"WHAT PRICE RELIABILITY?"

- An Inquiry into Land-based Steam Power Plant Practices.

INTRODUCTION

By all standards, including that of the reliability of the propulsion machinery of its ships, our Navy is reputed to be the best in the world. And, if this is true, it certainly did not happen by accident. No one has ever pulled a rabbit out of a hat without carefully putting it there in the first place. But this superiority may well be on a relative and not on an absolute basis. How reliable is this propulsion machinery? Apparently not to a degree satisfactory to the Navy personnel, since it has thought it sufficiently important a subject to convene this meeting.

The propulsion machinery of a ship is essentially a complete steam power plant combined with a propeller or propellers, driven through a set of reduction gears and it is to the reliability of the steam power plant itself that we shall address ourselves now. It is the purpose of this paper to examine the practices of land-based central steam stations and to determine how the knowledge of these practices can help us in improving the reliability of naval vessel propulsion machinery.

It would be most fruitful if we could examine these practices with respect to every single component of a land-based steam power plant, that is with respect to the boiler, the turbine and the many pieces of equipment which comprise the Fluid Handling Group of the plant. We would consider practices related to the design, installation and operation of the condenser, the circulating pumps, condensate pumps, vacuum-producing equipment, deaerator, boiler feed pumps and closed feedwater heaters, to say nothing of the gate valves, check valves, regulators and other related equipment.

Such an undertaking, I am afraid, would be beyond the scope allotted to a paper such as this, to say nothing of the fact that it would be beyond my own competence and capabilities. I have chosen instead to limit my inquiry to the practices regarding reliability with respect to a single piece of equipment: the boiler feed pump. I submit, however, that we can derive considerable help in examining this one piece of equipment. Reliability, to an engineer, is a way of life. You cannot divide reliability into compartments. You cannot have reliability of the steam turbine if you do not care sufficiently to design reliability into the boiler feed pumps, the deaerator or the condensate pumps.

At this point I would like to present a brief statement of the conclusions I reached following my inquiry into land-based steam power plant practices with regards to the reliability of boiler feed pumps:

1. Reliability is very definitely related to the price of the equipment and of such protective or supervisory controls that may be installed. Generally,

savings in the price of this equipment can only be achieved at the expense of the reliability of the boiler feed pumps.

2. Improvements in pump efficiency and a gain in reliability are fundamentally incompatible.

3. There is no clear-cut trend that might represent the general practice of all U. S. utilities. Because reliability is to some degree an intangible characteristic, it has been and still is a very controversial subject. Opinions range from a total disregard of such an intangible to the use of "value analysis" in which price - and efficiency - play a very secondary role.

SIMILARITIES AND DIFFERENCES

But before we can gain any insight from an investigation of land-based practices, we must set down what are the similarities and what are the differences between a central steam power station and a naval vessel and between the organizations that make policy decisions in the two cases. Oddly enough, there are more differences than similarities.

On the side of the similarities, we can start with the obvious fact that we are looking at a steam power plant in both cases. We can also state that in each case the power plant must be capable of operating over a wide range of loads and - if I stretch the point a little - that rapid fluctuations in load might be expected on land as well as aboard ship. Finally, the fundamental laws that govern the hydraulic and mechanical design of the equipment that comprises the steam power plant apply on land and at sea.

When we come to the differences, I am not certain whether I can reasonably be expected to prepare a complete catalog. But some of the most important differences are the following:

1. Navy vessel steam power plants generally operate at lower steam pressures and temperatures than large modern central stations.

2. Weight and space are relatively unimportant factors in the case of land-based stations, but of utmost importance aboard ship.

3. No one has yet insisted that a central steam station be made capable of withstanding a torpedo amidship and continue to send out kilowatts, albeit at a reduced rate.

4. Operators of land-based steam power plants resent unscheduled outages and especially those which shut a unit down. But these plants are generally part of an interconnected grid system with available reserve capacity. The shut-down of a unit is not a matter of life-and-death, quite literally, as for a ship or for a fleet.

5. A land-based plant is expected to be on the line for relatively long periods of time, possible a year, without requiring maintenance or overhaul. A ship will generally be available for overhaul more

frequently. But the time for a scheduled overhaul is quite unpredictable and, in case of war, any outage must be treated as unscheduled outage.

6. Certainly facilities and personnel for even routine maintenance are more amply available in the case of land-based plants.

7. "Maintenability," that is, ease of maintenance from the point of view of the space around the equipment is certainly more of a factor aboard ship than on land.

8. The Navy and the investor-owned utilities have vastly different purchasing policies. There is no such thing as "type approval" for land-based steam power plants. On the other hand, a privately owned utility reserves for itself the right to evaluate intangibles in choosing between two or more suppliers of equipment "apparently" designed to perform the same service equally well. It does not have to buy on a strictly numerically evaluated basis if it does not wish to do so.

I could continue to list more differences. But I think that I have proved my point, which is that major differences exist and that they should be taken into consideration when trying to apply any lessons we may learn from our examination of land-based steam power plant practice.

WHAT IS RELIABILITY?

There are probably as many definitions of reliability as there are engineers ready to define it. But the one definition that I have always preferred - and that I have frequently quoted - says that the reliability of a particular component or system of components is the probability that it will do what it is intended to do under certain operating conditions and for a specified period of time.

When it comes to applying this definition to the reliability of a boiler feed pump, we find that we can go so far and no further. We cannot assign a significant number to the probability that the pump will do what it is intended to do, that is, feed the boiler under all the possible circumstances that can - I did not say "should" - befall the installation.

Why is this? Why can we not say that statistically the reliability of such-and-such a pump is 99.3%, or some such number? For the simple reason that utilities have not assembled any statistics that would let us do this.

The amount of statistics compiled by the utility industry has by now reached very respectable proportions. Some of this is self-selected, that is, compiled by the choice either of the utilities themselves or of utility associations. A very great portion of it is imposed on the utilities by federal or state governing bodies. But, unfortunately for our purpose, these statistics do not include sufficient information to provide us with factual data on the availability of equipment other than the two major components of a steam power plant, that is, the boiler and the turbine - generator. The availability record of a vital component such as the boiler feed pump cannot be determined with any degree of accuracy whatsoever. We are forced, therefore, to speak of relative degrees of reliability, of relative probabilities of unscheduled outage and of the relative advantages of alternate design or application solutions.

But once we are willing to accept qualitative interpretations of the reliability of boiler feed pumps, we can use this qualitative concept in describing the general experience that has been observed in utility steam power plants. In one of my previous papers* I had presented a curve which describes qualitatively the possibility of failure of a piece of equipment such as a boiler feed pump at the end of a given number of operating hours. This curve (Fig. 1) serves mainly the purpose of focusing our attention on the classification of all failures into three separate groups:

(a) Infant mortality
(b) Random failure
and (c) Wear-out

Experience in land-based steam power plants has shown that it is the "infant mortality" which is the greatest enemy of boiler feed pump reliability. In addition, an analysis of the failures that beset a boiler feed pump in its early life will reveal that the overwhelming majority of these failures can be traced to sources external to the pump itself, such as:

1) Dirt in the piping (feedwater, condensate injection or lubrication).
2) Improper warm-up procedures.
3) Check valve failures.
4) Failures of the auxiliary power system.
5) Sudden and unusual load changes.
6) Unit trip-outs.

Yet, the effort to eliminate or to minimize circumstances contributory to this group of failures is not always apparent.

You will note that under this list of six contributory circumstances only the first two would normally be expected to be eliminated with time and therefore not to contribute to random failures in the later life of the boiler feed pumps. Check valve or auxiliary power failures, sudden load changes and unit trip-outs may all be slightly more frequent in the early stages of operation, but they remain probabilities throughout the life of the steam station. Why then did I list them under "infant mortality" causes?

The fact is that in too many instances the early warnings of the possibility of these contributory causes to boiler feed pump failure are disregarded. Steps to remedy the situation are only taken after one or more pump failures have convinced someone that the warning was justified. I am not speaking of any one particular utility, nor necessarily of the majority of utilities, but the fact that this happens frequently is to be deplored.

* "Criteria of Equipment Reliability Evaluation" by I. J. Karassik, presented at the June 14-18, 1959, Semi-Annual Meeting of the ASME, St. Louis, Missouri. (Worthington Reprint RP-1115)

Maybe these early warnings are not sufficiently loud and clear? This could well be, but I must explain here a psychological barrier that is sometimes erected in front of the manufacturer who feels it is his duty to bring the potential dangers to the attention of the buyer. Only too frequently has such a manufacturer found that he was the only one to talk of these dangers and to act the "Jeremiah."

And when this happens, he may also find that he has planted seeds of suspicion in the buyer's mind that this manufacturer's equipment is probably less sturdy than that of his competitors, less reliable since he is the only one to worry about such routine matters as unit trip-outs or sudden load changes.

Once, however, the equipment fails because of these external circumstances, corrective measures may be quite costly, beyond even the damage done to the equipment itself. You will find, for instance, cases where repeated failures of check valves during the early life of the plant are corrected by the installation of a second set of check valves in series with the first. If the belt breaks, the suspenders will hold the pants up.

Where auxiliary power failures cause excessive unscheduled pump outage because of consequential damage, expensive electrical interlocks and second-line defenses may be set up. If sudden load changes are too unhealthy for the boiler feed pumps that have been selected and installed, controls are superimposed to limit the permissible rate of load change in the future. And yet, it is quite possible that some other boiler feed pumps could have survived the sudden load changes much better.

RELIABILITY vs. AVAILABILITY

We have been speaking of reliability in rather general terms. We have defined reliability as best we could and we have noted that failures which reduce reliability can be classified into "infant mortality", random failures and wear-out. And we have also noted that a large proportion of infant mortality failures of boiler feed pumps can be traced to sources external to the pumps themselves. But while the source may be external, we must accept the fact that the relative vulnerability of the boiler feed pumps must be a factor in whether a particular circumstance will or will not cause a failure.

Our major concern, however, is with availability. This can be defined as the percentage of time that the equipment is in "operational readiness." Thus, availability incorporates the effect of both forced and scheduled outage.

By virtue of this definition, availability is not necessarily synonymous with reliability. For one thing, the concept of reliability does not incorporate within itself the factor of down-time. If two pieces of equipment can each be expected to suffer one failure in 8000 hours of operation, they could be considered as having the same degree of reliability. But if one requires 80 hours of down-time for maintenance after the failure and the second requires only 40 hours, these two machines will have an availability of 99% and 99.5% respectively.

We can refine this concept still further. Let us consider 3 boiler feed pumps on which we have the following data:

Pump	A	B	C
One failure per	16,000 hrs.	8,000 hrs.	40,000 hrs.
Down-time after failure	48 hrs.	40 hrs.	80 hrs.
Normal maintenance outage each	40,000 hrs.	40,000 hrs.	80,000 hrs.
Maintenance down-time	48 hrs.	40 hrs.	80 hrs.
Total down-time per 80,000 hrs.	336 hrs.	480 hrs.	240 hrs.
Down-time in %	0.42	0.60	0.30
Availability, in %	99.58	99.4	99.7

There is an interesting lesson to be learned here. While frequency of failure and of scheduled outages for maintenance as well as the down-time required for repairs or for preventive maintenance all enter into the calculation of availability, they cannot be given equal weight in our considerations of the "intangible" reliability of the three pumps.

The exact importance to be attached to each of these components of "unavailability" will vary considerably between various utilities and between various installations, because each installation has a different situation with regards to the permissible unavailability of a boiler feed pump. Different utilities may have different margins of reserve of installed capability. In addition, the seriousness of an interruption will be quite different in the case of an installation of three half-capacity pumps (one of which is a spare) than if only two such pumps are installed. As a matter of fact, we shall presently see how this consideration can be used in evaluating the advantages of spare equipment.

Generally, however, down-time for preventive maintenance is of considerably less importance than down-time following an unscheduled outage by virtue of the fact that all utilities have reserve capability and can schedule preventive maintenance to suit their particular load pattern. This is also true of Navy propulsion machinery to a certain degree, although for somewhat different reasons. Fundamentally, it is important to realize that preventive maintenance in the case of boiler feed pumps does not have the characteristics of emergency. If a pump can run 40,000 or 80,000 hours before the internal clearances need be renewed, a few months' delay in carrying out the necessary repairs will have no significant effect on the integrity and availability of the power plant.

HOW CAN WE IMPROVE INSTALLATION RELIABILITY?

Improvement of the reliability of a boiler feed pump installation can be achieved by four parallel approaches:

1) By removing or minimizing hazards of equipment failure through proper choice of design and materials and through more rigorous quality control.

2) By designing into the installation itself safeguards against hazards that threaten the integrity of the boiler feed pump through the interference of external circumstances.

3) By removing or minimizing hazards through monitoring or protective controls incorporated into the system.

4) By providing spare or standby equipment that will permit operation of the unit served by the boiler feed pumps during any down-time caused by unscheduled outage.

It should be very obvious that each one of these avenues of approach must cost money or, in some cases, efficiency which, in turn, can also be translated into money. Let us consider for instance the first item on our list. And let me state at the very outset of this analysis that regardless of the reliability of a given piece of equipment, it can always be improved through more expensive design, more expensive materials, more research and still more thorough quality control. There is not a boiler feed pump commercially available today that could not be made still more reliable if cost and commercial considerations were not a factor. Nor is there a boiler feed pump that could not be made more reliable by increasing internal clearances at the cost of reducing the pump efficiency. Lumping price and efficiency considerations together, I have on occasion illustrated this statement by plotting the qualitative relationship between cost and probabilities of failure in a curve such as shown on Fig. 2.

At first blush this sounds like a very embarrassing and damaging admission. But a few moments of objective analysis will show that there is nothing embarrassing or unethical about the position of a manufacturer who knows that he could design and build better equipment but also knows that he could not sell it. If it is true that people generally get the kind of government they deserve, it is equally true that a buyer gets the equipment he is willing to pay for.

The decision on the type of product a manufacturer wishes to produce rests on a vastly complex body of separate criteria. These criteria cannot be examined without first establishing some basic facts and formulating some basic assumptions with respect to the market the manufacturer intends to serve and the economic relations which dictate the relative success or failure of his enterprise .

The first assumption we can make is that in our free enterprise system, manufacturers are in business to make money. I might add, parenthetically, that they are given no insurance against the possibility that they will lose money and that too often the vagaries of the market place cause them to do just that.

And the first fact that we must consider is that in our particular economic system, ESSENTIALLY LIKE PRODUCTS WILL BE SOLD FOR ESSENTIALLY LIKE PRICES. This means, in other words, that the level of prices for equipment that is manufactured by one Corporation will be established by its competition. It may be difficult at times to accept the idea that competition must be viewed from the user's standpoint and not from that of an individual manufacturer. But regardless of whether one considers a particular competitor as a lower grade manufacturer or not, whether one considers his product as inferior or equal, he is an "equal" competitor if he is so considered by the prospective customers.

We must therefore translate our first fact into its equivalent: "COMPETITIVE PRICES ARE SET BY THE LOWEST COST MANUFACTURER WITH AN EQUALLY ACCEPTABLE PRODUCT". Note very carefully this "EQUALLY ACCEPTABLE qualification, for it is definitely a fact that not all customers have the same understanding of what constitutes "equal acceptability."

If we combine this with our assumption that all companies are in business to make money, we are inevitably forced to restate our first fact into "LIKE PRODUCTS MUST BE MANUFACTURED FOR LIKE COSTS". This is the basic reason why an increase in design, research, material, quality control or field service costs will penalize a manufacturer who wishes to build and sell more reliable equipment than he does now.

There is, of course, some balm in Gilead. You remember that I stated that not all customers have the same understanding of what constitutes equal acceptability. There are among utilities companies which give greater weight than others to the intangibles of service and reliability. And this is the only reason why all boiler feed pumps are not alike, why there are gradations available in the excellence of design, in the ability to withstand unfavorable conditions of operation, in brief, in the reliability of boiler feed pumps.

You might ask why shouldn't a manufacturer of boiler feed pumps follow the practice of the consumer-goods industry and offer two or more standards of reliability for utilities to choose from. This is quite customary for such products as tires, batteries or hot water tanks. In this latter case, for instance, you can get quotations on a wide variety of types, each carrying a different life-guarantee, and each with a different price. For example, you can choose from the following:

		Guarantee	Price
1.	Plain galvanized steel unlined 30 gallon tank..........	1 year......	$ 52.00
2.	Plain galvanized steel glass-lined 30 gallon tank......	10 years.....	$ 65.00
3.	Plain galvanized steel, glass-lined 30 gallon tank .... with deluxe controls and heavier metal gauge	15 years.....	$ 97.00

And if you wish to pay more and get still more for your money, you can choose from copper, cupro-nickel, stainless steel or all-monel tanks.

Let us plot these figures of price versus guaranteed life. After all, since the manufacturer guarantees different periods of operation, the probability of failure in a given period of time must also be different. Is it not remarkable to what degree this curve (Fig. 3) resembles the imaginary curve of cost vs. probability of failure plotted in Fig. 2?

Unfortunately, designing several lines of boiler feed pumps, each with a varying degree of reliability is not very practical for a variety of reasons. Not the least of these would be the psychological disadvantage of classifying utilities into what might be interpreted as first, second and third class citizens. Nor is it very practical for a manufacturer to react to the preference of just one customer who is willing to spend considerably more for a redesigned product that is normally part of a standard equipment line. If the entire cost of the redesign and of the special handling is assessed against this one customer, along with whatever additional cost in labor and material may be involved, the increased reliability will cost too much and the customer may not be able to justify the purchase. If this cost is allocated against a greater number of units in the expectation of selling these units in the future, the manufacturer runs the risk of having to ultimately write off most of the cost of the redesign because of optimism on his part with respect to the number of potential customers for this improved product.

The above should be understood as a generality and does not eliminate the possibility of such a transaction in some special case. It would be a tempting challenge to be able to design a super-reliable pump with a complete disregard for cost considerations. I am not quite certain of the lines along which such an attempt would proceed. One does not break certain restraints all too suddenly. The habit of weighing what every departure might do to the cost of a product will have to be eliminated before one could address oneself to such an undertaking.

Let us return for a minute to the curve of costs vs probability of failure on Fig. 2. It illustrates very vividly the fact that there is a point where very minor savings will result in a tremendous increase in the probability of failure. There is also an area beyond which any further reduction in this probability can only be achieved at an increase in cost which cannot be justified. As I once said in the paper referred to earlier, the general shape of the curve on Fig. 2 can teach us the futility of buying too cheaply or too dearly.

OTHER MEANS OF IMPROVING RELIABILITY

We have mentioned that in addition to improving the boiler feed pump itself, there are three other means available to us for improving the overall reliability of the installation. One of these is to design into the installation safeguards against hazards from sources external to the pump itself. Probably the best example of doing this is the use of sound judgment and thorough analysis in designing the installation so as to provide adequate suction conditions under all possible circumstances. The transient operating conditions that prevail in an open feedwater cycle installation immediately following a sudden load drop are well understood today and there is absolutely no reason why the margin necessary to provide against these transient conditions cannot be calculated accurately.

Nor is there any reason or excuse to employ excessive optimism in establishing a safe and sound value for the required submergence. But adequate suction conditions may frequently entail the expenditure of additional costs in the layout of a land-based central steam station and I must unfortunately observe that occasions still arise from time to time where the reliability of the boiler feed pump proves to be impaired because these additional costs were not considered to be justified.

When it comes to the application of monitoring or protective controls which would remove or minimize some of the hazards which can interfere with the reliability of operation, I feel that the majority of today's boiler feed pump installations could be more liberally supplied. This is particularly true with respect ot controls which would counteract the effect of insufficient NPSH or of inadequate condensate injection sealing supply. While some boiler feed pumps are capable of operating in a flashed condition with an excellent chance of coming through unscathed and while this transient condition may be of relatively short duration, it is still preferable to provide corrective controls that will obviate this condition. As to inadequate condensate injection sealing supply, this condition will almost always result in a partial or complete failure. Therefore, if proper protection is to be afforded the boiler feed pump, these two controls are essential.

In general, because of the increasing complexity of the boiler feed system, increasingly sophisticated control systems are required to protect the boiler feed pumps. But at this moment, there is very little agreement among utilities as to the need of supervisory and monitoring controls for this service. It is therefore commercially impractical for the manufacturer to include any such controls as standard equipment, lest the user assume that these controls are necessary for one make of pumps and not for another. Of course, I have some definite ideas regarding what controls are essential if reliability is to be improved, but whether many utilities would purchase them if they were included with the boiler feed pumps is questionable.

STANDBY EQUIPMENT

The final area I wish to explore is the question of standby or spare equipment. Until a few years ago it was standard practice for utilities to install either two full-capacity boiler feed pumps or three half-capacity pumps. In the first case, if one pump - or its driver suffered a casualty, the second pump would permit the unit to carry full load without interrruption. In the case of three half-capacity pumps, it was assumed that the two pumps in service would seldom suffer damage simultaneously and therefore the half-capacity spare pump provided adequate protection. In my opinion this assumption was fully justified.

But as the size of the units served by these boiler feed pumps grew and as the operating pressures increased, the cost of providing spare equipment mounted very rapidly. At the same time it was observed by the utilities that the reliability of the pumping equipment had been improving very markedly. The temptation to eliminate spare equipment became very strong because of the important dollar savings that could be achieved. Today, when half-capacity boiler feed pumps are used, the overwhelming majority of the utilities install but two pumps and no spare. If a pump designed to handle the full capacity requirements is used, a partial spare may be installed, capable of carrying from 33 to 60% of the normal flow requirements. And several installations of full capacity boiler feed pumps have been made without any spares whatsoever.

My personal opinion is that an installation of two half-capacity boiler feed pumps without spares is fully justified for a land-based central steam station. In most instances, an unscheduled outage will reduce load capability of the unit to about 60% rated and the deficiency can be easily compensated from the reserve capability of the system. The use of a single pump with no spare, on the other hand, appears to be less justifiable at this moment, especially if means are not being employed to protect the installation against failures caused by circumstances external to the pump itself.

But maybe we can examine the wisdom of these decisions numerically. Maybe we can calculate the cost incurred by an interruption in service and compare it to the savings resultant from the reduction in the costs of the installation? Two papers have been presented before technical societies within the last few years that contain data which can throw light on this matter. The first of these* indicates that an increase in the forced outage rate of a main unit of 1% requires that the reserve capacity of the system be increased from 4 to 5% if the same standard of system reliability in meeting the load is to be maintained. The second paper ** assumes that the forced outage of a boiler feed pump and all of the directly associated equipment is 1% and calculates the cost of providing the necessary reserve capability for a number of different pump arrangements. The paper reaches the following conclusions:

Arrangement	Increase in forced outage of main unit	Required increase in total capability in % of main unit
1) One 100% Capacity pump	1%	4%
2) One 100% and one 50% Capacity pumps	0.406%	1.62%
3) Two 50% Capacity pumps	0.802%	3.208%
4) Three 50% Capacity pumps	0.012%	0.048%

These figures can be applied to the installation of a 300 MW, 2400 psi unit which is assumed to cost $125/kw. If a 4% increase in reserve capacity is required for each percentage point increase in the main unit's forced outage rate, the following dollar penalties have been calculated:

One 100% Capacity Boiler Feed Pump	$ 1,500,000
One 100% and one 50% Capacity Pump	610,000
Two 50% Capacity Boiler Feed Pumps	1,200,000
Three 50% Capacity Boiler Feed Pumps	18,000

From the foregoing one might assume that the cost of a 50% capacity pump would have to reach $890,000 (the difference between $1,500,000 and $610,000) before

*"Economic Choice of Generator Unit Size" by L. K. Kirchmayer and A. G. Mellor. Paper No. 57-A-154, presented at the Annual Meeting of the ASME, New York, December 1-6, 1957.

** "Auxiliary Drives and Factors Affecting their Selection" by J. J. Heagerty. Paper 61-989, presented at the AIEE-ASME National Power Conference, San Francisco, California, September 24-27, 1961.

it is worth while to eliminate it and operate without any spare whatsoever. Or that this same spare would have to cost $1,182,000 (the difference between $1,200,000 and $18,000) before it would be sound practice to use two half-capacity pumps instead of three. Wherein lies the fallacy if this not be so?

The problem, of course, is that we do not know exactly the forced outage rate of boiler feed pumps, as we have already said before. It is strange to note that in other industries some very thorough statistical information has been compiled. I would like to cite one paper* for instance which provides a total of 46 separate tables listing electrical equipment failure statistics in industrial plants. An interesting example taken from this paper gives the annual failure rate from all causes for large induction motors 250 hp and larger as 9.86%. This rate was not established from a small sampling: 46 plants in USA and Canada were involved in the survey and the total number of motors in question was 1,420.

Obviously, the record of electric motors in a utility will be superior to that of motors installed in industrial plants. At least, I am totally unfamiliar with such a high percentage of failures. But if this record is better, it seems to me that it might be ten times, or twenty times better, but not 100 times better. Thus, the assumption of a 1% rate of forced outage for a boiler feed pump and all of its related equipment, including its driver, does not seem to be so outrageous. But until we decide to accumulate more accurate statistics in this connection than we have today, we shall not be much wiser and we shall not have any better criterion in deciding whether to include a spare pump or not than we have today.

We should take advantage of the analysis developed to evaluate the effect of possible forced outages on the additional investment required for reserve capacity and see whether it cannot shed a new light on making a choice between several boiler feed pump offerings. Let us return to the example of a 300 MW, 2400 psi unit with a cost of $125/kw. We have seen that an increase of 1% in forced outage rate requires the addition of 4% in reserve capacity, or 12,000 kws. Thus, an increase of 1% in forced outage should be penalized by $1,500,000. If one boiler feed pump design were to be as little as 0.10% less reliable than another, it should be assessed a penalty of $150,000 for purposes of comparison with the more reliable equipment. Because this figure is of the same order of magnitude as the price of two boiler feed pumps of half-capacity designed to serve such a 300 MW unit, we can state our conclusions in another way: if two such pumps were offered free of charge, it would not be economical to accept the gift, if these pumps were 0.10% less reliable than some others. We have already stated that it is difficult to establish an exact difference in reliability between two or more boiler feed pump designs, because of the lack of adequate statistical evidence. But it would seem to me that any design which has greater reliability by virtue of lower shaft deflections and larger internal clearances should certainly merit an evaluation of these intangible characteristics.

*"Report on Reliability of Electric Equipment in Industrial Plants" by W. H. Dickinson, Paper No. 62-61, in the July 1962 Transactions of the AIEE.

CONCLUSIONS

There is no question that a great many differences exist between naval ship propulsion machinery and that installed in a land-based central steam station. There are also differences in the operation of this machinery as well as in the manner in which it is selected and purchased. Nevertheless, I believe that in our desire to improve the reliability of naval ship propulsion machinery we can learn a great deal from the practices employed in central steam stations. We can learn much of what we should do and we can see the hazards to which we expose ourselves if we fail to do so.

Before new approaches can be developed to the improvement of the reliability of steam power plant components, the major causes of failure must be defined more systematically and with more precision than they have been in the past. A more comprehensive analysis must be made of all the interactions between the various components of the steam plant. A greater store of statistical data on availability will be required to establish a more exact basis for reliability evaluation.

But first and foremost, if we wish to endow this equipment and these plants with optimum availability, more than lip service must be given to the evaluation of intangibles in the selection of equipment and in the design of the system in which it is to operate. We must free ourselves of the prejudice that we can get the best, the most efficient, the most reliable equipment - at the lowest bid price.

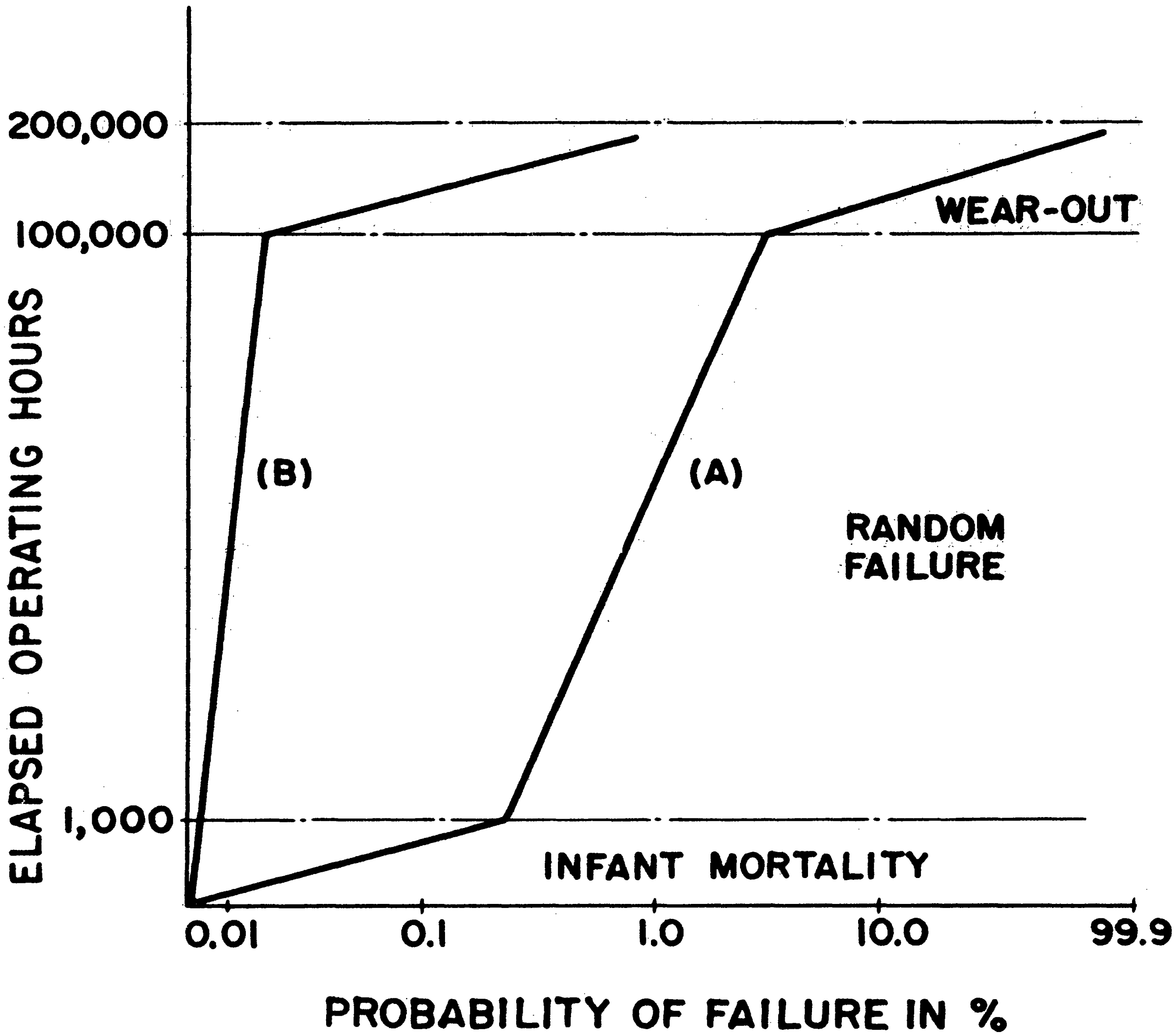

FIG. 1 FAILURE CURVES CAN BE DEVELOPED, ONCE FREQUENCY OF FAILURES HAS BEEN ESTABLISHED.

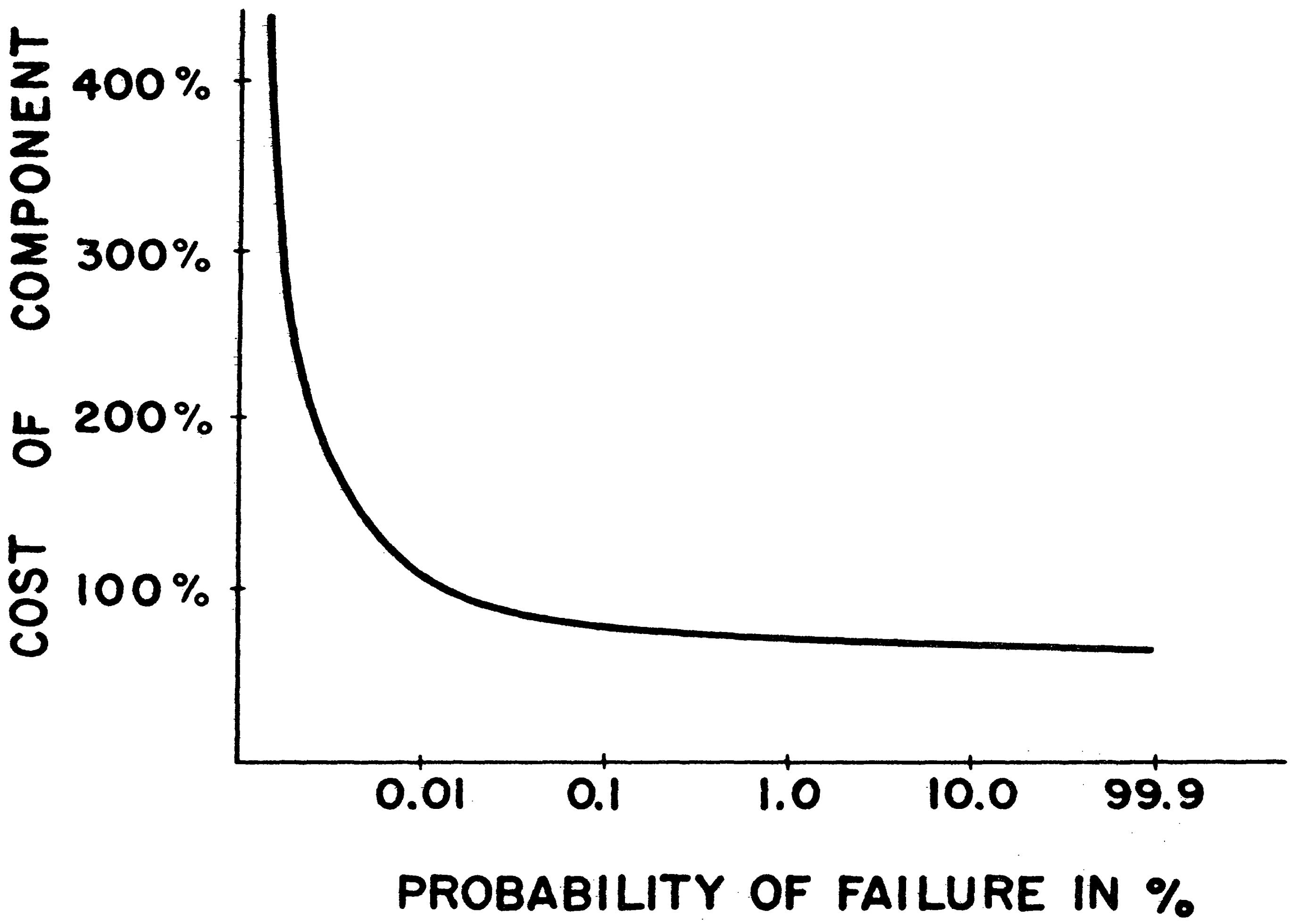

FIG.2 - RELATIONSHIP BETWEEN COST AND PROBABILITY OF FAILURE.

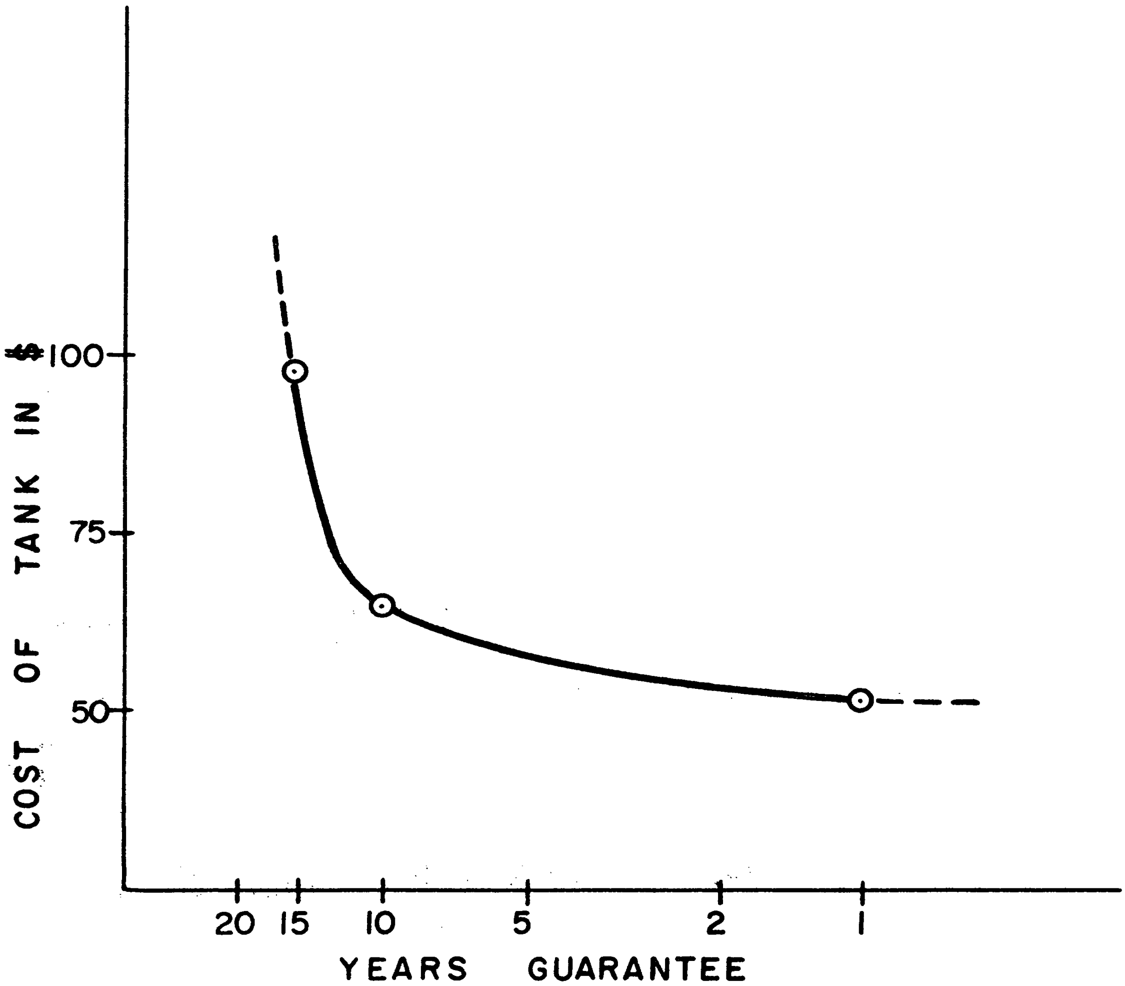

FIG. 3 - RELATIONSHIP BETWEEN COST OF HOT WATER TANK AND GUARANTEED LIFE.