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Remarks by
Dr. Glenn T. Seaborg, Chairman
U. S. Atomic Energy Commission
to The Regents of the
University of California
Berkeley, California
January 19, 1967

THE DISCOVERY OF URANIUM-233

Almost a year ago it was my pleasure and privilege to join with many of you in observing the 25th anniversary of the discovery of the man-made element and nuclear fuel, plutonium - element 94. On that occasion the small laboratory in which the discovery was made, Room 307 Gilman Hall, on the Berkeley campus of the University of California, was dedicated as a National Historic Landmark.

The significances of plutonium, and especially plutonium-239, are well known: it was a factor in ending World War II; it is credited with helping prevent the outbreak of major wars since; and it now opens to man vast new resources of electrical energy.

Less well known is the fact that there is another man-made nuclear fuel that may be the equal of plutonium-239 in energy potential and in ultimate importance to man. This fuel is an isotope of uranium, uranium-233, which should not be confused with the familiar uranium-235, about which I shall say more later.

Just as the fissionable isotope plutonium-239 is the key to the unlocking of the vast amount of energy stored in the abundant, but non-fissionable, isotope of uranium,

uranium-238, occurring in nature, so the fissionable isotope uranium-233 is the key to the unlocking of the enormous energy stored in the abundant and again non-fissionable isotope of thorium, thorium-232, found in nature. Uranium-233 and plutonium-239 taken singly or in combination provide man with an almost infinite source of energy - sufficient for centuries to come.

It is generally not recognized that this second nuclear fuel uranium-233, like plutonium-239, was first created by use of the Berkeley 60-inch cyclotron, and was first identified and then found to be a potential nuclear fuel in the same suite of laboratories on the third floor of Gilman Hall on the Berkeley campus. The cast of scientific characters who brought uranium-233 into the world was somewhat different from that engaged in creating plutonium. The labors in search of the two man-made isotopes paralleled each other. Thus, two weeks from today will be the 25th anniversary of the evening of February 2, 1942, when John W. Gofman, Raymond W. Stoughton and I were able to say that we had created and identified a second major source of nuclear energy. While the chemical separation of uranium-233 was carried on in Room 307, the same room in which plutonium was discovered, the important verification of the fissionability of uranium-233 with slow neutrons - in other words, its ability to sustain a fission chain reaction, and thus its capability of fueling the fires of a nuclear reactor - was carried on in Room 303 Gilman.

I am pleased that Dr. Gofman and Dr. Stoughton are here with me today. Both have had distinguished careers since 1942. Dr. Gofman went on to become a physician and biomedical researcher. At the Donner Laboratory he distinguished himself in the applications of radioisotopes in medicine, in research on the role of fatty molecules in arteriosclerosis, and in other studies. Today he is Professor of Medical Physics at Berkeley and Associate Director of the Lawrence Radiation Laboratory, Livermore, for biomedicine. There he is leading an important effort to assess the hazards of man-made radiation and to provide the means of protecting man from those hazards in a future in which radioactivity will be generated in increasing quantities. Dr. Stoughton continued to work on the development of the potential of uranium-233 as a nuclear fuel, first at the Metallurgical Laboratory in Chicago and then at the Oak Ridge National Laboratory in Tennessee. He has been a staff member since 1943 at the Oak Ridge National Laboratory, where his work on the chemical properties of uranium in aqueous solution and his other effective contributions, especially in high temperature aqueous solutions, have established for him an outstanding reputation as an inorganic chemist.

As I thought about President Kerr's kind invitation to me to say a few words to you about this discovery of uranium-233, I became involved in a bit of amusing fantasy. What would have been the reaction of an obscure young chemistry professor named Seaborg, if, through the medium of some Wellsian time machine the future as it has evolved in this last quarter of a century had been revealed to him 25 years ago? I assure you that the young nuclear chemist would have greeted the revelations with disbelief, if not derision. And a good thing, too. For had he believed and attempted to make believers of others, he surely would have spent a good part of the last 25 years in some institution that accommodates people with delusions.

I think I can illustrate this by briefly contrasting the situation a quarter of a century ago, and the rather unformed prospects of that time, with today's realities in nuclear energy. When we started the searches for plutonium and uranium-233 in 1940, we were completing a decade of expansion of knowledge of the atomic nucleus fostered by a rich collaboration of European and American scientists. Much of this development had been made possible here at Berkeley with the cyclotrons of the late Ernest O. Lawrence, whose genius and inspiration were so important in making the Nuclear Age a reality.

In that fall of 1940, we were still thinking and working primarily in the traditional academic manner. There was no government support for our research. Fortunately, California believed in higher education and in the importance of graduate study and research in the University. Our faculty salaries were paid by the University - I can remember that mine was $200 a month in the fall of 1940, a sum, incidentally, that in view of my experiences in the depression seemed like incredible wealth. We had some basic facilities, small funds for equipment and, when we were lucky, modest grants from generous private donors and foundations.

The basic research on the atomic nucleus carried on throughout the world had resulted in the surprising discovery of nuclear fission in 1939 by two German scientists, Hahn and Strassmann. A new powerful potential source of energy emerged.

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But most scientists were slow to think seriously of the new energy source as one that could be harnessed in a short period of time. It was discovered quickly, for example, that the natural isotope of uranium that fissioned with slow neutrons was uranium-235, comprising less than one per cent of natural uranium; and the separation of this isotope in quantity from natural uranium was initially considered to be a staggering and, as some believed, an impossible prospect. There were two other avenues that deserved some exploration. It might be possible, by adding a neutron to the plentiful uranium-238, to manufacture an isotope of element 94 with a mass number of 239, now known as plutonium-239. Such an atom, which did not exist in nature, might undergo fission with slow neutrons, like uranium-235; and, being a different chemical element, it might be produced in pure form more easily than uranium-235 could be separated from its sister isotopes of uranium. Similiarly by adding a neutron to the abundant thorium-232, it was thought possible to create another fissionable isotope of uranium, uranium-233, which did not occur in nature. This new uranium isotope could be produced in the absence of other naturally occurring uranium isotopes and be simply separated by known chemical means from its parent, thorium.

It is true that some European refugees and American scientists feared that Nazi Germany might somehow make a super weapon with nuclear energy, in which case Hitler would have Britain and the United States at his mercy. But in the fall of 1940, the possibility that nuclear energy might become a factor in World War II was not really appreciated. The ideas for harnessing nuclear energy at that time were pretty much in the blue sky category. In addition to the difficulties in separating uranium-235, the species plutonium-239 and uranium-233 had never been made. Nor was there assurance that they could be made or that, if made, they would undergo fission with slow neutrons. Moreover, the government did not provide funds for the search for plutonium until the summer of 1941 and for uranium-233 until the following fall. I do not mean to imply that we did not take our work seriously. On the contrary, on the chance that something practical might emerge, we academic scientists voluntarily imposed our own system of secrecy over the work even though the government had not become involved. Certainly, however, what was in store for us, for the country, and for mankind was by no means clear.

Using resources provided by the University of California and private donors, we began our two searches pretty much in the same way we had done earlier research. Dr. Edwin M. McMillan, now Director of the Lawrence Radiation Laboratory, and Dr. Philip H. Abelson, now Director of the Geophysical Laboratory at the Carnegie Institution in Washington, D.C., had discovered element 93, neptunium, in the spring of 1940, and in further work McMillan obtained data suggestive of, but not conclusive for, the existence of element 94. When McMillan was called to M.I.T. to do research on radar, I asked him, in the academic tradition, if I might continue his line of investigation. He approved. Subsequently, as I related last year, the late Joseph W. Kennedy, Arthur C. Wahl, and I proved the existence of plutonium beyond doubt on February 23-24, 1941. With the collaboration of Dr. Emilio Segre, of the Radiation Laboratory, we went on to demonstrate the fissionability of plutonium-239 with slow neutrons about a month later.

Meanwhile, I was looking for a good graduate student to begin work on the potential isotope, uranium-233. John Gofman showed up in Berkeley for the fall semester of 1940 after a post-graduate year as a medical student at Western Reserve University in Cleveland, Ohio. He had decided he wanted to make a career of medical research, with heavy emphasis on chemistry. He had come to Berkeley to gain an extensive background in chemistry. His first stop at Berkeley was a talk with G. N. Lewis, the "father of chemistry" here. Lewis advised Gofman to "go shopping" for a professor and to get to work on his research in a couple of weeks, a suggestion that appalled the young man. Fortunately, Gofman and I chose each other, and within two weeks he was indeed getting his feet wet in the laboratory. John tells me that I told him of uranium-233 that "it's not a bad problem for a thesis."

That fall we cleared away some preliminary questions about nuclear reactions leading to the formation of uranium-233. In early 1941, we made our first attempt to produce uranium-233 by bombarding thorium in the neutron beam of the 60-inch cyclotron. But this produced little, because the 10-gram target was too small and the hour-long bombardment was too short. We then prepared a bigger (kilogram) sample of thorium nitrate and irradiated it in the neutron beam of the cyclotron for weeks. Jack then spent most of the spring working up the sample chemically in Room 307 Gilman.

The suspected nuclear reaction was as follows: thorium-232, upon capturing a neutron, would be converted into thorium-233, which was known to have the short half-life of about 24 minutes; then the thorium-233 would emit a beta particle and be transformed into protactinium-233, with a

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half-life of 27 days; finally, the protactinium-233, upon emitting a beta particle, would turn into uranium-233. According to the theory, uranium-233 should decay by emitting an alpha particle - a rather heavy particle.

Our first problem was to separate protactinium-233 chemically from the thorium nitrate. The protactinium-233 would rather rapidly turn into uranium-233, and we could watch for some alpha particles growing into the sample - and this would be indicative of the presence of uranium-233 if our theory was correct. As you can see from all this, there were a number of different kinds of radiation involved, and one of the problems was to be able to identify the alpha particles when and if they emerged from the sample. The late Dr. Joseph W. Kennedy was a genius at developing counting techniques, and it was he who developed the instrumentation for detecting alpha particles in the presence of beta particle radiation.

Our array of counters was in Room 303 Gilman. This small room also served as an office for Joe Kennedy and myself. I assure you it was crowded, with our desks, file cabinets, work bench, counters, electrometers, and eventually alpha counters and fission chambers. But we didn't really know it was crowded at the time. Compared to certain of the facilities I had used in some of my initial work in nuclear chemistry - including an abandoned building and what I think was a janitor's washroom - it was a luxury.

By the end of the spring semester of 1941, we had observed alpha particles emerging from our sample, and were confident that we had discovered the long-lived alpha particle emitter, uranium-233. But we needed to produce a much bigger sample in order to establish the fission properties of uranium-233.

At this point, our work was interrupted by an incident that, in the light of today's level of scientific effort, seems almost incredible. Gofman, like virtually all students in those days and like a very large percentage today, was poor. During the school year he had supported himself on the small pay of a teaching assistant. But with the end of the semester, the job also ended. There were no summer jobs to be had. I tried to get money to pay Jack for working through the summer in the laboratory, without success. He tried to get an off-campus job, so he could remain in Berkeley and work part-time in the laboratory without pay. But all our efforts were fruitless. So Jack went back to Cleveland to live with his family until fall, when the job as teaching assistant would again be available. The plutonium problem was assuming an urgent phase, and I could not carry on the further investigation of uranium-233 alone. Thus, the search for this fantastic new source of energy ceased during the summer of 1941.

By fall, when Jack returned to his teaching assistant's job and to the work on uranium-233, the United States Government had provided a modest grant for this research. Although Jack continued to be supported solely by his University salary as a teaching assistant, the funds included $3000 to enable me to hire a Ph.D. research chemist. I received authorization to do this in response to my letter to Washington of July 10, 1941, which included the following entreaty:

> "In case it is decided that a contract for these projects, with a chemist assistant, is to be assigned to me, could you authorize me to hire a chemist to start to work as soon as possible without waiting for the official completion of the contract negotiations? Good unemployed chemists are becoming increasingly difficult to find, and I know of one who will be available provided I can give him some definite information soon."

The government funds enabled me to invite Ray Stoughton to join the project. Ray was a valuable member of our team and his shouldering of a good part of the heavy burden of chemical processing was an essential ingredient in our final success.

As soon as possible we put about 3 kilograms of thorium nitrate in the cyclotron's neutron beam. By February 2, 1942, a four-microgram sample of uranium-233 had been isolated chemically in Room 307 Gilman - a large sample by the standards of the day. The sample was taken to the clutter of Room 303 where it was possible easily to count the telltale alpha particles characteristic of uranium-233 decay. The fissionability of uranium-233 with slow neutrons was determined that same night and early the following morning. In a later experiment the half-life of this isotope was established as about 100,000 years.

Thus there were - and are now - three potential sources of nuclear energy. One was uranium-235, the scarce isotope of natural uranium, comprising less than one per cent of that element in nature. The other two were man-made:

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plutonium-239, which in a nuclear reactor could be manufactured from plentiful non-fissionable uranium-238; and uranium-233, which could be made in a nuclear reactor from plentiful non-fissionable thorium-232.

Even with nuclear development put on a crash basis, one would have been hard put to visualize the rapidity and scope of its development. Twenty-five years ago I could not have imagined, of course, the existence of the huge and diversified nuclear energy enterprise of the Federal Government, or that I would have a considerable responsibility for making nuclear energy a practical and economic reality.

Let us look briefly at the present status of nuclear energy and the future roles of these three nuclear energy sources, including the two man-made ones discovered at the University of California. The original fissionable material, and the only one occurring in nature, is the rather scarce uranium-235. In view of the huge amounts of energy released in fission, uranium-235 seemed to be a vast energy resource despite its relative scarcity. And so it is, in the sense that it provides a resource of energy exceeding that available from fossil fuels. However, used as the sole source of nuclear energy, and keeping in mind a long time scale, uranium-235 could be spent fairly quickly, like fossil fuels.

But, with the indirect burning of abundant uranium-238 and thorium-232 as nuclear fuels through the intermediate use of fissionable plutonium-239 and uranium-233, nuclear energy becomes a vast and, for all practical purposes, a virtually unlimited energy resource. There is over 100 times as much ordinary uranium (uranium-238) that can be converted into plutonium-239 as there is uranium-235. And the thorium (thorium-232) resources are about equal to, or greater than, those of ordinary uranium.

The key to this vast base of nuclear power is a bonanza known as the breeder reactor, which is in the early stages of development. Eventually, the breeder will produce electricity from plutonium-239 or uranium-233 and also produce <u>more</u> nuclear fuel - plutonium-239 or uranium-233 from uranium-238 or thorium-232 - than it burns while producing the electricity. The AEC has a program for the development of such reactors, in cooperation with industry, and these should be available for large scale practical use by the 1980's. Such reactors will make it possible to use relatively expensive uranium or thorium ores as sources of fuel for the

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generation of economic electricity. Hence they lead to a tremendous increase in the amount of nuclear energy available from uranium or thorium for two reasons: they utilize the uranium or thorium very efficiently and they make it possible to use relatively expensive sources which greatly increases the useful supply of these fuels.

In the meantime, and especially within the last year or so, nuclear power reactors which burn the less abundant uranium-235 have reached the point of development where they generate electricity economically. Last year, a milestone was passed, when electric power generating utilities in the U.S. ordered more nuclear generating capacity than conventional fossil fuel generating capacity for their future needs. Nuclear power has arrived, will become cheaper, and will give us flexibility in energy utilization.

Indeed, there is a rather interesting commentary on the discovery of these energy resources and on the subsequent development of practical nuclear power generation. The world is beset with a multitude of problems that sometimes do not appear easy to solve. Included in the long and discouraging list are overpopulation; shortages of food, water, and natural resources; pollution of air and water; congestion of our cities and blight of the land.

However, partly as a result of the discoveries of a quarter of a century ago here at Berkeley, there is one problem that once, but no longer, haunts the world. Resources authorities no longer worry about a technical civilization grinding to a halt as limited supplies of fossil fuels run out. It is now clear that the central requirement of a technical civilization - abundant energy - can be met by nuclear resources at whatever levels are required by the human race for many centuries to come. And the foundations of this abundance are the uranium-plutonium-239 and the thorium-uranium-233 cycles.

In addition to relieving us of concern about electrical power in the future, nuclear energy can be used to help solve some of our other gnawing problems. In the future, giant reactors will desalt sea water and relieve water shortages in arid areas. Nuclear reactors produce no smoke, and every time one is built it means we can have electricity without the smog-producing smokestacks of conventional power plants. One day reactors fueled by uranium-233 or plutonium-239 will provide the abundant and inexpensive energy needed to produce

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chemical fertilizers for increased food production; to produce synthetic materials of all kinds; and to help overcome raw materials resources by extracting and processing the world's lower grade mineral resources. Nuclear power will also be a means of preserving an important portion of our limited hydrocarbon resources, upon which we increasingly depend for prime raw materials of many kinds.

The discovery of these two man-made nuclear fuels here in Berkeley within one year constitutes, as we contemplate the future of nuclear electrical power generation, one of the most impressive payoffs on basic research in history. These discoveries, like nuclear fission itself, were the result of a decade of rapid expansion of knowledge on what appeared to be an abstruse and apparently impractical subject, namely, "What makes the atomic nucleus tick?"

I have described a number of aspects of this payoff, in particular the assurance of abundant energy for civilization for hundreds of years and the significance of abundant energy to the world of the future. There is another way to express the payoff, and that is in terms of dollars. When we compare the amount of energy derivable from U.S. uranium reserves through the uranium-plutonium-239 cycle with the cost of energy from fossil fuels today, the value of the potential nuclear energy comes to something around 50 quadrillion dollars. The value of uranium-233 derivable from thorium is estimated to be of a similar order of magnitude.

We are all aware, of course, that the release of nuclear energy was pressed initially as a means of preserving freedom against tyranny. In the future uranium-233 and plutonium-239 will be important instruments for man's continued security and material abundance. And men can have cause to celebrate the events that took place under the eaves of Gilman Hall on the Berkeley campus of the University of California a quarter of a century ago.

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Remarks by
Wilfrid E. Johnson, Commissioner
U. S. Atomic Energy Commission
before the
Washington Public Utility Districts' Association
Seattle, Washington
December 8, 1966

NUCLEAR POWER AND THE NORTHWEST

Gentlemen: It is a pleasure to return to the Northwest even for a brief visit and even in December. I have had complete freedom in choosing a subject and despite the fact that you are occupied in the power business day after day, it seemed to me that you might still like to hear something about one aspect of the power business, namely, the growth and prospects of nuclear power and particularly how nuclear power may lend itself to application in the Northwest.

I am sure that most of you are fully aware of the sudden spurt in the acceptance and growth of nuclear power. Chairman Glenn T. Seaborg of our Commission has called 1966 a banner year for nuclear power. Total orders in calendar 1966 are for approximately 16,500 electrical megawatts of nuclear capability representing an addition to the backlog in the nuclear power supply industry of about $2.0 billion. There are some aspects of this sudden growth that should be observed. Briefly, these are:

1. Some of the growth is probably an expression of the concern of certain utilities with the adequacy of their generating reserve margin. This would provide an explanation for the acceleration of orders for total electrical generating capacity. The sharply increasing ratio of nuclear

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to fossil fueled plants, however, must be attributed to the judgments by utilities that nuclear plants are economically the more attractive in many circumstances. Actually, somewhat in excess of 50% of the capacity of the thermal stations for which orders were placed this year is nuclear.

2. Another factor is that some of the orders that have been placed this year are for 1972 and 1973 delivery and normally might be expected to have been placed next year or the year after.

3. It is reported that at least one equipment manufacturer is endeavoring to stretch out deliveries for future orders.

4. Historically, power plant orders have exhibited a cyclical pattern with peaks occurring at roughly five-year intervals.

It is natural that estimates of growth of the nuclear power industry should be revised as a result of this recent experience. The latest Atomic Energy Commission estimate is that between 80,000 and 110,000 MWe of nuclear capacity will be installed by 1980.

It is proper to ask what the foundation of confidence is for this enormous commitment on short notice to a new technology. This is one of the few cases in industrial history where a new technology has entered a field to supply a service or product no different from one already furnished. The only other case that comes to mind is the supplanting of the steam locomotive with the diesel locomotive, and my recollection is that there were some years of testing and investigation and prooftesting of economics before the railroad industry really took the big step.

In the case of nuclear energy, we have only had 10-15 years to design, develop and prooftest nuclear plants. At the moment, only four plants can really be considered in the prooftest category and these are Shippingport, Dresden I, Yankee and Indian Point I. While Dresden and Yankee had impressive plant availabilities of 70% to 80% over the 1961-1965 period, this alone could not account for all the confidence that the utility industry is displaying. Part of this confidence must be coming from the cold-blooded analysis of economics. Perhaps the best example of this is the recent TVA study which showed capital costs of large stations to be about the same as between coal fired and nuclear plants. The same study also showed, however, energy costs amounting to 2.37 mills/kwh for nuclear fuel as against 2.83 mills/kwh for coal priced at 18.9¢ per M/Btu - a substantial saving. These figures are for base load operation. An important factor in the TVA decision was undoubtedly the fuel warranty provided by the equipment manufacturer. While warranties usually extend for several years to cover the consumption of two cores, in the case of TVA the fuel warranty applies to the first 12 years of operation of the plant. Clearly the warranties being offered illustrate the willingness of the nuclear equipment industry to share the risks inherent in the early utilization of this new technology with the utility customers and give evidence of the confidence of the nuclear equipment industry in its product.

A somewhat longer term consideration in nuclear power growth is the uranium supply and demand picture. Our estimate at the beginning of the year was 190,000 tons of reasonably assured reserves of U_3O_8 available at costs up to $10.00 a pound, of which about 40,000 tons remained to be delivered to the Commission in the 1966-70 period, leaving a balance of about 150,000 tons. Undoubtedly during this period new discoveries will be made to increase this figure.

Our current estimate of resources at up to $10.00 a pound that may remain to be discovered, within only those areas of the western United States known to be favorable for uranium, is another 325,000 tons U_3O_8. In addition, of course, some portion of the AEC stockpile will probably be available. Thus, estimated resources, if fully recovered, are probably adequate to support a light water reactor economy into the 1990's, or roughly for the next 25 years based on the annual consumption of uranium per unit of electric energy delivered. If the lifetime fuel requirement of each reactor installed is considered to be committed at the time the plant starts up, these reserves would be good for all the plants built through 1980.

Mining companies, of course, cannot afford to develop and prove out reserves too far in advance since the interest on their investment in doing so would soon exceed the ultimate return from future sales of the reserves discovered. At the same time, the utility industry cannot look with equanimity at the prospect of rising costs of fuel although there undoubtedly will be plenty of uranium fuel available if cost is not a limiting factor.

Actually, we in the Commission expect, and I think the mining industry and utility industry expect that uranium supplies will, in fact, be adequate at least into the 1980's with no major increase in cost.

However, it is clearly necessary that nuclear fuel supplies be extended and that we be able to do this by sometime in the decade of the 1980's. There are several ways in which the needed extension can be accomplished in whole or in part. These methods include the following:

1. Vigorous exploration for new reserves and their development (exploration activity by the uranium industry is once again in the process of rapid expansion).

2. Importation of fuel supplies - a move that we do not propose to encourage until our domestic mining and milling industry is on a reasonably good economic footing.

3. The application of plutonium recycle for existing light water thermal reactors. This technology is already developed to a great extent and is ready for confirmation in existing power reactors. This confirmation is expected to be achieved through programs such as that sponsored by the Edison Electric Institute. The successful application of plutonium recycle should extend uranium fuel supplies by about 30-40%.

4. The development of advanced converters and thermal breeders which would extend uranium supplies through more efficient fuel utilization and also offer the potential of using our vast thorium reserves.

5. Last and most important, at least from the point of view of the U. S. power industry, is the development of the fast breeder reactor. This concept presently involves sodium cooling - a difficult technology to master, but one that pays off handsomely in terms of breeding gain and thermal efficiency. Hopefully, the net breeding gain of fissile material after considering reprocessing will amount to a doubling of the reactor system inventory over 8-10 years. This is equal to or better than the "breeding gain" of money in the majority of investment situations. If this

happens, the economic balance will probably encourage full utilization of breeding in reactor cores and a consequent conservation of fuel supplies.

Of these five methods, I would like now to talk a little more in detail about the last one and what it means for the long pull. The Commission, as you probably know, is engaged in a program of developing the necessary technology for the Liquid Metal Fast Breeder Reactor. Our present objective is to have demonstration reactors of this type begin operation in the mid-1970's. Hopefully, the development will continue through the 1970's so that full-scale plants can enter the picture on an increasing basis starting about 1980. Assuming the success of this program, it is anticipated that the fast breeder type of reactor will initially complement and ultimately supersede the present types of light water thermal reactors. In addition, it is possible that the fast breeder may be supplemented one way or another by the thermal breeder using the thorium-uranium-233 cycle, but for today, let me concentrate for a few minutes on the longer-range implications of the fast breeder. Some of the interesting facets are:

1. The total fuel costs are expected to be about 1/3 of the fuel costs in today's light water thermal reactors. In other words, it would be about 1/2 mill/kwh, compared to today's expected fuel costs of about 1-1/2 mills/kwh. Further examination of these fuel costs indicates that the value of the plutonium produced may well pay for most or all of the other fuel costs such as fabrication and spent fuel recovery.

2. Assuming that in the longer run practically all of the new large power reactors are of the fast breeder type using the uranium-plutonium cycle, the plutonium produced will continue to have a value determined by its value in fueling new reactors which in turn will be determined by the costs or value of alternate fuels such as U-235.

3. Over a still longer range, we might look forward to a period in which most of the operating steam plants in the country use nuclear fuels and most of these are fast breeders. Assuming that the electric power business continues to double in output every ten years, it appears reasonable to anticipate, with the use of sodium cooling technology, a doubling time in the fissile fuel of approximately ten years so that the system will be producing

enough fissile material to meet the continuing demand for new reactor cores, without the need for an outside source of fissile material. As soon as any shortage develops, the value of plutonium will be measured by the cost of alternate fuels such as U-233 or U-235 that might be used for initial loadings. Should an excess supply develop, the value of the plutonium should, of course, drop and the market place would set a new price.

4. Looking at the very long-range picture, it is obvious that when fast reactor technology is utilized the real fuel is U-238. There are and will be very large stocks of depleted uranium available from uranium enrichment operations and these would presumably find their way to the market place. Gradually, however, it would be necessary to resort to mining more inaccessible uranium and eventually the cost of mining, milling and refining the ore is bound to increase even though there is a plentiful supply. Uranium, for example, exists in nearly all granite.

Fortunately, it appears quite likely that when and if the costs of uranium rise substantially some decades hence the nuclear plant capacity which will then be installed will be made up mostly of self-supporting breeder reactors, the economics of which will be insensitive to the cost of uranium. For example, using the capital charges typical of an investor-owned utility, the capital charges for the initial inventory of U-238 at \$8/lb of U_3O_8 is about 1/50 mill/kwh. This is based on approximately 50 Kg of U-238 per electric megawatt. Assuming now that the cost of mining and milling uranium increases so that yellow cake costs \$100/lb, the capital charge for the inventory, if it were capitalized, is still only about 3/10 mill/kwh. Also, burn-up charge for consumption of U-238 at \$100/lb is insignificant - only about 4/100 mill/kwh.

Incidentally, this figure of \$100 per pound is not a prediction. I am merely using it to illustrate the insensitivity of power costs of breeder reactors to extreme changes in the price of U_3O_8.

These favorable costs arise from the fact that one ton of U_3O_8 is equivalent in energy content to about 2-1/2 million tons of coal and breeder reactors are expected to utilize about 60% or more of this potential heat. The cost of the energy available from uranium even at \$100/lb of

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yellow cake is still only about one half a cent per million Btu compared to about 20 cents/million Btu for coal.

Whether we look at the future in terms of cold-blooded economics, in terms of conservation of resources, or both, we obviously don't need to wear any rose-colored glasses so far as the breeder reactor technology is concerned. Clearly, it is well worth the effort to master it and this we propose to do.

This brings me now to the prospects for the Northwest. I presume that most of you are familiar with the Advance Program of the Bonneville Power Administration. The need for power in the Northwest is, of course, a matter that your industry will continually appraise. However, I do want to say a word about the adaptability of nuclear fueled electric generating stations to the power complex of the Northwest. I think that by this time everyone conversant with the characteristics of the hydroelectric system recognizes that over the longer range the most KW hours can be sold on a firm basis by utilizing the natural peaking capability of the hydroelectric system in partnership with a base loaded thermal plant. I don't think there is any need for me to discuss the natural advantages of this coupling of the two systems. I do wish to point out, however, that nuclear power generation appears to be a natural for the Northwest. It lends itself to large size units and its incremental operating cost is low. Over the longer range, as you will have gathered from my comments on the breeder reactor, it will tend toward extremely low fuel costs and toward capital charges that will compare very favorably with those of hydroelectric dams. Considering all of the technical and economic factors, there seems to be no question at all about the desirability of coupling the hydroelectric system of the Northwest with nuclear power. The only problem is how to do it, and the solution of this problem will take some ingenuity, good will, and determination on your part.

The Northwest is unique in having an immense hydroelectric system in which the generating capability is owned in part by Federal agencies and in part by public and investor-owned utilities. You have managed over the years to operate this complex for the benefit of all through the coordination provided by the Northwest Power Pool. It will take the same kind of imagination and cooperation to provide a coupling between thermal power and hydroelectric

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power that will be advantageous to all. Particularly will it be necessary to do the coupling in such a way that the entire Pool gets the benefit even though the ownership of any particular plant may reside with investor-owned utilities, cooperatives, municipals, or public utility districts. There is no way to obtain a satisfactory coupling of thermal power to the hydroelectric system unless all the participants in the Northwest Power Pool, including the Bonneville Power Administration, can agree on what is needed to benefit the system as a whole.

This is the major challenge you face. I feel sure that you are fully aware of it. I am confident that Mr. Black and his associates in the Bonneville Power Administration are aware of it, and I am equally confident that the electric utility industries in the Northwest will have the foresight and the imagination to provide a solution.

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IMMEDIATE RELEASE

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Richland, Washington -- January 16 -- By April 1, the Atomic Energy Commission expects to complete plans for taking charge of construction management at Hanford Works, as provided in an agreement with its prime contractor, General Electric Company.

Since last September, when G.E. signed a five-year extension of its contract with the AEC, there has been a gradual reallocation of those responsibilities connected with construction and related architect-engineer-management functions performed by G.E. for the AEC. Prior to that time, G.E. had charge of construction management and services under its contract.

A supplemental agreement in the contract provides that the AEC accept assignment of existing construction contracts at Hanford Works and Knolls Atomic Power Laboratory in Schenectady, N. Y. Since late in 1951, the AEC has been awarding contracts directly for expansion of the two installations.

The reassignment of functions was undertaken so that G.E. could further concentrate its efforts on the research, development, design, and operation phases of the enlarged plant facilities, project officials said.

Under the change, the Commission may, from time to time, ask G.E. to handle all architect-engineer-management services for a given construction project. In most instances G.E. will provide engineering and research services.

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As part of its continuing responsibility, G.E. will provide complete scoping and design specifications of certain process plants, as well as the design, procurement and inspection of those units.

The AEC also will take over the management of the North Richland construction camp. G.E. will continue to provide police and fire protection and public health service along with handling leasing operation of commercial facilities and furnishing utilities to the camp site.

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