Wanted: A Single Purpose Nuclear Power Program[1]

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IT IS AN HONOR for me to be invited to participate in this Conference on Nuclear Engineering, particularly since my relationship to the field is more in the nature of a Sidewalk Superintendent compared to the intimate activities represented by the other contributors.

Like many of you here, I was brought up on the classified Information Meetings held behind guarded doors and open only to the Q-cleared. In contrast to that atmosphere, the openness of this meeting is refreshing. It is characteristic of what I hope represents the beginning of a new era in the field of reactor development. Although a great deal of technical information on reactor engineering is still guarded, I am convinced that this 1953 Conference will demonstrate that there is much of importance to the program that can be freely, openly, and usefully discussed, and that this will be followed by further unclassified conferences with an ever expanding area of technical discussion.

This new era is reflected in more open discussion of the numerous issues affecting the national interests which are involved in the development of nuclear power. One can scarcely pick up a daily paper or a magazine without finding an article on this subject. The recently completed series of open hearings before the Joint Congressional Committee has contributed greatly to the availability in the public forum of facts and views.

The development of the peaceful uses of nuclear energy touches upon many facets of our national life, including our economic welfare, our security, and our international relations. The formulation of a devlopment program in the best interests of the nation as a whole must be based upon the relationship of nuclear power to these aspects as well as upon technical considerations.

Reactor scientists and engineers have a special desire to push ahead with a vigorous program of nuclear power development, to put design conceptions to practical test, to move on to the next generation of technical problems. The point of diminishing returns has been reached in so far as technical-economic paper studies are concerned. The barriers currently faced in moving ahead are not technical. They stem rather from political and economic considerations. There is no dearth of proposals covering technical and financial approaches, but there is indecision as to which, if any, should be pursued.

The formulation of a realistic development program involves five elements: first, the specification of our national objectives; second, the specification of performance goals; third, a schedule for achieving these goals; fourth, specific technical approaches; and fifth, last but not least, a source of financial support. I would like to make a few brief remarks on each of these subjects.

National Objectives and Short-Term Program. Granted that it is technically feasible for us to produce nuclear power, the question we face today is should we press forward with its development as a competitive industrial process? It is necessary to have a clear understanding of our interests and objectives in order to formulate policies relating to the type of technical programs we should support, the schedules we should meet, and the designation of primary responsibilities for their execution. The lack of precise formulation of these policies is the cause of the indecision which exists today in our nuclear power program. The industrial and other proposals that have been submitted to the AEC have little basis for comparison among themselves. All have merits, but their specific provisions, technical and other, are based on different individual motivations or objectives, on different performance specifications, and on different appraisals of technical difficulties. Only the framework of our national interests and goals can provide a common ground for evaluation of different approaches.

For the purpose of having them clearly in mind, I will briefly enumerate our national interests in the development of nuclear power. Leaving aside the special military interests in stationary power plants, the benefits that this country can derive from the development of a practical nuclear power technology are of two kinds—what I call direct and indirect.

The direct benefits would derive from effects on our own industrial economy resulting from three conditions, namely, the availability of an additional source of energy for public and private use to meet expanding requirements, a greater flexibility in the selection of plant design characteristics to meet special situations, and the possibility of more effective utilization of the natural resources available directly to us.

The indirect benefits would derive from interactions on our own welfare from enhanced national prestige, expansion of our areas of technical assistance to our allies and other friendly nations, and a greater flexibil-

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ity in our capabilities to promote the well-being and strength of the free world.

The importance of making the distinction between direct and indirect benefits lies in the difference in time scale associated with realizing results. I do not have to elaborate on the fact that this country is well supplied with both natural resources of conventional fuels and efficient public and private utility concerns, a combination which assures us of ample low-cost electric energy for at least the next twenty-five years, and probably longer. On the other hand, the power situation is more acute in many foreign areas, including both highly industrialized and underdeveloped. Even accepting some of our more pessimistic estimates of the cost of energy from nuclear plants based on our present technology, it would appear that nuclear power might be of practical industrial use in certain foreign areas in the relatively near future, if not today, if it were available.

Just how, and where, and when we might be of help to other nations in the development and use of nuclear power is not too clear at this time. Our present legislative policies impose strict limitations to such actions. There are many unknowns with regard to developments in the international scene which might influence our future national policies in this area of activity. However, it will take time to develop our technology to the point where we can not only realistically evaluate the potentialities of nuclear power as a short-range element in promoting the industrial economy of our allies, but also be in a practical position to provide substantial technical aid if circumstances permit.

These considerations lead us to three conclusions: first, we, as a nation, have incentives to support a short-term program to develop practical nuclear power plants based on our present technology; second, the specifications for design and performance of the plants should be formulated to assure flexibility in potential applications; and third, primary responsibility for a program should be assigned to either or to both public and private organizations that are motivated by the short-term objectives and that can afford to assume the financial burden without regard to tangible profits in the near future.

Thus, the existence of indirect benefits provides us with incentives to invest technical effort and money in a development program that has little likelihood of showing substantial short-term direct benefits to this country's economy. This immediate program is an opportunity for us, not an urgent necessity. It will not mean the difference between survival or destruction of the free world. Further, although such a program would allow us an earlier start on meeting our long-term needs than could otherwise be economically justified, it would not significantly enhance our ability to meet energy requirements fifty or one hundred years from now.

The Technical and Economic Aspects of a Long-Term Nuclear Power Development Program. If we identify the major performance specifications that must be met by nuclear power plants if they are to contribute substantially to this country's energy demands, I think many would agree that we have a long hard technical development program ahead of us. We must shoot for a plant design that can not only provide for future energy demands at economic production costs but also provide the fissionable material inventory required for new plants needed to meet the forever expanding energy requirements. This means a plant that has minimum annual fuel requirements (consumes 100 per cent of feed material) and an inventory doubling time of the order of ten years. More specifically, the nuclear plant of the future must have a high breeding factor, a high specific power, or low fissionable material inventory, a high fuel burn-up per cycle, low cost fuel and fertile material processing, low investment in plant and equipment per kilowatt of generating capacity, safety of operation, long plant life, and reliability of performance. The achievement of these performance specifications will require improvements in our present estimated capabilities by several orders of magnitude.

The type of plant that is envisaged as the prototype of a large-scale nuclear power industry is usually referred to as a "breeder." The accepted technical definition of a breeder is a plant that produces more fissionable material than it consumes. I, of course, agree that a large breeding factor will be a necessary design characteristic of a future efficient nuclear power plant. However, since this characteristic is only one of a number, I think it is misleading and oversimplifying to use it as the basis for deriving a generic term to describe plants having highly developed overall performance efficiency.

From my reading of the unclassified scientific literature, the daily press, popular magazines, and professional journals, I gain the impression that the breeder has become, in many people's minds, the symbol of the quick and easy solution to the world's energy problems. A decade ago the words "atomic energy" occupied this position. But now that we are face to face with the specific technical and economic problems of current designs the symbol has been transferred to something equally vague, "the good breeder."

Part of the ballyhoo for the breeder is the claim that only this type of plant can give negligible nuclear fuel costs. The commonly quoted figure is 0.013 mill per kilowatt-hour. How negligible can we get? On the same basis of calculation, a nonbreeder with a feed utilization of only 10 per cent would have a fuel cost of 0.13 mill per kilowatt-hour, which for all practical purposes is also negligible. The fact is that any excess fissionable material produced by breeding has no effect whatsoever on the cost of the energy in the fuel. So far as the energy in feed material is concerned, one cannot do better than consume 100 per cent of it, and this is achieved with a plant that produces fissionable material in an amount exactly equivalent to that consumed, in other words, by definition, not a breeder. More important, the practical fuel costs per kilowatt-hour will be determined by the cost of reprocessing associated with utilization of the feed material, again independent of the breeding efficiency. If high values of fuel burn-up and low reprocessing costs can be developed for plants with large breeding factors, the same techniques can be applied with comparable economic gains to plants with small breeding factors and even nonbreeders.

The only true significance of a plant that produces more fissionable material than it consumes is the fact that it can provide for the inventory of new plants. This means that power production from nuclear plants can be expanded without resorting to the presumably more expensive method of obtaining the needed fissionable material for inventory from other sources, such as diffusion plants. However, here again the practical efficiency of a plant in producing excess fissionable material depends upon more than its breeding characteristics. It depends just as critically on the specific power.

On the basis of any desired set of performance standards, we can have good breeders and poor breeders, as well as good nonbreeders and poor nonbreeders. Each type will probably play a role in the long-term development of a nuclear power industry. There will be little difference between a good nonbreeder and a poor breeder with respect to design, performance, economics of energy production, or demands on raw materials for fuel or for plant expansion inventory.

With regard to the stages of development of nuclear power plants, I would expect a gradual improvement in plant performance characteristics, particularly breeding factor and specific power, at a rate determined by the availability of raw materials at economic prices and the incentives to expand power production from nuclear plants. These improvements will be accomplished within the economic limitations imposed by the local, both spatial and temporal, competitive cost of power. There is no reason to expect, so far as I can see, that improvements in breeding factor and specific power will do more than keep pace with expanding demands for raw materials to maintain the cost of feed and inventory at economic levels. It is unlikely that improvements in these performance characteristics, related to utilization of raw materials, will alleviate the problems connected with obtaining low plant cost per kilowatt of generating capacity and attaining low reprocessing cost per kilowatt-hour of energy produced.

I picture three broad phases in the growth of industrial utilization of nuclear power in this country. The first phase comprises plants that utilize natural or slightly enriched uranium as feed and inventory. The basic types of plants would include: (1) pressurized light water-cooled and moderated, (2) pressurized heavy water-cooled and moderated, (3) pressurized helium-cooled graphite moderated, (4) sodium-cooled graphite moderated. These would be what I call the poor nonbreeders. During this phase their performance characteristics would be gradually improved to the practical and economic limit of natural or low enrichment reactors. Perhaps some of the starters would drop out along the line.

The second phase would include good nonbreeders and poor breeders. Both would use highly enriched fissionable material as inventory, as well as fertile material. The early models of nonbreeders would require some fissionable material as feed, at most not more than a small amount, say 5 per cent, of total feed requirements. The later models would require only fertile material.

In this phase the availability of fissionable material at a cost which will not make inventory charges economically prohibitive will be a prerequisite to the practical feasibility of the plants. Thus, in addition to the requirement for a feed utilization at least close to 100 per cent, special emphasis will be placed on high specific powers, kilowatts per kilogram, in order to minimize fissionable material inventory requirements. The poor breeders of this phase are defined as not having a sufficiently large excess fissionable material production capacity to significantly contribute to the inventory requirements of new plants.

The third phase would see plants with large breeding factors and high specific powers combining to give relatively short inventory doubling times. In this phase nuclear power plants would begin to assume a substantial fraction of our annual requirements for expansion of energy production.

How Long Will It Take? The time when nuclear power can achieve this position in our industrial economy will depend upon a number of factors, most important being the economic incentives. Unless the long-term development of nuclear power is to be subsidized by public funds, the rate of improvement in plant performance will be determined by sound economic considerations.

Although the circumstances are certainly not analogous, some perspective may be gained by recalling the history of improvement in the efficiency of conventional thermal-electric plants. In 1888 it required thirty to forty pounds of coal to produce one kilowatt-hour. Today, less than one pound of coal produces the same energy, an improvement in efficiency of raw material utilization by a factor of thirty or forty over a period of sixty-five years.

The required range of improvement in nuclear plant efficiency is at least as great, if not greater. Arbitrarily assuming comparable technical difficulties, this comparison, together with the fact that nuclear plants must compete with an established and efficient process, leads one to expect a longer period for development.

An Immediate Program. In my opinion, both these long-range considerations and our short-term interests justify a reactor development program specifically oriented to attack the problems of economic nuclear power. Such a program should have the following broad areas of activity. First, projects for the design, construction, and operation of power-only plants designed on the basis of our present technology and investigating at least one, and preferably more than one, of the promising design approaches; second, a supporting development program directed at the problems of the next generation of plants; and third, a program directed at the longer-range problems associated with economic plants having high breeding factor and high specific power. This program should include the construction of small experimental reactors.

The immediate objective of the program would be to remove the present uncertainties associated with the practical performance and economics of current technically feasible nuclear power plant designs. If one or more of these plants can be demonstrated as having practical value as economic producers of energy, we will then have substantially promoted our short-term interests and the first hurdle in establishing a long-range self-supporting program will have been cleared.

What is the AEC Doing? As you know, the Atomic Energy Commission is specifically authorized by its enabling act to develop nuclear power for industrial use. Last May the Commission issued a Statement of Policy with regard to a program for the development of nuclear power. Among other things, it stated:

(1). The development of nuclear power is an objective of national importance.

(2). The objective of the AEC policy is to "further the development of nuclear plants which are economically independent of government commitments to purchase weapons grade plutonium."

(3). The time has not yet arrived to turn responsibility over to private enterprise—it is still the responsibility of the AEC "to continue research and development in this field and to promote the construction of experimental reactors which appear to contribute substantially to the power reactor art and constitute useful contributions to the design of economic units."

Since that Policy Statement was issued the nature of the Commission's immediate program in the area of power development for civilian use has been more specifically indicated. From the published hearings of the House Subcommittee on Appropriations and from the language of the Appropriations Act as passed by Congress, one learns the following:

(1). Funds are provided for "research and development for any reactor which will advance technology toward both ship propulsion and the generation of industrial power and for design of such reactors." The funds available for this activity, about $4 million for FY 1954, were originally earmarked for the aircraft-carrier propulsion plant. When the requirement for this plant was cancelled by the Department of Defense, the funds were reallocated as described.

(2). In addition, the Commission has authority to spend up to $7 million of money appropriated for research and development for the beginning of construction of such dual-objective reactors. It is important to note that funds for construction are not appropriated but must be obtained from savings in research and development programs.

(3). No other funds are appropriated for the construction of pilot or experimental plants, or for the engineering development of advanced breeder designs.

The nature of the program was described by Gordon Dean at his last press conference as Chairman of the Commission as "a kind of double-purpose project as now conceived."

The appointment of Admiral Strauss to succeed Mr. Dean as Chairman of the Commission has introduced some new uncertainties into the program. Although Mr. Strauss, in his statement before the Joint Committee at its recent open hearings, confirmed his general accord with the Commission's earlier statement of power policy, at the same time he noted that he "was not prepared to rule out the possibility of plants which are designed to produce weapons-grade plutonium as a by-product of power."

Thus, on the basis of available information, we must conclude that the Commission's current reactor development program and its plans for the immediate future do not include projects directed specifically toward single-purpose nuclear power plants for civilian use.

What About a Private Enterprise Program? A number of industrial concerns have been looking at nuclear power to determine what they are prepared to undertake with their own funds. It is significant that no unqualified proposals for the construction of experimental or prototype power-only plants have resulted from these studies. Even assuming the enactment of favorable government policies covering ownership of plants, materials, and patents, this is not surprising in view of the uncertain performance of power-only plants, the risk of substantial sums of money, and the necessarily prudent financial policies of organizations responsible to large numbers of stockholders.

The recent open hearings of the Joint Committee on Atomic Energy on the subject of atomic power and private enterprise have clearly established a number of interesting items. First, there is a wide range of opinion among responsible executives of private enterprise, even among those associated with companies engaged in the same type of business. Some hold that if the government should relinquish its monopoly, then private enterprise would push ahead with characteristic vigor. Others contend that the government should retain its prime responsibility for the development of nuclear power, at least for the first generation of plants, and that even if the present legislative provisions and patent policies were revised that, speaking for their own companies, they would not consider risking their stockholders' money in nuclear power ventures. These conflicting points of view by equally responsible industrial executives indicate the presence of other factors and motivations which are not superficially apparent. In view of the conflicting statements, one must form one's own opinion as to the probable effect of legislative and policy changes on the extent of support of a power-only program by private enterprise. My conclusion is that no short-range construction program would evolve.

Not only is there disagreement as to the desirability of making drastic changes in legislation and policy at this time, but a strong opposition is building up to any changes. This opposition has developed in the Congress and among certain public and private groups. These groups include labor organizations and publicly and cooperatively owned power systems. The opposition in most instances is directed against hasty and ill-considered action, and the timing of any action, rather than against the proposition that private enterprise should participate in the development of nuclear power. Many are of the opinion that there is no need for drastic legislative revisions at this time, that the AEC should and will support the necessary programs. In view of the abundant evidence to the effect that military interest is a prerequisite if a project hopes to obtain and retain financial support from public sources, I doubt that this approach is realistic.

I would not want to predict what actions, if any, will eventually be taken in the legislative field. However, I would venture to say that the formulation and enactment of specific revisions with regard to the major items of ownership of fissionable material, production plants, and patents which will be satisfactory to private enterprise and at the same time protect the public's interests will take a long time. At best, we cannot expect any firm commitments for power-only projects supported wholly by private risk capital until satisfactory legislative changes are consummated.

In concluding, I would like to specify a little more precisely the type of program called for in my title. First, it should have a single purpose. It should be directed solely toward the production of nuclear power for civilian uses—both short and long range. Second, the program and its objectives should be assured of continuing financial support, barring national emergencies or adverse technical developments. Third, it should require a minimum of associated administrative policy and legislative problems which would cause delays in schedule.

I would like to reemphasize what I said at the beginning. Whether or not this country establishes a strong single-purpose program to develop a practical nuclear power plant in the near future is not of vital importance to our general welfare or to our national security. So far as our own direct interests in nuclear power are concerned, it seems unlikely that a delay of ten years or more in starting a serious development program will have any serious effect.

However, the report of the President's Materials Policy Commission emphasized our dependence on other friendly nations for raw materials, uranium certainly not the least important of these, that add immeasurably to our own industrial and military strength. The technical and financial resources at our disposal would enable us, with relatively little extra effort, to develop a technology which shows promise of being of significant short-term importance to some of these countries. This is an opportunity to return "strength for strength." It is an opportunity that will not wait ten years, nor perhaps even half that length of time. It is rapidly slipping through our hands while other countries, presumably Russia included, are moving ahead with decisiveness.

The Immune-Adherence Phenomenon

An Immunologically Specific Reaction Between Microorganisms and Erythrocytes Leading to Enhanced Phagocytosis

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IN STUDIES designed to demonstrate phagocytosis of virulent *Treponema pallidum in vitro* (*1*, *2*), observations on control preparations led to a recognition of an immunologically specific reaction between normal human erythrocytes and treponemes sensitized with antibody from syphilis serum. The reaction required a heat labile substance in normal serum, presumably complement (C′). Although not definitive, the experiments suggested that this reaction was an essential precursor to phagocytosis of the treponemes by human leucocytes.

The present experiments provide additional data on the reaction of *T. pallidum* with erythrocytes, and demonstrate that a similar reaction occurs with other microorganisms, e.g., *Diplococcus pneumoniae, Shigella paradysenteriae, Salmonella typhi, Micrococcus aureus,* and *Mycobacterium tuberculosis.* Further, it is shown that the union of sensitized organisms with erythrocytes, hereafter termed the immune-adherence phenomenon, leads to an enhancement of phagocytosis.

EXPERIMENTS WITH *T. pallidum*

Requirement for Antibody (Table 1). Treponemes were isolated from testicular syphilomas of rabbits irradiated with 600 r prior to infection as previously

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