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SUBJECT: Speeches by Sir Christopher Hinton, Director, British Atomic Energy Authority

(1)

Submitted as enclosures to this despatch are the "Hinton speeches" together with selected newspaper articles commenting on the speeches and the Atomic Energy situation in general (Enclosures 1 to 12).

On a social occasion, British Commercial Counsellor Pearson mentioned to Ambassador Allison that he had assigned a British language officer to assist Sir Christopher in his travels throughout Japan. Subsequent events suggest that Sir Christopher's tour was most successful, and that he might have accomplished his objectives unassisted. Certainly, the attached documents give ample evidence that he represented British interests exceedingly well. Moreover, the charges were borne by a Japanese newspaper, according to a reliable source, which states that Sir Hinton was paid a fee equivalent to ¥5,000,000 for his sales efforts in Japan.

Submitted as enclosure No. 13 is the Basic Plan for Development and Utilization of Atomic Energy for the Fiscal Year of 1956, prepared by the Atomic Energy Commission.

It is suggested the copies of the attachments be supplied to Dr. Fox at Brookhaven, as well as to the Atomic Energy Commission.

For the Ambassador:

Harvey Klemmer
Harvey Klemmer
First Secretary of Embassy

Enclosures:

1. A Talk to People in the Inner Circle of Atomic Energy in Japan
2. First Lecture
3. Atomic Energy in Great Britain
4. Lecture - For Scientists
5. Panel Discussion on Atomic Power Generation in Britain

[illegible]

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Page 1 of
Encl. No. 1
Desp. No. [illegible]
From Tokyo

A Talk to People in the Inner Circle of Atomic Energy in Japan

By Sir Christopher Hinton

(Lecture by Sir Christopher Hinton,
at Tokyo, on May 17, 1956)

Any country setting out to establish an atomic energy industry must have a clear conception of what its exact objectives are. The atomic energy project in Great Britain was established in 1946 and our initial objectives were the production of fissile materials for defense purposes. With these objectives we set out first of all to build the research establishment at Harwell and immediately followed this by constructing the factories of the Industrial Group.

The first of these factories was Springfields which is our feed materials plant. Here uranium ore and uranium concentrates which have been imported from Africa or elsewhere are purified by relatively conventional chemical processes and reduced to uranium metal. This is then fabricated into cartridges for the piles. The first state in the process is the dissolution of the crude uranium and initial purification by precipitation and filtration. This produces uranyl nitrate which, although of satisfactory purity by normal chemical standards, is not pure enough for reactor work, and the final purification is carried out by a solvent extraction process. Ether is the solvent which has been used at Springfields so far, although better, and certainly safer, solvents are now known. The production of uranium metal is carried out first by the conversion of the uranyl nitrate to UF_4 by the use of HF and the subsequent reduction of the UF_4 by calcium or magnesium. The uranium metal is then cast into rods, machined to size and canned into cartridges for use in the reactors; the canning process is specialised and complex.

The construction of the second factory started soon afterwards at Windscale. Here we started the construction of two piles and the chemical plant required to extract and purify the plutonium and uranium from the irradiated cartridges. The piles are graphite moderated and have direct air cooling. Air is drawn in through filters and delivered to the piles by eight centrifugal blowers driven by electric motors of approximately 2000 H.P. After passing through the reactors the hot air is discharged by a 400 ft. chimney the heat of fission being wasted.

After the cartridges have been irradiated for the required period, they are discharged and stored under water for a few months. This allows the decay of the short lived fission products, some of which would be troublesome in the chemical plant. The partly cooled cartridges then have their aluminium sheaths removed and are transported in suitably shielded containers to the main chemical plant. Here the uranium bars are dissolved in nitric acid and the extraction processes carried out in multistage columns using suitable organic solvents. The first separation to be carried out is the removal of the majority of the fission products. Once this has been done the activity levels are greatly reduced and the difficulties are correspondingly diminished. In subsequent stages of the process the plutonium is separated from the uranium and the residual traces of fission products are removed from each stream. The plutonium is

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finally reduced to metal.

To avoid having too high a percentage of higher isotopes in the plutonium it is necessary to remove the uranium from the piles when only a small proportion of the U235 has been consumed. In view of the cost of natural uranium, it would not be reasonable to reject this partially depleted material which still contains about 90 percent of the original U235. Uranium depleted in U235 cannot, however, be used in the reactors and it is necessary first to restore the U235 content. This is done in the diffusion plant.

Our diffusion plant at Capenhurst was the third factory to be built. Here uranium is enriched to a greater or less extent in the fissionable U235 isotope. The plant is fed with the gaseous compound of uranium, UF_6, which is produced in part of the Springfields factory, either from natural uranium or from the partially depleted uranium which is returned from Windscale. The Capenhurst diffusion plant was necessary to the British project for three reasons. The first I have already mentioned, namely, to re-enrich the slightly depleted uranium from the production reactors at Windscale. The second is to provide enriched material for research into more advanced types of reactors. Finally, U235 was required for defense purposes.

When we started the construction of Springfields we had very much less information about the chemistry and properties of uranium than we have now, and we accordingly built the factory along fairly conservative lines. We did not for example, attempt to put in automatic or continuous processes until we had enough knowledge to ensure that they would be successful. We felt that the important factors to be considered in the design were the speed at which the plant could be built, the flexibility to alter processes as further experience was obtained and the certainty with which we could rely upon obtaining satisfactory cartridges on time. Greater elegance in the processes had to take second place and they were modified to give this later.

The same considerations weighed heavily in the design at Windscale. In the piles there, all the heat produced from fission is wasted. At the time the reactors were designed we did not know how to recover the heat at a high enough temperature to convert it economically into useful power. We did at that time give some thought to a design not dissimilar from that of Calder Hall, but our experience was too limited and time was too pressing to solve all the problems involved. Since that time a great deal of research work has been carried out and we have gained a great deal of practical experience of operating nuclear plant. For example we have investigated ways of treating the uranium to overcome irradiation damage, new canning materials have been tried and heat transfer characteristics have been improved. By 1953 we had developed to the stage where we were able to start the construction of the Calder piles in which the heat will be used usefully in the production of electrical power. At this stage we were able to lay down our programme for the generation of electricity in the U.K. from nuclear power.

The driving force behind this plan is the shortage of coal at the present time and the much more serious shortage that is predicted for the future. The problems of future fuel supplies facing us in Britain and you here in Japan [illegible]

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remarkably similar. In both countries we are producing the bulk of our present
fuel requirements internally; in both countries the increasing demand for fuel
is rising much more rapidly than the production of coal; in both countries the
deficiency is being made up principally by increases in oil imports which are
already imposing a heavy strain on our economy and will impose an impossible
strain in the future unless an alternative form of power can be developed. As
an example of the magnitude of our problem, the amount of coal used for electri-
city generation in the U.K. was equivalent to about 36 million tons last year
and, with a continuation of the present trends, we could expect the requirement
to have built up to the equivalent of 100 million tons by 1975. There appears
little hope of being able to expand our coal mining capacity to match this
demand.

The Government plan envisages the start of construction on two or possibly
three large nuclear power stations in 1957 and on two possibly three more
eighteen months later, with a total of at least twelve stations being constructed
in the next ten years. This programme would give a nuclear generation capacity
of approximately 2,000 MW by 1965 and would result in a saving of five million
tons of coal annually. This saving at first seems small but it must be re-
membered that in the first five years the foundations of the industry will be
laid and the increases in generating capacity should be very large from about
1965 onwards and should lead to a very substantial contribution to the U.K. power
requirements by the early 1970's. Even with an ambitious programme of this
magnitude it is doubtful if we will be able to do more than halt the increases
in conventional fuel requirements for power generation from about 1975. I do
not see nuclear power resulting in any reduction in conventional fuel require-
ments in the foreseeable future. The first ten years of our programme will
involve expenditure on nuclear power stations amounting to £200M and by 1975
we expect to be spending £200-£300M a year on nuclear power plants. The Calder
Hall reactors were not built simply for power production; they were built as
dual purpose reactors for power production and for the production of plutonium
for defense purposes. I think it would be misleading to attempt to quote any
cost of power generation from such dual purpose machines even if this was per-
missible. What is better is to calculate the cost of electricity that would be
generated from reactors of the Calder Hall type if they were enlarged and re-
designed with power production as the principal objectives; that is, the cost
of power from the stations that will be built for and operated by the British
electricity authorities.

As a result of our experience in the construction of Calder Hall we are con-
fident about the improvements that can be made in redesigning these reactors
specifically for power production. We can estimate the capital cost for a station
of any given output to within quite reasonable limits. At the present stage in
development this would amount to about double that of a conventional coal burning
station. We know the cost of uranium and the cost of fabricating it into
cartridges at our Springfields factory. We are less certain about how frequently
the fuel will have to be replaced, but I do not think our estimates are suffi-
ciently uncertain to invalidate our conclusions. Putting all these factors
together leads us to the conclusion that if we were to attribute no value to the
irradiated uranium the cost of electricity would be rather less than 1.0 pence
per unit; that is to say, the stations would not be competitive with the best

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coal fired stations on present coal prices. It is certain, however, that a credit should be given for the by-product plutonium; it is a fissile material which we ought to be able to use as a fuel in our "second stage" reactors and, although the technology of doing this has not yet been fully developed as yet, it is unthinkable that we are not capable of solving the problems that arise. The question is, how much value should we attach to the by-product. Plutonium is in many ways equivalent to U235 and it can be extracted from irradiated uranium very much more easily than U235 can be extracted from natural uranium in a diffusion plant. It is fairly clear that either U234 or plutonium is going to be required in substantial quantities in the future. It may be required for fast reactors; it may be required for package reactors; it may be required for more advanced liquid cooled reactors. It will certainly be wanted for some of these purposes. In view of the difficulties in handling plutonium, which is extremely poisonous and in view of the fact that there are other problems as yet unsolved we have been conservative in fixing a value but the credit which we feel entitled to give brings the cost of power from our first reactors down to 0.6 pence per unit which is competitive with the cost from an up-to-date power station.

It is not intended that the A.E.A. should construct power stations of established types for the Electricity Authorities. We have arranged that this should be done by groups of industrial firms who are the traditional constructors of electrical generating plant in the U.K. What we have done in the Atomic Energy Authority is to train four groups of firms, which comprise all the major companies employed in power station construction, in the technology of nuclear power and, in particular, the technology of designing gas cooled, graphite moderated reactors. In this training the firms have had guidance on the theory of nuclear reactors; they have had access to our design offices and opportunity to discuss problems with our staff. They have had opportunities to work on the production reactors at Windscale and they have seen the construction work at Calder Hall. We are assisting them in research that they are not yet able to undertake. These groups of firms are now preparing their first tenders for the Electricity Authorities and there is every reason to believe that their designs will come up to our best expectations.

By handing over the responsibility for building reactors of the Calder Hall type and much of the responsibility for making further improvements in them to industrial firms, the atomic energy authority has left itself free to devote the greater part of its resources in the wider field of reactor development. Here our aims must be to develop highly rated reactors in which we can burn the by-product plutonium from the first stage reactors; reactors which have lower weight per kW of power output and reactors which will ultimately be cheaper in capital and operating costs. A very large number of systems are feasible but of these the most promising and important are.

The Fast Reactor
The Sodium/Graphite Reactor
The Heavy Water Reactor
The Light Water Reactor
The Homogeneous Reactor

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The fast reactor has the outstanding advantage that it is a breeder; it can produce more plutonium than it burns. In the case of the natural uranium gas cooled reactor we are talking of achieving 3000 MWD/T irradiation in our fuel, i.e. a fuel utilisation of 0.3 percent. This may be good enough in the initial stages of a nuclear power programme but it is totally unsatisfactory if nuclear power is to make a significant contribution to world power requirements. The successful operation of the fast reactor would enable a very high fuel utilisation to be achieved. It is in principle possible to burn all the U 238 and also to use thorium 232 as well as to burn the U 235. The fast reactor is, however, a very different problem from the Calder Hall reactor. The ratings that have to be achieved to make the project appear even sensible are very high indeed. It is like getting the power output associated with a medium sized power station out of a reactor core of the size of a domestic cooker. The problems are very great; they will take a long time to solve. We are, at Dounreay, building a pilot fast reactor having a heat output of 60MW. The design of this is based on research which has been done at Harwell on two zero energy fast reactors, Zeus and Zephyr, which have been operated there. Almost certainly the Dounreay reactor will have to be followed by a full scale prototype and I doubt whether fast reactors will be in routine use for generation of industrial power in less than 12 years. We regard the fast reactor and the high fuel utilisation that it will permit, as an objective which it will ultimately be necessary to achieve. The fact that the problems are difficult should not divert us from our path.

The gas cooled reactor operating on natural uranium and rejecting uranium after a comparatively modest burn up, and the fast reactor breeding plutonium are the two extremes of a great variety of reactors and fuel cycles. At the one end of the series you have the Calder Hall type, heavy and cumbersome but safe, simple and almost conventional in design - the slow speed reciprocating engine of the reactor world, at the other end you have the fast reactor, highly rated, smaller and lighter but using materials and techniques which are as yet not fully established - perhaps you can regard it as the gas turbine of the reactor world. The other reactors which I am going to mention as showing promise lie between these two extremes.

The sodium/graphite reactor is capable of higher ratings than the gas cooled systems. It is capable of producing heat at a high enough temperature to use the steam pressures associated with the most up-to-date coal fired stations of today. This is of considerable importance because only about one third of the cost of a nuclear power station is the cost of the reactor itself. Poor steam conditions and low thermal efficiency all add to the costs of the conventional components of the stations. The sodium/graphite reactor does not have to be a pressurised system and avoids the difficulties associated with the fabrication of large pressure vessels. Against this the neutron economy is poor and the reactor only appears to be attractive in large sizes.

The heavy water reactor is attractive in that it will operate on natural uranium and the neutron economy is very good. To obtain even moderately satisfactory steam conditions in the turbine means that the reactor itself must be pressurised to a very much higher figure and 1500-2000 lb.sq.in. are frequently mentioned. The difficulties of fabricating large pressure vessels to stand up to 2000 lb.sq.in. should not be under-estimated. Small leaks of heavy steam

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be very expensive and I have never yet seen a steam plant that didn't leak somewhere sometime.

The light water reactor has similar problems to the heavy water reactor except that fears about leakages of the expensive moderator are replaced by difficulties in getting a sufficiently compact core. Both the heavy and light water reactors involve serious corrosion difficulties for which we have no immediate solution.

The homogeneous reactor, where the fuel is a solution in heavy water which also acts as the heat transfer medium, appears attractive in many ways. There are none of the metallurgical difficulties of fuel element design. From a reactivity point of view the reactor is remarkably stable, much more so than any of the other types we have considered. Continuous chemical processing should be possible with obvious theoretical advantages. Against this the practical problems are very great indeed. Perhaps we have only exchanged the metallurgical problems of the fuel elements for the metallurgical problems of the container vessel design. Very much more development work is required before this reactor could be considered for commercial operation.

Returning now to fuel utilization and fuel cycles, I have said that to burn natural uranium to 3000 MWD/T and then reject it is really being very wasteful in raw materials since we are only achieving 0.3 percent utilization. It would, however, be possible to extract plutonium from the irradiated fuel and put this back into the reactor together with the appropriate quantity of depleted uranium. By this means we would achieve a much better overall utilisation which might be as high as 3 percent of the total uranium feed. Whether or not it is economical to do this depends upon the cost of new uranium ore, the price you could obtain for the plutonium if used for other purposes and the cost of recycling. In the case of the gas cooled reactors it will probably not pay us to do this because I believe we can make better use of the plutonium either by using it as a fuel in fast breeder reactors or by using it to enrich the fuel in highly rated reactors of the sodium/graphite, light water or homogeneous types. It is interesting to note the differences in approach of the U.S. and the U.K. to this problem. In my country we favor starting with natural uranium power reactors and using the plutonium to initiate these other schemes. In the U.S. much more emphasis is laid on reactors using U235. This difference is to be expected in view of the differences in our economies. In the U.K. we are short of power and we are reluctant to erect large diffusion plants which would, in the first instance, only aggravate our troubles. In the U.S. there are areas where power is remarkably cheap and the production and sale of U235 could be regarded as a convenient way of transporting power from one area to another, or of exporting power.

I have outlined the history, programme and objectives of the British project in this way because I feel that it is the first essential in any country embarking on an atomic energy programme that they should have a clear and explicit conception of what their objectives are and a plan, as definite as sure for achieving them.

I am not able to speak constructively about Atomic Energy in Japan because

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I do not know what your objectives are. Looking at your problem from the outside, and in the light only of published economic information, it would appear that your incentive to develop an atomic energy industry is at least as great as ours. In one of your official printed publications I find the statement that "The Ministry of International Trade and Industry is determined to see that 8,200,000 KW are generated by atomic energy by 1975. As a first step MITI wants to start with 850,000 KW of power by atomic energy along about the fiscal year 1965". This, of course, is a very large programme, nearly half the magnitude of our British White Paper Programme, which, with ten years of development behind us, is stretching our resources pretty tightly.

On the other hand I have seen a programme in a paper on the "Development of Atomic Energy in Japan" which would appear to correspond with a slower rate of development and would appear to give little industrial output of power by 1965.

In launching your programme I suggest that one of the first decisions which you have to make is whether you would hope to aim at an intergrated programme or whether, at any rate in the early years of development, it would be more practical to have the ancillary processes (uranium extraction, fuel element manufacture, chemical extraction etc.) carried out elsewhere. It is quite possible to transport irradiated fuel elements by rail and sea to other countries for processing. In Britain we are proposing to use Springfields and Windscale as our two central processing plants for a large number of reactors which will be constructed in various parts of the country. We are proposing to transport fuel elements both new and irradiated by road and rail between the chemical plants and the reactors. The shielded containers for the irradiated fuel will admittedly be heavy, somewhere between 15 and 30 tons in weight for every ton of fuel carried depending on the type of fuel elements being transported and the quantity taken in a single consignment. However this is not a serious transport problem. I mention this to illustrate the feasibility of transporting irradiated fuel and to demonstrate that it is not essential to construct a chemical plant alongside every reactor or, for that matter, even in every country.

You ought I think to try to realise that, if you aim at a fully integrated programme, in the initial stages of development the problems of designing and commissioning the ancillary plants are far greater than those of designing the actual nuclear reactors. In the first eight years of the British Atomic Energy programme two thirds of our design and research effort and more than two third of our capital expenditure went into ancillary plants.

In arranging for the design and construction of your reactors you will presumably feel that you have three alternative courses open to you, namely:-

(a) To design and construct them yourselves

or

(b) To seek an agreement under which you can purchase reactors from the United States

or

(c) To reach a similar agreement with Great Britain

Your ability to adopt the first of these three alternatives depends on the time scale you are setting for your development work; the amount of money you are prepared to put into initial research and development and your resources of scientists and technologists (above all of metallurgists and design engineers) who you are prepared to allocate to the project.

With regard to the second course you are as well able to form an opinion from the information published on the development of large land based nuclear power plants in the U.S. as I am.

If you wished to adopt the third alternative and if any necessary over-riding agreements were negotiated we should certainly advise the adoption in the first place of reactors of the Calder Hall type. We feel that this is the only reactors which we could immediately put forward as being safe, reliable and achievable in the initial stages of development. It occupies the same place in the development of nuclear power that the slow speed reciprocating engine occupied in the development of conventional steam power plants in that it makes use of techniques and materials which are well established and well tried to give a safe, reliable and reasonably economical source of power. The early slow speed reciprocating engine held its own against other forms of prime mover for more than a century; during this time it was progressively developed; it was in course of time superseded for certain applications by the high speed reciprocating engine and then supplanted by turbine machinery. It is interesting to trace the course of this development in the graphs which show, plotted against time, the reduction, first in weight per horse power and then in cost per horse power. These reductions resulted from the development of new techniques and of new materials.

I believe that the development of nuclear power plants will follow a similar pattern. Like the early steam engines, the Calder Hall type of pile is capable of great improvement; as compared with the plants which are being designed today the rating and output can be raised and the capital cost per horse power will come down. I think that reactors of this type will still be sold in 30 or even 40 years time and that they will be in use in 50 years time.

But meanwhile other reactors capable of higher rating will be developed. These will initially use new and expensive materials in parts of their construction and initially they will not show a cost advantage as compared with reactors of the Calder Hall type except in certain limited fields, but as the demand for the special materials increases and the techniques of manufacture become better established costs will come down and ultimately these highly rated reactors will supersede the reactors of lower specific rating.

Perhaps it would useful if I concluded this lecture by summarising the points which [illegible] you ought at any rate to consider in designing your Atomic Energy developments:-

FIRSTLY:- It is essential that you should prepare a firm and realistic programme of the amount of nuclear power plant that you intend to have installed year by year. This programme will take into account not merely your power requirements but the scientific and practical problems involved and the financial resources you are prepared to devote to it. The programme ought to be regarded as firm for the first five years, less firm for the second five years and provisional for the last ten years. In preparing this programme you ought not to overlook the fact that the rate of development in almost all new industries is exponential and that in order to achieve a certain rate of development in five years or ten years time you may have to make an earlier start in industrial installation than you would otherwise desire.

SECONDLY:- You can not achieve industrial results simply by research, important as research is. In order to achieve these results research and industrial application must go hand in hand. If I may draw a military parallel, the research workers are the reconnaisance units while the industrial organisation is the main body of the army; it is no use for the reconnaisance troops to penetrate too far if the army is not able to follow up and consolidate the advances. I am, in fact, advising that while developing your research programme you should install an industrial reactor of some sort at the earliest reasonable date.

THIRDLY:- In the early stages of an industrial nuclear power programme it is much more important to be successful than to be clever. I constantly find it necessary to give this advice to my own people. In the early stages of a nuclear power programme the psychological effects of accident or failure would be very serious.

FOURTHLY:- Don't overlook the fact that the development of research ideas into industrial practice is done by practical engineers and in order to secure rapid and satisfactory industrial development it is necessary to build some sort of a team in which there is, from the outset, a happy and equal partnership between the industrial engineer and the research worker.

FIFTHLY If a fully integrated and self contained programme comprising uranium [illegible] fuel element manufacture, chemical extraction and re- [illegible] at; the expenditure of money and technical effort on these ancillary plant will during the first 5-6 years be far more than the expenditure on the reactors themselves.

With limited resources it may therefore be advisable to seek arrangement in which these services are provided by one of the countries with an established atomic energy industry.

I imagine that you feel that with pressing need for nuclear energy, you are making a late start. We, in England, had something of that feeling when, well behind the United States, we laid the foundations of our industry in 1946. We found, however, that careful planning and wise concentration of effort enabled us to make satisfactory progress and that we were right in regarding our late start as a challenge rather than a handicap.

First Lecture

(Lecture by Sir Christopher Hinton,
at Tokyo, May 19, 1956, YOMIURI,
May 20, 1956)

The "grand speech meeting on atomic generation" sponsored by the Yomiuri Shimbun to celebrate the visit of Sir Christopher HINTON was held from 1:00 p.m. on the 19th at the Chuo University auditorium in Kanda Surugadai, Chiyoda Ward, Tokyo. In his opening address, Vice President TAKAHASHI of the Yomiuri Shimbun stated: "Moves in Japan during the past year for atomic development have been remarkable, yet they are small in comparison with those in foreign countries. In Britain, it is ten years since the development of atomic power was seriously taken up by the Atomic Energy Bureau and the Atomic Energy Authority which succeeded the Bureau. Japan must make up for the lag of ten years." He further emphasized that if Japan is to maintain her position as one of the first-ranking industrial nations, she should secure electric power resources and atomic generation as necessary for that purpose.

Mr. TAKAHASHI then introduced Sir Christopher HINTON, responsible official of the Calder Hall Atomic Power Station which is scheduled to start its epoch-making operation in October this year. Sir Christopher HINTON explained theories ranging from the A B C of atomic energy to atomic generation, and gave an account of his experiences in theory and practice by means of about a dozen picture slides. His speech also touched upon the construction of a breeder reactor using fast neutrons, and gave a strong impression to the 3,000 audience which filled the auditorium. The following is the gist of his speech:

Ladies and gentlemen, I wish to speak to you on how atomic energy is utilized for industrial purposes.

In ordinary thermal power plants, energy is obtained as a result of combustion of carbon compounds. If you ask a technician in a thermal power plant where energy resources are obtained, I think he will not make any answer because the methods to secure energy resources are so familiar to all. On the contrary, obtaining energy resources by means of nuclear fission is not familiar to us. It is a more complicated phenomenon. In the case of nuclear fission as an energy source, we cannot see with our eyes what reaction is taking place. Therefore, I will speak first of all on the structure of matter.

What is generally called an atom can be divided into some small particles. To explain by comparing it to our solar system, the atom is composed of a central part called "atomic nucleus" which can be compared to the sun and "electrons" which move around the nucleus like the planets. The atomic nucleus consists of two different kinds of particles: one is the proton with a positive electric charge and the other is an electrically neutral particle called a neutron. Since the atom as a whole is electrically neutral, the number of protons in the nucleus equals that of the electrons which move around it. The chemical properties of an atom are decided by the number of protons which exist in the atomic nucleus. In other words, atoms which have the same number of protons have the same chemical properties. The number of neutrons in an atom will differ as the case may be, and its mass and physical properties will differ accordingly.

When the number of protons of two atoms is equal, their chemical properties are exactly the same, while on the contrary, when the numbers of neutrons differ, the physical property of these atoms will differ accordingly. We call these atoms isotopes. When a chemical reaction takes place between two atoms, the atomic nuclei of these atoms remain unchanged.

In the case of a nuclear reaction, on the contrary, transposition of electrons has no such decisive meaning as in the case of a chemical reaction. In this case, a change takes place within the atomic nuclei. The matter produced by a nuclear reaction is either more complicated or simpler than the original matter. In the case of a chemical reaction the difference of energy before and after the reaction takes the form of heat divergence. The energy produced by a nuclear reaction is larger than that produced by a chemical reaction. In ordinary cases, the former is several hundred million times the latter.

If two hydrogen atoms join into a heavy hydrogen atom, the two hydrogen atoms before the fusion have their respective energy, and the heavy hydrogen atom created by the reaction also has its energy. However, since the energy of the heavy hydrogen is less than that of the two hydrogen atoms, there takes place a divergence of heat. In this reaction two hydrogen atoms join and consequently a new atomic nucleus is produced. This is what we call nuclear reaction, which differs from chemical reaction. The energy created in the production of a helium atom is far larger than that in the generation of a heavy hydrogen molecule, and this energy comes out as heat. In fact, in the case of such a nuclear reaction, the energy (which is hundred million times that in a chemical reaction) is released. Unfortunately indeed, however, it is very difficult to unit atomic nuclei in this way. I mean that it is very difficult to bring two atomic nuclei to a condition enabling them to undergo such a reaction.

However, there is an exceptional case where this nuclear reaction can be caused comparatively easily. This reaction is called "nuclear fission". For instance, when a neutron is subjected to the atomic nucleus of uranium 235, there occurs a very complicated phenomenon in which the nuclei are, as a whole, divided into two groups and then an enormous heat is generated. Generally, this phenomenon is accompanied by the emanation of 2.5 units of neutrons. It follows, then, that a nuclear fission results in the creation of nuclear fission products, the generation of heat and the emanation of neutrons. When fission takes place in comparatively large volume, one reaction brings about another and thus the fission goes on consecutively. However, when the volume is small, these neutrons disappear without being subjected to other nuclei. If the volume is large, the fission reaction will cease at this point. If a large quantity of uranium is employed in this case, the probability of neutrons being lost decreases, because the number of atoms to which neutrons are bombarded increases by the law of cube while the surface from which neutrons disappear increases by the law of square.

The minimum necessary quantity of fuel material for causing consecutively occurring reactions, namely the chain reaction, is called "critical quantity". In natural uranium, the isotope 235 which causes such fission is contained only to the extent of 0.7 per cent. The greater part of the remainder causes no fission. An average of 0.5 of the 2.5 units of neutrons which are emitted from fissioned uranium 235 is lost for some cause or another; one unit hits uranium 238 and the remaining one unit serves to sustain the chain reaction. Such a state takes place consecutively, and this is the phenomenon which is seen in an ordinary atomic reactor.

If the chain reaction is to take place continuously, as I have just said, a certain quantity of fuel has to be consumed. If there is too much loss of neutrons, the chain reaction cannot continue. On the other hand, when the quantity of fuel is larger than its critical quantity, the chain reaction will occur and the heat it generates can be utilized for industrial purposes. Whether or not it is possible to harness this energy depends on the extent to which heat can be taken out of the central part of the fuel. This we call heat efficiency.

In case ordinary uranium or only a little concentrated uranium is used as fuel, it is conceivable that all neutrons will be captured by uranium 238. If such a condition arises, the neutrons will be unable to cause nuclear fission in succession by being bombarded to uranium 235, and then the chain reaction will be discontinued. Uranium 238 is about 140 times more abundant than uranium 235, so we must invent some device if the chain reaction is to be continued.

The neutrons emitted when nuclear fission takes place have a very high velocity, and they are called fast neutrons. It is possible to increase the probability of the next nuclear fission being caused by lowering the velocity of these neutrons and also to decrease the probability of such neutrons being captured by uranium 238. As a means to decelerate the neutrons, it is conceivable to deprive them of their energy by bombarding them to certain other nuclei. The materials which are used to thus decelerate neutrons are called moderators. Often used as moderators are graphite and heavy water. The velocity of neutrons can be lowered by moderators to the level of molecular movements of ordinary gases. The neutrons which are decelerated to such an extent are called thermal neutrons, and those reactors which use such neutrons are called thermal reactors.

If an atomic reactor is to be operated in a stabilised state, it is necessary to keep constant the number of neutrons which exist in the reactor. This is possible through the process of having surplus neutrons captured when the number of neutrons increases, namely, by putting into the reactor a substance which will capture neutrons. Often used for this purpose is boron, which is put into the reactor in the form of a "control rod". When the control rod is put deep into an atomic reactor, for instance, the quantity of neutrons which are captured by it will increase, and those necessary for continuing a chain reaction will decrease. In the same sense, in the case of an utmost emergency and danger, for instance, it is possible to stop the operation of a reactor by putting into it a material which will capture neutrons. This is called "cutting method". An atomic reactor can thus discharge an enormous heat. The fuel used in atomic reactors is metallic uranium, which is coated with aluminium or other material. In this case, of course, part of the fuel will be transmuted, yielding nuclear fission products. It is possible to refine these "ashes" and separate plutonium which can be used for other fuel purposes. That is to say, uranium 238 in itself will not undergo any fission, but it will capture neutrons and is transmuted into an element called uranium 239 which does not exist in the natural form. Uranium 239 is a substance with an instable nature, and changes into another element by emitting electrons with a negative electric charge. Losing this negative electric charge means acquiring a higher atomic number. A new element named neptium with atomic number 93 which does not exist in the natural form is thus created, but this also is not stable and changes into another element, namely plutonium, atomic No. 94, while discharging negative-charged electrons again. This plutonium is a somewhat stabilized element, subject to nuclear fission.

The first atomic reactor in Britain was established in Harwell for research purposes. Later, a reactor for the purpose of extracting a large quantity of plutonium was constructed in Windscale near Harwell. However, the entire heat generated by the latter reactor was wasted without being harnessed at all. The reactor was dangerous because of its emanation of very strong radioactivity. The central part of the reactor was therefore shielded with a concrete wall with a thickness of about 9 inches (about 23 centimeters), and owing to this shield, radioactivity of the reactor was successfully lowered to below the tolerable limit.

However, as there was a danger that the concrete shield might be damaged by thermal neutrons, another type of shield was devised so as to absorb neutrons coming out of the reactor. This was called a shield against thermal neutrons. The reactor constructed in Windscale was a graphite reactor, and it was cooled by means of air circulation. The air used for cooling the center of the reactor was discharged through a chimney about 400 feet high.

For some decades to come, the Windscale reactor will remain as a reactor which was built up by our own hands. As to utilisation of heat generated in an atomic reactor, it becomes very important for the economical management of the reactor to contrive to obtain such heat in a higher temperature. With regard to the said reactor, people had originally possessed very limited knowledge about how to utilise the heat economically. However, as the technique achieved remarkable progress later, there are at present definite prospects on the economical utilization of such heat.

A generation reactor which can thus be operated economically is now near completion in Calder Hall. This reactor, just as the Windscale reactor, is a graphite moderation reactor, cooled by means of carbon dioxide. The carbon dioxide is pressurized and circulates around the fuel. A steam turbine is run by the heat carried with the carbon dioxide, and power is thus obtained. Operation of this reactor is to be started by the hand of the Queen in October this year.

Twelve atomic power plants are to be constructed by 1965, according to our program. They alone are expected to save 5 to 10 million tons of coal. Furthermore, it will become possible by 1975 to obtain from atomic reactors electric power equivalent to 50 million tons of coal. After 1975, in Britain, construction of ordinary water or thermal power generation are not planned, but, according to the program, electric generation will be carried out exclusively by atomic power plants.

Thermal reactors like that in Calder Hall, yield plutonium as a by-product. The question which naturally follows is in what field the plutonium can be used. It is possible to utilise the plutonium for other types of reactors. The so-called fast neutron breeder reactor is conceivable as a reactor appropriate to use the plutonium as a fuel. We are constructing a very large plutonium reactor in Downley in the north of Scotland. The hitherto mentioned reactors which use slow neutrons require moderators in order to decelerate neutrons. I meant that the use of moderators is for the purpose of preventing a number of neutrons from being captured by uranium 238. If most of the fuel to be used is made of a substance which can easily split, there would be no necessity of decelerating neutrons by expressly using the moderator. This is the reason we have to consider constructing fast reactors which do not use any moderator. Also, if no moderator is used, it will be unlikely that neutrons will be absorbed into impurities contained in the moderator.

The core of a fast reactor is surrounded by uranium 238. One of the reasons why this type of reactor is very economical is that most neutrons emitted from atomic nuclei are captured by uranium 238 and can also be transformed into plutonium 239 which undergoes nuclear fission. This reactor can produce plutonium in a larger quantity than fuel consumed; hence the name of breeder reactor.

The thermal output of the said generation reactor in Downley is about 60,000 KW. It core is very small, about 2 inches (5 centimeters) in diameter. A heat equivalent to about 30,000 ordinary heating stoves can be obtained from the centre of the fuel part. Any gas cooling device is not necessary for such a small central fuel part, and the use of liquid natrium as a cooler is conceivable instead. The natrium will be circulated around the reactor core by means of an electric pump. This will involve great technical difficulties, as such a large quantity of liquid natrium has never been used before.

If the natrium circulation is stopped for some cause or other, it is conceivable that the center of the reactor will be melted. In order to prevent very strongly radioactive materials from thus flowing away and contaminating things outside, the reactor core is placed in a steel container having a diameter of about 140 feet. Surrounding the reactor center, uranium 238 is placed as a "blanket".

The thermal reactor in Calder Hall and the fast reactor in Downley can be regarded as representing both extremes, the former being very heavy and less efficient, but safe and reliable as well as simple to design, while the latter is small, very light and efficient but involve many technical difficulties.

Various ways of reactor designing can be conceived between the two extremes. To itemise according to the velocity of neutrons, there are three types using fast neutrons, intermediate neutrons and very slow thermal neutrons respectively. Also conceivable are those using no moderator at all, using ordinary water, heavy water, graphite or beryllium as a moderator, and using gas, water, carbon dioxide or liquid metal as a cooler.

We can also conceive reactors using fuel metals not only in solid form but also as a solution or uranium colloid. They are called homogeneous reactors. It will require further studies to decide which of them will be the most useful for industrial purposes.

In Britain, we are now constructing fast reactors and have also started designing two or three other types of reactors which use neutrons of an intermediate velocity. However, the keenest attention at present is focused upon the thermal reactor which is to be completed in Calder Hall. I also think that there are unlimited possibilities of atomic generation being realised by means of new types of reactors.

Atomic Energy in Great Britain

(Lecture by Sir Christopher Hinton)
(at Osaka, on May 21, 1956.)

Introduction

The development of atomic energy in Britain can really be said to have started after the war, and the first step in the establishment of a British atomic energy project was the formation of the research organization under Sir John Cockcroft at Harwell.

This organization is engaged in long-term research and in devising the processes which are to be used in the industrial factories. It also does a considerable amount of applied research in aid of these industrial processes, but the Industrial organization has a Research and Development Section which does most of the chemical engineering and other development work which is necessary for the translation of Harwell flowsheets into industrial designs.

Review of the Past

The Industrial Group was formed a little later than Harwell, but still early in 1946. It first task was to design and construct the first large Harwell experimental pile. This pile is air-cooled and graphite moderated and was put into operation early in 1948.

Simultaneously with the construction of the Harwell experimental pile, the Industrial Group was engaged in building its factory at Springfields for the conversion of uranium ore into canned uranium metal slugs. Processes had been developed during the war by Imperial Chemical Industries for the manufacture of uranium metal from pure oxide on a pilot plant scale, but the extraction from ore and preparation of a pure oxide had not progressed beyond the test tube scale. The uncertainty about the effects of exposure to radioactivity and the poisonous nature of uranium raised problems of protection for the workers and a further difficulty was to achieve the required degree of purity, which is higher than is needed for most pharmaceutical products. The plant which was designed is not perfect but has operated well from the start in spite of these problems.

The ore arrives at the factory in steel drums and if the ore is pitchblende the drums contain a small amount of radon produced by radioactive decay. They therefore have to be unheaded in a closed chamber by remote control, after which the ore is tipped into a jaw crusher followed by a cone crusher. The radioactive gas is drawn off and diluted to a safe concentration before being released to the atmosphere. The crushed ore has to be carefully sampled to determine the uranium content and is then wet ground in a ball mill and the resulting slurry pumped to a stock tank. From the tank it is pumped to the first of three cascade dissolvers where mixed sulphuric and nitric acid is added. This dissolves the uranium and the solution, together with the insoluble matter in suspension, passes to the second tank where barium nitrate is added. The barium is precipitated and carries down with it the radium which is the main source of activity. After passing to the third vessel the liquid is pumped through filter presses which remove the suspended impurities. The uranium in the solution, which is now only slightly active, is precipitated by the addition of hydrogen peroxide and removed by filter pressing. This filter cake, though a pure uranium oxide by commercial standards, requires further purification to meet atomic energy standard and is re-dissolved in acid and extracted into ether. The impurities remain in the aqueous phase and the uranium, as uranyl nitrate, is then washed out of the ether and precipitated with ammonia in the form of ammonium diuranate, which is collected and dried on a Nutsch filter.

The ammonium diuranate is then converted to uranium tetrafluoride. It is packed in trays which are loaded into a cylindrical reactor and this is lowered into an electric furnace. The conversion proceeds in three stages; the diuranate is first heated to decompose it to uranium trioxide, this is reduced with hydrogen to the dioxide and the dioxide is then treated with anhydrous hydrofluoric acid gas to convert it to uranium tetrafluoride.

The final step in the manufacture of uranium metal is the reduction of the tetrafluoride with metallic calcium. A mixture of calcium chips and uranium tetrafluoride is tipped into a conical mild steel mould lined with calcium fluoride. The mould, which is mounted on a bogie, is run into the firing chamber, and the contents ignited by a pellet of potassium nitrate and lactose. This initiates a violent reaction. The uranium metal becomes molten and sinks to the bottom of the mould whilst the calcium fluoride, which is the other product, forms a slag on top. After leaving to cool the mould is broken down and the uranium billet removed. The billets are formed into bars which are machined to size and canned in aluminium ready for insertion into the piles.

It had initially been the intention that we should build water-cooled graphite moderated piles. However, for safety reasons we decided to build air-cooled piles for the production of plutonium. We felt, and I am sure that in our case it was true, that the disadvantages of the air cooled pile were outweighed by the fact that the air-cooled graphite moderated pile is inherently safe, and by adopting this type of pile we were able to build our factory on a site which was already developed and which was not so remote as to be inconvenient. The first of the two piles built in this factory was in operation rather less than 3½ years from the date when the site was chosen.

At this Windscale factory we have also the chemical plants for the extraction of plutonium and uranium from the irradiated metal. It was decided at a firly early date that we ought to adopt solvent extraction processes for these chemical separations, not merely because we wished to achieve the high efficiencies of which they are capable, but also because we felt that it was essential to adopt from the outset chemical processes which enabled us to recycle the uranium and so secure economy in its use. Construction of the chemical separation plants started late in 1948 on the basis of research work which had been carried out at the Chalk River Laboratories in Canada by Dr. Spence, who is now head of the Chemistry Division at Harwell. This work was done on only 20 milligrams of plutonium, and as there was no time for the construction of pilot or semi-technical plant before construction work started, we went into the full scale construction of the primary separation plant, which was very large and quite costly, on the basis only of Dr. Spence's research carried out on so small a quantity of plutonium. It is, of course, not difficult to scale up a chemical process in this way if the full scale process is to operate batchwise, but in this case we were scaling up from laboratory bench work to a continuous process and the results of chemical engineering research on the more difficult sections of the plant became available to the designers only after construction was well under way. In spite of this, the plant went into operation on the programmed date, virtually without trouble.

Early in 1950 it was decided to proceed with the construction of a gaseous diffusion plant for the manufacture of uranium slightly enriched in the fissionable 235 isotope. This plant was necessary for re-enrichment of the purified uranium separated from the irradiated slugs in the chemical plant at Windscale and made available for re-cycling through the piles. The plant was built at Capenhurst in Cheshire and started operation early in 1953. Alongside it has been built a plant for the manufacture of highly enriched uranium.

Plans for the Immediate Future

In the Windscale piles all the heat of fission is wasted; this is because, at the time they were built we did not have enough technological knowledge to enable us to recover the heat at a high enough temperature to generate power. These difficulties were sufficiently overcome by 1953 to enable us to start constructing reactors which would both make plutonium and generate electric power. They are now approaching completion at Calder Hall, in Cumberland. This factory will ultimately consist of four gas-cooled, graphite-moderated reactors and will have a full-load generating capacity of 180 megawatts at 11 KV. The station is to be run by the Atomic Energy Authority and will be opened by H. M. The Queen on October 17 of this year.

Based on this development a Government White Paper was produced in February 1955 which outlined the first stages of the programme for the development of industrial nuclear power in Great Britain. This programme starts with the construction of two gas-cooled, graphite-moderated stations, each with two reactors, and these should be in production in 1960 or 1961. By 1964 there should be twelve stations in operation, with a total generating capacity of around 2,000 mw. It is hoped that by 1975 nuclear power stations in Britain will be saving about 40 million tons of coal every year. Let us now consider two of the more important problems which lie in the way of producing useful power from nuclear energy.

(a) Firstly the problem of operating at high temperatures and high ratings.

Unfortunately there is no known way of converting nuclear energy into power without going through a heat cycle. It follows therefore that in order to get the maximum thermal efficiency we must use the heat which is available from our fission energy at the highest possible temperature. This can only be done if our fuel elements can be operated at high temperatures. Moreover, in order to get the greatest economy in capital cost, it is necessary to remove as much heat as possible from every ton of nuclear fuel that we put into the reactor. It cannot be over-emphasised that whereas the dimensions of the core of a nuclear reactor are determined primarily by nuclear physical considerations, the permissible rate of heat release, as well as the temperature at which we can operate our fuel element, depend on metallurgical engineering considerations.

In piles which use natural uranium as a fuel the fissile U235 is diluted by non-fissile U238 and because of this reasonably economical piles can be built with moderate heat releases per ton of fuel. But as we move into the field of reactors which use enriched material and progress even further into the fast reactor field where we must use a fuel which consists of almost pure fissile material we find that we must use very much higher rates of heat release. The need for this arises from the fact that our enriched fuels are very expensive and we must therefore get large quantities of heat per ton of fuel if our reactor is to be economical. At the high rates of heat evolution which we have to achieve in these highly rated reactors the problem lies not so much in getting the heat away from the surface of the fuel element as in conducting it through the mass of fuel in which it is generated to the surface from which it has to be removed. The rate of heat flux in the metal is such as to give very high thermal stresses both on the fuel and in the canning material which encloses it. To my mind the limiting problem in reactor design for many years to come will be the design of the fuel element; the reactors which we shall build will be as economical as our knowledge of fuel element design enables us to make them. This is one of the principal limitations in reactor design.

(b) Secondly the problem of safety

A nuclear reactor presents a potential hazard because of the accumulation of highly active fission products within the fuel. Any accident with a reactor, in the way of a fire or uncontrolled supercriticality, which resulted in the release of fission products from the core, could lead to the contamination of a surrounding area. For normal power station operation in the United Kingdom, therefore, it is essential either to build reactors which are inherently safe from the fire or supercriticality point of view, or alternatively to provide adequate containment of the entire reactor plant so that, whatever accident might occur, there could be no release of fission products sufficient to constitute a danger.

Let us consider a possible cause of an accident to a reactor. In the case of thermal reactors the core contains both moderator and coolant in addition to the fuel element. If the coolant is more effective as an absorber of neutrons than it is as a moderator, any loss of coolant from the core may result in an increase of the reactivity of the pile. This is because the neutrons that have previously been absorbed in the coolant now become available to cause further fission and so increase the activity. Such a reactor, for instance some designs of graphite or heavy water moderated piles using ordinary light water as coolant, may be inherently dangerous. On the other hand a graphite-moderated pile with air, CO_2 or helium cooling is inherently safe because loss of coolant will not increase the number of neutrons available to cause further fissions. Similarly it is possible to design a light or heavy water reactor using the same substances both as moderator and coolant in such a way that no sudden increase of reactivity can occur.

In the case of the more highly rated thermal reactors which can be built when enriched uranium is used, accidents are possible because of the small thermal capacity of the core.

It is probable that such reactors will use liquid metals as coolants; if for any reason circulation of the coolant ceases, the heat capacity of the core is so small that the temperature would rise sufficiently quickly to cause structural disintegration of the core and vapourisation of the liquid metal which might then catch fire and cause dispersal of fission products. The result of such an accident can be contained by housing the reactor in a suitable vessel which will stand the calculable pressure which may arise. This is being done on our fast reactor at Dounreay by housing the core of the fast reactor in a steel sphere.

It would be a mistake to suppose that the probability of an accident need be any higher in the case of a nuclear power plant than with any more conventional power plants, but the results might be more widespread if attention were not paid to the hazards which have been described.

Let us now look at a few of the alternative types of reactor which have been or are being developed for the generation of industrial power.

The Calder Hall type of reactor is a natural development from the BEPO and Windscale piles. We have an active core in the form of a cylinder of approximately 30 ft. diameter. We aim at reliable operation with a maximum surface temperature for the fuel elements around 400°C. It is necessary to put the gas coolant circuit under pressure, of 100 p.s.i., and this involves enclosing the entire core in a steel pressure vessel. The pressure vessel is about 40 ft. diameter. Difficulties arise in supporting the great weight of the graphite core and carrying the load through the pressure vessel on to the main supporting structure or foundations.

The uranium lies in vertical channels in the graphite moderator. Such an arrangement is convenient so far as the design of the coolant circuit is concerned and also from the point of view of the graphite structure. It leads to difficulty however in the method of supporting the weight of the fuel elements. If the reactor is arranged with horizontal channels the latter difficulty disappears but the design of the graphite structure becomes much more awkward. In either case there is difficulty in arranging a suitable mechanism for charging and discharging the fuel elements. If a separate hole through the shell of the pressure vessel is provided for every channel the design problem is extremely awkward. If, on the other hand the channels are grouped for charging and discharging the mechanism becomes more complex.

The coolant gas which is CO_2 is circulated round the closed coolant circuit by means of motor-driven blowers and the outlet temperature of the gas leaving the reactor is in the neighbourhood of 350°C. The heat exchangers or boilers are situated outside the main biological shield surrounding the reactor itself and the turbo-alternator plant is of conventional design.

The advantages of the graphite-moderated gas-cooled reactor are its inherent safety and stability and the large thermal capacity of the core. Heat ratings are quite modest, in the range between 1 and 2 MW per tonne of uranium, and this means that the capital investment of uranium is large. The main disadvantages of this type of reactor are the large investment of uranium required, the need to use high-purity graphite, and the difficulty of constructing the pressure shell. However, the graphite-moderated gas-cooled reactor is the one for which the greatest amount of knowledge and design experience are available, it uses techniques and materials of construction which are well established and is the only type of reactor which we could today put forward as a sound industrial proposition.

It is difficult to give a precise estimate of the cost of power generation from such a reactor owing to the problematical value to be allowed for the plutonium which it produces as a by-product. Two a half years ago the best estimate for the first prototype was a penny a unit, neglecting any credit for the plutonium. The figure, taking account of technical advances and making a reasonable allowance for the value of the plutonium, was given in the White Paper as 0.6 pence per unit for the reactors of this type which are included in the programme for the next ten years. More recent work suggests that this figure is not over optimistic.

If this competitive price can be achieved in the first nuclear power stations, it should be possible, with the development of techniques, to make considerable improvements and to generate electrical energy from nuclear power at prices lower than those which can be achieved by the use of conventional fuels. There is good reason for believing that this will be achieved. In conventional power stations, approximately two-thirds of the total generating charges are taken up by the cost of fuel; the other one-third is taken up by capital and operating charges. In our first nuclear power stations, these proportions are approximately reversed: one-third of the generating charges are taken up in the cost of fuel and approximately two-thirds are taken up in operating and capital charges, of which the capital charges represent a very considerable part.

Now, it is common experience in the engineering industry that capital charges decrease as techniques of design are developed. [Fig. 16 shows the way in which the capital cost of steam power stations and land-based oil engines has fallen off with time since they were first introduced.] For example in the second half of the 18th century, the cost per HP of a steam power station was over £2,000 - in the middle 1950's this cost per horse-power had fallen to about £40.

Every technical consideration suggests that the unit cost of nuclear power stations will follow a similar trend. But a steady fall in capital cost is of greater importance when capital charges represent nearly two-thirds of production costs than when they represent rather less than one-third, and it seems highly probable, therefore, that with the passage of time the cost of power produced in nuclear power stations will fall relative to that of power produced in conventional stations.

The gas cooled reactor is not capable of very high ratings and liquid cooled reactor must be developed because in these it will be possible to achieve these higher ratings; in the long run. This will reduce costs and reactors with high ratings are essential to enable us to burn up the plutonium produced as a by-product in gas cooled reactors.

Heavy Water Moderated Natural Uranium Reactor

From a physicist's point of view, heavy water is the best moderator for a thermal reactor since it gives the best neutron economy that is known to be possible. Because of this economy the critical size of the core is smaller and to take advantage of this we must get our heat away from a small surface area. The use of a gas coolant is therefore no longer possible and we must use a liquid coolant. Ordinary light water would be an obvious choice were it not for the fact that this would give us an inherently dangerous reactor. It is therefore desirable to choose heavy water for use as coolant as well as moderator. We should now be able to go to ratings in the range between 5 and 10 MW per tonne of uranium.

The estimated cost of power generation from a heavy water moderated reactor depends very much on the price to be paid for heavy water since this is a major capital item, but when the technological difficulties have been overcome it should be but about 1.0 pence per unit. In many ways the heavy water reactor is an attractive piece of plant. However, it has the great disadvantage of the limited availability of heavy water.

Light Water Moderated Reactor Using Enriched Uranium

As an alternative to the heavy water reactor, it is possible to employ ordinary light water both as moderator and coolant provided enriched uranium can be used as the fuel. We could thus save the cost of heavy water at the price of paying for enriched uranium from a diffusion plant.

The use of light water should give greater freedom in the design of the charging and discharging arrangements but the metallurgical and engineering problems of designing water cooled and moderated reactors for power production should not be underestimated.

Intermediate or Fast Reactors

The next step in the sequence of possible power producing reactors is to dispense with the moderator altogether and to use a highly enriched fuel. The core of such a reactor, in which the fission process would be carried on by intermediate or fast (as opposed to thermal) neutrons, would contain a fuel having a relatively high proportion of one of the fissile elements or isotopes, U233, U235 or Pu239 together with one of the fertile elements, i.e. an element which can absorb neutrons to form a fissile material such as Th232 or U238.

It is a reactor of this type that we are building at Dounreay. The absence of moderator results in an active core of very small volume. This volume can of course be increased by dilution of the fissile element with a greater quantity of the fertile element or alternatively by the addition of some other diluent to the core. Either course of action, however, introduces materials which absorb neutrons and therefore increase the investment of fissile material necessary to give a critical assembly. Since the capital cost of the fissile material in the core is the major item in the economic of this type of reactor, we must therefore face the problem of designing a core of very small size, say a cylinder of 2 ft. diameter and length with a heat rating of perhaps 100 MW.

This is a difficult problem but there are strong reasons for facing it because probably fast reactors can be made to breed more fissile material than they consume and so, while generating power, they can increase our stock of fissile material. Moreover, if a large number of thermal reactors are to be built and operated for power generation there will be a corresponding production of by-product plutonium and this could conveniently be used as a fuel in fast reactors.

The whole problem of the fast reactor is centered on the small size of the core. It is not so much the heat transfer from the surface of the fuel elements to the coolant that is the stumbling block, although this is difficult enough since we may be asking for a heat flux around 3×10^6 BTU/hr per sq.ft.

The real difficulties with these very high heat ratings are the large temperature gradients and thermal stresses occurring in the fuel elements themselves, the difficulty of maintaining reasonably uniform temperature conditions round the surfaces of the elements, and the distortion of the elements which may take place.

In outlining some of the problems of the fast reactor I have implied that the reactor core would be of conventional design in having solid-metal fuel elements. Because of our limited knowledge of the physics and engineering of other systems, this is the only form of construction which can be followed at the present time but one inevitably searches for a better and radically different design. One would like to separate the heat-transfer problem from the nuclear physics of the core, and, in fact, to transfer the heat outside the core. One would like to provide for continuous removal of gaseous fission products. One would like an arrangement in which the fuel is already liquid so that the problem of melting of the fuel elements, in the event of disturbance of the coolant flow, would disappear. Any such scheme which would involve circulating a liquid fuel through the reactor brings up a host of chemical, physical, and metallurigical problems. As regards heat transfer, an evaporative system would be better than a liquid coolant arrangement. A homogeneous reactor core consisting of a solution of the fissile material in some solvent, which would be allowed to boil continuously, would be a possibility. A great deal of work remains to be done and immense possibilities are open to those who work in this, most interesting and important field of producing useful industrial power from nuclear energy.

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Lecture - For Scientists

(Lecture by Sir Hinton
at Tokyo on May 23, 1956)

In presenting lectures on the work we have done in developing our atomic energy programme I am usually speaking to a group of scientists or engineers with specific interests. Thus I may be talking to engineers on the design of a particular type of reactor, to physicists on reactor controls or to chemists on the ancillary chemical processes. But when I prepared this lecture, as I did, half the world away from my audience, I understood that today I should be speaking to scientists generally and not to scientists with one common and specific interest. I shall, therefore, try in this paper to indicate the scope and nature of the research programme which we have found necessary in support of our atomic energy programme, and I hope that you will find this useful.

I indicated in my first lecture what we have already achieved in Great Britain but I think it worth while to recapitulate the stages of development that we have passed through and our plans for the future.

The Atomic Energy organisation in Great Britain was established in 1946 and our immediate objective was the manufacture of plutonium for defence purposes. I briefly outlined in my first lecture the extraction process at the Springfields factory where the uranium fuel elements are fabricated. The next stage was to build a reactor and at that time our knowledge of reactor technology was not sufficient to enable us to design a dual purpose pile where we could use the heat generated in the reactor core as well as manufacture plutonium. Therefore, in the Windscale piles, the reactor is cooled by a current of air which is passed out to atmosphere through a 400 ft. chimney and the heat of fission is wasted.

In order to generate power from heat it is necessary that the heat should be available at a high enough temperature and research work on the heat transfer and metallurgical problems involved in doing this continued whilst operating experience was obtained on the Windscale piles. By 1953 our knowledge was such that construction work could commence on the first of our power-producing reactors at Calder Hall, on a site adjacent to the Windscale piles. These Calder reactors are, like their Windscale predecessors, graphite-moderated. Carbon dioxide gas was chosen as coolant in view of its low cost, ease of availability, neutron absorption cross section, and low chemical reactivity under pile conditions. The gas is circulated from the reactor through a heat exchanger, where the heat is used to form super-heated steam to drive conventional turbo-alternator generating sets.

The British programme for the development of nuclear power starts with the construction of two or probably three gas-cooled graphite-moderated stations, similar to the prototype station at Calder, each station having two reactors. Construction of these should start about mid 1957 and they should come into operation in 1960-61. The construction of two further stations will begin about 18 months later, in these the reactors will be of a similar type but they should show an improved performance, particularly in heat rating. By 1965, twelve stations should be in operation and this group should supply between 1,500 and 2,000 megawatts of electrical power. The first reactors of this group will be of the gas-cooled graphite-moderated type but the last two or three may be of the liquid-cooled type which may then have been developed sufficiently to be economically satisfactory.

Our planning of the development of the industrial uses of atomic energy in England has largely been conditioned by the coal supply situation. Our present usage of coal for generation of electricity is about 36 million tons a year and, without nuclear power, it is estimated that by 1975 we should be using 100 million tons per annum. Coal is becoming increasingly difficult to obtain so that the price will rise and reliance on coal alone as a source of power would mean that cost of electricity would increase considerably and rapidly.

In the position of urgently requiring power from atomic energy we have placed our reliance firstly on the gas-cooled graphite-moderated reactors. While these have short-comings, they have the advantages of being inherently safe, of being simple in engineering design and of using materials and techniques of construction which are well established - no great difficulties are expected in getting them into operation. They are, moreover, capable of great improvement; but in our second stage of development they will have to be supplemented, and perhaps ultimately superseded, by reactors which are capable of high ratings. These will certainly be necessary to burn the bye product plutonium produced in the first stage reactors. To this end a prototype fast reactor is under construction in the north of Scotland - this type of reactor is very highly rated uses concentrated nuclear fuel and is capable of creating more fissile material than it destroys. We are also working on the design of thermal reactors which are capable of high ratings.

Our long-term programme may therefore be summarised as follows. We aim first of all at securing a reliable output of power from reactors of the Calder Hall type, we aim next at improving these reactors to make them more economical, and we aim next to develop scientific knowledge, materials, and techniques, to enable us to build the highly rated reactors of the second stage.

A programme of this magnitude obviously calls for large design and development groups and an extensive research programme. For the nuclear physical research which is necessary the use of experimental reactors is essential and those which are used can be divided into two general types

(a) reactors built and operated as research tools in which irradiation of materials is carried out or measurement of nuclear constants is made.

(b) reactors built to study problems specific to the design of a single full scale project.

In considering the first of these classes, we find that there is a bewildering choice of types. In order to carry out irradiation quickly and obtain early results, the scientist demands a reactor with a high neutron intensity in the core.

Irradiation of nuclear fuel is conveniently expressed in MWD/T or percent burn-up; 10,000 MWD/T is about 1 percent burn-up. For economic reasons we need to achieve about 0.3 percent burn-up in a reactor using natural or near-natural U; probably 1 percent with uranium enriched 1.5-2 times and perhaps 5 or 10 percent in a fast reactor having 10-25 percent fissile material in the fuel. Now BEPO the first Harwell experimental pile has a flux of 1 or 2.10^{12} ns per cm^2 per sec. and will give a burn-up of 0.1 percent of natural uranium in 16 years. One might use, say, 5 Cs uranium for metallurgical experiments on fuel and reduce this to 3 years but evidently no very useful experiments of this sort can be done in a reactor of this type. Pluto has a flux about 100 times as great and can produce 1 percent burn-up in test-specimens in 3 or 4 months; it is therefore very useful for this sort of work. When irradiating other materials one needs to displace, by fast neutron collision, say 1 percent of the atoms to get significant results. [Assume a target area of 10 barns per atom. This is 10^{-23} cm^2. The material must therefore experience an integrated fast neutron flux of 10^{21} ns per cm^2.] If this is to be achieved in 1/3 of a year [(10^7 seconds)] one needs, once again, a neutron flux of 10^{14} ns per cm^2 per sec. Hence Pluto is the right reactor for materials testing, but the volume of its core is small and it will accommodate only a small number of tests at any one time. The practical technologists (the engineer) is not happy to design his plant on the basis of a few experimental results which may be fortuitous - he needs results from a reactor in which the core has a sufficient volume to give a statistically adequate number of experiments. BEPO has this large core volume but gives only a small flux. If we try to build a reactor with a big core volume and a big neutron flux we have a reactor on the industrial scale with big capital cost, big burn up of feed and big operating costs. I know of no royal road to the solution of this problem. Except by making the programme for the construction and operation of industrial reactors keep in step with the research programme.

It will be clear that there are great advantages to be gained from making an early start on an industrial programme since the reactors built combine high flux values with a large volume and much valuable statistical data can be derived from their normal operation.

A full research programme must however include some provision of high neutron flux research reactors of which the following are examples:-

1. Dido and Pluto reactors in the U.K. with a maximum neutron flux of 10^{14}ns/cm^2/sec. and 10 MW heat rating. These reactors use heavy water moderation and cooling.

2. M.T.R. and CP5 reactors in the U.S.A. These are different in type from one another. CP5 may be regarded as a smaller version of the Dido-Pluto reactors with heavy water moderator and coolant, and a maximum neutron flux of 1.7 x 10^{13}ns/sq.cm/sec. at a power of 1 MW. The M.T.R. reactor is moderated and cooled with ordinary water which gives a high fast neutron flux and a high total neutron flux of 4 x 10^{14}ns/sq.cm/sec. at a heat rating of 30 MW. It is therefore a powerful and useful research reactor.

3. N.R.X. and N.R.U. reactors are used in Canada. Both have heavy water

as a moderator but the earlier reactor N.R.X. has natural water as a coolant while N.R.U. uses heavy water as coolant. These are high powered reactors, N.R.X. being rated at 40 MW for a maximum neutron flux of 7×10^{13} while N.R.U. has a heat rating of 200 MW and a maximum flux of 3×4^{14} nn/sq.cm/sec. and is therefore an expensive piece of research equipment.

The British and U.S. reactors have roughly the same core size which can be taken as approximately a cube of 2 foot side (the effective core volume is 12 cubic feet) but the Canadian reactors are larger.

It is interesting to note that these powerful research reactors are all water cooled. Gas cooled reactors have been built for research purposes as at Harwell (Bepo) and Brookhaven but gas cooling only allows lower ratings and fluxes (e.g. Brookhaven, 4.10^{12} nn cm^{-2} sec^{-1}). The enriched U reactors all use "sandwich plates" for fuel elements with a central sheet of U - Al alloy (10 - 20 percent U by weight) about 0.02" thick, clad in pure Al sheets of about same thickness. The plates are welded into a box construction with 5 to 20 plates per box. These elements were invented in U.S.A., adopted in U.K. and are extremely successful. NRU uses thick U sheets, 0.156" thick, clad in 0.040" aluminium. NRX uses 1.36" dia. U rods, clad in 0.080" Al.

The "Swimming Pool Reactor" uses the same type of fuel elements as Dido and CP5, but is cooled by convection. It is very cheap and yet gives a flux 10^{12} nn cm^{-2} sec^{-1} (100 K W total power) and is useful for some experiments mainly in connection with shielding but not for materials testing. By Pluto is expensive both in capital and operating costs. The easy access to the core of Swimming Pool reactor is convenient for fuel element handling, maintenance and insertion and withdrawal of experiments. However, its low flux and power, limits the usefulness of the Swimming Pool Reactor and its main use in technological work is confined to shielding experiments and for training purposes.

Experimental reactors with a large core volume must normally use natural or near natural uranium since we cannot afford to fill a large volume with highly enriched uranium. Air is convenient as a coolant since the heat rate per unit mass of fuel will be low if the total power output is kept down to a level consistent with reasonable capital and operating charges. On cost grounds graphite would ordinarily be selected as moderator since heavy water is very expensive. Typical experimental reactors of this type are Gleep, and Bepo at Harwell and the similar reactor at Brookhaven. This is the sequence in which they were built and it shows a progressive rise in neutron flux values (3.7×10^{10}, 2×10^{12} and 4×10^{12} nn/sq.cm/sec. respectively) and also in complexity. Bigger reactors of this type are probably not justified for experimental work alone.

If a large volume is required at a not-too-small flux, the overall power must be high and hence the reactor might as well be a plutonium and perhaps a power producer. The Windscale piles, built for Pu production, have proved very useful for experimental work. Their chief disadvantages are that one would like a 3 or 4 times higher flux and that they have not enough experimental holes in the graphite or space outside for associated equipment. One never is sufficiently far ahead with research reactors, and much must be learnt, perforce, from each

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generation of industrial reactors to be applied in the next. Thus much information used in the design of Calder Hall reactors was derived from the Windscale piles and Calder Hall in its turn will give useful facts for the first actual power stations of the central electricity authority.

Reactors of the type described so far are useful for general experiments in the physics, chemistry, engineering and metallurgy of reactors. Sometimes additional experiments are necessary closely simulating the proposed design of a specific reactor and to ensure that in that reactor the power output specification can be reliably met. These experiments need considerable quantities of fuel and sometimes other expensive materials long before they would be needed for building the finished power reactor.

In order to design a nuclear reactor it is necessary to predict certain design parameters (for example the well known thermal utilization and resonance escape factors in thermal neutron reactors) which essentially describe the average fates of the neutrons produced in fission. Unfortunately neutron cross-section data alone is insufficient for this purpose and additional information is required on the neutron flux distribution within the lattice cell of a heterogeneous reactor and on the neutron spectrum at various points in the lattice cell. Classical diffusion theory is generally used for thermal reactor design calculations and for some fast reactor work and is the only practical theory where large numbers of cases are to be investigated using desk type computing machines, but this theory is known to predict the neutron flux distribution incorrectly and furthermore no account is taken of neutron spectrum effects. However, the diffusion theory method of calculation can be correlated with experimentally determined neutron fates in two types of integral experiment:

(a) Exponential experiments
(b) Zero energy experiments

(a) In an exponential experiment neutrons from an extraneous source are fed into an assembly of fuel and moderator which is smaller than the critical size (about 1/40 - 1/10 by volume) and by means of measurements of the neutron flux distribution within the assembly some of the design parameters can be obtained. Such experiments are only suitable for large sized systems (for example natural uranium and graphite moderated reactors) where the loss of neutrons by leakage from the experiment is not serious enough to make the neutron flux too low for measurement.

The exponential experiment has the advantage that, apart from the cost of the reactor materials (which can often to some extent be re-used in an actual reactor) they are cheap to carry out, involving no shielding (other than that incidental to the neutron sources) and no instrumentation relevant to the assembly itself. However they do suffer from the disadvantage that only information relevant to the lattice cell of the reactor may be obtained and no data can be gathered about the effects of reflectors, control rods and other perturbations. In large systems these effects are either not very important or their estimation from diffusion theory is not subject to gross errors.

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(b) In the case of thermal reactors using enriched fuels or fast reactors the size of the reactor is so small that the neutron fluxes obtainable in an exponential experiment would be too low for accurate measurement, so that in order to obtain the design parameters it is necessary to build a zero energy reactor. In this experiment an assembly of fuel and moderator (if any) is built large enough to be just critical and having some excess reactivity which can be used in the course of experiment. The neutron flux, although adequate for activating detectors, is never allowed to rise to such an extent that large amounts of heat are evolved. In spite of this, however, the experiment is essentially a reactor so that adequate biological shielding must be provided together with instrumentation, control gear and in general all the usual features of any normal reactor except the means of removing large amounts of heat from the core. The experiment is necessarily expensive in comparison with exponential experiments but does have the advantage that in addition to yielding all the usual design parameters, fuel structure and neutron spectrum information, data can be gathered on the effects of reflectors, control rods and other perturbations. This is fortunate since these effects are not always easy to estimate for a small reactor even by the relatively simple diffusion theory.

The low cost of exponential experiments and the ease with which the lattice pitch and structural features such as coolant channel sizes can be varied leads to their use for the general correlation of experiment and theory. In the United Kingdom for example, experiments have been carried out on upwards of 30 different graphite-natural uranium lattices covering a wide range of volume of moderator to volume of uranium ratios and the results have been correlated with a specific method of calculation based on diffusion theory. This programme required the provision of large quantities of graphite (~ 100 tons) and uranium (~ 30 tons) several years in advance of any requirements for a specific project.

On the other hand the high cost of a zero-energy experiment and its somewhat lower flexibility (particularly in case of handling) leads to its use as an experiment for the guidance of a specific project. An example of this is the zero-energy fast reactor ZEPHYR which was designed to provide basic information for the design of a high power fast reactor. The core consists of nickel sheathed plutonium fuel elements in a uranium cylinder with a natural uranium reflector and blanket. The total cost of ZEPHYR was 200,000 (£70,000) including the fuel and uranium. Even with the information from ZEPHYR it was found that some design parameters for the project could not be predicted with the necessary accuracy. This experiment was therefore followed by a more specific zero-energy experiment ZEUS in which the actual design adopted was so closely simulated that information could be obtained on the effects of reflectors, control rods and other disturbing influences.

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It is, however, always wise to remember that (as a first approximation) it is true to say that the heat output of any reactor system depends not on the nuclear characteristics of that system (provided that it has been made

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supercritical) but on our ability to remove heat from the system. Thus the limiting rating of a reactor system (provided we neglect in this first approximation the effects of poisoning) depends not on nuclear physics but on metallurgy and engineering. It may be of interest to you to know that in the laboratories of the U.K. Atomic Energy Authority, approximately 75 percent of the staff never or rarely make use of irradiation facilities in experimental reactors.

Let us first of all consider some of the metallurgical problems of fuel element manufacture for reactors of the Calder Hall type.

One of the first problems which has to be considered is the choice of canning material. In the Windscale piles aluminium cans have proved to be very satisfactory. For reactors of the Calder Hall type, however, it is desirable for economic reasons to increase both the maximum can temperature and the total irradiation. At the same time the neutron absorption must be reasonably low and oxidation resistance must be satisfactory at the working temperatures in CO_2, which was selected as the coolant. The increase in temperature over the Windscale piles weighed against aluminium, which is extremely soft at the probable working temperatures. Steel and other possible metals were ruled out on grounds of absorption cross-sections. Beryllium is very attractive but extraction and fabrication techniques are hardly sufficiently advanced at present to allow of immediate application. Zirconium is possible but both its strength and oxidation resistance at the higher temperatures are marginal and fabrication techniques are still rather novel. Choice for the first reactors has therefore fallen on magnesium.

The suitability of magnesium was not immediately obvious and very careful study has been required to confirm this, especially with regard to oxidation and deformation characteristics. Special alloys have been developed, however, which are surprisingly satisfactory in their oxidation behaviour both in air and CO_2. A more difficult problem is to obtain an alloy with a satisfactory balance between strength and ductility. In the hotter parts of the reactor the cans must at least retain their shape while in the cooler portions some local deformation due to small changes in shape or contour must be accepted without cracking. Since magnesium has limited deformation mechanisms and a tendency to form large grains, it can in some circumstances be lacking in ductility. The alloy which has been developed is believed to be adequate in both these respects, even with the complication of irradiation, but the solution is a rather finely balanced one. Having selected the alloy, developing and proving the actual production and fabrication methods required a major effort since atomic energy requirements demand a freedom from defects, such as inclusions, well beyond that normally specified.

Under the conditions of the Calder piles, the most notable effect of irradiation on the fuel arises from the anisotropy of uranium and its temperature dependent deformation mechanisms. Under the intense and highly localised thermal effects of fission, transient stresses occur resulting in plastic deformation.

Unfortunately, it is believed that these plastic deformations on heating and cooling are not entirely reversible and there can be a net change in external shape of the crystal. Depending on the [illegible] structure these individual crystal

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deformations can give rise to bowing, surface wrinkling or to overall changes in length. Such behaviour may be controlled by suitable metallurgical structures, but the phenomena are not by any means simple and a very extensive irradiation programme over a range of temperature and irradiation conditions is necessary before these structures can be defined. In addition, the temperatures required impinge on the creep range for uranium, and this can be important if the reactor design requires the uranium to bear some load. Creep resistance can be improved by alloying, but these additions are costly in neutrons. Accordingly, good design requires the selection of a uranium alloy, from a range being developed, which has adequate strength and minimum neutron loss.

When we consider the similar problems that arise in connection with highly rated reactors, the pattern becomes even more complex. Here we require higher burn-ups, temperatures and temperature gradients in more concentrated fuels. In addition to the problems previously mentioned there are several potential effects as yet imperfectly understood. The most obvious one is that the degree of burn-up sought involves a significant increase in volume due to the formation of additional atoms by fission. Since some of these new atoms may be inert gases it is possible that gas bubbles could be formed to cause further swelling, which will be assisted by the softening of the uranium at the higher temperatures. Also the thermal stresses due to the temperature gradients represent a problem well beyond normal engineering experience. A further complication may arise as a result of minor fluctuations in the temperatures, especially where a boundary between two allotropic forms of uranium occurs within the fuel. The effects of the movement of isotherms through an anisotropic material which also has a large volume change on phase transformation are difficult to predict but may result in changes in shape or density. Such phenomena are exceedingly difficult to study experimentally, except in a reactor of the type under consideration. Some ingenious and elaborate experiments have been devised, however, which enable one to construct a reactor experiment in which more accurate studies may be made.

Canning materials for highly rated reactors are clearly a key problem. Designs are likely to require the strength of the canning materials to contribute largely to the strength of the core structure, in addition to withstanding possibly large stresses from the changes in the fuel outlined above. Temperatures and probable stresses are such that the better creep-resisting steels and alloys would be attractive; unfortunately, most of these form low melting point eutectics with uranium and must be ruled out unless one is prepared to accept an unattractively low temperature. In these reactors, the neutron absorption conditions are rather less restrictive, fortunately, although still not a negligible feature. The canning material may also require to withstand attack by liquid metal coolants. No final choice of canning material for such reactors may be made for some time. However, many of the metals of interest, such as tantalum, molybdenum, niobium and tungsten are not readily available in suitable forms and formidable development problems must be overcome if these materials are to be utilised.

In liquid metal cooled reactors it is obvious that novel requirements will be met but even in reactors employing water as coolant or moderator severe corrosion problems are involved, particularly an efficient power producers involve high temperatures, pressures and flow rates. Such a reactor could, in fact, very well be used as a demonstration of some classical corrosion phenomena. For example, it is almost impossible to avoid the use of dissimilar metals in the circuit, flow conditions could well produce erosion and cavitation and, where two parts rub together, fretting corrosion is possible. Irradiation may be expected to enhance some of these reactions. Further, in the parts of the circuit at lower temperatures and not subject to direct irradiation, it might be expected that corrosion products might be deposited with consequent difficulties in heat transfer or blockages. Solutions for many of these difficulties have been proposed. Quite elaborate experiments are required, however, to develop and prove these ideas, since in this field any considerable departure from the actual conditions of interest is liable to give misleading results. Thus, experimental loops in a high flux testing reactor are essential and appropriate conditions of temperature, pressure and flow conditions must be provided, not only in the irradiated section, but also in the out of flux portion, especially when mass transfer or crud formation are being studied. Such a loop requires an important investment in high grade engineering effort both to design and to operate it and costs a lot of money.

Zirconium alloys are of particular interest in relation to water cooled reactors. The technology of zirconium is rather behind that of titanium and, by analogy with the latter, is likely to require a large scale development effort before it is readily available in a suitable variety of shapes and properties.

There are two other features of the water cooled reactors of interest. One is that the design and construction of the pressure vessel, involving as it does fairly frequent access to part or all of the internal space, is a uniquely difficult problem. Arising partly from this, it is more desirable than in some other reactors that the progress of defects in fuel elements should not be rapid, so that special unscheduled shut-downs may be avoided. At the same time, ordinary uranium is extremely rapidly attacked by the coolant water. For reasonable operation, therefore, it seems necessary to develop fuels which are corrosion resistant in high temperature water.

I quote these metallurgical problems only by way of illustration that nuclear energy development depends on a combination of technologies in engineering, metallurgy, chemistry and physics and undue emphasis on any one branch of science will not bring success. In Japan you have had great success in some of the newer branches of metallurgy, e.g. in the field of magnetic materials, and I would hope you would be able to make a similar contribution in the field of nuclear energy.

Some of the most interesting engineering problems on which research is required in connection with the design of highly rated reactors are largely connected with heat transmission. As we go to higher ratings in our reactors carbon dioxide, as used at Calder Hall, will be regarded as increasingly unsatisfactory as a heat transfer fluid. Our White Paper programme, visualises the ultimate use of liquid coolants which in the first place must be either water or liquid metals. Water is a good heat transfer medium and also a good working fluid in a heat engine but it suffers from the fact that even for moderately high temperature use, very high pressures may be required. For this reason liquid metals which permit higher temperatures without high pressure are of very great interest.

The choice of liquid metals suitable for use in a nuclear reactor is limited to sodium, sodium-potassium, lead-bismuth, lead-bismuth-tin, and mercury. From the corrosion aspect, sodium and sodium potassium are the logical choice, and of these two, sodium is to be preferred on grounds of neutron economy, sodium has a reaction absorption cross section 0.0258 b/cc. compared with NaK eutectic cross section, .0234 b/cc.; U cross section .365 b/cc.; Stainless Steel cross section 0.239 b/cc.

The chief disadvantage of sodium as compared with the eutectic is its higher freezing point of 97°C, but this can be offset by suitable handling techniques.

Liquid metals possess the advantage of a wide range of working temperature between melting point and boiling point, (Na - melting point 97.8°C, boiling point 881°C) and furthermore, the high temperature at which they can be used enables a high overall thermal efficiency to be achieved. The high thermal conductivity of liquid metal gives a low temperature drop between the nuclear heat source and the liquid metal stream, thus allowing the heat source to work at a lower temperature for a given coolant outlet temperature, than would be the case for instance with a gaseous coolant or with water.

Compared with gaseous coolants the pumping power required for a sodium circuit is extremely low, the sodium requiring about 1/10th of the power absorbed by a gas circuit.

The use of sodium has some disadvantages, chiefly associated with handling and corrosion, which have been overcome by the use of appropriate techniques, and sodium is now handled in ton quantities without difficulty.

The corrosion difficulties are mostly brought about by the presence of oxide in the sodium, and can be dealt with by cold filtration and cold trapping techniques. Sodium loops have now been running for thousands of hours in our laboratories.

Good engineering design is needed to ensure the safe and reliable running of a sodium plant. A few surprises await the uninitiated but In the main our experimental work has confirmed published theoretical predictions. We are confident that considerable use of liquid metal coolants will be found in nuclear energy and shall continue our own programme of experimental work.

In these circumstances you may be surprised to know that we are still working hard in studies of heat transfer in gas cooled systems. We are constantly applying a considerable effort to the study of the most suitable surfaces to employ in particular reactors. Many economies are possible as a result of work of this kind and although it is not to be regarded as basic scientific research, from an economical point of view, it is most important. For we believe that gas cooled graphite moderated reactors will continue in use for many years.

Although to-day I am speaking to a scientific audience, of the research and development effort in a nuclear energy project, I have not attempted to deal with all research subjects but only to choose examples as illustrations. For instance in all this I have said nothing about research work on uranium extraction processes nor on the chemical treatment of irradiated fuel elements, and in my first lecture I made only passing reference to these plants. My reason for this is that in the early stages of developing a Japanese project, you might find it possible to avoid the need for building such plants. It is possible that you could arrange to procure fuel elements and have them processed after irradiation by one of the countries which already has well established plants doing this work.

In conclusion, I should like to emphasise once again, what I have already said and what I consider to be one of the most important points that I have tried to indicate in this lecture. Research aimed at developing an atomic energy industry for peaceful purposes is not merely research on nuclear physics; it is a fully integrated programme comprising the appropriate aspects of chemistry, metallurgy, classical physics and engineering as well as the nuclear physics field.

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Panel Discussion on Atomic Power Generation in Britain

Japanese Government, industrial and scientific circles are attaching much hope to the visit to Japan of Sir Christopher HINTON, who is the director of the Industrial Group of the British Atomic Energy Authority. The Yomiuri Shimbun asked Sir Christopher HINTON, Atomic Energy Commission Chairman SHORIKI and Advisor to the Atomic Energy Commission Dr. Ryokichi SAGANE to discuss the development of atomic energy industries and atomic power generation in Britain. Mr. SHORIKI and Mr. SAGANE also asked for advice on Japan's atomic energy development. During discussion on the cost of atomic power generation, Sir Christopher HINTON made a very significant statement that "If plutonium is counted as fuel for the atomic power plant, the cost of atomic power generation will be 0.6 pence" and that there is possibility of further cutting down the cost. This has brought new hope for atomic power generation which had been considered too costly to become paying.

The following is report of the panel discussion participated in by Sir Christopher HINTON, Mr. SHORIKI and Dr. SAGANE.

SHORIKI: In Japan, some people hold the view that Japan's energy condition resembles that of the British energy condition and that therefore Japan should follow the example set by Britain. It is true that both countries lack energy resources and that both are worried about the day when supply of power will not be able to cover the increasing demand. However, the real situation is that Britain is a first-rate country when we consider the ratio of energy supply to the people's income. Japan, on the hand, is worse off in this respect than Hungary or Argentina. If such a situation is permitted to continue, it will never be possible for Japan to keep pace with the world's leading powers. Japan can never become one of the world's leading powers so long as she persists in a negative program for power generation, that is, a program which will merely try to cover the shortage of electric power. I earnestly desire the Japanese people's realization of this fact and awaken to the need of greater efforts in this line. I cannot but pay my greatest respects to Britain, which, although being in an unfavorable circumstance, made such great efforts to develop atomic power generation in advance of the other nations of the world. First, I would like to hear about Britain's atomic power policy.

HINTON: In planning for atomic power development in the initial stage, the general principle would be to adopt a method which seems to bring the best results. In Britain, we used the best materials and highest technology available and tried our best to make atomic power development a paying enterprise. The program is now tending toward expansion. The initial program which aimed at building two atomic power generation reactors in eighteen months is now being changed to a program of building three reactors in the same period of time. The reactors we have today produce plutonium only as a by-product. You cannot produce a

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large amount of plutonium in a reactor which uses graphite as a moderator. Therefore, it is most important to make a breeding-type reactor which will produce plutonium in large quantities, which in turn could be used as fuel. However, there are many difficult problems in making such a reactor. We are not sure that even fifteen years from now, a really practicable reactor of this type can be made.

SHORIKI: I suppose you were confronted with charges of wasting State funds and criticisms that the project was dangerous, that it was still too early to launch into such a project, etc. How did you overcome these oppositions?

HINTON: There were no difficult problems in Britain. It was because, in Britain, atomic energy was first developed for military purposes and then moved toward large-scale peaceful use of atomic energy. In the initial stage, atomic energy was a closely guarded secret. It was not until after we had gained confidence technologically through development for military purposes that atomic energy development was revealed to the people. In this respect, we were fortunate.

SAGANE: Do the British people feel safe about atomic energy development?

HINTON: As I said just now, the people were not told about atomic energy development during the war, so they had nothing to worry about. After the end of the war, we have taken every opportunity to inform the people that it is not dangerous. Dr. John COCKROFT has even gone around the country. telling the people that there was no danger, and that instead, atomic energy will benefit the people. However, there is no machine which is absolutely safe. It is merely a matter of comparison. The people will understand if you tell them that although there may be some danger in the atomic reactor which we have built there is less danger from an atomic reactor than from other machines. The local people generally reacted favorably to atomic power generation. The natural-uranium-graphite type reactor with a gas-cooling system which we are building at Calder Hall is perfectly safe.

SAGANE: You seem to have perfect confidence that atomic power generation at Calder Hall will be economical from the beginning. Will you give us the grounds for your confidence?

HINTON: The atomic reactor being built at Calder Hall is primarily for the production of plutonium with power generation as a sort of by-product. In Britain today, the cost of atomic power generation is slightly less than one pence per kilowatt. This price does not include the profit from the plutonium produced as a by-product. If we fix the price of plutonium at slightly lower than the average of the highest price of enriched uranium and the price of natural uranium, the cost of atomic power generation will be about 0.6 pence per kilowatt.

SAGANE: The question of atomic power generation cost is a very important matter and if you will explain a little further ...

HINTON: The cost is less than one pence even without taking plutonium into consideration. The reactor which will be ordered next January will probably cut down the cost further.

SAGANE: Is it natural to take plutonium into consideration?

HINTON: Of course it is. Although it calls for a complicated operation to separate plutonium from the cinders of natural uranium, plutonium should be taken into account as it is important both for military purposes and as fuel for atomic reactors.

SAGANE: Does the cost that you mentioned take into consideration the expenses for the planning and construction?

HINTON: Of course, the cost includes all such expenses. When we take plutonium into consideration, the present cost will be about 0.6 pence. When, in about three or four years, the reactor which we will order next January starts operating, the cost will probably be lowered to about 0.5 or 0.4 pence. If we can make better reactors in the future, we will be able to cut down the cost further. The price of coal may go up, but will never go down. That is why the future prospects for atomic power generation are very hopeful.

SHUZUKI: What are your prospects for atomic power generation, technically and economically, for the next five years?

HINTON: Views differ as to how atomic reactors will change in the next five years. We expect considerable improvements to be made in the type of reactors we have now, that is, the type which uses natural uranium and graphite cooled by gas. We may get reactors which uses water as a moderator and with a water-cooling system. There may be reactors which uses metal in the cooling system. All these will be made possible with new technique and new materials. In ten years time, I am confident that these will be used for industries. Atomic power generation will follow the course of steam-power development. It will become better and better. The question is, when can we make a highly efficient and paying atomic power reactor.

SAGANE: in what aspect, in comparison to the other nations of the world, does Britain have the greatest confidence? What are the greatest hopes in Britain attached to atomic power generation? What are Britain's prospects for the future development of breeding-type reactors?

HINTON: Let me explain about the breeding-type reactors. Britain has, or is in the process of completing, three breeding-type reactors. Now, two of them do not produce energy. The third one now being constructed will have considerable power generating capacity and will start operating in 1958. However, there are difficult problems, such as how to induct energy out of the reactor, what effects the various gases will have on the atomic fuel cartridge, and how we can burn the fuel without taking out atomic ash frequently. It will take about two years after the

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reactor starts working to study these problems. Therefore, the next power generating breeding-type reactor will not be completed until 1964. I think we will be fortunate if we can put such a reactor on an operating basis by 1965.

SAGANE: What are the technological superiorities which Britain feels she has over other countries?

HINTON: Britain has only recently started exchanging information with the United States, and therefore, we know little more than you do as to technical matters in the United States.

SAGANE: Why did Britain start her atomic power generation with a natural-uranium-graphite reactor when it is certain that in the future there will be better reactors?

HINTON: It was because this type of reactor is the safest and yet somewhat efficient. Furthermore, this type of reactor will still be in use for the next twenty years or so. In making enriched uranium, a large amount of electricity is needed. Britain, however, lacks electricity. Therefore, it was decided that we should start out with the natural uranium type and then proceed to the enriched uranium type.

SHORIKI: What definite aims do you have as to the future of atomic power generation, not merely as a means of covering the shortage of electric power resources but in other aspects?

HINTON: In ten years time, atomic power generation will become cheaper than thermo-power generation. In coal-power generation, the expenses for the construction of a new power plant is only about one-third of the total expense, with the fuel accounting for two-thirds of the expense. In the case of atomic power generation, it is the other way round, with construction expenses costing about two-thirds of the total expense and fuel accounting for one-third. However, construction expenses of atomic power plants are going down.

SAGANE: Do you think the price of atomic fuel will also go down?

HINTON: That depends solely on the world price of uranium. The world price of uranium is determined by the amount of uranium the United States buys up for defense purposes. The situation ten years from now will determine the price of uranium.

SHORIKI: Are there any special projects for the use of isotopes? What are your plans in this field?

HINTON: Dr. COCKCROFT is the expert on this matter. However, I do know that a new and cheap way of separating cesium from the reactor's atomic ash has been devised. Cesium, as you know, is coming to replace cobalt 60 as a generator of the gamma ray.

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SHORIKI: What cooperation can Japan expect from Britain in her atomic energy development?

HINTON: We would like to help as much as we can. However, large-scale programs for atomic power development are being carried out now. We cannot even keep pace with the increasing demand for atomic power generation. We are also lacking in uranium and graphite. It may be possible to offer you plans for the atomic power plants, but in such a case, agreements will have to be concluded with the British Government. You could also purchase complete reactors from British firms under certain agreements. There are many difficult problems which we must solve. We must join hands and continue our researches.

SHORIKI: Your statement that by fixing the price of plutonium at a reasonable price the cost of atomic power generation will be only 0.6 pence is very significant for Japan.

HINTON: The cost of 0.6 pence is what it is today. When we get our new atomic power generating reactor, the cost will certainly be lower than 0.6 pence.

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YOMIURI (Summary of Article — 3/4 of full article) May 19, 1956

HINTON Gives Valuable Advice on Atomic Energy Development

At Calder Hall in Great Britain, the world's first full-scale atomic power plant will start operating this autumn and the most effective man-made power will be provided to factories and homes. Today, the Yomiuri Shimbun has asked Sir Christopher HINTON and Japanese leaders of atomic science and industry to discuss the progress of and the future of British atomic energy development.

Participants:

Sir Christopher HINTON, Director, Industrial Group, British Atomic Energy Authority
Ichiro ISHIKAWA, Member of the Atomic Energy Commission
Yoshio FUJIOKA, Member of the Atomic Energy Commission
Sakuji KOMAGATA, Director of the Atomic Research Institute
Koji FUSHIMI, Chairman, Special Committee on Atomic Energy, Japan Council of Science
Moderator: Editor-in-Chief KOJIMA, Yomiuri Shimbun

* * * * * * * * * * * * *

Moderator: How much interest and understanding do the British people show toward atomic power generation?

HINTON: The British people know that at the rate of coal we are now using for power generation we will need one hundred million tons of coal in 1975. They also know that we cannot possibly obtain that much coal for power generation. It is clear that if Britain continued in the present state, she would not be able to compete in the export competition which she now faces. In short, the British people know very well that the question of "energy" is closely related to the welfare of the people. Therefore, they are welcoming atomic power generation. Furthermore, British policy on atomic power development was carried on without change even when the Government changed. Neither were there any party conflicts.

FUJIOKA: I have heard that in Great Britain, atomic energy researches are centered around the Industrial Group of the British Atomic Energy Authority. What were the attitudes of the researchers in universities on atomic energy studies?

HINTON: The Industrial Group delegates researches to the universities. The Industrial Group also encourages and advises promising researchers in the universities. When the Industrial Group concludes a contract with a university for the study of a certain project, the university will get appropriate remuneration.

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From TOKYO

ISHIKAWA: Recently, the Japanese Government, the political parties, scholars, scientists, and industrial leaders have come to accord on the need of developing atomic energy. Japan must solve her power problem in the next ten years. Japan also lacks food, and by utilizing radioisotopes, Japan can increase production. Such being the situation, Japan must definitely develop atomic energy industries. Until very recently, the scientists carried on their own researches independently with no unity. We have finally formed a system under which the researchers can be brought together to cooperate in the peaceful use of atomic energy. I earnestly hope that Japan will soon reach the stage where, like in Britain, smooth cooperation between the authorities concerned and the universities is realised

Another point in Japan's atomic energy researches is that since Japan is a poor country, we will have to gather together in one place various types of reactors. Our hope is that a radioisotope center as well as a joint research center of various universities can be built on the same site.

Japan, at present, lacks atomic scientists and researchers. A good educational and training institute is needed to overcome this shortage.

FUJIOKA: In explaining Britain's atomic energy development at the Geneva meeting last year, you mentioned that Britain built atomic reactors suited to Britain, that construction of atomic reactors should be done in countries advanced in science and technology, that it should not be started in underdeveloped countries and that a high scientific and technical level is needed for atomic energy development. Will you elaborate on these points?

HINTON: Atomic energy development is possible only in countries where there are many scientists and technicians. In order to develop atomic energy industries, the scientists and technicians must be helped to move into new fields of research. Therefore, atomic energy can be developed on a full-scale only in plants where there are a great number of scientists and technicians. On the other hand, a nation can improve its scientists and technicians by developing atomic energy industries.

It is only natural that the Japanese, who were the victims of atomic and hydrogen bombs, are afraid of atomic energy. In Britain, however, such fears have been wiped out. We have explained to the people that atomic energy industries are no different from other industries. They "mystery" shrouding atomic energy was thus dispelled.

I would like to say a few words concerning production and use of isotopes. Won't you people consider constructing a BEPO type reactor as your second reactor? The BEPO type reactor which uses graphite has many faults when compared with other types of high efficiency reactors. However, in producing isotopes, it has its

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advantages. In a country like Japan, which is far away from isotope-producing countries, thought should be given to this problem.

FUJIOKA: In other words, you recommend Japan's building a HEPO type reactor?

HINTON: No, I did not mean it that way.

ISHIKAWA: We are not entirely disregarding the point you made, but at present, we are centering our plans on training technicians. We plan to definitely fix our plans on the type of reactors we will want by this summer.

FUJIOKA: It is almost certain that we will first build a CP-5 reactor. We are also considering making a Japan-built reactor. We are also considering producing home-made isotopes at the same time. The difficulty lies in deciding on whether to choose a type which uses heavy-water or one which uses graphite.

HINTON: It would be difficult to combine the two. You will have to choose between a high-efficiency reactor with a small pile space or one with less neutron concentration but with a larger pile space. Anyway, since the price of reactors are very high, you will not be able to set up two experimental reactors.

FUJIOKA: In Britain, you are mostly concentrating on graphite type reactors and in Canada they are building heavy-water types. Norway produces a large quantity of heavy-water. Now Japan has electric-dissolvent pools, so we think that Japan can produce heavy-water like Norway.

HINTON: Do you mean to produce heavy-water by electric dissolution when you lack in electric power?

FUJIOKA: No, in Japan we can make heavy-water as a by-product at chemical fertilizer plants. However, the United States is laying stress on production of heavy-water. I have heard that Britain has called off her plan to start producing heavy-water in New Zealand. In other words, the world situation seems to have changed.

HINTON: With the money you intend to spend for the purchase of heavy-water, you can produce heavy-water yourself or buy another reactor.

FUJIOKA: Does Britain place emphasis on the graphite type reactors?

HINTON: In the initial stage, we are placing emphasis on graphite type reactors. Even when we start using high-efficiency reactors, we probably will go on using the graphite type reactors. There is not much difference in the efficiency of a reactor which uses light water as a moderator and uses enriched uranium, and that of a reactor which uses heavy water as moderator and uses natural uranium. The question lies in whether we want to spend our money on enriched uranium or on

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heavy-water. The concentrating of uranium is not as easy as producing heavy-water.

FUJIOKA: We have started on atomic energy research by forming the Atomic Research Institute. We intend to first construct experimental reactors to conduct basic studies and then go on to studies on atomic power reactors. There are two views on how and when Japan should start on industrial atomic power generation reactors. One view is that Japan should take about two or three years for basic studies, that by then Japan will find out the merits and the faults of the various types of atomic power reactors being constructed in the world, and that Japan should decide her course after taking these points into consideration. In other words, this view preaches discretion, though not necessarily meaning that Japan should go slow on her atomic energy development program.

The other view lays stress on the fact that Japan will face a severe shortage of energy resources ten years from now, and that in this respect, Japan should try to start atomic power generation as soon as possible. Of course, the people who hold this view are not saying that there is no need of basic studies, but they hope that atomic power generation and basic studies will be conducted at the same time.

HINTON: Before deciding on which of the two views is better, Japan should draw up a long-range program to meet the increase in demand for electric power. Maybe, you will find that you will have to start atomic power generation as quickly as possible. Perhaps, you may find that you will have time before the anticipated shortage of electric power becomes acute. Then, I would advise you to follow the course taken by Britain. Then, even though a home-made reactor may not at first be as good as an imported one, the Atomic Energy Commission will be able to say that it will make its own reactor and gain experience and knowledge. However, I do not know whether this will be a practicable method for Japan. This is a question which Japan must solve by herself.

KOMAGATA: What is the relationship between the Atomic Energy Authority and other industrial companies?

HINTON: The Atomic Energy Authority drew the blue-prints in some cases, while in others, the industrial companies made the blue-prints according to instructions from the Atomic Energy Authority. Almost all the plants were built by industrial companies. The Atomic Energy Authority is training four construction companies which have traditionally handled power plant construction. We are teaching them the construction of graphite type reactors with the gas-cooling system. Actually, they will be the companies to construct atomic reactors for home use as well as for overseas orders.

KOMAGATA: Did the Atomic Energy Authority do all the researches on the

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materials to be used for the construction of a reactor?

HINTON: Atomic reactors of the Calder Hall type already have been handed over to the companies I just mentioned. They are encouraged to improve these reactors. However, there are researches which are beyond them. The Atomic Energy Authority conducts the studies in these fields. In this way, the Atomic Energy Authority can use all of its researchers to study and develop fast reactors and other types of high-efficiency reactors.

FUSHIMI: I recently read in a book called the British Atomic Factory that Britain has succeeded in experiments in laboratories with 20 milligrams of plutonium so that without having to go through interim tests, the process was taken up on a large-scale in a factory.

HINTON: Those experiments which started with just 20 milligrams of plutonium were the most impressive experiments in my whole life as a scientist.

FUSHIMI: Is it really possible to carry an experiment direct from the laboratory to the factory?

HINTON: If our scientists are good enough, it is possible.

FUSHIMI: Japanese fear of nuclear bombs was mentioned a while ago. But it is more from a humanistic viewpoint than from fear that the Japanese people feel that they must not produce nuclear weapons. The people's feelings being such, Japan must strictly keep her atomic energy development in the bounds of peaceful utilization. Will the atomic reactor at Calder Hall be a paying proposition, apart from the production of plutonium for military purposes?

HINTON: Even without taking plutonium into consideration, the cost of power production will be less than one penny for one kilowatt. Plutonium could be used for faster reactors, too.

ISHIKAWA: Japan has finally chosen Tokai Village for the site of the Atomic Research Institute after studying the possibilities of over twenty places. How large is the site of Calder Hall and how far is it from a city?

HINTON: There is a small village with a population of about 2,000 two miles from Calder Hall. The next town is about eight miles away. The site is about 400 acres in size.

ISHIKAWA: Have there been any accidents?

HINTON: No. There were no cases any worse than some X-ray diseases in some hospitals. Slight indispositions happened, but after a month or two of rest, they all came back to work again. Radioactivity is being constantly checked and studies as to how high the chimney of an atomic industry factory should be and other such issues are being made.

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ISHIKAWA: How about radioactivity outside of the plant?

HINTON: We have set the maximum tolerable limit at one-tenth of the internationally accepted maximum tolerable limit, but radioactivity around the plant is always much lower than our limit. Furthermore, with the Calder Hall type reactor, when the temperature rises due to disorder of the carbon dioxide cooling system, the efficiency of the reactor decreases and it stops operating after a while.

ISHIKAWA: How much does a Calder Hall type reactor cost?

HINTON: The cost will be 150 pounds for each kilowatt.

Moderator: I think it will be an appropriate way of closing this meeting with Sir Christopher HINTON giving a message to the Japanese people.

HINTON: I would like to tell the Japanese people that atomic energy can be developed safely and economically. Also, there is no need to worry that Japan was somewhat late in launching into atomic energy development. If technical knowledge is effectively used, Japan will without doubt succeed in her atomic energy development.

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Desp. No. 98
From Tokyo

YOMIURI (Summary of Signed Article — 9/10 of full article) June 5, 1956

Valuable Hints on Selection of Atomic Reactors Given by Lord HINTON, by Dr. Ryokichi SAGANE, Adviser to the Atomic Energy Commission

Some say that "since Lord HINTON committed himself on the subject of atomic power generators, Japan should install power generators soon", while opponents say: "Lord HINTON is not in a position to assume any responsibility. He said that electricity can be generated by atomic power on a commercial basis. But we are unable to take seriously what such an irresponsible scientist said."

After all, supporters of these two conflicting views seem preoccupied with their respective ways of thinking; one is that "generation of electric energy through atomic power may gradually become commercially paying" and the other is that "it is a whopping lie that electricity can be generated through atomic energy on a commercial basis in the foreseeable future."

I even feel that subconsciously "they themselves will be annoyed unless they hold such preconceived ideas." At any rate, it can be said that at a time when Japanese discussions on atomic energy continue in utter confusion, the visit here of Lord HINTON — who mapped out a large-scale atomic power generation program to be implemented on a commercial basis for the first time in the world in England and who is responsible for all details of its implementation — has had a considerable impact upon Japanese quarters concerned.

During his two-week stay here, Lord HINTON delivered four popular and specialised lectures and held round-table conferences and other social gatherings several times. It was very impressive that through these lectures and meetings, he talked to experts in political, management and academic circles as well as to the general masses with full confidence in each and every word he expressed.

Then, as a matter of content, what subject was most impressive? Needless to say, the impressions of his listeners differed. As for me, however, I was made to realise that although I thought that I was acquainted with the situation in foreign lands, I did not understand it truly.

As everybody knows, according to the British White Paper on Atomic Power Generation released a couple of years ago, it is planned that electric energy can be generated through atomic power on a commercial basis in that country. In our country, on the other hand, most atomic scientists (of course, including me) thought that commercial power in Britain is feasible only because the British military authorities purchase by-product plutonium at a high price. According to Lord HINTON, however, plutonium is not recognised as a by-product in Britain. In other words, the cost of atomic power generation will stand at one penny only (about 4 yen in Japanese currency) per kilowatt hour even if the value of plutonium is not taken into account. The cost of 0.6 penny (about 2.40 yen) which is often referred to, it was made clear, means one to be computed by taking into consideration the value of plutonium when utilised for the purpose of power generation. According to him, furthermore, the generation of electric energy can be made at an awfully cheap cost when it is calculated that plutonium will be

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used for military purposes.

In this respect, to be sure, I myself had hugged a misconception. Moreover, my observation thus far that the understanding by Japanese scientists of the situation in foreign countries may be dubious as far as atomic energy is concerned has been endorsed by Lord HINTON.

Most of the subjects he dealt on in his lectures were already covered by the British White Paper on Atomic Power Generation, but we have benefited by his explanation of the data contained therein. Also through his lectures and other meetings, Lord HINTON taught us a number of far more important things. They are as follows:

1. The atomic reactors for generating electric energy for business purposes, which are now under construction or for which plans are almost completed in England, do not envolve military secrets in any way. In other words, they can be handled as merchandise if only business negotiations succeed.

2. Prices of uranium will flunctuate politically the world over, so he was unable to indicate a meaningful average price.

3. If Japan is interested in installing atomic reactors of the British type, she should conduct negotiations with the British Atomic Energy Commission on fuel and other materials and with British makers on atomic reactors. In that case, he predicted, it would be difficult to import only one atomic reactor. Rather, it would be necessary for Japan to have to purchase several atomic reactors in the future.

4. Under the present situation, the production of uranium and graphite is not sufficient to meet the demand in Britain. Therefore, Britain can afford to export only a few number of natural uranium-graphite atomic reactors together with materials.

5. In Japan where the production of coal is insufficient and where atomic power generation is urgently required on account of her inadequate water power supply, Lord HINTON recommended the use of natural uranium-graphite atomic reactors with which he is concerned, for two major reasons: a) Very high safety. b) Operable on a paying basis.

6. Economically, it is very disadvantageous to operate small type natural uranium-graphite reactors. Therefore, it is recommended that a large one (100,000 kilowatts) be used from the outset. In order that Japan, which has no experience whatever in this field may succeed in operating a large one, it is advisable for her to conclude an overall contract including technical assistance for installation and operation. The cost of installation is estimated at 150 pounds sterling per kilowatt plus or minus 10 percent. By the way, it can be considered that even the cost of the above extra technical services will be sufficiently covered by the 10 percent. Nevertheless, even if Japan succeeds in obtaining fuel, graphite and other materials from other countries, it will take four years for her to complete constructing a natural uranium-graphite reactor.

7. In the calculation of commercial cost factors, it is estimated that the interest rate is set at 4 percent per annum and the depreciation period at 20 years. It is the so-called core part of an atomic reactor whose life cannot be calculated exactly because of the lack of past results. Since uranium fuel will be replaced continuously, the problem is, after all, the extent to which graphite will be deformed on account of radioactive effect over a long period, with the result that the reactor will become unusable. In other words, it is that the life of an atomic reactor cannot be estimated exactly because of deformation of graphite (I think the life is about 15 years).

In point of power demand and supply, Japan is analogous to Britain. In the case of Britain, the three following points merit attention: a) She can obtain uranium fuel in South Africa and other areas under her influence. b) She has preferred air cooling to liquid cooling in the past several decades. c) In Britain home production of uranium is strictly required for military reasons.

On the other hand, in the case of Japan, the self-supply of uranium fuel is an unknown quantity and rather pessimistic. Moreover, the use of atomic energy is strictly confined to peaceful purposes. She is bound by economic restrictions in relation to the international situation. Chief makers are staffed with managers and engineers who are accustomed to introducing foreign technique for the past several decades. In view of these points, it is necessary for us to thoroughly study whether or not we should adopt the British method immediately.

Generally speaking, it is a fact that the visit here of Lord HINTON will greatly assist Japan in determining a basic plan for atomic power development, based on the following: a) Whether she should install natural uranium reactors. b) Whether she should install enriched uranium reactors. c) How to combine the two types of reactors in her annual planning.

The almost simultaneously arrival here of the Brookhaven atomic survey team of the U.S. resulted in warm debates in the national legislature on the import of reactors. It is a matter for self-congratulation that far more advanced scientific information is now available for study in arriving at a solution to these problems.

U.S. President EISENHOWER, at a press conference, said: "Discussions on atomic energy should be thorough." Such an attitude has been minimized up to the present. Lord HINTON, it can be said, has given us a "great present" in that we have been offered a happy chance to correct this defect in our thinking.

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From Tokyo

ASAHI (Summary of Signed Article -- 3/4 of full article) May 17, 1956

Speedy Preparations for Atomic Power Generation Urged
By Tamaki IPPOMMATSU, Director of the Kansai Power Company

Electric power industrialists have announced that it is necessary to order the construction of a test atomic power plant two years hence, have it completed five years hence, start the construction of a commercial reactor six years hence and have it completed ten years hence. This is necessary, they say, because it is estimated that this country will need 450,000 kw of power generated by atomic energy ten years hence, 2,800,000 kw 15 years hence, 6,420,000 kw 20 years hence and 11,240,000 kw 25 years hence.

It is reported that the Japan Science Council and some scholars are criticizing this announcement. There is no basic difference in opinion between the industrialists and the council, but I think the announcement contains some points which need further explanation, so I wish to express my view frankly, and ask all circles to cooperate with each other at this time when it is necessary to develop atomic energy.

Criticism by academic circles boils down to the following two points. Firstly, they criticise the program based on an estimate of demand for power for 25 years ahead. They argue that long-term estimate for demand should be decided after making full investigations. They think that considerable power can be saved through improvement of thermal generation techniques, utilisation of low-grade coal and rational utilisation of energy and that it is possible to import heavy oil or coal. They therefore conclude that electricity thus saved will be enough to cover the 450,000 kw of power which is to be generated by atomic energy 10 years hence.

Secondly, they contend that atomic power generation being at an experimental stage, its facilities will become old-fashioned and useless if commercial operation is hurried excessively and that moreover, atomic power generation will be accompanied by "strings" or restrictions. They point out that we have not yet decided what type of reactor we will adopt and that we have no prospects for the supply uranium for fuel. They insist that for the time being basic study only should be conducted.

I don't believe that the estimated 25-year requirement is overstated. It is postulated in the program that the rate of increase in power demand will gradually decrease yearly from 7.3 per cent to 4 per cent during 25 years. The Public Utilities Bureau, Ministry of International Trade and Industry, estimates that the rate of increase in power demand will decrease from 6.7 per cent to 4 per cent during 20 years. Needless to say, we have taken into consideration mitigation of losses, improvement of coal efficiency and rationalisation of use. Thus whoever may make estimates, the results may be substantially the same. New causes for an increase in power demand may be as follows:

(1) Rise of new atomic industries. (2) The present industries will use more power in the future. (3) Automation. (4) Improved living standards.

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as a moderator but the earlier reactor N.R.X. has natural water as a coolant while N.R.U. uses heavy water as coolant. These are high powered reactors, N.R.X. being rated at 40 MW for a maximum neutron flux of 7×10^{13} while N.R.U. has a heat rating of 200 MW and a maximum flux of 3×4^{14} n/sq.cm/sec. and is therefore an expensive piece of research equipment.

The British and U.S. reactors have roughly the same core size which can be taken as approximately a cube of 2 feet side (the effective core volume is 12 cubic feet) but the Canadian reactors are larger.

It is interesting to note that these powerful research reactors are all water cooled. Gas cooled reactors have been built for research purposes as at Harwell (Bepo) and Brookhaven but gas cooling only allows lower ratings and fluxes (e.g. Brookhaven, 4.10^{12}ns cm^{-2} sec^{-1}). The enriched U reactors all use "sandwich plates" for fuel elements with a central sheet of U - Al alloy (10 - 20 percent U by weight) about 0.02" thick, clad in pure Al sheets of about same thickness. The plates are welded into a box construction with 5 to 20 plates per box. These elements were invented in U.S.A., adopted in U.K. and are extremely successful. NRU uses thick U sheets, 0.156" thick, clad in 0.040" aluminium. NRX uses 1.36" dia. U rods, clad in 0.080" Al.

The "Swimming Pool Reactor" uses the same type of fuel elements as Dido and CP5, but is cooled by convection. It is very cheap and yet gives a flux 10^{12}nx cm^{-2} sec^{-1} (100 K W total power) and is useful for some experiments mainly in connexion with shielding but not for materials testing. By Pluto is expensive both in capital and operating costs. The easy access to the core of Swimming Pool reactor is convenient for fuel element handling, maintenance and insertion and withdrawal of experiments. However, its low flux and power, limits the usefulness of the Swimming Pool Reactor and its main use in technological work is confined to shielding experiments and for training purposes.

Experimental reactors with a large core volume must normally use natural or near natural uranium since we cannot afford to fill a large volume with highly enriched uranium. Air is convenient as a coolant since the heat rate per unit mass of fuel will be low if the total power output is kept down to a level consistent with reasonable capital and operating charges. On cost grounds graphite would ordinarily be selected as moderator since heavy water is very expensive. Typical experimental reactors of this type are Gleep, and Bepo at Harwell and the similar reactor at Brookhaven. This is the sequence in which they were built and it shows a progressive rise in neutron flux values (3.7×10^{10}, 2×10^{12} and 4×10^{12} n/sq.cm/sec. respectively) and also in complexity. Bigger reactors of this type are probably not justified for experimental work alone.

If a large volume is required at a not-too-small flux, the overall power must be high and hence the reactor might as well be a plutonium and perhaps a power producer. The Windscale piles, built for Pu production, have proved very useful for experimental work. Their chief disadvantages are that one would like a 3 or 4 times higher flux and that they have not enough experimental holes in the graphite or space outside for associated equipment. One never is sufficiently far ahead with research reactors, and much must be learnt, perforce, from each

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generation of industrial reactors to be applied in the next. Thus much information used in the design of Calder Hall reactors was derived from the Windscale piles and Calder Hall in its turn will give useful facts for the first actual power stations of the central electricity authority.

Reactors of the type described so far are useful for general experiments in the physics, chemistry, engineering and metallurgy of reactors. Sometimes additional experiments are necessary closely simulating the proposed design of a specific reactor and to ensure that in that reactor the power output specification can be reliably met. These experiments need considerable quantities of fuel and sometimes other expensive materials long before they would be needed for building the finished power reactor.

In order to design a nuclear reactor it is necessary to predict certain design parameters (for example the well known thermal utilization and resonance escape factors in thermal neutron reactors) which essentially describe the average fates of the neutrons produced in fission. Unfortunately neutron cross-section data alone is insufficient for this purpose and additional information is required on the neutron flux distribution within the lattice cell of a heterogeneous reactor and on the neutron spectrum at various points in the lattice cell. Classical diffusion theory is generally used for thermal reactor design calculations and for some fast reactor work and is the only practical theory where large numbers of cases are to be investigated using desk type computing machines, but this theory is known to predict the neutron flux distribution incorrectly and furthermore no account is taken of neutron spectrum effects. However, the diffusion theory method of calculation can be correlated with experimentally determined neutron fates in two types of integral experiment:

(a) Exponential experiments
(b) Zero energy experiments

(a) In an exponential experiment neutrons from an extraneous source are fed into an assembly of fuel and moderator which is smaller than the critical size (about 1/40 - 1/10 by volume) and by means of measurements of the neutron flux distribution within the assembly some of the design parameters can be obtained. Such experiments are only suitable for large sized systems (for example natural uranium and graphite moderated reactors) where the loss of neutrons by leakage from the experiment is not serious enough to make the neutron flux too low for measurement.

The exponential experiment has the advantage that, apart from the cost of the reactor materials (which can often to some extent be re-used in an actual reactor) they are cheap to carry out, involving no shielding (other than that incidental to the neutron sources) and no instrumentation relevant to the assembly itself. However they do suffer from the disadvantage that only information relevant to the lattice cell of the reactor may be obtained and no data can be gathered about the effects of reflectors, control rods and other perturbations. In large systems these effects are either not very important or their estimation from diffusion theory is not subject to gross errors.

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(b) In the case of thermal reactors using enriched fuels or fast reactors the size of the reactor is so small that the neutron fluxes obtainable in an exponential experiment would be too low for accurate measurement, so that in order to obtain the design parameters it is necessary to build a zero energy reactor. In this experiment an assembly of fuel and moderator (if any) is built large enough to be just critical and having some excess reactivity which can be used in the course of experiment. The neutron flux, although adequate for activating detectors, is never allowed to rise to such an extent that large amounts of heat are evolved. In spite of this, however, the experiment is essentially a reactor so that adequate biological shielding must be provided together with instrumentation, control gear and in general all the usual features of any normal reactor except the means of removing large amounts of heat from the core. The experiment is necessarily expensive in comparison with exponential experiments but does have the advantage that in addition to yielding all the usual design parameters, fuel structure and neutron spectrum information, data can be gathered on the effects of reflectors, control rods and other perturbations. This is fortunate since these effects are not always easy to estimate for a small reactor even by the relatively simple diffusion theory.

The low cost of exponential experiments and the ease with which the lattice pitch and structural features such as coolant channel sizes can be varied leads to their use for the general correlation of experiment and theory. In the United Kingdom for example, experiments have been carried out on upwards of 30 different graphite-natural uranium lattices covering a wide range of volume of moderator to volume of uranium ratios and the results have been correlated with a specific method of calculation based on diffusion theory. This programme required the provision of large quantities of graphite (~ 100 tons) and uranium (~ 10 tons) several years in advance of any requirements for a specific project.

On the other hand the high cost of a zero-energy experiment and its somewhat lower flexibility (particularly in case of handling) leads to its use as an experiment for the guidance of a specific project. An example of this is the zero-energy fast reactor ZEPHYR which was designed to provide basic information for the design of a high power fast reactor. The core consists of nickel sheathed plutonium fuel elements in a uranium cylinder with a natural uranium reflector and blanket. The total cost of ZEPHYR was 200,000 ($570,000) including the fuel and uranium. Even with the information from ZEPHYR it was found that some design parameters for the project could not be predicted with the necessary accuracy. This experiment was therefore followed by a more specific zero-energy experiment ZEUS in which the actual design adopted was so closely simulated that information could be obtained on the effects of reflectors, control rods and other disturbing influences.

Heat

It is, however, always wise to remember that (as a first approximation) it is true to say that the heat output of any reactor system depends not on the nuclear characteristics of that system (provided that it has been made supercritical) but on our ability to remove heat from the system. Thus the limiting rating of a reactor system (provided we neglect in this first approximation the effects of poisoning) depends not on nuclear physics but on metallurgy and engineering. It may be of interest to you to know that in the laboratories of the U.K. Atomic Energy Authority, approximately 75 percent of the staff never or rarely make use of irradiation facilities in experimental reactors.

Let us first of all consider some of the metallurgical problems of fuel element manufacture for reactors of the Calder Hall type.

One of the first problems which has to be considered is the choice of canning material. In the Windscale piles aluminium cans have proved to be very satisfactory. For reactors of the Calder Hall type, however, it is desirable for economic reasons to increase both the maximum can temperature and the total irradiation. At the same time the neutron absorption must be reasonably low and oxidation resistance must be satisfactory at the working temperatures in CO_2, which was selected as the coolant. The increase in temperature over the Windscale piles weighed against aluminium, which is extremely soft at the probable working temperatures. Steel and other possible metals were ruled out on grounds of absorption cross-sections. Beryllium is very attractive but extraction and fabrication techniques are hardly sufficiently advanced at present to allow of immediate application. Zirconium is possible but both its strength and oxidation resistance at the higher temperatures are marginal and fabrication techniques are still rather novel. Choice for the first reactors has therefore fallen on magnesium.

The suitability of magnesium was not immediately obvious and very careful study has been required to confirm this, especially with regard to oxidation and deformation characteristics. Special alloys have been developed, however, which are surprisingly satisfactory in their oxidation behaviour both in air and CO_2. A more difficult problem is to obtain an alloy with a satisfactory balance between strength and ductility. In the hotter parts of the reactor the cans must at least retain their shape while in the cooler portions some local deformation due to small changes in shape or contour must be accepted without cracking. Since magnesium has limited deformation mechanisms and a tendency to form large grains, it can in some circumstances be lacking in ductility. The alloy which has been developed is believed to be adequate in both these respects, even with the complication of irradiation, but the solution is a rather finely balanced one. Having selected the alloy, developing and proving the actual production and fabrication methods required a major effort since atomic energy requirements demand a freedom from defects, such as inclusions, well beyond that normally specified.

Under the conditions of the Calder piles, the most notable effect of irradiation on the fuel arises from the anisotropy of uranium and its temperature dependent deformation mechanisms. Under the intense and highly localised thermal effects of fission, transient stresses occur resulting in plastic deformation.

Unfortunately, it is believed that these plastic deformations on heating and cooling are not entirely reversible and there can be a net change in external shape of the crystal. Depending on the [illegible] structure these individual crystal

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deformations can give rise to bowing, surface wrinkling or to overall changes in length. Such behaviour may be controlled by suitable metallurgical structures, but the phenomena are not by any means simple and a very extensive irradiation programme over a range of temperature and irradiation conditions is necessary before these structures can be defined. In addition, the temperatures required impinge on the creep range for uranium, and this can be important if the reactor design requires the uranium to bear some load. Creep resistance can be improved by alloying, but these additions are costly in neutrons. Accordingly, good design requires the selection of a uranium alloy, from a range being developed, which has adequate strength and minimum neutron loss.

When we consider the similar problems that arise in connection with highly rated reactors, the pattern becomes even more complex. Here we require higher burn-ups, temperatures and temperature gradients in more concentrated fuels. In addition to the problems previously mentioned there are several potential effects as yet imperfectly understood. The most obvious one is that the degree of burn-up sought involves a significant increase in volume due to the formation of additional atoms by fission. Since some of these new atoms may be inert gases it is possible that gas bubbles could be formed to cause further swelling, which will be assisted by the softening of the uranium at the higher temperatures. Also the thermal stresses due to the temperature gradients represent a problem well beyond normal engineering experience. A further complication may arise as a result of minor fluctuations in the temperatures, especially where a boundary between two allotropic forms of uranium occurs within the fuel. The effects of the movement of isotherms through an anisotropic material which also has a large volume change on phase transformation are difficult to predict but may result in changes in shape or density. Such phenomena are exceedingly difficult to study experimentally, except in a reactor of the type under consideration. Some ingenious and elaborate experiments have been devised, however, which enable one to construct a reactor experiment in which more accurate studies may be made.

Canning materials for highly rated reactors are clearly a key problem. Designs are likely to require the strength of the canning materials to contribute largely to the strength of the core structure, in addition to withstanding possibly large stresses from the changes in the fuel outlined above. Temperatures and probable stresses are such that the better creep-resisting steels and alloys would be attractive; unfortunately, most of these form low melting point eutectics with uranium and must be ruled out unless one is prepared to accept an unattractively low temperature. In these reactors, the neutron absorption conditions are rather less restrictive, fortunately, although still not a negligible feature. The canning material may also require to withstand attack by liquid metal coolants. No final choice of canning material for such reactors may be made for some time. However, many of the metals of interest, such as tantalum, molybdenum, niobium and tungsten are not readily available in suitable forms and formidable development problems must be overcome if these materials are to be utilised.

In liquid metal cooled reactors it is obvious that novel requirements will be met but even in reactors employing water as coolant or moderator severe corrosion problems are involved, particularly an efficient power producers involve high temperatures, pressures and flow rates. Such a reactor could, in fact, very well be used as a demonstration of some classical corrosion phenomena. For example, it is almost impossible to avoid the use of dissimilar metals in the circuit, flow conditions could well produce erosion and cavitation; and, where two parts rub together, fretting corrosion is possible. Irradiation may be expected to enhance some of these reactions. Further, in the parts of the circuit at lower temperatures and not subject to direct irradiation, it might be expected that corrosion products might be deposited with consequent difficulties in heat transfer or blockages. Solutions for many of these difficulties have been proposed. Quite elaborate experiments are required, however, to develop and prove these ideas, since in this field any considerable departure from the actual conditions of interest is liable to give misleading results. Thus, experimental loops in a high flux testing reactor are essential and appropriate conditions of temperature, pressure and flow conditions must be provided, not only in the irradiated section, but also in the out of flux portion, especially when mass transfer or crud formation are being studied. Such a loop requires an important investment in high grade engineering effort both to design and to operate it and costs a lot of money.

Zirconium alloys are of particular interest in relation to water cooled reactors. The technology of zirconium is rather behind that of titanium and, by analogy with the latter, is likely to require a large scale development effort before it is readily available in a suitable variety of shapes and properties.

There are two other features of the water cooled reactors of interest. One is that the design and construction of the pressure vessel, involving as it does fairly frequent access to part or all of the internal space, is a uniquely difficult problem. Arising partly from this, it is more desirable than in some other reactors that the progress of defects in fuel elements should not be rapid, so that special unscheduled shut-downs may be avoided. At the same time, ordinary uranium is extremely rapidly attacked by the coolant water. For reasonable operation, therefore, it seems necessary to develop fuels which are corrosion resistant in high temperature water.

I quote these metallurgical problems only by way of illustration that nuclear energy development depends on a combination of technologies in engineering, metallurgy, chemistry and physics and undue emphasis on any one branch of science will not bring success. In Japan you have had great success in some of the [illegible] branches of metallurgy, e.g. in the field of magnetic materials, and I would hope you would be able to make a similar contribution in the field of nuclear energy.

Some of the most interesting engineering problems on which research is required in connection with the design of highly rated reactors are largely connected with heat transmission. As we go to higher ratings in our reactors carbon dioxide, as used at Calder Hall, will be regarded as increasingly unsatisfactory as a heat transfer fluid. Our White Paper programme, visualises the ultimate use of liquid coolants which in the first place must be either water or liquid metals. Water is a good heat transfer medium and also a good working fluid in a heat engine but it suffers from the fact that even for moderately high temperature use, very high pressures may be required. For this reason liquid metals which permit higher temperatures without high pressure are of very great interest.

The choice of liquid metals suitable for use in a nuclear reactor is limited to sodium, sodium-potassium, lead-bismuth, lead-bismuth-tin, and mercury. [From the corrosion aspect, sodium and sodium potassium are the logical choice, [and of these two, sodium is to be preferred on grounds of neutron economy, sodium has a reaction absorption cross section 0.0256 b/cc. compared with NaK eutectic cross section, .0234 b/cc.; U cross section .365 b/cc.; Stainless Steel cross section 0.239 b/cc.]

The chief disadvantage of sodium as compared with the eutectic is its higher freezing point of 97°C, but this can be offset by suitable handling techniques.

Liquid metals possess the advantage of a wide range of working temperature between melting point and boiling point, [(Na - melting point 97.8°C, boiling point 881°C)] and furthermore, the high temperature at which they can be used enables a high overall thermal efficiency to be achieved. The high thermal conductivity of liquid metal gives a low temperature drop between the nuclear heat source and the liquid metal stream, thus allowing the heat source to work at a lower temperature for a given coolant outlet temperature, than would be the case for instance with a gaseous coolant or with water.

Compared with gaseous coolants the pumping power required for a sodium circuit is extremely low, the sodium requiring about 1/10th of the power absorbed by a gas circuit.

The use of sodium has some disadvantages, chiefly associated with handling and corrosion, which have been overcome by the use of appropriate techniques, and sodium is now handled in ton quantities without difficulty.

The corrosion difficulties are mostly brought about by the presence of oxide in the sodium, and can be dealt with by cold filtration and cold trapping techniques. Sodium loops have now been running for thousands of hours in our laboratories.

Good engineering design is needed to ensure the safe and reliable running of a sodium plant. [A few surprises await the uninitiated but.] In the main our experimental work has confirmed published theoretical predictions. We are confident that considerable use of liquid metal coolants will be found in nuclear energy and shall continue our own programme of experimental work.

In these circumstances you may be surprised to know that we are still working hard in studies of heat transfer in gas cooled systems. We are constantly applying a considerable effort to the study of the most suitable surfaces to employ in particular reactors. Many economies are possible as a result of work of this kind and although it is not to be regarded as basic scientific research, from an economical point of view, it is most important. For we believe that gas cooled graphite moderated reactors will continue in use for many years.

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Although to-day I am speaking to a scientific audience, of the research and development effort in a nuclear energy project, I have not attempted to deal with all research subjects but only to choose examples as illustrations. For instance in all this I have said nothing about research work on uranium extraction processes nor on the chemical treatment of irradiated fuel elements, and in my first lecture I made only passing reference to these plants. My reason for this is that in the early stages of developing a Japanese project, you might find it possible to avoid the need for building such plants. It is possible that you could arrange to procure fuel elements and have them processed after irradiation by one of the countries which already has well established plants doing this work.

In conclusion, I should like to emphasise once again, what I have already said and what I consider to be one of the most important points that I have tried to indicate in this lecture. Research aimed at developing an atomic energy industry for peaceful purposes is not merely research on nuclear physics; it is a fully integrated programme comprising the appropriate aspects of chemistry, metallurgy, classical physics and engineering as well as the nuclear physics field.

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From Tokyo

YOMIURI (Summary of Article — 3/4 of full article) May 17, 1956

__Panel Discussion on Atomic Power Generation in Britain__

Japanese Government, industrial and scientific circles are attaching much hope to the visit to Japan of Sir Christopher HINTON, who is the director of the Industrial Group of the British Atomic Energy Authority. The __Yomiuri Shimbun__ asked Sir Christopher HINTON, Atomic Energy Commission Chairman SHORIKI and Advisor to the Atomic Energy Commission Dr. Ryokichi SAGANE to discuss the development of atomic energy industries and atomic power generation in Britain. Mr. SHORIKI and Mr. SAGANE also asked for advice on Japan's atomic energy development. During discussion on the cost of atomic power generation, Sir Christopher HINTON made a very significant statement that "If plutonium is counted as fuel for the atomic power plant, the cost of atomic power generation will be 0.6 pence" and that there is possibility of further cutting down the cost. This has brought new hope for atomic power generation which had been considered too costly to become paying.

The following is report of the panel discussion participated in by Sir Christopher HINTON, Mr. SHORIKI and Dr. SAGANE.

SHORIKI: In Japan, some people hold the view that Japan's energy condition resembles that of the British energy condition and that therefore Japan should follow the example set by Britain. It is true that both countries lack energy resources and that both are worried about the day when supply of power will not be able to cover the increasing demand. However, the real situation is that Britain is a first-rate country when we consider the ratio of energy supply to the people's income. Japan, on the hand, is worse off in this respect than Hungary or Argentina. If such a situation is permitted to continue, it will never be possible for Japan to keep pace with the world's leading powers. Japan can never become one of the world's leading powers so long as she persists in a negative program for power generation, that is, a program which will merely try to cover the shortage of electric power. I earnestly desire the Japanese people's realization of this fact and awaken to the need of greater efforts in this line. I cannot but pay my greatest respects to Britain, which, although being in an unfavorable circumstance, made such great efforts to develop atomic power generation in advance of the other nations of the world. First, I would like to hear about Britain's atomic power policy.

HINTON: In planning for atomic power development in the initial stage, the general principle would be to adopt a method which seems to bring the best results. In Britain, we used the best materials and highest technology available and tried our best to make atomic power development a paying enterprise. The program is now tending toward expansion. The initial program which aimed at building two atomic power generation reactors in eighteen months is now being changed to a program of building three reactors in the same period of time. The reactors we have today produce plutonium only as a by-product. You cannot produce a

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large amount of plutonium in a reactor which uses graphite as a moderater. Therefore, it is most important to make a breeding-type reactor which will produce plutonium in large quantities, which in turn could be used as fuel. However, there are many difficult problems in making such a reactor. We are not sure that even fifteen years from now, a really practicable reactor of this type can be made.

SHORIKI: I suppose you were confronted with charges of wasting State funds and criticisms that the project was dangerous, that it was still too early to launch into such a project, etc. How did you overcome these oppositions?

HINTON: There were no difficult problems in Britain. It was because, in Britain, atomic energy was first developed for military purposes and then moved toward large-scale peaceful use of atomic energy. In the initial stage, atomic energy was a closely guarded secret. It was not until after we had gained confidence technologically through development for military purposes that atomic energy development was revealed to the people. In this respect, we were fortunate.

SAGANE: Do the British people feel safe about atomic energy development?

HINTON: As I said just now, the people were not told about atomic energy development during the war, so they had nothing to worry about. After the end of the war, we have taken every opportunity to inform the people that it is not dangerous. Dr. John COCKROFT has even gone around the country. telling the people that there was no danger, and that instead, atomic energy will benefit the people. However, there is no machine which is absolutely safe. It is merely a matter of comparison. The people will understand if you tell them that although there may be some danger in the atomic reactor which we have built there is less danger from an atomic reactor than from other machines. The local people generally reacted favorably to atomic power generation. The natural- uranium-graphite type reactor with a gas-cooling system which we are building at Calder Hall is perfectly safe.

SAGANE: You seem to have perfect confidence that atomic power generation at Calder Hall will be economical from the beginning. Will you give us the grounds for your confidence?

HINTON: The atomic reactor being built at Calder Hall is primarily for the production of plutonium with power generation as a sort of by-product. In Britain today, the cost of atomic power generation is slightly less than one pence per kilowatt. This price does not include the profit from the plutonium produced as a by-product. If we fix the price of plutonium at slightly lower than the average of the highest price of enriched uranium and the price of natural uranium, the cost of atomic power generation will be about 0.6 pence per kilowatt.

SAGANE: The question of atomic power generation cost is a very important matter and if you will explain a little further ...

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HINTON: The cost is less than one pence even without taking plutonium into consideration. The reactor which will be ordered next January will probably cut down the cost further.

SAGANE: Is it natural to take plutonium into consideration?

HINTON: Of course it is. Although it calls for a complicated operation to separate plutonium from the cinders of natural uranium, plutonium should be taken into account as it is important both for military purposes and as fuel for atomic reactors.

SAGANE: Does the cost that you mentioned take into consideration the expenses for the planning and construction?

HINTON: Of course, the cost includes all such expenses. When we take plutonium into consideration, the present cost will be about 0.6 pence. When, in about three or four years, the reactor which we will order next January starts operating, the cost will probably be lowered to about 0.5 or 0.4 pence. If we can make better reactors in the future, we will be able to cut down the cost further. The price of coal may go up, but will never go down. That is why the future prospects for atomic power generation are very hopeful.

SHORIKI: What are your prospects for atomic power generation, technically and economically, for the next five years?

HINTON: Views differ as to how atomic reactors will change in the next five years. We expect considerable improvements to be made in the type of reactors we have now, that is, the type which uses natural uranium and graphite cooled by gas. We may get reactors which uses water as a moderator and with a water-cooling system. There may be reactors which uses metal in the cooling system. All these will be made possible with new technique and new materials. In ten years time, I am confident that these will be used for industries. Atomic power generation will follow the course of steam-power development. It will become better and better. The question is, when can we make a highly efficient and paying atomic power reactor.

SAGANE: In what aspect, in comparison to the other nations of the world, does Britain have the greatest confidence? What are the greatest hopes in Britain attached to atomic power generation? What are Britain's prospects for the future development of breeding-type reactors?

HINTON: Let me explain about the breeding-type reactors. Britain has, or is in the process of completing, three breeding-type reactors. Now, two of them do not produce energy. The third one now being constructed will have considerable power generating capacity and will start operating in 1958. However, there are difficult problems, such as how to induct energy out of the reactor, what effects the various gases will have on the atomic fuel cartridge, and how we can burn the fuel without taking out atomic ash frequently. It will take about two years after the

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reactor starts working to study these problems. Therefore, the next power generating breeding-type reactor will not be completed until 1964. I think we will be fortunate if we can put such a reactor on an operating basis by 1965.

SAGANE: What are the technological superiorities which Britain feels she has over other countries?

HINTON: Britain has only recently started exchanging information with the United States, and therefore, we know little more than you do as to technical matters in the United States.

SAGANE: Why did Britain start her atomic power generation with a natural-uranium-graphite reactor when it is certain that in the future there will be better reactors?

HINTON: It was because this type of reactor is the safest and yet somewhat efficient. Furthermore, this type of reactor will still be in use for the next twenty years or so. In making enriched uranium, a large amount of electricity is needed. Britain, however, lacks electricity. Therefore, it was decided that we should start out with the natural uranium type and then proceed to the enriched uranium type.

SHORIKI: What definite aims do you have as to the future of atomic power generation, not merely as a means of covering the shortage of electric power resources but in other aspects?

HINTON: In ten years time, atomic power generation will become cheaper than thermo-power generation. In coal-power generation, the expenses for the construction of a new power plant is only about one-third of the total expense, with the fuel accounting for two-thirds of the expense. In the case of atomic power generation, it is the other way round, with construction expenses costing about two-thirds of the total expense and fuel accounting for one-third. However, construction expenses of atomic power plants are going down.

SAGANE: Do you think the price of atomic fuel will also go down?

HINTON: That depends solely on the world price of uranium. The world price of uranium is determined by the amount of uranium the United States buys up for defense purposes. The situation ten years from now will determine the price of uranium.

SHORIKI: Are there any special projects for the use of isotopes? What are your plans in this field?

HINTON: Dr. COCKCROFT is the expert on this matter. However, I do know that a new and cheap way of separating cesium from the reactor's atomic ash has been devised. Cesium, as you know, is coming to replace cobalt 60 as a generator of the gamma ray.

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SHORIKI: What cooperation can Japan expect from Britain in her atomic energy development?

HINTON: We would like to help as much as we can. However, large-scale programs for atomic power development are being carried out now. We cannot even keep pace with the increasing demand for atomic power generation. We are also lacking in uranium and graphite. It may be possible to offer you plans for the atomic power plants, but in such a case, agreements will have to be concluded with the British Government. You could also purchase complete/ reactors from British firms under certain agreements. There are many difficult problems which we must solve. We must join hands and continue our researches.

SHORIKI: Your statement that by fixing the price of plutonium at a reasonable price the cost of atomic power generation will be only 0.6 pence is very significant for Japan.

HINTON: The cost of 0.6 pence is what it is today. When we get our new atomic power generating reactor, the cost will certainly be lower than 0.6 pence.

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From TOKYO

YOMIURI (Summary of Article — 3/4 of full article) May 19, 1956

HINTON Gives Valuable Advice on Atomic Energy Development

At Calder Hall in Great Britain, the world's first full-scale atomic power plant will start operating this autumn and the most effective Man-made power will be provided to factories and homes. Today, the Yomiuri Shimbun has asked Sir Christopher HINTON and Japanese leaders of atomic science and industry to discuss the progress of and the future of British atomic energy development.

Participants:

Sir Christopher HINTON, Director, Industrial Group, British Atomic Energy Authority
Ichiro ISHIKAWA, Member of the Atomic Energy Commission
Yoshio FUJIOKA, Member of the Atomic Energy Commission
Sakuji KOMAGATA, Director of the Atomic Research Institute
Koji FUSHIMI, Chairman, Special Committee on Atomic Energy, Japan Council of Science
Moderator: Editor-in-Chief KOJIMA, Yomiuri Shimbun

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Moderator: How much interest and understanding do the British people show toward atomic power generation?

HINTON: The British people know that at the rate of coal we are now using for power generation we will need one hundred million tons of coal in 1975. They also know that we cannot possibly obtain that much coal for power generation. It is clear that if Britain continued in the present state, she would not be able to compete in the export competition which she now faces. In short, the British people know very well that the question of "energy" is closely related to the welfare of the people. Therefore, they are welcoming atomic power generation. Furthermore, British policy on atomic power development was carried on without change even when the Government changed. Neither were there any party conflicts.

FUJIOKA: I have heard that in Great Britain, atomic energy researches are centered around the Industrial Group of the British Atomic Energy Authority. What were the attitudes of the researchers in universities on atomic energy studies?

HINTON: The Industrial Group delegates researches to the universities. The Industrial Group also encourages and advises promising researchers in the universities. When the Industrial Group concludes a contract with a university for the study of a certain project, the university will get appropriate remuneration.

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ISHIKAWA: Recently, the Japanese Government, the political parties, scholars, scientists, and industrial leaders have come to accord on the need of developing atomic energy. Japan must solve her power problem in the next ten years. Japan also lacks food, and by utilizing radio-isotopes, Japan can increase production. Such being the situation, Japan must definitely develop atomic energy industries. Until very recently, the scientists carried on their own researches independently with no unity. We have finally formed a system under which the researchers can be brought together to cooperate in the peaceful use of atomic energy. I earnestly hope that Japan will soon reach the stage where, like in Britain, smooth cooperation between the authorities concerned and the universities is realized

Another point in Japan's atomic energy researches is that since Japan is a poor country, we will have to gather together in one place various types of reactors. Our hope is that a radioisotope center as well as a joint research center of various universities can be built on the same site.

Japan, at present, lacks atomic scientists and researchers. A good educational and training institute is needed to overcome this shortage.

FUJIOKA: In explaining Britain's atomic energy development at the Geneva meeting last year, you mentioned that Britain built atomic reactors suited to Britain, that construction of atomic reactors should be done in countries advanced in science and technology, that it should not be started in underdeveloped countries and that a high scientific and technical level is needed for atomic energy development. Will you elaborate on these points?

HINTON: Atomic energy development is possible only in countries where there are many scientists and technicians. In order to develop atomic energy industries, the scientists and technicians must be helped to move into new fields of research. Therefore, atomic energy can be developed on a full-scale only in plants where there are a great number of scientists and technicians. On the other hand, a nation can improve its scientists and technicians by developing atomic energy industries.

It is only natural that the Japanese, who were the victims of atomic and hydrogen bombs, are afraid of atomic energy. In Britain, however, such fears have been wiped out. We have explained to the people that atomic energy industries are no different from other industries. They "mystery" shrouding atomic energy was thus dispelled.

I would like to say a few words concerning production and use of isotopes. Won't you people consider constructing a BEPO type reactor as your second reactor? The BEPO type reactor which uses graphite has many faults when compared with other types of high efficiency reactors. However, in producing isotopes, it has its

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advantages. In a country like Japan, which is far away from isotope-producing countries, thought should be given to this problem.

FUJIOKA: In other words, you recommend Japan's building a HYPO type reactor?

HINTON: No, I did not mean it that way.

ISHIKAWA: We are not entirely disregarding the point you made, but at present, we are centering our plans on training technicians. We plan to definitely fix our plans on the type of reactors we will want by this summer.

FUJIOKA: It is almost certain that we will first build a CP-5 reactor. We are also considering making a Japan-built reactor. We are also considering producing home-made isotopes at the same time. The difficulty lies in deciding on whether to choose a type which uses heavy-water or one which uses graphite.

HINTON: It would be difficult to combine the two. You will have to choose between a high-efficiency reactor with a small pile space or one with less neutron concentration but with a larger pile space. Anyway, since the price of reactors are very high, you will not be able to set up two experimental reactors.

FUJIOKA: In Britain, you are mostly concentrating on graphite type reactors and in Canada they are building heavy-water types. Norway produces a large quantity of heavy-water. Now Japan has electric-dissolvent pools, so we think that Japan can produce heavy-water like Norway.

HINTON: Do you mean to produce heavy-water by electric dissolution when you lack in electric power?

FUJIOKA: No, in Japan we can make heavy-water as a by-product at chemical fertilizer plants. However, the United States is laying stress on production of heavy-water. I have heard that Britain has called off her plan to start producing heavy-water in New Zealand. In other words, the world situation seems to have changed.

HINTON: With the money you intend to spend for the purchase of heavy-water, you can produce heavy-water yourself or buy another reactor.

FUJIOKA: Does Britain place emphasis on the graphite type reactors?

HINTON: In the initial stage, we are placing emphasis on graphite type reactors. Even when we start using high-efficiency reactors, we probably will go on using the graphite type reactors. There is not much difference in the efficiency of a reactor which uses light water as a moderator and uses enriched uranium, and that of a reactor which uses heavy water as moderator and uses natural uranium. The question lies in whether we want to spend our money on enriched uranium or on

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heavy-water. The concentrating of uranium is not as easy as producing heavy-water.

FUJIOKA: We have started on atomic energy research by founding the Atomic Research Institute. We intend to first construct experimental reactors to conduct basic studies and then go on to studies on atomic power reactors. There are two views on how and when Japan should start on industrial atomic power generation reactors. One view is that Japan should take about two or three years for basic studies, that by then Japan will find out the merits and the faults of the various types of atomic power reactors being constructed in the world, and that Japan should decide her course after taking these points into consideration. In other words, this view preaches discretion, though not necessarily meaning that Japan should go slow on her atomic energy development program.

The other view lays stress on the fact that Japan will face a severe shortage of energy resources ten years from now, and that in this respect, Japan should try to start atomic power generation as soon as possible. Of course, the people who hold this view are not saying that there is no need of basic studies, but they hope that atomic power generation and basic studies will be conducted at the same time.

HINTON: Before deciding on which of the two views is better, Japan should draw up a long-range program to meet the increase in demand for electric power. Maybe, you will find that you will have to start atomic power generation as quickly as possible. Perhaps, you may find that you will have time before the anticipated shortage of electric power becomes acute. Then, I would advise you to follow the course taken by Britain. Then, even though a home-made reactor may not at first be as good as an imported one, the Atomic Energy Commission will be able to say that it will make its own reactor and gain experience and knowledge. However, I do not know whether this will be a practicable method for Japan. This is a question which Japan must solve by herself.

KOMAGATA: What is the relationship between the Atomic Energy Authority and other industrial companies?

HINTON: The Atomic Energy Authority drew the blue-prints in some cases, while in others, the industrial companies made the blue-prints according to instructions from the Atomic Energy Authority. Almost all the plants were built by industrial companies. The Atomic Energy Authority is training four construction companies which have traditionally handled power plant construction. We are teaching them the construction of graphite type reactors with the gas-cooling system. Actually, they will be the companies to construct atomic reactors for home use as well as for overseas orders.

KOMAGATA: Did the Atomic Energy Authority do all the researches on the

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materials to be used for the construction of a reactor?

HINTON: Atomic reactors of the Calder Hall type already have been handed over to the companies I just mentioned. They are encouraged to improve these reactors. However, there are researches which are beyond them. The Atomic Energy Authority conducts the studies in these fields. In this way, the Atomic Energy Authority can use all of its researchers to study and develop fast reactors and other types of high-efficiency reactors.

FUSHIMI: I recently read in a book called the British Atomic Factory that Britain has succeeded in experiments in laboratories with 20 milligrams of plutonium so that without having to go through interim tests, the process was taken up on a large-scale in a factory.

HINTON: Those experiments which started with just 20 milligrams of plutonium were the most impressive experiments in my whole life as a scientist.

FUSHIMI: Is it really possible to carry an experiment direct from the laboratory to the factory?

HINTON: If our scientists are good enough, it is possible.

FUSHIMI: Japanese fear of nuclear bombs was mentioned a while ago. But it is more from a humanistic viewpoint than from fear that the Japanese people feel that they must not produce nuclear weapons. The people's feelings being such, Japan must strictly keep her atomic energy development in the bounds of peaceful utilization. Will the atomic reactor at Calder Hall be a paying proposition, apart from the production of plutonium for military purposes?

HINTON: Even without taking plutonium into consideration, the cost of power production will be less than one penny for one kilowatt. Plutonium could be used for faster reactors, too.

ISHIKAWA: Japan has finally chosen Tokai Village for the site of the Atomic Research Institute after studying the possibilities of over twenty places. How large is the site of Calder Hall and how far is it from a city?

HINTON: There is a small village with a population of about 2,000 two miles from Calder Hall. The next town is about eight miles away. The site is about 400 acres in size.

ISHIKAWA: Have there been any accidents?

HINTON: No. There were no cases any worse than some X-ray diseases in some hospitals. Slight indispositions happened, but after a month or two of rest, they all came back to work again. Radioactivity is being constantly checked and studies as to how high the chimney of an atomic industry factory should be and other such issues are being made.

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ISHIKAWA: How about radioactivity outside of the plant?

HINTON: We have set the maximum tolerable limit at one-tenth of the internationally accepted maximum tolerable limit, but radioactivity around the plant is always much lower than our limit. Furthermore, with the Calder Hall type reactor, when the temperature rises due to disorder of the carbon dioxide cooling system, the efficiency of the reactor decreases and it stops operating after a while.

ISHIKAWA: How much does a Calder Hall type reactor cost?

HINTON: The cost will be 150 pounds for each kilowatt.

Moderator: I think it will be an appropriate way of closing this meeting with Sir Christopher HINTON giving a message to the Japanese people.

HINTON: I would like to tell the Japanese people that atomicenergy can be developed safely and economically. Also, there is no need to worry that Japan was somewhat late in launching into atomic energy development. If technical knowledge is effectively used, Japan will without doubt succeed in her atomic energy development.

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From Tokyo

YOMIURI (Summary of Signed Article — 9/10 of full article) June 5, 1956

Valuable Hints on Selection of Atomic Reactors Given by Lord HINTON, by Dr. Ryokichi SAGANE, Adviser to the Atomic Energy Commission

Some say that "since Lord HINTON committed himself on the subject of atomic power generators, Japan should install power generators soon", while opponents say: "Lord HINTON is not in a position to assume any responsibility. He said that electricity can be generated by atomic power on a commercial basis. But we are unable to take seriously what such an irresponsible scientist said."

After all, supporters of these two conflicting views seem preoccupied with their respective ways of thinking; one is that "generation of electric energy through atomic power may gradually become commercially paying" and the other is that "it is a whopping lie that electricity can be generated through atomic energy on a commercial basis in the foreseeable future."

I even feel that subconsciously "they themselves will be annoyed unless they hold such preconceived ideas." At any rate, it can be said that at a time when Japanese discussions on atomic energy continue in utter confusion, the visit here of Lord HINTON — who mapped out a large-scale atomic power generation program to be implemented on a commercial basis for the first time in the world in England and who is responsible for all details of its implementation — has had a considerable impact upon Japanese quarters concerned.

During his two-week stay here, Lord HINTON delivered four popular and specialised lectures and held round-table conferences and other social gatherings several times. It was very impressive that through these lectures and meetings, he talked to experts in political, management and academic circles as well as to the general masses with full confidence in each and every word he expressed.

Then, as a matter of content, what subject was most impressive? Needless to say, the impressions of his listeners differed. As for me, however, I was made to realise that although I thought that I was acquainted with the situation in foreign lands, I did not understand it truly.

As everybody knows, according to the British White Paper on Atomic Power Generation released a couple of years ago, it is planned that electric energy can be generated through atomic power on a commercial basis in that country. In our country, on the other hand, most atomic scientists (of course, including me) thought that commercial power in Britain is feasible only because the British military authorities purchase by-product plutonium at a high price. According to Lord HINTON, however, plutonium is not recognised as a by-product in Britain. In other words, the cost of atomic power generation will stand at one penny only (about 4 yen in Japanese currency) per kilowatt hour even if the value of plutonium is not taken into account. The cost of 0.6 penny (about 2.40 yen) which is often referred to, it was made clear, means one to be computed by taking into consideration the value of plutonium when utilised for the purpose of power generation. According to him, furthermore, the generation of electric energy can be made at an awfully cheap cost when it is calculated that plutonium will be

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YOMIURI (Summary of Signed Article — 9/10 of full article) June 5, 1956

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used for military purposes.

In this respect, to be sure, I myself had hugged a misconception. Moreover, my observation thus far that the understanding by Japanese scientists of the situation in foreign countries may be dubious as far as atomic energy is concerned has been endorsed by Lord HINTON.

Most of the subjects he dealt on in his lectures were already covered by the British White Paper on Atomic Power Generation, but we have benefited by his explanation of the data contained therein. Also through his lectures and other meetings, Lord HINTON taught us a number of far more important things. They are as follows:

1. The atomic reactors for generating electric energy for business purposes, which are now under construction or for which plans are almost completed in England, do not envolve military secrets in any way. In other words, they can be handled as merchandise if only business negotiations succeed.

2. Prices of uranium will flunctuate politically the world over, so he was unable to indicate a meaningful average price.

3. If Japan is interested in installing atomic reactors of the British type, she should conduct negotiations with the British Atomic Energy Commission on fuel and other materials and with British makers on atomic reactors. In that case, he predicted, it would be difficult to import only one atomic reactor. Rather, it would be necessary for Japan to have to purchase several atomic reactors in the future.

4. Under the present situation, the production of uranium and graphite is not sufficient to meet the demand in Britain. Therefore, Britain can afford to export only a few number of natural uranium-graphite atomic reactors together with materials.

5. In Japan where the production of coal is insufficient and where atomic power generation is urgently required on account of her inadequate water power supply, Lord HINTON recommended the use of natural uranium-graphite atomic reactors with which he is concerned, for two major reasons: a) Very high safety. b) Operable on a paying basis.

6. Economically, it is very disadvantageous to operate small type natural uranium-graphite reactors. Therefore, it is recommended that a large one (100,000 kilowatts) be used from the outset. In order that Japan, which has no experience whatever in this field may succeed in operating a large one, it is advisable for her to conclude an overall contract including technical assistance for installation and operation. The cost of installation is estimated at 150 pounds sterling per kilowatt plus or minus 10 percent. By the way, it can be considered that even the cost of the above extra technical services will be sufficiently covered by the 10 percent. Nevertheless, even if Japan succeeds in obtaining fuel, graphite and other materials from other countries, it will take four years for her to complete constructing a natural uranium-graphite reactor.

7. In the calculation of commercial cost factors, it is estimated that the interest rate is set at 4 percent per annum and the depreciation period at 20 years. It is the so-called core part of an atomic reactor whose life cannot be calculated exactly because of the lack of past results. Since uranium fuel will be replaced continuously, the problem is, after all, the extent to which graphite will be deformed on account of radioactive effect over a long period, with the result that the reactor will become unusable. In other words, it is that the life of an atomic reactor cannot be estimated exactly because of deformation of graphite (I think the life is about 15 years).

In point of power demand and supply, Japan is analogous to Britain. In the case of Britain, the three following points merit attention: a) She can obtain uranium fuel in South Africa and other areas under her influence. b) She has preferred air cooling to liquid cooling in the past several decades. c) In Britain home production of uranium is strictly required for military reasons.

On the other hand, in the case of Japan, the self-supply of uranium fuel is an unknown quantity and rather pessimistic. Moreover, the use of atomic energy is strictly confined to peaceful purposes. She is bound by economic restrictions in relation to the international situation. Chief makers are staffed with managers and engineers who are accustomed to introducing foreign technique for the past several decades. In view of these points, it is necessary for us to thoroughly study whether or not we should adopt the British method immediately.

Generally speaking, it is a fact that the visit here of Lord HINTON will greatly assist Japan in determining a basic plan for atomic power development, based on the following: a) Whether she should install natural uranium reactors. b) Whether she should install enriched uranium reactors. c) How to combine the two types of reactors in her annual planning.

The almost simultaneously arrival here of the Brookhaven atomic survey team of the U.S. resulted in warm debates in the national legislature on the import of reactors. It is a matter for self-congratulation that far more advanced scientific information is now available for study in arriving at a solution to these problems.

U.S. President EISENHOWER, at a press conference, said: "Discussions on atomic energy should be thorough." Such an attitude has been minimized up to the present. Lord HINTON, it can be said, has given us a "great present" in that we have been offered a happy chance to correct this defect in our thinking.

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From Tokyo

ASAHI (Summary of Signed Article -- 3/4 of full article) May 17, 1956

Speedy Preparations for Atomic Power Generation Urged

By Tamaki IPPOMATSU, Director of the Kansai Power Company

Electric power industrialists have announced that it is necessary to order the construction of a test atomic power plant two years hence, have it completed five years hence, start the construction of a commercial reactor six years hence and have it completed ten years hence. This is necessary, they say, because it is estimated that this country will need 450,000 kw of power generated by atomic energy ten years hence, 2,800,000 kw 15 years hence, 6,420,000 kw 20 years hence and 11,240,000 kw 25 years hence.

It is reported that the Japan Science Council and some scholars are criticizing this announcement. There is no basic difference in opinion between the industrialists and the council, but I think the announcement contains some points which need further explanation, so I wish to express my view frankly, and ask all circles to cooperate with each other at this time when it is necessary to develop atomic energy.

Criticism by academic circles boils down to the following two points. Firstly, they criticise the program based on an estimate of demand for power for 25 years ahead. They argue that long-term estimate for demand should be decided after making full investigations. They think that considerable power can be saved through improvement of thermal generation techniques, utilization of low-grade coal and rational utilization of energy and that it is possible to import heavy oil or coal. They therefore conclude that electricity thus saved will be enough to cover the 450,000 kw of power which is to be generated by atomic energy 10 years hence.

Secondly, they contend that atomic power generation being at an experimental stage, its facilities will become old-fashioned and useless if commercial operation is hurried excessively and that moreover, atomic power generation will be accompanied by "strings" or restrictions. They point out that we have not yet decided what type of reactor we will adopt and that we have no prospects for the supply uranium for fuel. They insist that for the time being basic study only should be conducted.

I don't believe that the estimated 25-year requirement is overstated. It is postulated in the program that the rate of increase in power demand will gradually decrease yearly from 7.3 per cent to 4 per cent during 25 years. The Public Utilities Bureau, Ministry of International Trade and Industry, estimates that the rate of increase in power demand will decrease from 6.7 per cent to 4 per cent during 20 years. Needless to say, we have taken into consideration mitigation of losses, improvement of coal efficiency and rationalization of use. Thus whoever may make estimates, the results may be substantially the same. New causes for an increase in power demand may be as follows:

(1) Rise of new atomic industries. (2) The present industries will use more power in the future. (3) Automation. (4) Improved living standards.

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Households will no doubt come to use more electric lights, fans, radio sets, irons, mixers, refrigerators, television sets, etc.

Academic circles say we should not start atomic power generation in a hurry. We don't mean to start it right now. We intend to carry out commercial operation of atomic power generation 10 years hence, otherwise it will be impossible to meet demand. We want to establish a 100,000 kw atomic generation plant on a commercial scale which needs ¥10 billion to ¥20 billion. We know best that we must take a prudent attitude toward establishment of an atomic power generation plant.

Atomic power generation is now at its test stage, but judging by the situations at home and abroad, we can see that atomic power generation will be commercially possible in about 10 years.

It is said that the cost of generation in a 100,000 kw atomic power generation plant of the Calder Hall type is about one penny (4.20 yen). This is about the same as the present commercial rate in Japan. We don't think Britain will invest as much as 20 billion yen in a generation plant which will soon become old-fashioned, much less 300 billion yen in setting up 12 plants of this kind in 10 years.

The generation cost of the 100,000 kw generation plant at Shippingport in the U.S. is high at the moment, but Mr. GOODMANN said it will become five to six yen in five years.

Various American power companies are reportedly planning to increase their atomic power output to two million kw in several years. This indicates that the U.S., despite her abundance in other cheap energy resources, is unusually enthusiastic to develop atomic power generation.

In ten years it will become difficult for Japan to develop both hydroelectric and thermal power generation, and generation costs will become higher. As hydroelectric and thermal generation approach their limits, it will become necessary to switch to atomic power generation. Therefore, in order to start commercial operation ten years hence, it is necessary to order a test plant two years hence, complete its construction five years hence and start construction of a commercial plant six years hence. It is impossible to learn techniques unless an atomic reactor is imported and actually handled.

In conclusion, I will add that power companies are enterprises and under an obligation to supply power. Therefore, they are not allowed to talk about pure theories alone like some scholars.

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From Tokyo

YOMIURI (Summary of Editorial — 4/5 of full article) May 18, 1956

Way to Atomic Generation

Sir Christopher HINTON, industrial section chief of the British Atomic Energy Authority and world-famous authority on atomic generation, arrived in Japan on the 16th at the invitation of the Yomiuri Shimbun. During his two-week stay in this country, we believe, he will contact learned persons of Government and private circles and give instructive suggestions to them.

Upon his arrival in Japan, HINTON expressed his hopes by saying: "We have managed to come to the stage where the atomic power plant at Calder Hall will start operation in October this year. I wish to reveal the story which I have never told to anybody before."

Based on the fact that she is not rich in natural resources while having a comparatively large population, Britain has been vigorously pushing her atomic generation program. This is partly due to the fact that her atomic generation program, based upon researches for military purposes, made a start only when she became confident of her technical ability. In this connection, the efforts exerted by HINTON as the central figure for peaceful utilization and development of atomic energy were of great importance.

In Japan, it has been decided that Tokai Village, Ibaraki Prefecture, will become the atomic center of this country, but the question of establishing a basic plan for development of atomic energy still remains unsolved. The core of the problem is the decision to be made on atomic reactors. Needless to say, the Atomic Energy Commission has decided to import a CP-5 reactor, besides a water-boiler reactor, from the U.S. within the year and to seek to establish domestic technique so that a home-made natural uranium-heavy water reactor may be completed in 1958. Yet, the existing plan fails to touch upon the question of generation reactors.

This is because academic circles and others call for prudence in the atomic generation project and adjustment of opinions has not been made between these circles and the industrial quarters which favor an early realization of atomic generation. Anticipating that hydro-electric generation in Japan will come to a deadlock fifteen years hence and also that thermal generation will suffer an increase in the price of coal in the future, electric power circles are putting up a positive proposal that two pilot generation reactors be imported next year and that 100,000 KW generation reactors be purchased five years hence. It is said that the generation cost by a Calder Hall type reactor will be less than one penny (about ¥4.20) per kilowatt when the price of plutonium is not taken into calculation and possibly 0.5d. when it is counted.

We can safely expect the future of atomic generation to be bright. We therefore think it appropriate for Japan to carry on her basic plans for research and application simultaneously rather than to withhold application until research is completed. Without actual reactors, training of technicians and development of technique would be impossible.

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What impresses us on the occasion of HINTON's visit to our country is the fact that in Britain's atomic development program, first-class specialists are taking charge of the fields of application, fundamental research and arms and are cooperating with one another. Apart from the field of arms, we wish that a HINTON and a COCKROFT will be produced in Japan.

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From TOKYO

SAHI (Summary of Article — 3/4 of full article) May 24, 1956

Establishment of Over-All Energy Supply Program Urged, by Koichi AKI, Doctor of Engineering, Professor of Tokyo University

The Atomic Energy Commission says that it will decide upon a basic program for the development of atomic energy by the end of June, but the discussions now under way make me feel that the program will be worked out easily. The core of the program is that some call for the immediate purchase of generation reactor while others are taking a cautious attitude on this score. It will probably be impossible to establish a policy for future atomic study unless this question is solved.

In my opinion, this question should be discussed on the basis of a adequate understanding of Japan's future energy situation and the possible effects of atomic power development upon expansion of Japan's economy, and also on the basis of definite knowledge about the present stage of technique on atomic energy utilization in Japan.

I think that supply and demand of energy in the future cannot be foretold so correctly as generally expected, because in present-day industrial nations, the point of the energy problems is shifting from "quantity and technique" to "quality and economy".

The sharp increase in energy demand in the last several years has unbalanced the demand and supply of various kinds of fuel. In Japan, this trend is more remarkable than in any other country. Frankly speaking, Japan is no longer a "hydroelectric power country" as she was in the past, nor is it possible for her to expect coal supply in larger quantities and at lower prices. In order to expand her industrial activities, I think Japan should restudy her production processes and industrial structure.

If there is a necessity for a substantial change in the concept of energy, it becomes difficult to presume the future situation on the basis of past experiences. There are many questions also in the atomic generation issue itself. I was greatly impressed by the speech delivered by Sir John COCKROFT in Geneva last August. His impression of the conference which lasted for two weeks was: Probably, about ten atomic power plants with a capacity of 100,000 to 200,000 KW each will be established within five years. However, all of them will be test reactors, and it will be after they are operated for several years that their reliability, safety and economic efficiency will be made known. Until then, it is improper to hurry atomic generation.

As for Japan, in my opinion she should construct reactors of the highest efficiency and with the most convenient materials when the efficiencies of various reactors become known. Now is the age of research competition on generation reactors. The question is how we shall take part in the competition.

I think that Japan's industry is now at a perplexing crossroad. An atomic development project which requires an enormous sum of money for construction

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should be considered in relation to an overall economic development program.

Further efforts are needed to solidify the groundwork, and it is not too late for Japan to make efforts at this stage. Every time I consider this issue, I remember that all of those who attended the Geneva conference last summer expressed their desire to make that conference the first of its kind. I hope that the international atomic energy agency will go into activity as soon as possible.

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YOMIURI (Summary of Articles — 3/4 of full article) May 26, 1956

Electric Enterprises Federation Discloses Prospects for Power Supply Situation

The Denki Jigyo Rengokai (Federation of Electric Enterprises) on the 25th made a special announcement entitled "present and future situation of electric power supply in Japan". This was from the fear that the critical attitude assumed by the Japan Science Council's Atomic Project Committee toward the federation's previously announced 25-year atomic generation program might cause misunderstanding among the people and delay realization of atomic generation for practical uses.

The latest announcement was also based upon the advice given by Sir Christopher HINTON, industrial section chief of the British Atomic Energy Authority, to "establish a program covering as long a period as possible". The data made public by the federation were presented to the Atomic Energy Commission immediately. The gist of the announcement was as follows:

1. In order to judge when Japan will need atomic generation, it is necessary to obtain a correct forecast on future economic development, particularly in the fields requiring electric power. However, under the present circumstances, any long-range forecast in the future cannot but be a rough one based upon many assumptions.

2. Electric power demand in 1965 and 1980 is estimated at 1.5 times and 3.7 times as large as that in 1955. Considering that the U.S., Britain and France are assuming that 20 years hence it will be 4 to 4.5 times as large, the above estimation is by no means exhorbitant.

3. Japan has hydro-electric energy equivalent to 23,010,000 kilowatts in electric power, but 40 percent of it has already been developed. As for coal production in Japan, the economical limit of her annual output is said to be 50 to 55 million tons, and coal consumed for electric generation last year accounted for 14 percent of 43 million tons actually produced. Even if future economies in the consumption of coal through electrification of railways and the use of low-quality coal are taken into account, the limit of the quantity of coal which can be secured for electric generation in the future is expected to be 14 to 15 million tons. In the meantime, Japan's usable petroleum reserves are estimated at only 5,230,000 kiloliters, and 95 percent of the petroleum to be consumed by her has to be imported every year.

4. Even if the existing energy resources are fully used, our calculation shows that Japan will be short of energy supply by a coal equivalent of 1,430,000 tons in 1965 and 31,720,000 tons in 1980. In order to make up for these deficits, therefore, Japan will have to import a large quantity of coal or petroleum or to rely upon atomic energy as "new fuel". Judged from information obtained from various other countries, the cost of atomic generation about ten years hence is expected to be lowered to a level of successfully competing with that of hydro-electric and thermal generation economically.

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ASAHI (Summary of Article — 2/3 of Full Article) June 8, 1956

"SHORIKI Statement" and Its Repercussions

Chairman SHORIKI of the Atomic Energy Commission on June 6 declared, "I would like to dispatch investigators to Britain to purchase atomic reactors." The statement attracted the attention of various quarters. The AEC Chairman in this connection has clarified his attitude by saying: "In case power reactors are imported from the U.S., we must conclude a power agreement with that country. As for a secret agreement anticipated in this case, Lord HINTON says that there is no such need if Japan intends to import from Britain. If cost and other points are exactly as referred to by Lord HINTON, I think I will ask the Government to appropriate in the next fiscal year's budget expenses for the import of a power reactor with an output of 100,000 kw (¥15 billion)."

In this connection, Managing Director IPPONMATSU of the Kansai Electric Power Company says, "If a power reactor of the British type, as mentioned by Chairman SHORIKI, is commercially paying here five years hence, I will agree to importing one." However, Mr. IPPONMATSU adds: "As both natural uranium and enriched uranium types are likely to be used jointly in the future, the import of enriched uranium pilot power reactors also should be realized as early as possible." In the meantime, Chairman FUSHIMI of the Japan Science Council's Atomic Energy Special Committee speculates like this: "The electric power companies and industrial circles have connections with Westinghouse and General Electric of the U.S., but Chairman SHORIKI has no such background, so he cannot play his part freely. This may be why he has chosen a new direction."

On the other hand, however, Counselor TANAKA of the AEC argues: "It is undesirable that Japan's power resources should be placed under the domination of a specific country, and it is noteworthy that the AEC chairman has had an eye on the British-type reactor using natural uranium." And this view is shared by many others.

There are also warnings and sharp criticisms on Mr. SHORIKI's way of thinking. Mr. TANAKA points out: "The import of one atomic reactor alone won't do. A long-range program for atomic generation should first be fixed. Otherwise, related industries would not make any development." And Mr. FUSHIMI advises the AEC chairman to "push the program while fostering the nation's atomic industry, whichever of the U.S. and British types he may choose." As for cost accounting, Mr. FUSHIMI emphasizes that "it requires more study to determine whether the British type will cost less." Moreover, Mr. IPPONMATSU wonders if Britain really has surplus power to export reactors. Finally, Mr. FUSHIMI is very pessimistic about the most important point, that is, he says: "It is highly doubtful if Japan need not conclude any secret agreement if she imports reactors from Britain. Since the U.S. and Britain have concluded a cooperation agreement on the matter, it is inconceivable that Britain alone has no secrets." Anyway, the opinion is strong that it is improper for the AEC chairman to make such important utterances without seeking views of the AEC.

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BASIC PLAN FOR DEVELOPMENT AND UTILIZATION OF ATOMIC ENERGY FOR THE FISCAL YEAR OF 1956

June 1, 1956 Atomic Energy Commission

(This plan may be adjusted along the line of a Long-term Plan for Development and Utilization of Atomic Energy to be worked out hereafter)

1. Objective

The object shall be to promote planned and effective utilization of atomic energy for peaceful purposes by establishing a basic and overall policy and goal regarding the development and utilization of atomic energy for the fiscal year of 1956.

2. Policy

(1) The current fiscal year being the year when the researches and development of atomic energy of this country will shift from the preparatory stage heretofore to the stage of practice, emphasis will be placed on consolidating the administrative organizations and research and development organs and on making them more efficient.

(2) In view of the fact that in this sphere of activities, Japan is over ten years behind other advanced countries, efforts will be focused on basic researches on an extensive basis while introducing foreign technology for the purpose of catching up with other countries as fast as possible. Efforts will also be made for fostering related industries and overall promotion of technology.

(3) For the purpose of exchanging information regarding atomic energy technology and induction of technology and other matters, cooperation with foreign countries will be made closer and for that purpose resident officers in charge of atomic energy will be dispatched overseas.

(4) In order to regiment technicians on atomic energy all over the country and to operate the funds effectually, researches on atomic reactors shall be conducted centering around the Japan Atomic Energy Research Institute, which will be made more perfect in its setup.

(5) With regard to prospecting and production of nuclear fuels, the chief role will be played by the Geological Survey Institute and the Atomic Energy Fuel Corporation, but encouragement will be given to researches and prospecting in private circles by granting subsidies and by other means.

(6) In order to accelerate utilization of radioactive isotopes, an isotope center will be speedily established; regarding the establishment of a national overall research institute for radiation medical science aimed at prevention of ray-injury and studies of radiation for medical purposes, a plan will be established during the course of this year.

(7) Laws and regulations urgently necessary for promotion of researches

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and development of atomic energy, such as laws for prevention of rad-injury and for control of atomic reactors and atomic fuels shall be drafted during the course of this year.

(8) A detailed agreement pursuant to the Japan-US Atomic Energy Agreement will be concluded in order to consolidate the setup for receiving uranium concentrates.

(9) Regarding an atomic reactor for motive power, basic investigation and studies for its materialization will be conducted during this year.

(10) Regarding nuclear fusion, basic investigation will be promoted and information will be collected.

3. Contents of Plan

(1) Plan for construction of Atomic Reactor

(A) 1 set of water-boiler type atomic reactor (heat-capacity 50 KW; neutron flux density 10^{12}) will be purchased from the US and will be established in the Japan Atomic Energy Research Institute so that it may be installed in a complete form by the end of this fiscal year.

The objects of establishment of this atomic reactor shall be as follows:

(a) Education and training of technicians;

(b) Basic researches necessary for construction of a homemade reactor, especially equipment and experiment of exponential function reactor to be conducted with natural uranium and heavy water imported from the US, learning of processing technology of fuel and experiments on property of material.

(c) Experimental production of radioactive isotopes.

(B) 1 set of CP - 5 type atomic reactor (with neutron flux density 10^{14}) will be purchased from the US and will be established in the Japan Atomic Energy Research Institute. But in view of the long length of time required for its manufacture, the selection of the maker to be ordered from and conclusion of a contract will be accelerated so that an order may be put during the first half period of the fiscal year of 1956. (It is estimated that at least 2 years will elapse between placing the order and the arrival of the reactor.)

The objects of establishment of this reactor shall be as follows:

(a) Experiments on materials for atomic reactors

(b) Experimental production of radioactive isotopes

(c) Various types of basic researches and education and training

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of technicians

(C) 1 set of a natural-uranium-heavy-oil type atomic reactor (neutron flux density $10^{12} - 10^{13}$) will be established in the Japan Atomic Energy Research Institute. Basic researches for designing of the reactor and for the establishment of productive technology of fuels, mechanical apparatuses and reactor materials necessary for the establishment as well as the researches for industrialization will be conducted continuously from last year, and efforts will be made so that requirements may be met with home-made materials as far as possible.

The objects of the establishment of the reactor shall be:

(a) Establishment of technology of designing atomic reactors.

(b) Production of radioactive isotopes.

(c) Chemical disposal of fuel and tentative production of plutonium.

(d) Establishment of productive technology of fuel, machine facilities, reactor materials to be used to power testing reactors and other atomic reactors.

(2) Researches on fuel.

(A) With regard to the development of nuclear fuel materials, basic investigations and investigation for industrialization shall be conducted for the purpose of surveying and confirming geographical distribution conditions of uranium and thorium deposits. With regard to basic investigation, air-borne investigations shall be conducted chiefly in mountainous districts in the middle part of Japan and in Kitagami; investigations by means of carbon, etc. shall be conducted in various districts in Gifu, Okayama, Tottori prefectures; and in 10-odd prefectures such as Fukushima, Tottori, Okayama, soil and deposits investigations, geological chemical survey, drilling, etc. shall be conducted. (The above will be undertaken by the Geological Survey Institute.) With regard to investigation for industrialization exploitation by means of drift excavation shall be conducted in some districts in Tottori Ken. (The above will be undertaken by the Atomic Fuel Corporation.) A prospecting subsidy shall be granted, according to circumstances, to private enterprises that are to conduct investigation for industrialization with a view to promoting their enterprise.

(B) With regard to the development of nuclear fuel materials, with a view to establishing refining technology, such researches as have been conducted since last year shall be continued, and at the same time the construction of interim refining experimental facilities in the Atomic Fuel Corporation shall be started.

(3) Plan to bring up relevant technology and industries.

With a view to establishing production technology concerning designing of reactors, machine facilities and reactor materials, relevant technology and industries shall be fostered this year, too, as in last year, under the entrusting charges and subsidies to be granted by the Government, according to details mentioned below. In this case, researches which have been conducted continuously from last year shall be undertaken as a general rule by the same researchers for this year. Consideration shall be given lest researches should overlap one another.

(A) Designing of reactors

The designing of a natural uranium heavy water-type atomic reactor, whose completion is expected in 1959, has been investigated and studied by the Science Promotion Association (Gakujutsu Shinko-kai) until last year, but the investigations and studies shall be taken over by the Japan Atomic Energy Research Institute this year.

(B) Machine facilities

Measuring instruments for basic purposes have been tentatively manufactured and studied last year, and a rough prospect of the situation has been obtained. This year, emphasis shall be placed on tentative manufacturing and studies of machines connected with atomic reactor control, and other auxiliary machinery and tools and machinery and tools for preventing ray-injuries.

(C) Reactor materials

With regard to reactor materials, there are materials necessary to the natural uranium heavy water-type atomic reactor, such as heavy water, plumbago, materials for screening, etc. and materials especially necessary to the power test reactor to be constructed in the future, such as stainless steel, zirconium, etc. Researches shall be conducted continuously this year too, regarding the former, and as to the latter, the basic studies shall be started this year.

(a) With regard to heavy water, researches shall be continued on low concentrates by the exchange reaction method, and on high concentrates, by the reclamation electrolytic method. Other methods shall remain in the stage of investigation and study. With the completion of technology necessary to its production on an industrial scale scheduled for 1957, the construction of interim experimental facilities shall be started this year.

(b) With regard to plumbago, with the completion of technology necessary to its production on an industrial scale scheduled for 1957, interim experimental facilities shall be constructed this year.

(c) With regard to cement for screening, researches shall be continued on those kinds of cement expected most hopeful,

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based on the study results of last year.

(d) With regard to studies concerning processing, etc. of metal materials, such as stainless steel, zirconium, aluminium and metal uranium, basic studies shall be conducted.

(D) Disposition, chemical separation and utilisation of scrap

In view of the situation peculiar to this country, study will be made of the disposition of scrap on preferential basis.

(4) Promotion of utilisation of isotopes

(A) In order to speedily promote the utilisation of isotopes in this country, an Isotope Center, whose functions are to carry on studies of production and utilisation of isotopes and to handle matters concerning import and distribution thereof, will be immediately established. In this connection, plans will be drawn up as to necessary establishments and researches.

(B) Promotion of researches on isotopes

With regard to the branches of research which cannot be entrusted to private isotope research groups, national experimental and research organs will take charge thereof. These organs will carry on researches this year on the following themes:

(a) Sterilisation and preservation of agricultural and marine products

(b) Plant breeding

(c) Fertilisation

(d) Highly polymerised compounds

(e) Mutation of ferment fungus

(f) Anti-radial rays structure

(g) Drift sand and snowdrifts

(h) Other themes

(C) Popularisation of utilisation of isotopes

(a) To promote research concerning the utilisation of isotopes and to exchange the results thereof, research conferences will be held.

(b) To popularise the achievements concerning the utilisation of isotopes and to further the utilisation thereof, training courses for the technicians will be held. At the same time partly for the purpose of enlightening the public, exhibitions and lecture meetings will be held and guidance books will be published and distributed.

(5) Prevention of ray-injuries

(A) To prevent impediments which will be caused by radial rays, adjustment of relevant laws and ordinances will, first of all, be carried out this year and researches will be made as to the permissible limit of radioactivity to human bodies, prevention of impediments of this kind, diagnosis and medical treatment for the case. At the same time, dispatch of members to international gatherings in this connection and holding of institute classes will be put into practice so that all is right in preventing possible impediments of this kind.

(B) For the purpose of preventing impediments caused by radial rays and of applying radial rays to medical treatment, a National Radial Rays Medical Science Overall Research Institute will be inaugulated in 1957. In this connection, a minor preparatory committee will be organized within this year to draw up basic plans and business programs.

(6) Training of technicians

In view of the progress of the atomic reactor construction program in this country, researches concerning the designing, construction, operation of atomic reactor and other series of researches regarding this type of mechanism will mainly be left this year to the technicians to be dispatched to research institutes in foreign countries for necessary training. With regard to the construction of water-boiler type atomic reactor however, training of these technicians will be partly carried on at home with the Japan Atomic Energy Research Institute as the nucleus. The training of technicians handling heavy water, black lead and other metalic materials which are used as fuel and materials for constructing the reactor, will chiefly be carried out at home in view of the situation overseas. In the light of the actual conditions of domestic utilization of isotopes, technicians for the utilization of isotopes technicians for the utilization of isotopes will undergo necessary training at home or abroad. In order to conduct the training of these technicians at home, institute classes will be held and authorities on this branch of science will be invited from foreign countries.

Scientific researches as to the prevention of radial ray impediments, along with researches on the disposition of scrap, are considered to be of no small importance in this country, and so technicians will be sent to foreign countries to undergo necessary training.

For the above-mentioned purposes, 30 persons will be dispatched from Government agencies to foreign countries. Civilian researchers who want to study abroad will also be given as many conveniences as possible.

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