ELECTRIC POWER FROM NUCLEAR ENERGY

Commercial production of electric power from nuclear fuel is on the way. Shall we wait for the day when we learn how to make electric power alone in an atomic reactor — or enter the field now by co-producing plutonium and power?

By LAWRENCE C. WIDDOES

LAST JANUARY, the Atomic Energy Commission announced that at Arco, Idaho, electric power had been generated from nuclear energy. This was the first authentic record of such an achievement. In February, President Truman revealed that a nuclear-powered engine for the submarine *Nautilus* was under construction. In June, the Monsanto Chemical Company and Union Electric Company of Missouri recommended that the AEC start the design and development work necessary to construct a plutonium-power pilot plant reactor.

Obviously, commercial production of electric power from nuclear fuel is on the way. Because of the economics involved, it does not seem likely that earlier predictions of large-scale production of electric power alone from a nuclear reactor will be realized in the near future. On the contrary, the first large-scale electric power will probably be a co-product of the manufacture of plutonium.

In the field of atomic energy, we might say that we are in a plutonium economy. The government is most anxious to increase its ability to stockpile plutonium. Since it appears technically feasible to produce plutonium and power simultaneously, the economics of the situation seems to dictate that this method be tried first. Ultimately—perhaps after a decade spent in improving our technology—it may be possible to build nuclear reactors producing only electricity, and to operate them in competition with coal-fired plants.

The proposed method of producing both plutonium and electric power is perhaps better understood against the background of plutonium production. Plutonium is made in a nuclear reactor containing a combination of U-235 and U-238. The neutrons required for plutonium production come from the fission of a U-235 nucleus. The resulting fission fragments have an enormous kinetic energy which eventually must be removed from the reactor as heat.

The reactors at Hanford, Washington, used for the production of plutonium, were an epic achievement. After 10 years they are still invaluable as producers of plutonium. Ten years ago, the demand for plutonium was paramount; no time was wasted in the atomic race with the Germans in an attempt to produce useful power. In the interest of making plutonium, the heat from the Hanford reactors is removed at such a temperature level that it is thermodynamically and economically impractical to use this energy to run a steam turbine and produce electricity.

In studying the practicability of producing electric power from nuclear fuel, the question arises: If new plutonium production reactors were to be built today, could they be designed so that the heat energy could be economically converted to electrical energy—thereby decreasing the cost of plutonium?

Since a great deal of heat is released in the production of a unit of plutonium, it appears simple, at first consideration, to remove this heat at a temperature sufficiently high to produce economical power. After all, with the Idaho power experiments and the Navy's plans for nuclear-powered submarine engines as far advanced as they are, one would think that the problem of converting nuclear energy to economic power would be easy. Though the technical information obtainable from these two developments will be invaluable, the fact remains that one is designed primarily to determine the technical feasibility of breeding—while the other is designed as a military power source. (A breeder, loosely defined, is a reactor which produces more fissionable material than it consumes.)

About 24,000 kw hours of heat energy are released when one gram of U-235 is fissioned. This is the equivalent to the combustion of about 3.3 tons of coal. At current market prices the heat from this amount of coal is worth about $20. On the other hand, the value of the plutonium produced when this gram of U-235 is fissioned—measured in terms of a military explosive—must certainly be far greater than $20. Thus, if removing the heat energy from the reactor at a high temperature causes an appreciable decrease in its plutonium output, then the decision to produce power faces serious economic problems.

Indeed, this problem of high temperature heat versus plutonium production is one of the more serious problems facing the designer of a dual purpose plutonium-power reactor today.

Take, for example, a hypothetical metallic uranium fuel element surrounded by a hypothetical coolant. With known materials of construction, there obviously exists a certain upper limit on the fuel temperature. Just as obvious is the fact that the colder the coolant, the larger the over-all temperature gradient between the limiting temperature of the fuel and the bulk temperature of the coolant. Since the rate of heat removal and, therefore, the rate of plutonium production is proportional to the over-all temperature difference, the colder the coolant, the greater the plutonium production. But cold coolants simply do not make good heat sources for steam electric plants.

Recommendation to the AEC

Although it appears that there are other problems as well, it does seem to be possible to produce plutonium and electric power in the same reactor without sacrificing plutonium production. In 1951, the AEC signed one-year contracts with four industrial groups for a feasibility study of the problem of simultaneously producing electric power and plutonium. One of these groups was the joint Monsanto-Union Electric team. At the end of the year's study, this team felt that a solution was possible, and recommended that the AEC start the design and development work necessary to build a pilot plant which would fill in some remaining gaps in the technology.

In resolving the conflict between the temperature of the coolant and the rate of plutonium production, some technical factors have been agreed upon. Since all reactor coolants and their containers are to some extent neutron absorbers, the neutron economy in the reactor tends to decrease as the volume of coolant associated with a given volume of fuel is increased. Thus, even though the reactor may run faster with a colder coolant, it does not necessarily run as efficiently.

Obviously, therefore, there is some optimum cross-sectional coolant area to be associated with a given area of fuel to provide the maximum plutonium production in a given reactor. The hope for electric power and plutonium co-production in the near future lies in fuel elements which can develop such a high specific power that, even though plutonium production is maximized, the outlet coolant is hot enough so that at least part of the heat energy can be skimmed off to produce electrical power.

The solution of technical problems is not the final hurdle which must be crossed. A large-scale plutonium-power producer must fulfill certain other requirements before private enterprise will be willing to invest the necessary capital. The nuclear power plant must compete with many other attractive investments. The production of power and plutonium must not only promise a reasonable profit during the plutonium economy; it must show promise of a profitable future beyond any period of military demand for plutonium.

If it is possible to build a dual purpose reactor which maximizes plutonium production, reduces unit costs below the Hanford level, and still permits power production, it would appear that the larger part of the high capital loading would be charged to the plutonium production.

The capital involved here would be that amount required to build a nuclear reactor and heat-dump system designed for production of plutonium alone. The incremental capital required to add more heat-exchanger area and a turbo-generator would be charged against the electricity produced. Furthermore, it would seem fair to amortize both sections of the plant over the period during which plutonium would be sold to the government. Operating costs also could be fairly apportioned between the two products in a similar manner.

With the incremental capital chargeable to power production less than the capital normally necessary for a complete coal-fired steam electric plant and with heat almost free, low cost power could be had if the amortization period were comparable to normal utility practice.

The capital charges per kilowatt hour in a coal-burning plant are usually based on a 35-year amortization schedule. Because of the uncertainty in the market for plutonium—and since there is no assurance that the nuclear-fired plant will last for 35 years—the atomic power complex must be amortized over a more conservative period, variously estimated from five to ten to fifteen years.

As the amortization period is reduced in the nuclear plant, there is a point when the increased capital charges completely offset even free heat, and it costs as much to produce power as it would in a coal-fired plant. Therefore, if the power from a plutonium-power complex is to be competitive with power from coal-fired stations, a firm contract for military plutonium over a certain minimum period of time appears to be necessary.

When the military requirements for plutonium have been met, it is conceivable that an even greater demand for plutonium to be used as a nuclear fuel may develop—but, of course, at a much lower price. Because of its nuclear characteristics, it is possible that plutonium could be used to fuel a fast breeder and, through these breeders, it is possible that our entire supply of U-238 could be converted into fissionable material, increasing the fuel resources of the world by a large factor.

When this power economy commences, if these dual-purpose plutonium-power producers have useful life left, the question arises as to whether they can compete with coal-fired plants or with the more improved types of reactors which surely will be built in the future.

No plutonium-power complexes have been built to date. Therefore, no really reliable cost comparison between reactors and coal-fired plants can possibly be made, because of lack of basic data. On the basis of the past performance of the chemical industry, it seems probable, however, that fuel and operating costs of the twin-purpose reactor can be appreciably reduced after a few years' experience has been gained. If this can be done, then the *amortized* plant can probably compete in the production of both power and nuclear fuel with almost any plant (coal-fired or nuclear) which can possibly be conceived today.

Another hurdle for the eventual private production of plutonium and power may possibly be the Atomic Energy Act of 1946. Section 4(b) of the Act seems to prohibit private ownership of facilities for the production of fissionable material in the quantities and in the size contemplated in discussion of even pilot plant units. If it is determined that this prohibition in fact exists, then it would be necessary for the Congress to pass the necessary enabling legislation which would, of course, require that the safety and security controls remain completely within the jurisdiction of the government, with adequate policing powers so that no threat would exist to our nation's security from such private ownership.

Additionally, it appears that this same Act reserves exclusively to the government all patents and inventions in the field of atomic energy. Section 11(a) (2) says:

"No patent hereafter granted shall confer any rights with respect to any invention or discovery to the extent that such invention or discovery is used *in the production of fissionable material or in the utilization of fissionable material* or atomic energy for a military weapon. . . ."

The italicized phrases in this quotation from the law indicate the area of concern in this discussion of patents. Admittedly, patents and inventions dealing solely with the utilization of atomic energy for military purposes must remain the exclusive property of the government.

While it is understandable that such a law should have governed during times when almost all inventions were obtained at government expense, it seems that with the approaching possibility of major industrial programs in the field of atomic power, a review of such policy is in order.

Patent protection

Eminent patent attorneys who have been closely associated with the atomic energy program argue that the patent section of this law should be overhauled to give maximum encouragement to the industrial development of atomic power reactors. They feel that the traditional method of encouraging inventive genius through reward in the form of protection to the inventor must be retained if we are to make sufficient progress with the development of atomic energy in its peace-time applications. It is doubtful that many companies will invest money, time, and talent, unless there is the patent protection for any inventions that they may achieve through research and development to apply atomic reactors as direct tools and aids for use in industry.

Electric power is a keystone of industrial expansion in this country. We are using our reserves of gas, petroleum, and coal, at an ever increasing rate. Indeed, some experts feel that we might conceivably deplete our power fuel reserves seriously by the end of this century. We do not yet possess sufficient technology to draw on the solar energy which appears to be the world's ultimate and only long-term fuel source—but there is no doubt that eventually this technology will come.

We should be prepared, however, for an era in which our conventional fuels become more scarce and expensive—and perhaps before we learn how to utilize solar energy. The hope for this era is nuclear power.

We can enter the field of nuclear power now by co-producing plutonium and power, or we can wait for the day when we learn how to make economic power alone in an atomic reactor. Entering the field now will result in a significant advance in the technology within the next four to six years. It will give us full-scale operating plants from which we can derive accurate capital and operating costs. In short, it will hasten the day when industry will have the confidence and know-how to construct atomic power complexes which will be competitive with coal-fired sources.

While we do not achieve the ultimate by producing both plutonium and power, we significantly advance the technology and help to add to the urgently required stockpile of plutonium.