure of boiler feed pumps has been one of the significant contributors to the low availability of both nuclear and fossil plants. The objective of this 8-month project is to determine which components in feed pumps have failed, the cause of the failues, and the remedy for the failures of all units 500 MW and larger, fossil and nuclear.

EPRI RP-734. "Acoustic Emission and Vibration Signature Analysis of Fossil-Fueled Power Plant Components." Atomics International Company.

The objective of this 2-year project is the adaptation of on-line diagnostic systems for use in fossil fuel power plants. The principal application will be on rotating machinery components to detect deterioration of equipment before it actually fails.

EPRI RP-912. "Corrosion Fatigue of Steam Turbine Blading Materials in Operational Environments." Westinghouse Electric Corporation.

This 4-year project will provide extensive data on the range of corrosive conditions in turbines connected to different types of boiler and feedwater conditions, under both steady state and cycling conditions. Project results should contribute to the development of a general theory of the mechanics of fatigue that will relate stress concentration, crack initiation, and crack growth.

*EPRI RP-1036. "Cycling of Large Steam Turbogenerators."

The objective of this project is to establish safer and more economic startup and operating procedures for cyclic turbines by improving the reliability of procedures used to set allowable rates of loading, and by detecting and assessing the effects of transients to which cyclic turbines are subjected, during planned and forced load changes.

*EPRI RP-1077. "Failure Cause Analysis - Fossil Fired Boilers, Pressure Parts."

The research objectives are: (1) to provide information on the underlying causes of fossil-fired boiler plant unreliability in order to establish priorities for future research projects, and (2) to recommend immediate remedial action where possible. Data will be collected from boiler vendors, and both from utilities using oil and those using a variety of coals and water treatments. Particular emphasis will be placed on the collection of data on pressure part failures and boiler operating history.

*Asterisk denotes contract under negotiation.

EPRI RP-311. "Corrosion Studies in Support of Nuclear System Reliability." Ohio State University; San Diego State University; Battelle, Columbus Laboratories; and CEBELCOR (Belgium Center for Study of Corrosion).

The primary objective of this program is to determine and quantify the ranges of compositions and environments that produce damage to structural materials used in nuclear power plants. The program will emphasize the chemical-mechanical reliability of materials and those aspects of corrosion processes that may lead to costly equipment failures.

EPRI RP-501. "Human Factors Review of Nuclear Power Plant Control Board Design Approaches." Lockheed Missiles and Space Company; NUS Corporation was also a contractor on first-phase work.

Using the findings of a review completed in the first phase (EPRI Report No. NP-309, March 1977), the Lockheed Missiles and Space Company's human factors team is developing and evaluating several approaches to control board design. The control boards being evaluated range from hardware systems with dedicated displays to computer-based information processing systems with decision analysis capability and include varying degrees of control automation. The project will describe effective methods for developing and selecting control board designs and will demonstrate design approaches that integrally include human factors considerations.

EPRI RP-502. "A Program to Increase the Reliability of Steam Turbine Rotors." Southwest Research Institute; Battelle, Columbus Laboratories; and Westinghouse Electric Corporation.

The objective of this 24-month program is to increase the reliability of steam turbine rotors by advancing in-service nondestructive evaluation techniques and interpreting the significance of their results in an analytical lifetime prediction system. Primary program emphasis is placed on ensuring the integrity of the forged turbine rotor spindle.

EPRI RP-623. "Steam Generator Model Boiler Program." Combustion Engineering.

This 2-year program is a study of materials and chemistry parameters associated with pressurized water reactor steam generators by use of two types of model boilers. This test apparatus will permit use of special instrumentation and also allow simulation of fouling conditions in steam generators caused by sludge accumulations. The information produced is expected to be valuable in helping to reduce or avoid the significant loss in plant availability, maintenance effort, and man-rem due to corrosion damage in steam generators.

EPRI RP-700. "Failure Analysis and Failure Prevention in Electric Power Systems." Failure Analysis Associates.

This 1-year project, a follow-on of RP-217-1, is directed toward more accurately defining the reliability of components and subsystems in power plants and reducing the frequency and/or severity of malfunctions that result in costly, extended outages. Tasks include: (1) root-cause failure diagnostics, (2) development of improved probabilistic failure prediction methods, and (3) specific application of Task (2) failure prediction methods to pressure vessel reliability, weld HAZ sensitization quantification, condenser, steam generator, and feedwater systems malfunction analysis.

EPRI RP-701. "Stress Corrosion Cracking Investigation of Boiling-Water Reactor (BWR) Piping Remedies." General Electric Company.

This is a 2-year project designed to: (1) identify and confirm to higher assurance levels than now available, the conservative factors related to cracking in weldments of austenitic stainless steel piping, (2) demonstrate that recommended field remedies have a statistically determinable probability of being immune to cracking in weldments for the lifetime of the plant, and (3) further evaluate practical applications of highly discriminating acoustic emission monitoring techniques believed to apply to this type of stress corrosion cracking. Testing is on full-size pipe segments. Three candidate remedies have been selected via extensive screening. Statistical qualification by pipe testing is proceeding.

EPRI RP-705. "Development and Maintenance of a Nuclear Reliability Data Base". Science Applications, Inc.

Under this 2-year project failure data on safety systems and plant components extracted from required reports of 12 utilities to the Nuclear Regulatory Commission will be abstracted into computer form and logged into a rapid retrieval data base. The data can then be analyzed to answer questions pertaining to plant availability and equipment reliability. Planned reports are:

- <u>Trends in Major Nuclear Power Plant Outages</u>

  This report will be a summary of major outages which have occurred in light water reactor plants during the period Janury 1971 to June 1977. The trends in outages for various reactor systems and components will be presented as a function of age of the plant and calendar year. Only outages greater than 100 hours are included in this study. The outage history of each operating nuclear plant >150 MWe will also be presented, along with a brief summary of those outages greater than two months.

- <u>Reasons for Extensions of Refueling Outages</u>

  This report will deal with a study to determine what the principal contributors are to extended nuclear plant refueling outages. Refueling outages are a major component of nuclear plant unavailability and often a great deal more work than the actual refueling process takes place during these outages.

EPRI RP-769. "Performance Measurement System for Training Simulators." General Physics Corporation.

In this 18-month project, the measurement system will be tested on the Brown's Ferry Nuclear Power Plant training simulator. The system is capable of automatic recording of statistical information about operator actions. Data collected could be used both in probabilistic safety studies and in studies directed toward improved hardware design.

EPRI RP-771. "Analysis of Reliability/Availability Industry Data Systems." Stone & Webster.

In this project, Stone & Webster will analyze the raw data in three electric power industry data systems and prepare comprehensive reports on the meaningful information that can be extracted from the systems concerning power plant availability, operational and administrative problems, and recognizable trends. This project will help to demonstrate the effectiveness and utility of all the data that power plants are asked to the subject data systems. The data systems to be analyzed are: Edison Electric Institute's "Equipment Availability Data System"; Nuclear Regulatory Commission's "Operating Units Status Report"; American National Standards Institute's "Nuclear Plant Reliability Data System." Planned reports are:

- Power Plant Outage Analysis

  This report will be a summary of power plant outages (both fossil and nuclear) which have been reported in the EEI Equipment Availability Data Base and the NRC Operating Units Status Reports (Gray Books). Outage trends, outage causes, outage rates, outage durations, and other outage statistics will be presented.

- Power Plant Equipment Failure Analysis

  This report will provide an assessment of equipment failures which have occurred over the years in nuclear and fossil fueled power plants. To the extent possible, generic equipment failure rates, failure trends, and other failure statistics will be given. The data sources are the EEI Equipment Availability Data Base, the NRC Operating Units Status Reports (Gray Books), and the Nuclear Plant Reliability Data System (NPRDS).

- Assessment of Industry Data Bases

  This report will provide an assessment of the usefulness of existing industry data bases in providing the necessary data to perform meaningful reliability analyses of power plants. This assessment will be based upon experience gained in using the data bases to study plant outages and component failures.

EPRI RP-819. "Boiling-Water Reactor (BWR) Radiation Assessment Control." General Electric Company.

The primary goals of this 42-month project are to identify techniques whereby radiation fields can be controlled in present day BWRs, and then to test and implement these techniques in operating BWRs. A further goal is to identify design changes in future plants that will reduce radiation fields without adversely affecting plant availability. The successful development of radiation control techniques will increase the availability of plant personnel and in turn increase plant availability.

EPRI RP-824. "On-Line Vibration Diagnostics for Power Plant Machinery." Shaker Research Corporation, with Northeast Utilities Service Company.

The objective of this 3-year project is to demonstrate the application of advanced, on-line diagnostic techniques to a nuclear power plant. On-line spectral analysis will be performed using demodulated signals from sensor stations on four different types of pump units. Advance warning of equipment problems, with diagnosis included, is needed to avoid forced shutdowns and to aid in maintenance scheduling.

EPRI RP-826. "Optimization of Reliability Data Systems." Holmes & Narver, Inc.

This one-year project is an assessment of the needs of the industry in the area of a total plant reliability data base. This assessment will be compared with the existing industry reliability data systems. Based on this assessment and comparison, the format for upgraded plant reliability data systems is being defined. The research project is being conducted by Holmes & Narver, Inc. In addition, because of the strong utility experience available with the S. M. Stoller Corporation, Stoller is assisting EPRI through consultation, participation in industry interviews, and project review. The planned report is:

- <u>Power Plant Data Systems (Final Report)</u>

  Through a variety of survey methods, it was learned that none of the existing reliability data systems completely satisfies industry needs. This report describes the features needed to make a data system more responsive to the industry and describes modifications to the existing data system, where practical. The report provides a plan for the development of a single national data system which would meet recognized needs and significantly reduce industry report in requirements.

EPRI RP-894. "Limiting Factor Analysis of High Availability Nuclear Plants."

The purpose of this 16-month study is to determine the various limitations on nuclear power plant availability, the extent of their impact on plant performance, and what EPRI research programs should be initiated to improve design or retrofit changes to alleviate limitations. Plant availability is important to both utility economics and system reliability. Even small percentage improvements in availability and capacity factor can lead to large savings in reserve capacity requirements and replacement fuel costs. Contractor teams are now reviewing both BWR and PWR plants: Combustion Combustion Engineering and Stone & Webster at Maine Yankee; General Electric, Bechtel, and Philadelphia Electric at Peach Bottom-2; and Babcock & Wilcox and Duke Power at Oconee.

EPRI RP-968. "Qualification of Alternate Boiling Water Reactor (BWR) Piping Material." General Electric Company.

This 4-year project has the objective of providing a piping material alternative to the standard Type 304 stainless steel used in BWR piping systems. The material will have a high assurance of reliable performance for plant design lifetime and a substantial tolerance for abuse or atypical operating conditions. The project will also provide a demonstration of predictive capabilities on crack propagation.

EPRI RP-970. "Determine Electrical and Mechanical On-Line Instrumentation Monitoring Needs for Generators." Westinghouse Electric Corporation.

The project will determine what advances in electrical and mechanical on-line generator monitoring systems are needed to improve generator reliability and availability. Generator characteristics associated with incipient faults and distinguishable from normal operating variations will be identified, and a monitoring system capable of measuring the identified characteristics and diagnosing the faults will be developed in concept.

EPRI RP-1126. "Human Factors Review of Nuclear Power Plant Maintainability." Lockheed Missiles & Space Company.

This 18-month project will identify and evaluate human factors problems associated with nuclear power plant maintenance and instrumentation and control activities. Suggestions will be made for remedial actions to alleviate problems that degrade maintenance effectiveness and that increase the likelihood, duration, or cost of plant outages.

EPRI TPS-77-722. "Assessment of the Feasibility of Consolidating Power Plant Data Systems." S. M. Stoller Corporation.

The final report from this study will address the feasibility and methodology of consolidating and automating the data reporting requirements of the power plants. Organizations outside the utility industry which are using large computerized data systems have been interviewed to ensure their experiences are factored into the report conclusions.

EPRI TPS-75-750. "Electric Utility Industry Early Alert Report System." S. M. Stoller Corporation.

The final report from this study will provide recommendations on the scope of an industry equipment problem alert system, the methodology that should be used in implementing and operating it, and the money and manpower requirements.

ANNOTATED BIBLIOGRAPHY

BOOKS

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Proceeding of an ANS-EEI-EPRI cosponsored meeting. The paper deals with all aspects of power plant reliability.

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A comprehensive handbook on maintainability concept and applications. It is based on DOD material but differs, because of cost considerations, in the civilian market.

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Provides information and direction to the designer which will help him engineer reliability into an equipment during its basic design stage. It complements MIL-HDBK-217B.

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PAPERS AND REPORTS

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   Key Words: availability
   reliability analyses
   failure modes
   computer program

2. D. Anson. Availability Patterns in Fossil-Fired Steam Power Plants. EPRI Special Report FP-583-SR. November 1977.

   This report compares the availability of units over 600 mw with those of 200-389 mw and 390-599 mw during the five years 1970 through 1974. The reasons of the observed differences are discussed.

   Key Words: availability
   fossil-fueled units

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   Key Words: availability
   fossil-fueled units

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   Discusses the effort required to achieve efficient technical communication. British power industry practice provides an example

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Key Words: reliability programs

5. G. E. Apostolakis and P. O. Bansal. Effect of Human Error on the Availability of Periodically Inspected Redundant Systems. IEEE Transactions on Reliability Vol. R-26 No. 3. August 1977.

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Key Words: redundant systems
human error testing
common-cause failure

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Key Words: availability
nuclear power

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Key Words: fault tree
reliability analysis
mathematical models

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Key Words: availability
nuclear power

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Key Word: availability

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Key Words: fault tree
reliability analysis

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Key Words: component reliability
reliability analysis

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Key Words: component availability
testing frequency

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Key Words: availability
nuclear power

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Key Words: availability
fault trees
allocation
risk

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Key Words: reliability
apportionment

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Key Words: availability
nuclear power

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Key Words: reliability
maintainability
allocation
prediction

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Key Words: failure analysis
failure modes

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Key Words: availability
NRC requirement

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Key Words: outage management

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Key Words: decision analysis
equipment reliability

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Key Words: availability
capacity

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Key Words: availability
cost-benefit
standardization
data feedback

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Key Words: availability
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coal

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Key Words: reliability
cost-benefit

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Key Words: component reliability
reliability analysis

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Key Words: reliability analysis
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human factors

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Key Words: availability program

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Key Words: availability

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Key Words: availability
nuclear power

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Key Words: reliability analysis
human error

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Key Words: reliability criteria
systems reliability

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Key Words: availability
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nuclear power

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Key Words: availability
reliability analysis

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Key Words: electronic equipment
reliability

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Key Words: availability
nuclear reactors

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Key Words: availability
maintainability
nuclear reactors

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Key Words: fault trees
computer program

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Key Words: maintenance
nuclear reactors

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Key Words: availability
reliability analysis

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Key Words: availability
nuclear power

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Key Words: preventive maintenance
failure rate
human factors

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Key Words: availability
regulation

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Key Words: availability
coal

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Key Words: reliability improvement
failure modes
reliability estimation

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Keywords: availability
nuclear power

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Key Words: availability
reliability analysis

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Key Words: maintenance
nuclear power

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Key Words: availability
nuclear power

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Key Words: reliability models
redundancy
optimization techniques

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Key Words: availability
testing

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Key Words: availability

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Key Words: forced outage rate
loss-of-load probability
availability

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A study was made of nuclear and fossil power plant operating experience to compare plant availability and to determine the cause and safety significance of plant outages for nuclear plants.

Key Words: availability
nuclear power

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Key Words: reliability criteria

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Key Words: availability
reliability analysis

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Key Words: availability

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Key Words: availability

60. H. H. Zurn and V. H. Quintana. Several Objective Criteria for Optimal Generator Preventive Maintenance Scheduling. IEEE Transactions on Power Apparatus and Systems, Vol PAS-96, p. 984. May/June 1977.

A number of objective criteria of optimal maintenance scheduling of thermal generators are discussed. The criteria are based on generation operating cost, reliability indices, deviations from a desired schedule and/or constraints violation penalties. A comparison of the performance of all these criteria is presented by maintenance scheduling a realistic 30 thermal-unit system. Also, the relationships between the several reliability indices are discussed.

Key Words: unit availability
maintenance scheduling
reliability indices

KEY WORD INDEX

All papers and reports listed in the Annotated Bibliography and all EPRI reports are tabulated by key words in this part of Appendix B. Numbers refer to item numbers of papers and reports, listed on pages B-22 to B-34, and to EPRI reports, listed on pages B-9 to B-19.

APPENDIX C

SUPPLEMENTAL PAPERS

USE OF RELIABILITY AND MAINTAINABILITY (RAM) TECHNIQUES IN THE ELECTRIC UTILITY INDUSTRY

E. I. Parascos
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A NEW APPROACH TO THE ESTABLISHMENT AND MAINTENANCE OF EQUIPMENT FAILURE RATE DATA BASES

E. I. Parascos
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AVAILABILITY GOALS

P. F. Albrecht
General Electric Company

INHERENT AVAILABILITY

Alan A. Jarrett
California State University

COMMENTS ON INHERENT AVAILABILITY

R. J. Squires
Commonwealth Edison Company

COMMENTS ON EPRI NP-493, "ASSESSMENT OF METHODS FOR IMPLEMENTING AVAILABILITY ENGINEERING IN ELECTRICAL POWER PLANTS"

J. R. Fragola
IEEE Standards Department

USE OF RELIABILITY AND MAINTAINABILITY (RAM) TECHNIQUES
IN THE ELECTRIC UTILITY INDUSTRY

Edward T. Parascos
Consultant, Quality Assurance and Reliability
Consolidated Edison Company of New York

ABSTRACT

The electric utility industry is undergoing tremendous changes because of the constant increasing demands for electric power. The user is aware that these changes are taking place, but he is not aware of the magnitude of the changes or the new technologies that utilities have adopted to accomplish some of these changes.

Electric utilities are starting to use more of the technology and the skilled manpower, developed by aerospace, to solve some of the problems electric utilities are facing.

This paper describes some of the aerospace technologies which can be used. Applications involving reliability and maintainability techniques as modified for electrical utilities can be useful in power generation, electrical power transmission, and distribution.

This paper illustrates how reliability and maintainability analyses can be useful on electric utility's equipment.

INTRODUCTION

There are three basic functions involved in converting raw fuel into electric power for use in the home, office, and factory. These functions are:

- Power Generation (power plant operation), where fuel is converted into electric power
- Transmission (high tension power lines), where high tension power lines transport, very efficiently, electric power from power plants to local areas
- Distribution, where high tension power is transformed to usable voltage levels and transported to the ultimate user

Some utilities provide as service one or two of these functions. Others, like the Con Edison Company, provide all three. Con Edison has the most complex system (because it operates in an extremely high density area) for providing these three functions.

Several years ago, Con Edison organized a corporate Quality Assurance and Reliability Group. Figure 1 presents the position of this group in the Con Edison organization. The corporate QA&R Group was organized to service power generation (nuclear and fossil), transmission, and distribution. As a result of this organizational change, Con Edison has put together the nucleus of a reliability engineering group whose purpose is to run pilot studies and assess the value of applying system effectiveness techniques.

AVAILABILITY

"Availability" is commonly used in both aerospace and electric utility industries. It was always calculated by utilities in order to assess their day-to-day requirements. This calculation was made by dividing the uptime by the uptime plus the downtime. This is known as the operational availability.

Aerospace availability is defined by the reliability engineering and maintainability engineering parameters, mean time between failures (MTBF) and mean time to repair (MTTR). The basic reliability relationship

$$R = e^{-t/m}$$

Where

R = reliability or probability of success

e = the base of the Napierian log

t = mission time in hours

m = mean time between failures in hours

is stripped of all its parameters except MTBF for use in the availability relationship.

The basic maintainability relationship

$$MTTR = \frac{\Sigma (\lambda \; Rp)}{\Sigma \lambda}$$

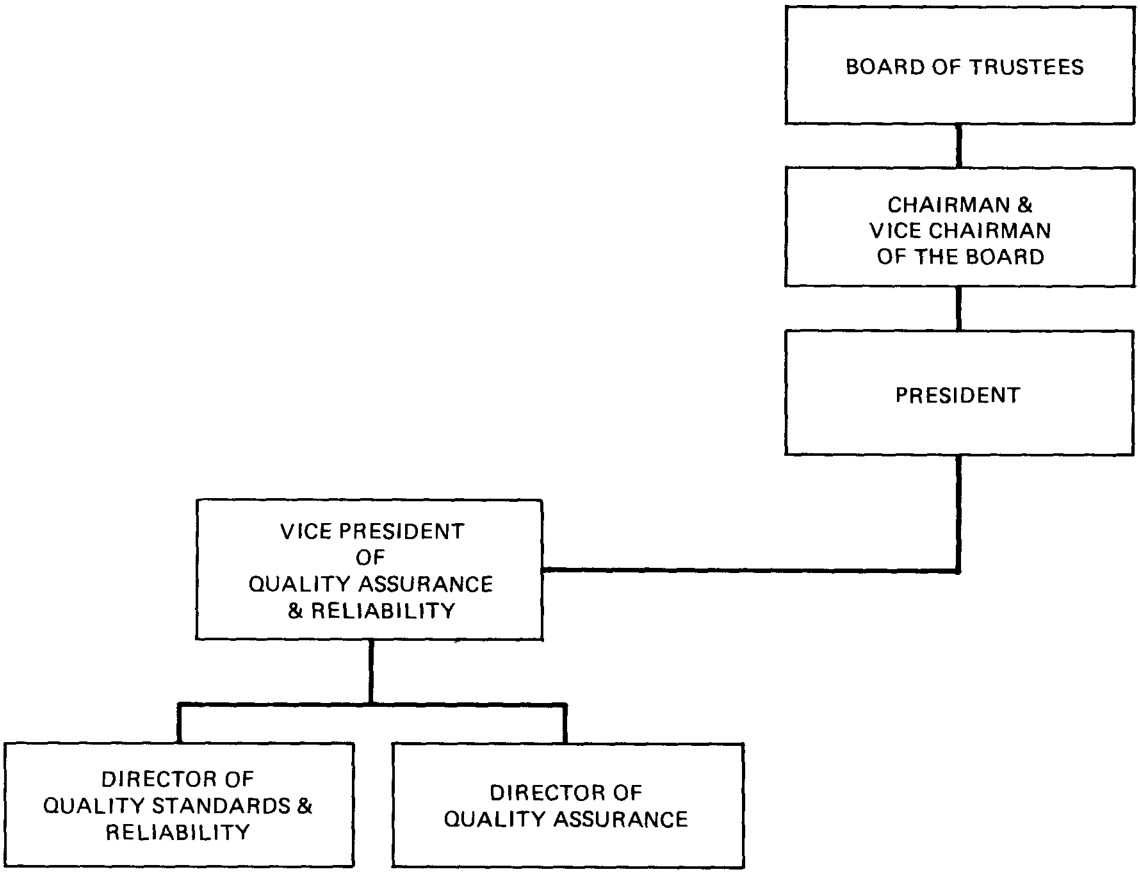


Figure 1. Organizational Position of the QA&R Group at Con Edison

Where

MTTR = mean time to repair in hours

λ = the failure rate in failures per million hours (the inverse of MTBF)

Rp = repair time in hours (this time only includes the actual time it took to make the repair; it does not include logistic time)

is used directly in the availability relationship which follows:

$$A = \frac{MTBF}{MTTR + MTBF}$$

Where

A = availability

MTBF = mean time between failures in hours

MTTR = mean time to repair in hours

This availability relationship is one that lends itself easily to design. Reliability and maintainability are design parameters and can be used in engineering specifications for components, equipment, and systems.

To illustrate the use of this availability relationship let us use a fictional power generation, transmission, and distribution system. Figure 2 is a block diagram of a hypothetical power plant which uses fossil fuels to produce electric energy. Figure 3 combines a transmission system coupled with a distribution system.

Using the relationships just defined for availability we can calculate the total system availability.

Most likely failure and repair rates were applied to each component of the power plant shown in Figure 2. Table 1 presents these rates.

Figure 4 summarizes the predicted availability of the electric power generating plant. This hypothetical system has a predicted availability of 96.2%.

Most likely failure and repair rates were applied to each component of the transmission and radial distribution system shown in Figure 3. Table 2 presents these rates.

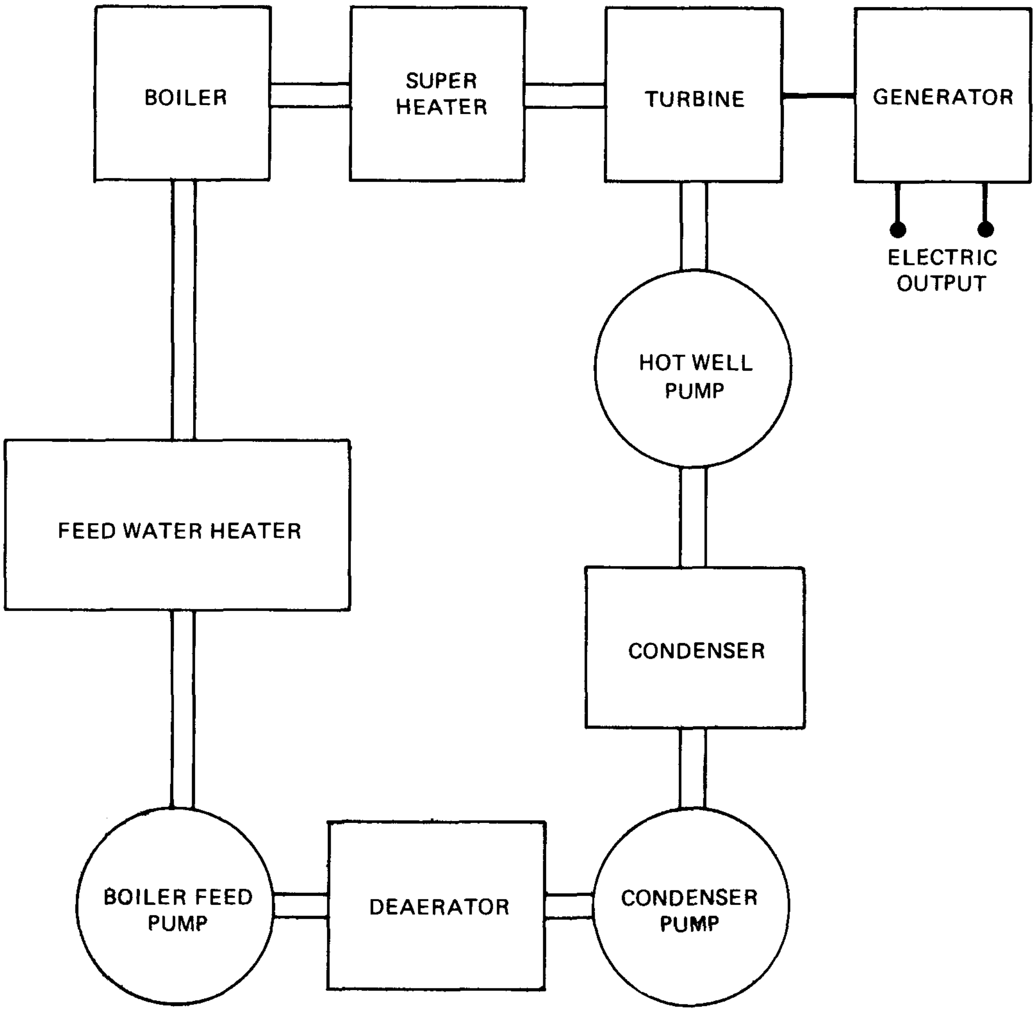


Figure 2. Block Diagram of an Electric Power Generating Plant

TABLE 1

Power Plant Component Description	Failure Rate (λ) Fail/10^6 Hrs	MTBF $\frac{10^6}{\lambda}$ in Hrs	Repair Time (Rp) in Hrs	λRp
1. Generator	111.55	8,965	124.5	13,888
2. Turbine	48.42	20,653	142.5	6,900
3. Hotwell Pump	27.73	36,062	48.3	1,339
4. Steam Condenser	19.59	51.046	148.6	2,911
5. Condenser Pump	16.04	62,344	39.5	634
6. Deaerator	10.94	91,408	96.3	1,053
7. Boiler Feed Pump	11.68	85,616	42.5	496
8. Feedwater Heater	8.90	112,306	98.5	876
9. Boiler	115.58	8,652	96.3	11,130

$\Sigma\lambda$ = 370.43 $\qquad\qquad$ $\Sigma(\lambda Rp)$ = 39,227

$$\text{MTBF } \frac{10^6}{\Sigma\lambda} = 2,699$$

$$\text{MTTR} = \frac{\Sigma(\lambda Rp}{\Sigma\lambda} = \frac{39,227}{370.43} = 105.9$$

$$A = \frac{\text{MTBF}}{\text{MTBF} = \text{MTTR}} = \frac{2,699}{2,699 + 105.9} = 96.2\%$$

TABLE 2

	Trans & Radial Dist. Sys. Comp.	Failure Rate (λ) Fail/10^6 Hrs	MTBF $\frac{10^6}{\lambda}$ in Hrs	Repair Time (Rp) in Hrs	λRp
1.	Secondary Cable	11.4	87,719	24.0	273.6
2.	Radial Network Comp.	24.5	40,816	96.0	2,352.0
3.	Primary Cable (4 KV)	5.7	175,439	24.0	136.8
4.	Unit Substation	34.1	29,326	120.0	4,092.0
5.	138 KV Trans. Line	5.7	175,439	24.0	136.8
6.	Substation	11.0	90,909	120.0	1,320.0
7.	345 KV Trans. Line	2.0	500,000	24.0	48.0

$\Sigma\lambda =$ 94.4 $\Sigma(\lambda Rp)$ = 8,359.2

$$MTBF = \frac{10^6}{\Sigma\lambda} = 10,593$$

$$MTTR = \frac{\Sigma(\lambda Rp)}{\Sigma\lambda} = \frac{8,359.2}{94.4} = 88.6$$

$$= \frac{MTBF}{MTBF + MTTR} = \frac{10,593}{10,593 + 88.6} = 99.2\%$$

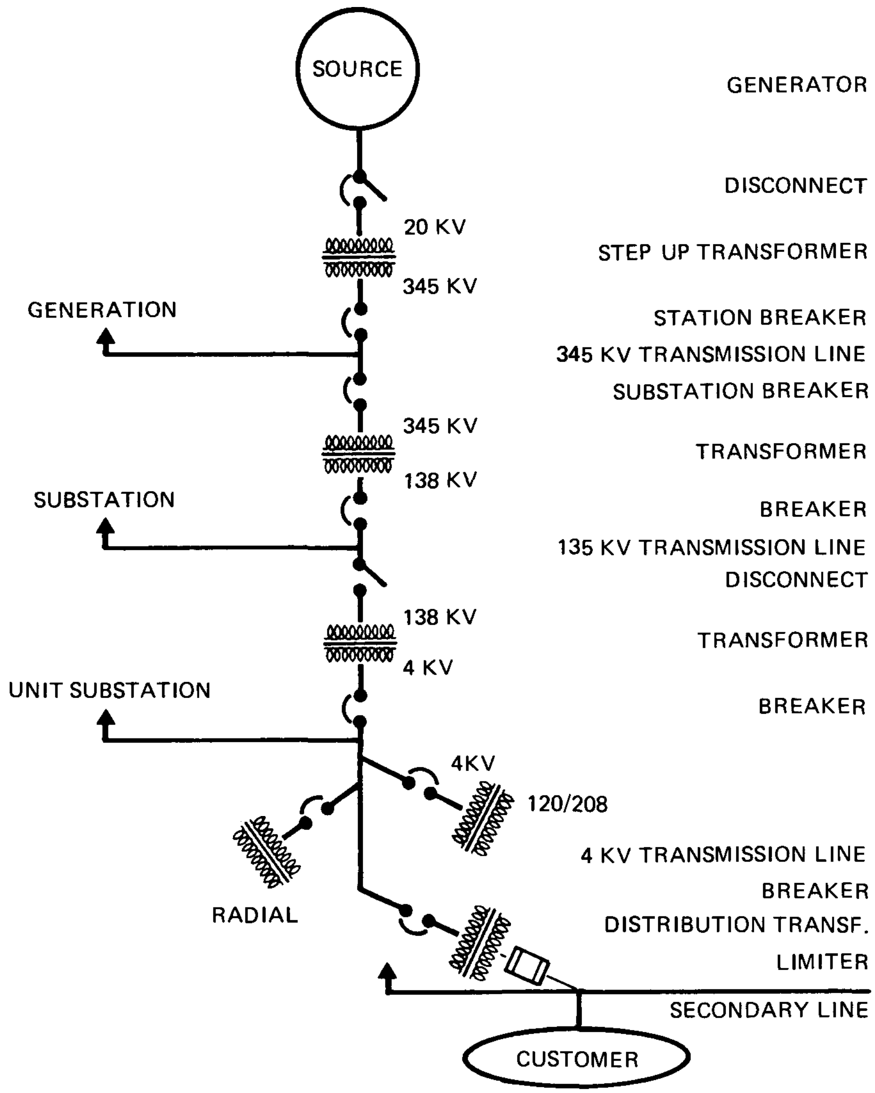
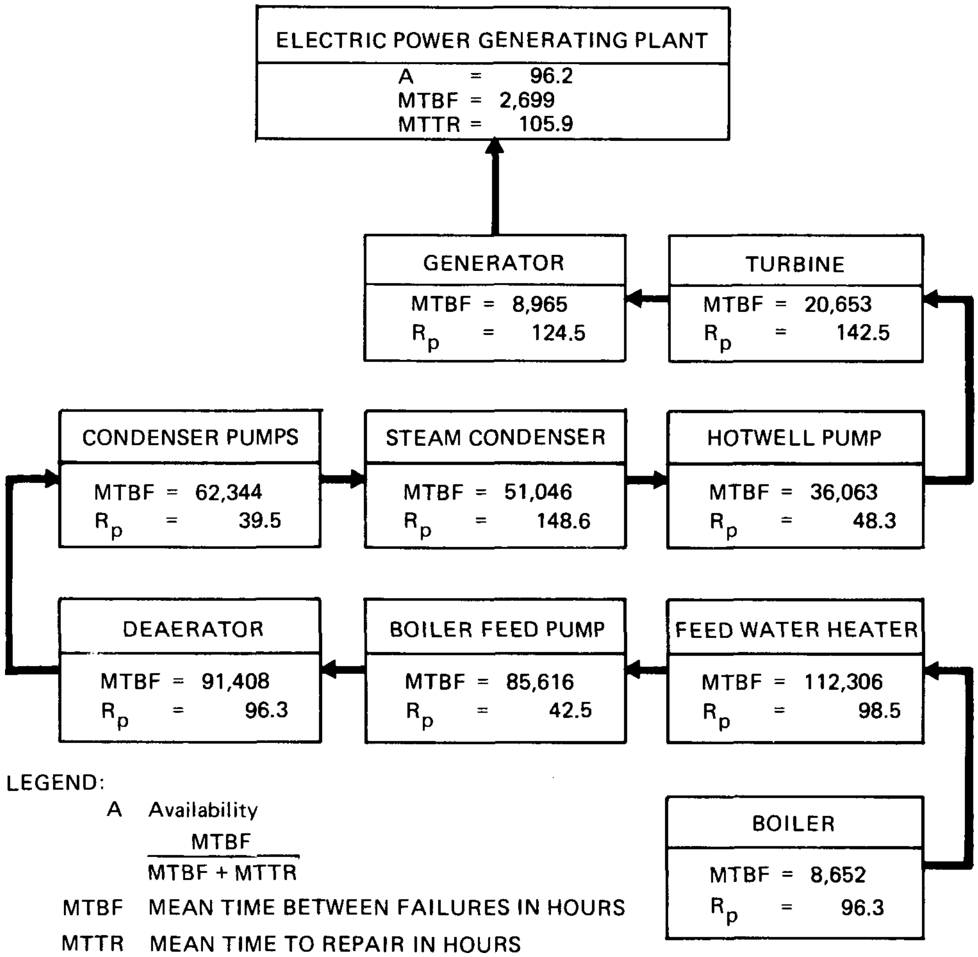


Figure 3. Transmission & Radial Distribution System



LEGEND:

A Availability $\frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$

MTBF MEAN TIME BETWEEN FAILURES IN HOURS

MTTR MEAN TIME TO REPAIR IN HOURS $\frac{\Sigma(\lambda R_p)}{\Sigma \lambda}$

λ FAILURE RATE IN FAILURES/10^6 HRS

R_p REPAIR TIME IN HOURS

Figure 4. Availability Prediction for an Electric Power Generating Plant

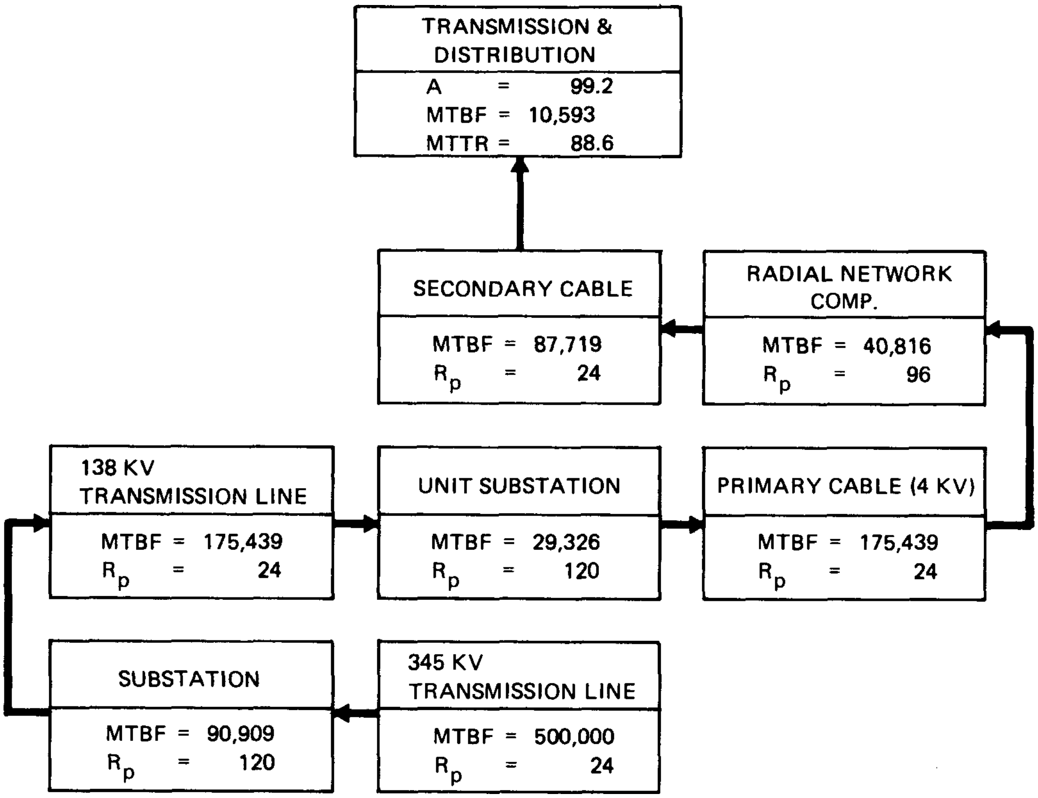
Figure 5 summarizes the availability of the electrical transmission and distribution system. This system has an availability of 98.8%.

The combined availability for the entire system is 95.5%, shown in Figure 6. This figure of availability may be good enough for some aerospace systems, it may be good enough for some consumer items, but it is not good enough for the customers of electric utilities. If, for example, the electric utility customer demands an availability of electrical power of 99.92% (or an outage of less than eight hours in a one-year period), an availability of electrical power of only 95.5% would not only cause great customer dissatisfaction, but would, in addition, represent loss of revenue and reputation by the utility. So here, then, we can see that the use of reliability and maintainability disciplines early enough in the design cycle of power generation, transmission and distribution systems and equipment can reap great rewards in designing the optimum configuration to meet the required availability.

The three main functions of utility operation--power generation, transmission and distribution--can also use other disciplines of system effectiveness, those of safety factor engineering and human factor engineering. Every operation must be fail-safe because of the man-machine interfaces involved. Here the aerospace technique called failure mode effects and criticality analysis (a tool of safety factor engineering) could be extremely useful. The man-machine interfaces also lend themselves to such human factor engineering techniques as operation sequence diagrams (OSD's) and functional flow diagrams. These two techniques, when applied to new designs, can reduce the extensive operator skills that may be required.

How can we apply these new assurance techniques in utility operation? There are several answers to this question. These answers include the following:

- Apply these disciplines on all newly designed systems and equipment.
- Apply these disciplines to modifications and new purchases.
- Apply the techniques in these disciplines to cull out culprits in the system and force redesign or new manufacturers into the field to replace incompetent vendors and subcontractors.



LEGEND:

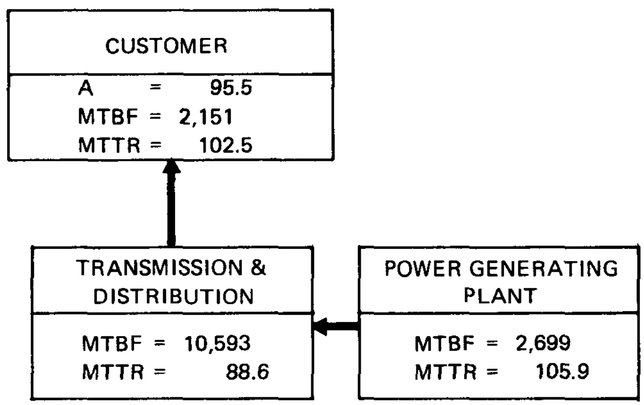
$$A = \frac{MTBF}{MTBF + MTTR} = \text{AVAILABILITY}$$

MTBF = MEAN TIME BETWEEN FAILURES IN HOURS

MTTR = MEAN TIME TO REPAIR IN HOURS

R_p = REPAIR TIME IN HOURS

Figure 5. Availability Prediction for Transmission & Radial Distribution System



LEGEND:
A = Availability
MTBF = MEAN TIME BETWEEN FAILURES IN HOURS
MTTR = MEAN TIME TO REPAIR IN HOURS

Figure 6. Customer Availability Prediction

To illustrate the third item here, one of the reliability engineering statistical tools called the Weibull distribution can be used. The Weibull distribution is of the following form:

$$R = e^{-ba^{c}}$$

Where

R = "probability of success" or reliability

e = base of the Naperian log

a = equipment age

b = characteristic life or scale parameter

c = the slope or shape parameter

if $c < 1$ = decreasing failure rate

$c = 1$ = constant failure rate

$c > 1$ = increasing failure rate

This hypothetical example illustrates the use of the Weibull distribution as a decision making tool in choosing the optimum transformer manufacturer or design. Assume that there are 150 27-KV transformers in operation in the field at day zero and that all of these transformers were purchased to the same specification. Assume also that different manufacturers (Manufacturers A, B, and C) received equal orders of 50 transformers. After 21 years of operation, the following failure data are recorded for this population of transformers:

	Transformer		
Failures	A	B	C
1st	2.7 Yrs	1.03 Yrs	12.5 Yrs
2nd	5.3 Yrs	3.6 Yrs	15.5 Yrs
3rd	7.7 Yrs	8.2 Yrs	17.5 Yrs
4th	10.5 Yrs	16.3 Yrs	19.4 Yrs
5th	15.3 Yrs	21.0 Yrs	21.0 Yrs
6th	21.0 Yrs	-	-

Which transformer is the best? Which transformer has the highest failure rate? How many of each type will still be operating in the 30th year of operation? In the 45th year of operation?

These Weibull analyses indicated the following slope parameter for each:

Transformer	Weibull Slope Parameter, C	Failure Rate Type
A	1.058	Constant
B	0.627	Decreasing
C	3.721	Increasing

Which transformer is the best? Transformer B. In over a 20-year period this transformer has exhibited a decreasing failure rate. How many of each type will still be operating in the 30th year of operation? In the 45th year of operation?

Transformer	Remaining After 30 Years	Remaining After 45 Years
A	41	37
B	44	42
C	33	8

Failure of a transformer in a system ranges in cost upwards from $10,000. The costs in inconvenience to customers and general public relations (in certain cases) is immeasurable. How useful, therefore, is it that the transformer exhibiting the least failure rate be chosen?

CONCLUSION

The reliability and maintainability analyses just illustrated are currently being used at Con Edison to optimize the availability of our equipment.

A NEW APPROACH TO THE ESTABLISHMENT AND MAINTENANCE OF EQUIPMENT FAILURE RATE DATA BASES

Edward T. Parascos
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ABSTRACT

In determining the reliability of an equipment in operation the most essential tool is a "real-time" failure reporting, analysis, corrective action and feedback system. With the advances made in recent years in the data processing industry it is surprising how relatively few organizations use the available technologies to optimize this important aspect of an equipment's operation (failure reporting). This paper will present the following items necessary in the establishment and maintenance of a successful real-time failure rate data base:

- The principles of form development for failure reporting and analysis
- The use of optical scanning for rapid data input
- The use of computer time-sharing techniques
- Reliability engineering techniques useful in establishing equipment failure rates

In addition the paper will include proposals for the development of electro-mechanical and mechanical equipment failure rate data bases, the methodology to be used in the application of these data bases, and the development of a data pooling organization to administrate the receipt and disbursement of failure rate data.

Finally this paper will present several examples of established failure rate data-base systems in the electric utility industry, using these new techniques. The costs associated with their establishment will also be discussed.

FAILURE REPORTING, ANALYSIS, CORRECTIVE ACTION, AND FEEDBACK

A piece of equipment fails. How are systems, other pieces of equipment, individuals, or organizations affected by this failure? If this failure is not documented and analyzed, but just repaired or replaced, it becomes merely an operating cost and has no other effect. This approach of not affecting anything has been so attractive to the business world that it has become the only way of doing business. The recent trend toward increasing costs of raw energy (oil, gas, coal, etc.) has fostered a new awareness of equipment failures. This development tends to encourage the reduction of equipment failures to reduce life cycle costs, and, to some extent, compensate for the increased cost of energy.

If, when equipment fails, the failure is documented and then analyzed in detail, corrective actions (redesign, etc.) can be specified so that an improved model of the equipment will evolve. This new model will have a lower life cycle cost because the documented failure mode has been eliminated through design improvements. This development process may then be repeated again with the improved model. The success of this process depends heavily on the documentation of each failure occurrence.

In designing an optimum failure reporting and documentation system the following principles are essential.

- "Half the Job Concept" Personnel who are responsible for the repair of a failed equipment must be made aware that reporting (documenting) defects is just as important as repairing that item.
- "Pre-recording Static Information" Analysis of most existing failure reporting systems reveals that a high percentage (up to 60%) of the reporter's time is spent on recording static information. Wherever possible, an optimum system has the static information pre-recorded on the form during the printing process or by computer printed headings following the printing process.
- "Eliminating Code System" The failure reporting form should be entirely in English language to eliminate the requirement of looking up or memorizing codes.
- "My Card Concept" The end user must be involved in the design of the card. It should not be designed by engineers alone. If the end user feels that the failure report form is his, the program will succeed.
- "Human Factored Form Design" The failure reporting form should be clear, simple, and highly visible so that it can be completed quickly and accurately.
- "Total System Concept" The failure report form should be more than a reporting medium. It should be used to initiate work requests, order spare parts, specify manpower requirements, etc. Let it be an optimum user system.

- "Rapid Data Inputting" Input the failure data rapidly using optical scanning and computer time sharing techniques for total system use.
- "Feedback" Analyze the failure data as soon as possible. Report all evaluations, corrective actions, and results to all levels of management.

OPTICAL SCANNING TECHNIQUES

In applying the principles just stated for an optimum failure reporting system it is essential to input data rapidly. Optical scanning of mark sense data (MSD) has been used in electric utility operation very successfully for the last five years. Mark reading systems cut data coversion costs dramatically by using the source document, filled out at the point of data collection, as the input medium. Document data can be computer generated or hand marked with simple pencil strokes. The optical scanner automatically reads the documents and converts the marks to computer-compatible data. An 8-1/2" x 11" failure report form completely filled out can be entered into a remote computer main frame in ten seconds. Such a system is shown in Figure 1.

COMPUTER TIME-SHARING TECHNIQUES

Once the failure data are recorded it is essential that the information be immediately available to any potential user. The time-sharing approach enables a potential user to sit down at a time-sharing terminal (similar to a typewriter) and, in English language, gain access to the data for analysis. Time-sharing computer organizations have libraries of pre-programmed statistical techniques to expedite these analyses. There is also a network of time-sharing organizations who, for a modest cost, eliminate the user's need to establish a massive and expensive computer facility. Even if the potential user already has an in-house computer facility, conversion of a portion of the facility to time-sharing with appropriate support personnel is recommended to establish the required information response for the user. The important aspect of time-sharing is that the user can, in <u>real time</u>, access and analyze data without having to do any computer programming or use anything but the English language.

RELIABILITY ENGINEERING TECHNIQUES

To analyze failure data several statistical techniques can be used. Some of those techniques have been adapted by the reliability engineering discipline for

FUNCTIONAL REPRESENTATION OF OPTICAL SCANNING DATA BASE OPERATION

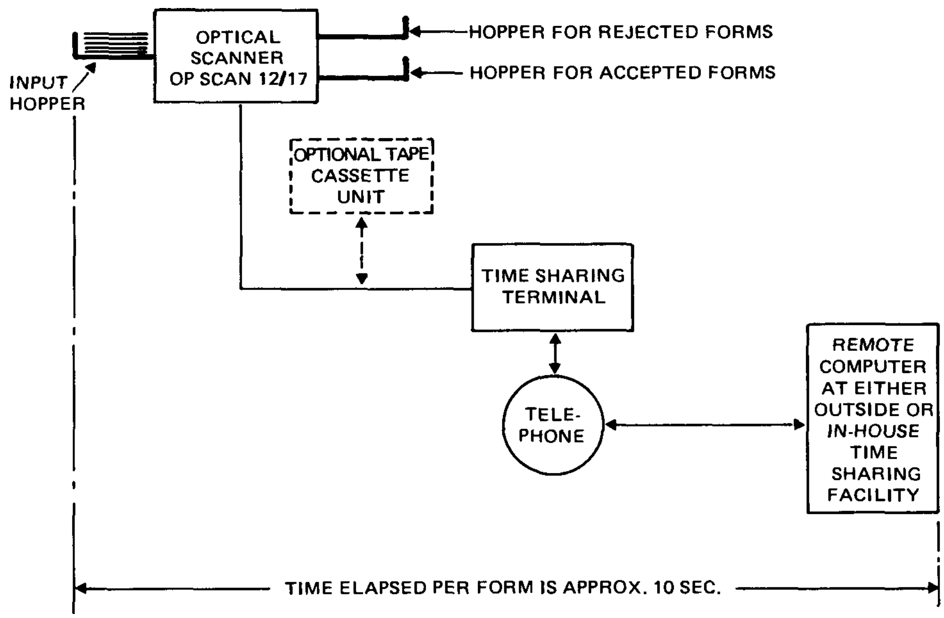

Figure 1. Optical Scanning Functional System

use in developing life cycle costs of equipment. In determining the failure rate of an equipment the following relationship may be used:

$$MTBF = \frac{2T}{\chi^2 (DF)\ (CL)} = \frac{1}{\lambda}$$

Where

MTBF = Mean time between failures

T = Total equipment operating time

χ^2 = Chi-squared table, look up function for (DF) and (CL)

DF = Degrees of freedom = 2N + 1

N = Number of failures

CL = Confidence limit (typically 90%)

λ = Failure rate

In determining the repair rate of an equipment, the following relationship can be used:

$$MTTR = \frac{\Sigma\ (\lambda\ Rp)}{\Sigma\ \lambda}$$

Where

MTTR = Mean time to repair

λ = Failure rate

Rp = Repair time

The final relationship to be presented here is that for equipment availability, which follows:

$$A = \frac{MTBF}{MTBF + MTTR}$$

Where

A = Equipment availability

MTBF = Mean time between failures

MTTR = Mean time to repair

There are many more such relationships, but these are the fundamental ones.

REQUESTS FOR PROPOSALS FOR FAILURE RATE DATA BASES

The following areas could support requests for proposals (RFP's) in establishing equipment failure rate data bases.

- Area #1 An RFP could be written for "The Development of Electromechanical and Mechanical Failure Rate Data Bases." These data bases could follow the format of MIL-HDBK-217B, which deals primarily with electronic equipment. It is essential that the data bases be completely computerized. Sources of the data should be from electric utilities, commercial industries, and the military. These data bases should have the following characteristics:
    - Readily accessible
    - Frequently updated
    - Inexpensive to use
- Area #2 An RFP could be written to develop the methodology for "The Application of Electro-Mechanical and

Mechanical Failure Rate Data Bases." The analytical tools must be developed to translate equipment failure rates into design improvements. The following items should be considered:

- Applicability of the analytical tools used in electronic equipment to electro-mechanical and mechanical equipment
- Cost benefits associated with the newly developed techniques

- Area #3 An RFP could be written to develop a data pool organization for administrating failure data submitted by electric utilities, commercial organizations, and the military. Such an organization would need to consider the following:
  - Common reporting forms
  - Data pool participation requirements
  - Documentation requirements
  - Funding arrangements

NORTHEAST UTILITIES POOL

At the present time, there are several data pools established for the electric power utilities. Only one, however, uses optically scannable failure reporting forms. This data pool is known as the Northeast Utilities Pool. It is composed of nine participating utilities who use optically scannable forms and a central time-sharing computer system. Their present objective is to pool equipment failure data and develop equipment failure rates. Once failure rates are developed, manufacturers of equipment will be asked to provide the cost benefits associated with the reduction or elimination of identified failure modes. Figure 2 is one of the forms used by the Northeast Utilities Data Pool to record overhead network transformers.

COST OF ESTABLISHING AN OPTIMUM FAILURE DATA BASE

Table 1 presents the costs associated with the establishement of an optimum data base using optical scanning and remote time-sharing computer techniques.

In summary, in order to establish, maintain, and perpetuate a failure rate data base it is imperative to design it with rapid input and retrieval capabilities. The system shown in this paper was initiated five years ago at Con Edison with one optical scanner and one failure report form, as shown in Figure 2. There are now 22 scanners and 112 different report forms presently in use at Con Edison. In addition, there are nine northeast utilities also using this approach. These utilities have entered into a data-sharing agreement with Con Edison.

OVERHEAD TRANSFORMER FAILURE REPORT

1. UTILITY NAME

1. Northeast Utilities
2. Consolidated Edison
3. Long Island Lighting Company
4. Public Service Electric & Gas
5. Orange & Rockland Utilities
6. New York State Electric & Gas
7. Central Hudson Electric & Gas
8. Rochester Gas & Electric
9. Niagara Mohawk

2. INSTALLATION DATE (Yr.)

4. MANUFACTURER (First Two Letters)

3. FAILURE DATE (Yr.)

5. PHASES

6. SIZE (KVA)

7. HIGHEST VOLTAGE (KV) PRIMARY

8. TYPE UNIT

1 Conventional — 2 CSP
3 Stepdown — 4 Dual

9. IF DUAL LOWER VOLTAGE (KV)

MARK BELOW ALL BOXES THAT APPLY

10. TYPE PRIMARY FUSING
- Internal Oil Leak
- Current Limiting Fuse
- External Cutout
- None

11. SECONDARY PROTECTION
- Breaker
- Limiters
- Fuses
- None

12. TYPE ACCEPTANCE OR FIELD TEST BY UTILITY (New Unit)
- None
- Visual Inspection Only
- Energization at Normal Voltage
- D C Hi Pot
- Oil Sample

13. FAILURE MODE - EXTERNAL
- Oil Fire
- Bulged Tank
- Cover Blown
- No Visual Affect

14. FAILURE MODE - INTERNAL
- Primary Winding to Case
- Secondary Winding to Case
- Primary Winding - Open
- Secondary Winding - Open
- Windings Shorted to Each Other

15. PROBABLE CAUSE OF FAILURE
- Lightning
- Overloads
- Leaking Covers, Bushings, Breaker - Water
- Improper Installation or Operation

16. SERIAL NUMBER

	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9

17. DIVISION OR DISTRICT

	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
	0 1 2 3 4 5 6 7 8 9
	0 1 2 3 4 5 6 7 8 9

EMPLOYEE SIGNATURE

18. PURCHASE DATE

MO		0 1
		0 1 2 3 4 5 6 7 8 9
DAY		0 1 2 3
		0 1 2 3 4 5 6 7 8 9
YR		0 1 2 3 4 5 6 7 8 9
		0 1 2 3 4 5 6 7 8 9

19. DATE OF REPORT

MO		0 1
		0 1 2 3 4 5 6 7 8 9
DAY		0 1 2 3
		0 1 2 3 4 5 6 7 8 9
YR		0 1 2 3 4 5 6 7 8 9
		0 1 2 3 4 5 6 7 8 9

20. EMPLOYEE I.D.

	0 1 2 3 4 5 6 7 8 9
	0 1 2 3 4 5 6 7 8 9
	0 1 2 3 4 5 6 7 8 9
	0 1 2 3 4 5 6 7 8 9
	0 1 2 3 4 5 6 7 8 9
	0 1 2 3 4 5 6 7 8 9

Figure 2. Overhead Transformer Failure Report

TABLE I

COST OF ESTABLISHING DATA BASES

	Cost Element	Estimated Cost
1.	Optically Scannable Failure Reporting Forms	
	a. Design and Printing First 10,000	$ 600
	b. Additional 10,000 Forms	$ 250
2.	Optical Scanner	
	a. 3-Year Lease Purchase & Maintenance From 300 Forms/Hr. to 3,000 Forms/Hr.	$ 600/Month
	b. At the End of 3rd Year - Maintenance	$ 100/Month
3.	Time-Sharing Terminal & Telephone	$ 200/Month
4.	Time-Sharing Computer Costs	
	a. Initial Programming per Form	$5,000
	b. Storage Costs (1 megabit to 100 megabits)	$5,000/Month
	c. Special Report (in English Language)	$1,000/Each

NOTE: In a data pool relationship items 1 and 4 are shared by the pool members. Participating members must have at least one of items 2 and 3.

O'HARA: What is the reject percent of the scanner?

PARASCOS: The reject rate associated with the scanner is less than 1/2 of 1%. We check our scanners before every run with a special test form. If they are running out of specifications we have them adjusted. This doesn't happen too often (approximately 2 times per year).

O'HARA: What type of equipment is available at the site to produce the reports?

PARASCOS: The types of equipment at the site are:

a. A time-sharing terminal

b. A tape deck

c. An optical scanner

O'HARA: Are the rejected sheets corrected and, if so, who makes the corrections?

PARASCOS: Rejected sheets are sent back to the originator along with computer generated critique and the originator makes all corrections. Obvious or simple errors are corrected by clerks who re-enter the forms.

AVAILABILITY GOALS

Paul Albrecht
General Electric Company

I would like to comment again on the general question of setting quantitative goals. The view was expressed several times that in addition to being a goal the worth of reliability must be considered. I believe that the worth factor is, in fact, of paramount importance, but by setting quantitative goals the worth factor will be largely removed from consideration. To illustrate my point, I would like to call attention to the evaluation of heat rate and efficiency. It is generally agreed that both efficiency and reliability should be as high as possible. Further, it is widely recognized that there is great economic value associated with a 1% change in either parameter. Historically, both manufacturers and utilities have placed considerable emphasis on achieving improvement in heat rate. Yet the present EEI data show that there has not been similar emphasis on improvement in availability. This fact is largely responsible for the Availability Workshop being held. The basic solution to availability improvement as proposed at this Workshop has been that utilities must set quantitative goals for availability, establish formal programs to achieve these goals, and that a new discipline called availability engineering is needed to accomplish this.

The observation I wish to make is that this is <u>not</u> the approach that has been taken to achieve improvements in heat rate. I believe that the reason heat rate and efficiency have received such attention is that utilities have explicitly recognized the economic value of efficiency in bid evaluations. By contrast, they have generally <u>not</u> made similar evaluations of availability. Although it is not as easy to calculate availability as it is to calculate heat rate, this situation will improve with the expansion of data collection programs and improvement in modeling and analysis techniques. My concern, however, is that the result of the calculation is viewed as input to a formalized program directed at achieving a specific numerical goal for a total unit. Several speakers at the

Workshop expressed concern that this will lead to large expenditures of funds on "reliability assurance," with reports and paperwork as the main output. If utilities begin to evaluate availability in bid evaluations in a manner similar to heat rate, equipment manufacturers will have the incentive to improve equipment availability. The manufacturers will set their own availability goals internally at a level consistent with the worth of reliability established by utilities in bid evaluations.

In summary, quantitative availability goals have an important role. However, these goals should be established in the most cost-effective manner with a minimum of nonproductive administrative activity. This can be done if equipment manufacturers establish equipment goals based on reliability worth values provided by the user.

INHERENT AVAILABILITY

Alan A. Jarrett
California State University

DEFINITION

Inherent availability is the maximum achievable availability by elements of the design and the way they are interconnected when used with "optimum" operating and maintenance procedures. Optimum requires careful consideration because it is not necessarily the best but considers cost, value received and specified management operating policies. Design inherent availability is fundamental to understanding what availability engineering can and cannot do.

If higher availability can be achieved by planning and design, then plants or units of different design can have different inherent availabilities. Inherent availability cannot be tested, manufactured, or inspected into a system after the design is finalized. That is, the inherent availability cannot be modified or changed without a corresponding change in design.

If a system is not operating to its expected level of inherent availability, modifications may be required to increase either the inherent reliability or maintainability of the system. Reliability can be increased by reducing the frequency of failures by redesign of components and subsystems such as reducing environmental stresses, derating, redundancy, changing interaction of components, etc. Maintainability can be increased by reducing the duration of outages by spares provisioning, maintenance planning, enhancing accessibility, upgrading repair facilities and equipment, etc. The modes and causes of poor performance may indicate the means by which the increase of availability can be achieved.

MANUFACTURING, CONSTRUCTION AND O&M PRACTICES

Inherent availability can only be achieved when equipment is manufactured, constructed, installed, operated, and maintained under carefully specified and controlled conditions using supporting personnel, equipment, and procedures which have been specified and using them in the manner intended.

Unfortunately, equipment may not have been manufactured, installed, or constructed as specified, e.g., poor manufacturing techniques, inferior workmanship, or inadequate inspection and testing. It may have been shipped or handled carelessly. Furthermore, equipment may sometimes have to be operated outside of specified conditions, environmental conditions may not be ideal, supporting equipment may not be used exactly as intended, and maintenance may not be carried out perfectly. These factors will tend to degrade the performance of equipment so that the inherent availability cannot be achieved during operation. These effects are not inherent in the design of the equipment and, thus, the achieved availability is less than the inherent availability by the effects of these factors, i.e., the achieved or use availability is equal to the inherent availability times the degradation factors.

Under these circumstances, units of the same inherent availability could have different use availabilities due to differences in manufacture, construction, operating conditions, O&M procedures, and the capability or training of personnel. Thus, the actual availability of a particular unit may be different from a similar unit operated by the same utility. If the inherent availability can be degraded, the use availability can be improved by revised operating conditions, improved maintenance procedures, and upgraded operating practices.

MATURATION AND AGE

The results of many observations of the performance of electric power plants have shown conclusively that there is an increase in the availabiity of new plants which is a function of the maturity of the design and the age of a specific plant. This improvement is called maturation, or growth. Studies indicate that design maturity does not occur until about the third replication of a new design. It has been reported in the literature that new generating units achieve operating maturity in about three to five years. The availability growth rate of a system is dependent on both its age and the maturity of design.

One cause of low availability is failures that occur when equipment is initially put into operation. This arises because some parts may be defective as a result of weaknesses not detected and corrected during manufacture and testing. The high failure rate of parts during early life is frequently compared to the high mortality rate among infants and children, and for this reason is sometimes called infant mortality.

After the initial learning experience of a new unit and the maturation of new designs, early causes of failure are corrected and the remaining degradation of inherent availability is by O&M practices alone. Another type of failure occurs later in the life of a part due to physical changes as parts age, especially in mechanical components.

CONCLUSION

It then follows that the maximum availability that can be achieved from a unit is not the same for every unit, but each has a unique value based on its design, age, and operating and maintenance procedures. I am concerned that availability goals will be imposed on all units in a system and perhaps on all systems, which could impose impossible goals on an individual unit without consideration of design differences or management operating and maintenance policies.

Based on the postulated electrical energy growth of 5 to 6% per year, i.e., the slow birth rate of new facilities, coupled with the current trend to extend the usable life of existing facilities, the major improvement in system availability for at least the next 12 to 15 years will have to come from plants currently on line. Not counting the learning curve (early failures or infant mortality), design maturity, and operating maturity associated with new units nor wearout failure modes of older facilities, if a utility is to achieve a significantly higher productivity during the next 10 to 15 years, the name of the game is outage management of existing capacity.

COMMENTS ON INHERENT AVAILABILITY

R. J. Squires
Commonwealth Edison Company

The reactor coolant pump seal problem I mentioned can be used to help amplify this concept. The reactor coolant pump seals of the Westinghouse PWR design are very reliable. Here is a component with a very high reliability; why did we have problems? It had to do with not just the seal itself, but the interaction in the system. Our steam generators are inverted U tube bundles. This means that when we drain the primary system, we have an inverted U tube that has air inside it. We don't remove all of the air when we drain the whole primary system, which means that we have a trapped air bubble.

I want to relate this trapped bubble to the system effect, that is, to the interaction actually on the operation of the seal. It is a floating seal, and when we have injection water coming in it forces the two faces apart. While part of the injection water comes in through the seal, part of the injection water goes through the primary and thus there is a hydraulic lag. Therefore it is being kept apart by the force sphere that is connected to the primary system. If you lose your primary system pressure, then you lose the pressure here and allow these seals to come into contact.

When we were starting up, we were faced with the fact that we were running the seals for the first time, trying to sweep the air bubble out of the steam generator, pulling it through the reactor coolant pump depressurizing the seal, depressurizing the system, and therefore running a risk of pulling the seal through, wiping out the rubber O-ring behind it, then causing leakage through the other rubber O-ring. We have actually failed two of them in that manner. So it is not just the inherent reliability of the seal; it's very good if you operate it the way it was designed. But the system effect when you drain the primary system does not always allow you to operate it in that manner. We now have four steam generators drained because we are doing some inspection at the Zion Plant. We are working with Westinghouse to sweep out one of these loops first, and then using that one swept loop to sweep out the other three loops. This time we are not going to run the risk of depressurizing four loops and possibly of wiping out all four seals on a particular start-up. You can have a reliable design in a component, but you have to be very familiar with the system operation. How are we going to operate that within the plant? Is there something there that could destroy the design principle or the basis for it to operate?

COMMENTS ON EPRI NP-493, "ASSESSMENT OF METHODS FOR IMPLEMENTING AVAILABILITY ENGINEERING IN ELECTRICAL POWER PLANTS"

J. R. Fragola
IEEE Standards Department

I have reviewed the subject document and find it to be a good attempt at tailoring availability technology to the electric power industry. It is my opinion that there is no doubt that if the technology of availability is systematically applied it has the potential of producing significant economic benefits to the industry. Your report goes a long way toward highlighting the procedures and tasks required for a successful systematic implementation of availability engineering.

I had originally planned to attend your workshop in Albuquerque; schedule problems, however, have prohibited me from doing so. For this reason, I would like to offer the following written comments. I do this as someone who has had some experience in the aerospace and power industry and who has seen some of the pitfalls involved in applying the methodology of availability.

My first comments are of a general nature addressing the entire report; other more specific comments follow. Let me state at the outset that the comments are mine alone and may or may not reflect the general feelings of the IEEE.

COMMENT 1

Experience has shown me that the establishment of a top-level availability goal or range of goals is by far the most important problem in the application of availability engineering. Errors in the systematic process that lead to this goal selection can cause even a well organized and correctly developed availability program to produce results which management may consider nonproductive or, worse, counterproductive. Also, while errors in the allocation or analysis process can produce significant errors in design decisions, they do not usually affect the overall program, and they may at least be offset to some degree by correct decisions made in other plant areas. However, errors made in the establishment of a goal can cause the entire program to go sour, which has in some cases turned management off entirely to the idea of applying availability engineering in the future. Thus, I suggest that your report be revised so that it addresses in a much more thorough way the establishment of a top-level goal.

In my experience, the major types of errors that occur in goal establishment are those which incorrectly assess the environment in which the goal decision is being made. These errors I have seen to be of two types, which for lack of better terms I will call technical and temporal. Technical errors are those which incorrectly assess the environment at the time the analysis is made. An example would be making incorrect assumptions at the start of the analysis, or not realizing that some incorrect assumptions underlie the analysis. Temporal errors are those which neglect to adequately take into account changes in the decision environment between the time the analysis is made and the time the decision is implemented. I feel that if one were to apply the techniques as outlined in the report without further guidance, the implemented availability improvement programs could fall prey to both types of errors.

One example might help to make the point a little clearer. Suppose a goal is justified on an economic basis by the potential savings it will produce to a particular investor-owned utility. Suppose further that the program to achieve that goal costs the utility x dollars and will save y dollars, where $x > y$. Is the program successful? The answer to this question is not as obvious as it might seem. Further questions must be asked. (a) When is the investment in the program spent and when do the savings accrue? That is, is the net present value of $x-y > o$? (b) What underlying business base has been assumed, and how sensitive is x-y to changes in the business base? More clearly, if projection is based on a growth in usage of 5%, do the savings disappear or become negative if the actual growth is 3%? (c) How is the return to the utility calculated by the appropriate regulatory bodies, and what impact will change in this regulatory process have on the savings? That is will the savings be passed on to the consumers in the form of rate relief or to the shareholders?

Many people (myself included) feel that any availability improvement program must be of real economic value to a utility before it is undertaken. Of course, programs can be established to respond to regulatory requirements, but this is certainly not the preferred method, and even if this method is chosen, some economic thinking of the type described above must go into the establishment of the imposed requirements. Otherwise, enforcement would be in severe difficulty.

The types of analyses that must form the basis for the establishment of an availability goal for a plant must include:

- A return on investment (ROI) analysis, which considers the time value of money
- An economic regression analysis, which considers changes in the time value of money (discount rate), as well as changes in the assumed business base
- An expected return analysis, which considers the present and future regulatory environment to determine what portion of the potential return is expected to actually be returned to the shareholders

COMMENT 2

When an availability engineering program is initiated at a company, it should be done gradually and systematically with as little disruption as possible to the normal course of activities. One way to accomplish this is to have the individual in charge of the program perform a program requirements/corporate capabilities analysis. This analysis is performed by simply making a matrix of the availability engineering tasks that make up the program vs. the existing corporate departments and sections. Each block in the matrix is filled in with whatever portion of the normal functions are applicable to the performance of the given availability task. The results of this analysis can sometimes be quite remarkable. It is often found, for example, that well over 50% of the essential tasks are actually already being performed in some fashion within the company. In some instances it may even be found that essentially all the basic work is being done, and only standardization, coordination, control, and follow-up are necessary by the availability engineering specialists. Another benefit drawn from this type of analysis is that it is one of the best ways to introduce the availability personnel and their tasks to the rest of the corporate personnel. It also identifies interfaces and lines of communication that are essential to the performance of any good availability program.

COMMENT 3

The inclusion of a critical items list (CIL) among the tasks to be performed is an excellent idea. The CIL were, I believe, one of the most fruitful concepts to come out of aerospace applications of availability engineering. However, the report fails to make clear the close relationship that exists between the CIL and performance of the FMECA, or failure mode and effects and criticality analysis. This analysis identifies the components that are important to system capability and then assesses the probability of their becoming inoperable. It identifies the critical components from a reliability standpoint. The next step is to perform a maintenance assessment to determine the maximum and mean downtimes given the failure. The items can be initially ranked in descending order by their expected contribution to unavailability, which is approximately given by your formula on page 2-5:

$$U = \frac{\lambda\tau}{\lambda\tau + 8760} \times 100$$

where: λ is the failure rate and τ is the mean downtime.

This list is then updated regularly with rankings changing according to the actual failure frequencies and actual downtimes observed since last publication. A good technique to get management attention and action is to publish an abbreviated CIL on the top twelve items (called the "dirty dozen") and to institute a corporate requirement for action and reporting within a certain period of time on each of these.

An analogous list which was not mentioned in the report is the limited life list (LLL), which gives the maintenance or replacement intervals in ascending order for those components which are known to be more than normally susceptible to wearout phenomena. This list indicates the time of last maintenance or replacement and the date of the next scheduled action. It can also give an abbreviated description of the maintenance procedure, as well as the specific references to where the detailed procedures can be obtained.

COMMENT 4

A specific comment is directed at the chart on page 2-5. This chart comes from the equations above which were derived from the Billinton book. The equation is an approximation to the solution of a two-state MARKOV model and as such is only valid within certain bounds. Unfortunately, the chart goes beyond the bounds of applicability of the approximation. For example, if we take x = 10 failures/yr. and an outage time for each of 1000 hours (which is completely possible on the chart) the answer which results is ridiculous, even at first glance, since, according to the chart, the system would be unavailable for 10,000 hours in an 8600 hour year. Wherein lies the error? In simple terms, the approximation does not hold when the total downtime due to failures is a significant portion of the interval over which unavailable time is being calculated, since the system cannot fail and go down when it is already down for repair.

COMMENT 5

I am very disappointed that the document did not address degraded modes of operation and their effect on availability. The fact is that the mode of system failure can have a very significant effect on availability in power plants. Partial or delayed forced outages are of extreme importance especially when one considers units which are not base loaded. The expansion of the MARKOV model from a simple two-state one to at least four states, as has been suggested by Billinton and others, is essential to the proper establishment and assessment of plant availability goals. Even this model may not be accurate enough because of the effect of planned outages and nonpeak delayed repair possibilities. An additional problem with nuclear plants is the treatment of refueling outages, especially their extension due to the uncovering of problems during the outage. Probably the best way to handle the modelling problem is with a simulation (Monte Carlo) using one of the standard approaches (e.g., GPSS or GASP). The use of a standard model of this type which can be tailored to include individual plant variations as subroutines could be of great benefit. Considerable experience is being developed with standard models in the IEEE Subcommittee on Probability Applications headed by Billinton. Although their past work has been directed towards the availability of power to a net from a model set of plants (i.e., a load and generation planning model), most of the theoretical developments should be applicable to this problem. Developing this standard model in conjunction with them has the additional possible future benefit of allowing combination of more realistic individual plant models with an existing standard load and generation planning model.

COMMENT 6

The use of a single or even a range of availability worth numbers is very dangerous. The value of a percentage improvement in availability depends greatly on the individual plant and its environment, as well as how the already achieved level compares to the economically achievable level. These points must be considered in addition to the other points of fuel and replacement power mentioned on page 2-14. Thus, much stronger caveats must be placed upon any mention of worth numbers precisely because they are just as wrong as they are "handy."

RESPONSES TO J. R. FRAGOLA'S COMMENTS ON EPRI NP-439

E. B. Cleveland
Holmes & Narver, Inc.

I have read your comments very carefully and appreciate your viewpoints. My reaction to each comment is noted below.

For brevity I have paraphrased your comments.

Comment 1

A poorly set availability goal can be counterproductive.

Comment 6

Availability worth numbers can be misleading unless carefully set and their application qualified.

I agree in principle but feel that both are necessary. The availability goal and its value, in $/% availability, should be established by each utility for each unit of interest. These two numbers will very likely differ from one unit to another depending on generation mix, load requirements, fuel costs, and many other factors too numerous to have been adequately covered in the study. There will also be situations in which sets of values are only applicable for certain times of the year, such as when hydro capability can be used instead of thermal generation. Also, for certain peak load periods the goal may be represented by mission reliability rather than availability. The point is that there cannot be one goal and one worth factor for all units.

A worth factor is essential to guide the many thousands of detailed design and procurement decisions which, in the end, will result in the most cost effective level of availability. When all conceivable cost effective ideas have been exhausted without reaching the goal then--and only then--should the goal be lowered. An availability goal is not a hard and fast requirement. If the initial goal turns out not to be cost effective, the utility should settle for the highest value which can be economically achieved.

I doubt that anyone has the wisdom or ability to determine at the beginning of a program just what it will cost, in x dollars, to gain y dollars of increased income. However, the amount that could reasonably be invested to gain an increment of availability should be well within the capability of utility economists to determine. Putting this worth factor into the design grist mill, along with an availability goal, should ultimately result in a cost effective design.

Comment 2

An availability engineering program should be introduced gradually to avoid disrupting normal activities.

I disagree. While the suggestion of a capabilities matrix is a good one, it has been my experience that almost none of the necessary availability engineering tasks will be found being performed. Until very recently, few companies (1) had an availability goal, (2) had allocated R/M values to systems or equipment, (3) had placed R/M requirements in specifications, (4) had collected R/M data, and (5) had attempted to estimate availability or control the factors affecting installed availability. Initiation of these activities is bound to disrupt an organization. In fact, the imposition of an availability engineering program should "make waves." If it does not, it is probably ineffective. If it's business as usual, you can only expect the "usual" availability.

Comment 3

The report fails to relate the CIL to FMECA's.

You are right; the report does fail to point out the close association between the CIL and FMEA's. The example FMEA Figure 2-6, p. 2-20, shows, in the next to last column, an annual $ loss expectation which could be used as one basis for selecting items for the CIL. Since this report was to only outline the methods, it should probably be followed by an instructional manual that would explain these details.

Comment 4

Figure 2-1, p. 2-5, exceeds the applicability of the approximation.

You are correct. Figure 2-1, p. 2-5, should probably be cut off beyond an outage rate of about 1000 hrs/yr.

Comment 5

I am disappointed that degraded modes of operation were not addressed.

Your concern for degraded modes of operation is valid. These states must, in fact, be taken into account, ideally as a continuum rather than as discrete states. But we felt this whole subject would have complicated the presentation and would, perhaps, have interfered with the basic intent of the report, which was to be a primer on basic methods. You, Billinton, and others will have to expand this beginning to help teach the detailed methodology. When you do, please be very careful to advocate the use of models no more complex than warranted by the accuracy of available data or needed to make valid decisions between alternatives.

Thank you for your thoughtful review. Your comments and L. Booth's and my replies will be put into the workshop proceedings.

FURTHER COMMENTS

L. E. Booth
Bechtel Power Corporation

It was interesting to note that many of your comments were covered during the workshop and resulted in many lengthy discussions among the people who attended. Several people share your feeling that "...errors made in the establishment of a goal can cause the entire program to go sour and have in some cases turned management off entirely to the idea of applying availability engineering in the future."

Several others, myself included, expressed the feeling that any availability program must include an "economic analysis" such as you pointed out in Comment 1.

The point I would like to make is that if availability goals are treated as goals and the resulting availability apportionment (based on past operating history of similar subsystems and components) is used to identify problem areas, then there are few drawbacks to the methodology - expecially if the goal is established with sound economic analysis. But the job is not complete by simply identifying problem areas and selecting alternatives with the highest potential for availability improvement. To complete the job, design alternatives must be evaluated not only for potential availability improvement but also for total cost of implementing, operating, and maintaining a particular design over the life of the plant. In other words, it may turn out that the design that has the highest availability may also have the highest life cycle cost. If the life cycle cost outweighs the gain in availability, then the wrong alternative was chosen. So, even if an overall goal was properly chosen and properly apportioned to subsystems, the selection of a design alternative could still be wrong.

In Comment 5 you refer to the fact that the document did not address the degraded mode of operation, which is quite true. However, the subject report was consistent with its own definition of availability (Reference page 2-2). This is not to say that the degraded mode of operation is not important; it is. This just means that in order to include the degraded mode, either the definition must be changed or the scope of the document should be changed to accommodate the degraded mode (plant productivity? capacity factors?).

An example of this type of analysis, which might be termed "Productivity Analysis" is as follows:

Suppose a coal fired plant has two 50% capacity boiler feed pumps. If one pump fails you lose half the unit's generating capacity for the length of time it takes to return the failed pump to service. The projected lost generating capacity (over the total life of the plant) can be determined by using the failure frequency of the pumps. The total projected lost generating capacity has a dollar value, of course. This dollar value becomes the basis for selecting design alternatives. Note that this procedure has nothing directly to do with a goal; it is an optimization procedure. If one were to propose the use of two 100% capacity pumps and include all life cycle costs, move the cost to present worth and compare this with the two 50% pump configurations a true degraded state optimization trade off would have been performed. As previously noted, the above example also has nothing directly to do with availability, since the unit still operates (assuming single failures).