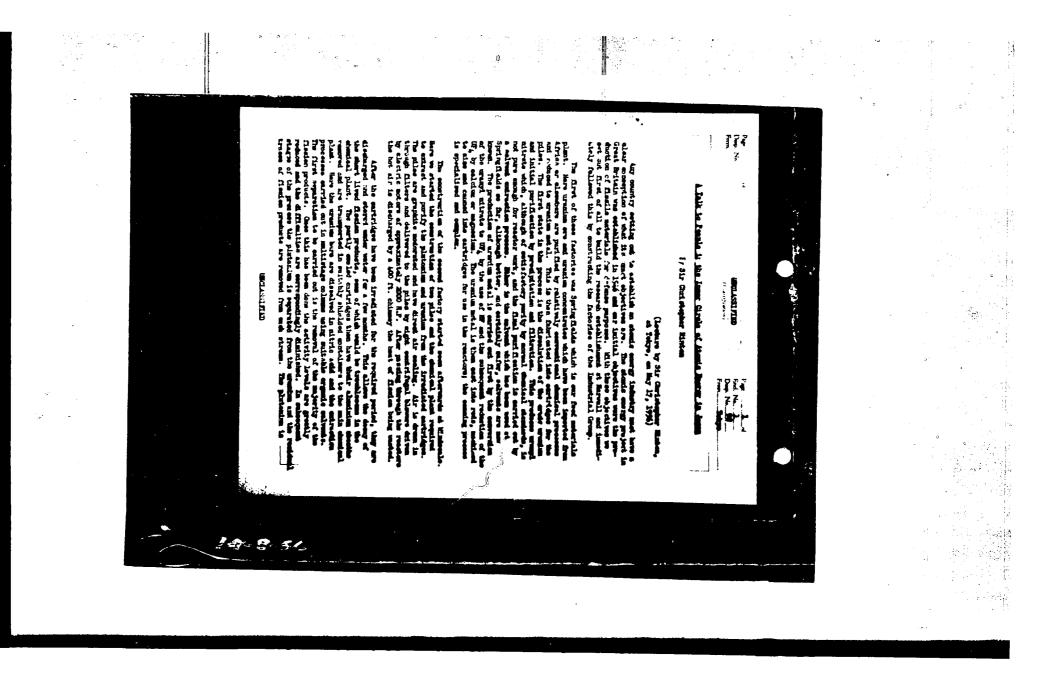
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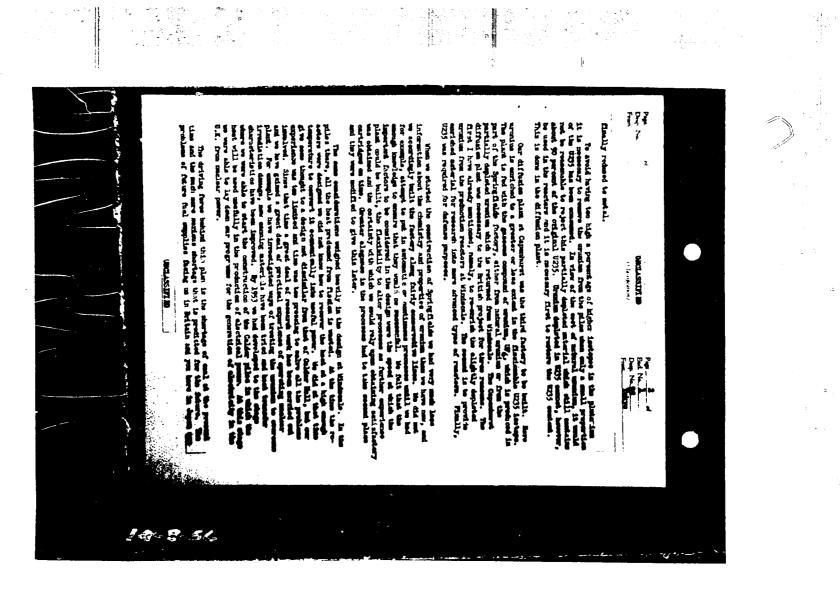
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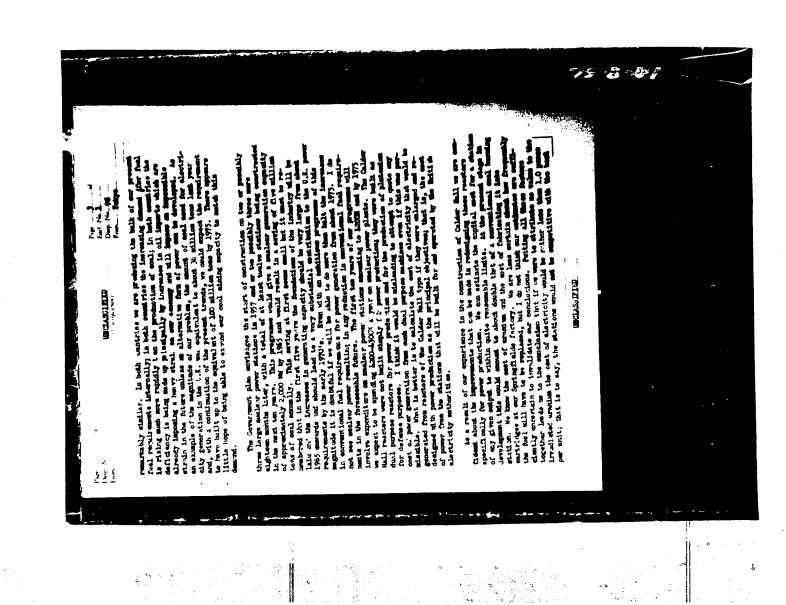


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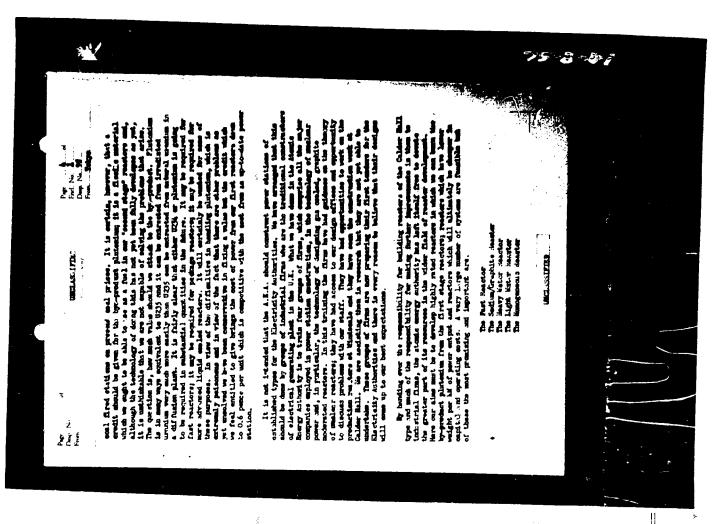
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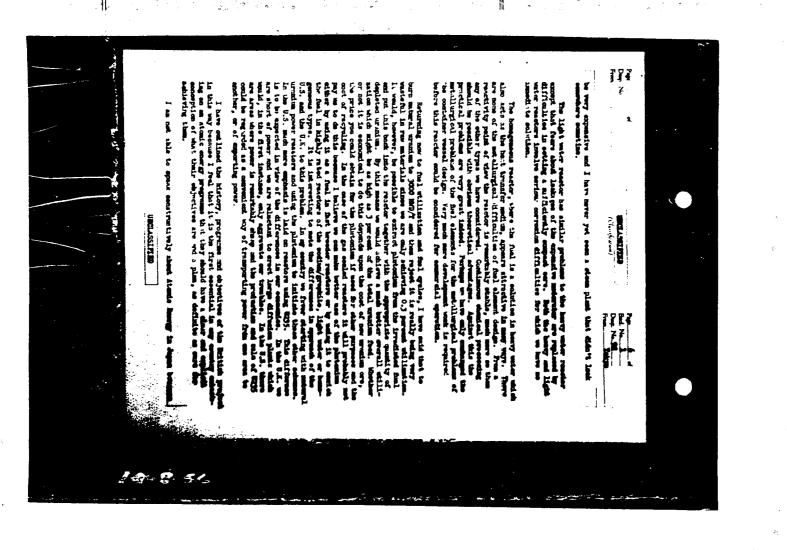
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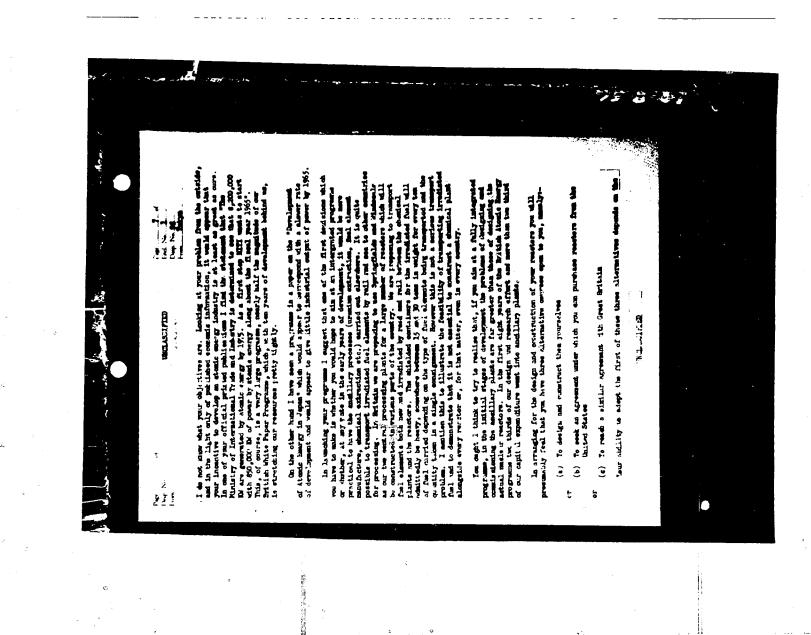
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The fast reactor has the valuturing advantage that it is a brander; it was a problem more plateodia bias it berrs. In the case of the sales it are fast, i.e. a field subject was subjected as a set of 0.2 percent. This may be addressed in our fast, i.e. a field subject and of 0.2 percent. This may be addressed. The sale of the sa The module/graphic reactor is expails of higher reting the system. It is expails of profecting hast at a high enset for the show pressures associated dith the mast up-to-date small fly todays. This is of considerable importance because maly about out of a mediase power station is the east of the rester fitted conditions and hav themail afficiency all add to the serie of the components of the short can. The andthe graphic remarker fitted components of the short can. The andthe graphic remarker whether the preservate of a media which the difficulties associated with the of large preserve vectors. Against this the mattern example with of large preserve vectors. **]]**] The heavy weter reactor is stimulty in this it will generate and the matrice economy is very good. To obtain even seture, state conditions in the traine mount with the reaches weaveled to a very main higher fundament in 500-2000 H. and stimuled. The difficulties of fundamenting large presses we 2000 lb.eq.im. mbuild not be under-originated. Amali leads The gas cooled reactor operating on natural wreatm and rejecting wreatments to compare through modest here up, and the fast reactor wreated phristerian of a grant writer of reactors and hall splice. At the cold the continues of a grant writer hall type, heavy and embersons but math, is ind the fast near the fast representing entries in the two distributions of a grant writer hall type, heavy and embersons but math, is ind there are no the fast reactors. At the emberson is and, the table of the fast reactors which is the fast reactors which are as yet and the other write the mathematic set of the reactor write the mathematic set of the reactors which is an entry of the table of the transfer of the reactors (14. The other reactors which is an entry of an the table at the table of the table 3 MCLAUSTERN INCLASSIFIED

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time scale you are setting for your dev lopment work; the amount of memory 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 ble to form an epinion from the information published on the deve eponet of large last based medear power plants in the U.S. as I am.

If you wished to adopt the third alternative uni if any necessary over-riding agrouments were negotiated we should certainly advise the adoption in the first place of reactors of the Calder Hali 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 machan power that the slow speed reciprocating angine occupied in the development of conventional steam proser plants in that it makes use of technicans and materials which are well established and well tried to give a safe, reliable and reasonably secondical source of power. The carly slow speed reciprocating engine held its own against other forms of prime mover for more than a contury; 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 them in cost per horse power. These reductions resulted from the development of new techniques and of new materials.

I believe that the development of malear 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 cutput can be raised and the capital cost per herse power will come down. I think that reactors of this type will still be sold in 30 er even 40 years time and that they will be in use in 50 years time.

But meanhile 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 Hull 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 lawer specific rating.

Perhaps it would useful if I concluded this lecture by summarizing the points which CONTRACTOR POLICY PRODUCTION FOR THE POLICY POLICY

FIRETLY:- It is espectial that you should prepare a firm and realistic programme of the amount of malsar power plant that you intend to have installed your by your. This programme will take into account not morely your power requirements but the scientific and proctical problems involved Page Desp. No. From

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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 tan 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 in. In order to abieve times results research and industrial application must go hand in hand. If I may draw a military parallel, the research workers are the recommisance units while the industrial organisation is the main body of the army; it is no use for the recommisance troops to penstrate 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 programs you should install an industrial reactor of some sort at the earliest resemble date.

- THIRDLY:- In the early stages of an industrial nuclear power programme it is much more important to be successful than to be clover. I constantly find it necessary to give this advice to my can people. In the early stages of a nuclear power programme the psychological effects of accident or failure would be very serious.
- FOURTHLI: 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 ind satisfactory industrial development it is measury to build some sort of a term in which there is, from the outset, a happy and equal partnership between the industrial engineer and the research worker.
- FIFTH? If a fully integrated and calf contained programs comprising wranted - fuel element manufacture, shemical extraction and re-- and the standard of any shemical effort on these ancillary plane 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, yes are saking a late start. We, in England, had something of that feeling when, well behind the United States, we had the foundations of our industry in 1966. We found, however, that careful planning and wise concentration of effort emailed us to make satisfactory progress and that we were right in regarding our labe start as a challenge rather than a handicap.

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First Lecture

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

The "grand speech meeting as atomic generation" sponsored by the <u>Yoniuri</u> <u>Shimbum</u> to calabrate the visit c. Sir Christopher HIMTON was held from 1:00 p.m. on the 19th at the <u>Chuo</u> University anditorium in Kanda Suragadai, Chiyoda Mard, Totro. In his opening address, Vice President TAKAHASHI of the <u>Yoniuri</u> <u>Shimbun</u> stated: "Hoves 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 at is ter years since the development of atomic power was serievely taken up by the Atomic Energy Bureau and the Atomic Energy Authority which succeeded the Bureau. Japan must make up for the log of tem (Bars." 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. TAXAHASHI then introduced Sir Christopher HINTON, responsible official of the Colder Hall Atomic Power Station which is scheduled to start its epochmaking 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 plature slides. His speech also doughed upon the construction of a breeder reactor using fast neutrons, and gave a strong impression to the 3.000 cudience 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 for industrial purposes.

In ordinary thermal power plants, energy is obtained as a result of combustion of carbon compands. If you ask a technician in a thermal power plant where energy resources are obtained, I think he will not make any answer bustom the methods to secure energy resources are so fumiliar to all. On the contrary, obtaining energy resources by means of nuclear fiscion is not familiar to us. It is a more complicated phenomenon. In the case of malear fiscion as an energy source, we same see with our eyes what reaction is taking place. Thurefore, 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 stom is composed of a control part called "atomic nucleus" which can be compared to the sum and "alactrons" which move around the nucleus like the planets. The atomic mediane 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 chartering which nove sound its. The charical properties of an atom are decided by the number of protons which ended in the atomic nucleus. In other words, stars thich have the sum number of

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protons have the same chamic l properties. The number of mitrons in an atom will differ as the case may be, and its mass and physical properties will differ accordingly.

when the header of protons of two atoms is equil, their chemical properties are exactly the same, while on the contrary, when the numbers of neutrons differ, the physic 1 property of these stoms 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 cloctrons 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 produced by a nuclear 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 by fore 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 belium atom is far larger than that in the generation of a heavy by arogen molecule, and this energy (which is hundred million times that in a chemic 1 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 emparatively easily. This reaction is called "nuclear fission". For instance, then 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 emunation of 2.5 units of neutrons. It follows, then, that a nuclear fission results in the creation of nuclear fission products, the generation of neat and the emunation of neutrons. When fission takes, place in comparatively large volume, one reaction brings about another and thus the fission goes on consecutiv 17. The even the volume is anally the se nutrons disappear without being a b octed to ther nuclei. If the volume is large, the fission reaction will cause at this point. If a large quantity of uranian is employed in this case, the prob bility of neutrons being lost decreases, because the manor of atoms to the probability of neutrons are bability of by the law of cube while the surface from which neutrons disappear increases by

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The minimum necessary puncity 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 cont. The greater part of the remainder sames 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 stamic 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 cuantity, the chain reaction will occur and the heat it generates can be utilized for industrial purposes. Thether or not it is possible to harmess 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 uranism or only a little concentrated uranism is used as fuel, it is conceivable that all neutrons will be captured by uranism 238. If such a condition arises, the neutrons will be unable to cause nuclear dission in succession by being bombarded to uranism 235, and then the chain reaction will be discontinued. Uranism 238 is about 140 times more abundant than ur nium 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 volocity, 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 noderators. 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 measured 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 in stonic reactor, for instance, the cu multy of neutrons which are captured by it will increase, and those necessary for continuing a chain reactions will decrease. In the same sence, in the case of an utmost emergency and

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danger, for instance, it is possible to stop the eperation of a reaster by putting into it a material which will capture neutrons. This is called "antting method". An atomic reactor can thus discharge an enormous heat. The fash used in atomic reactors is metallis wranium, which is soated with aluminium or other material. In this case, of course, part of the fash will be transmitted, 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 expluse mestrons and is transmuted into an element called uranium 239 which does not exist in the natural form. Franium 239 is a substance with an instable mature, 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 mened meptium with stanic 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 stomic reactor in Britain was established in Harwall for research purposes. Later, a reactor for the purpose of extracting a large quantity of plutonium was constructed in Windscale near Harwall. However, the entire heat generated by the latter reactor was wasted without being harmossed at all. The reactor was dangerous because of its exenation of very strong redisactivity. 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 telerable limit.

However, as there was a danger that the consrete shield might be decayed by thermal neutrons, another type of shield was devised so as to absorb meutrons 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 esoled 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 utilization of heat generated in an atomic reactor, it becomes very important for the connexical 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 utilize 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 genuration reactor which can thus be operated economically is now mear completion in Calder Hall. This reactor, just as the Windscale reactor, is a graphite moderation reactor, cooled by means of carbon dioxide. The earbon dioxide is pressurised and circulates around the fuel. A steam turbing is remby 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 Ostober this year.

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Ivelve stomic power plants are to be constructed by 1965, according to car program. They alone are expected to save 5 to 10 million terms of coal. Parthermore, it will become possible by 1975 to obtain from atomic reastors electric power equivalent to 90 million tons of coal. After 1975, in Britsin, construction of ordinary vetor or thermal power generation are not planned, but, according to the program, electric generation will be carried out employingly by atomic power plants.

Thermal reactors like that in Calder Hall, yield plutenium as a hyperduct. The question which naturally follows is in what field the plutonium een be used. It is possible to utilize the plutonium for other types of reactors. The so-called fast neutron breeder reactor is constructing a very large plutenium reactor in Downley in the north of Scotland. The hitherto mentioned reactors which use allow neutrons require moderators in order to decelerate mentrons. I neart that the use of moderators is for the purpose of preventing a member of neutrons from being 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 abcorbed into impurities contained in the moderator.

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

The thermal output of the said generation reactor in Domaley is about 60,000 NM. It core is very small, about 2 inches (5 cuntimeters) 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 matrium as a cosler is conserivable instead. The matrium will be circulated around the reactor core by means of an slectric pump. This will involve great technical difficulties, as such a large quantity of liquid matrium has never been used before.

If the natrium direulation is stopped for some cause or other, it is emoutvable that the center of the reactor will be malted. 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, urenium 258 is placed as a "blanket".

The thermal reactor in Calder Hall and the fast reactor in Downley eas 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.

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Various ways of reactor designing can be conserved between the two extremes. To itemise according to the valodity of neutrons, there are three types using fast neutrons, intermediate neutrons and very also thermal neutrons respectively. Also conscivable are these using no melerator at all, using ordinary valor, beavy water, graphite or beryllium as a mederator, and using gas, water, carbon diaxide or liquid metal as a cooler.

We can also conserve reactors using fuel metals not only in solid form but also as a solution or wrentum colloid. They are called humgenous 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 asstrons of an intermediate velocity. However, the beenest attention at present is focused upon the thermal reactor which is to be completed in Calder Mail. I also thisk that there are unlimited possibilities of atomic generation being realised by mins of new types of reactors.

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(Asstars by Sir Christopher Huten) (at Omin, on May 2, 1956.)

Lateration

storids emergy project me the Sir John Controlt at Barwall. The development of stands started after the war, and the of stands energy in Britchs and really be and to have , and the first step in the ostablishment of a British was the formation of the recentsh organization under

This ergenization is emposed in largetern research and in deviating the provence which are to be used in the industrial factories. It also does a conviderable ensure of capilor research is aid of these industrial preserves but the Industrial ergendantion has a Bassurch and Development Section which does nost of the chanteni engineering and other development work which is researcy for the translation of Harvall filerabets into industrial designs.

Bertine of the Past

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

Similar scale with the construction of the Harmall experimental plic, the industrial Group was engaged in building its factory of Springfields for the conversion of uveries are into comment uveries main along. Treasure but here developed during the war by Imperial Granical Industries for the manney there of uveries metal from pure acids as a plice plant scale, but the extraction free even and proparation of a pure acids and plant scale, but the extraction take scale. The unsertainty about the effects of exponent to realize the primerous matter of uveries relate had not programed byper the test warkers and a further difficulty use to schieve the required degree of protocols. The plant warkers and a further difficulty use to schieve the required degree of period. The plant warkers and a further difficulty use to schieve the required degree of period. The plant which was designed is not perfect but has querted will from the start in quite shiels was designed is not perfect but has querted will from the start in quite shiels we designed is not perfect but has querted will from the start in quite of these problem.

recalling sharry pusped to a stock tank. From the tank it is pusped to the first of three exceeds discolvers where mixed subhurds and mixeds and the added. This discolves the urandum and the solution, together with the transmission matter is supposed on, passes to the second tank where barium mitures is subject. The burium is predigitated and carries down with it the reduce which is the minute The are arrive at the fastory in steel drame and if the are is pitchilents the drame contain a small assess of reden produce: by redientive decay. They thank have to be unbound in a closed chanker by remate emiral, after which the ere is tipped into a jew. evaluer fullowed by a cone crusher. The redi-active gas is drawn off and diluted to a safe consentivelian being ne-lensed to the stancephere. The crushed are has to be sarefully employ to Leased to the stanoghers. The studied are has to be carefully sampled to detarmine the unnature context and is then wet ground in a ball still and the recelling slarry proped to a stack tank. The studies the tank is the standard in a ball still and the

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source of activity. After passing to the third vescel the liquid is perped through filter presses which remove the suspended impurities. The armnium in the solution, which is now only slightly active, is precipitated by the addition of hydrogen peroxide and removed by filter pressing. This filter sets, though a pure uranium oxide by commercial standards, requires further perification to most stands emergy standard and is re-dissolved in acid and extracted into other. The impurities remain in the aqueous phase and the uranium, as uranyl mitrate, is then washed out of the other and precipitated with amounts in the form of amountum diurenate, which is collected and dried on a Mutech filter.

The annonium diuranate is then converted to ursaium tetrafluoride. It is packed in trays which are loaded into a cylinkrical reaster and this is lowered into an electric furnace. The conversion proceeds in three stages; the diuranate is first bested to decompose it to uranium triaxide, this is reduced with hydrogen to the diaxide and the diaxide is then treated with anhydrous hydrofiverie acid gas to convert it to uranium tetraflueride.

The final step in the manufacture of uranium metal is the reduction of the tetrafluoride with metallie filcium. A mixture of solaium chips and uranium tetrafluoride is tipped into a conical mild steel mould lined with soleium fluoride. The would, which is now led on a begie, is run into the firing shamber, and the contents ignited by a pollet of potassium mitrate and lastees. This initiates a violent reaction. The uranium metal because malten and sinks to the bottom of the mould whilst the colcium fluoride, which is the other product, forms a alag on top. After leaving to cool the mould is bruken down and the uranium billet removed. The billets are formed into have which are unchined to size and cannot in aluminium ready for insertion into the pilce.

It had initially been the intention that we should held water-evaled graphite mederated piles. However, for safety reasons we decided to build aircooled piles for the production of plutonium. We fult, and I am sure that in our case it was true, that the disadvantages of the air evaled pile were extendeded 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 remute as to be immonvemient. The first of the two piles built in this factory was in operation rether loss than 31 years from the date when the site was chopen.

At this Windseele factory we have also the chemical plants for the extration of plutonium and uranium from the irradiated motal. It was decided at a firly early date that we eight to adopt solvent axtraction processes for these chemical separations, not morely because we wished to achieve the high efficiencies of which they are capable, but also because we falt that it was eccential to adopt from the cutset chemical processes which enabled us to recycle the uranism and so secure economy is its use. Construction of the chemical separation plants started late in 1948 on the basis of research work which had been carried est at the Chalk River Laboratories in Canada by Dr. Spence, who is now beed of the Chemistry Division at Harwell. This work was done on only 20 milligrens of plutonism, and as there was no time for the construction of pilet or emistechnical plant before construction work started, we want into the fall centle erestruction of the primary separation plant, which was very large and quite Page Dece N. Frier

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costly, on the basis only f Dr. Spence's research carried out on so small a quantity of plutonium. It is, of course, not difficult to scale up a chamical process in this way if the full scale procees is to eperate batchedse, but in this case we were scaling :p from laboratory banch 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 thus, the plant went into eperation 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 alightly enriched in the fissionable 235 isotope. This plant was necessary for re-enrichment of the purified uranium separated from the irradiated alugs in the chunical plant at Windocale and made available for re-enviling through the piles. The plant was built at Capanhurst in Cheshire and started operation early in 1953. Alongmide it has been built a plant for the manufacture of highly enriched uranium.

Plans for the immediate Putare

In the Ministric piles all the heat of fission is unstady this is because, at the time they were built we did not have enough technological insuladge 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 Comberland. This factory will ultimately consist of four gas-cooled, graphite-mederated reactors and will have a full-load generating especity of 100 megawatte at 22 KV. The station is to be run by the Atomic Energy Authority and will be speed by H. M. The queen on October 17 of the year.

Based on this development a Government White Paper was produced in Polymany 1955 which outlined the first stages of the programme for the development of industrial makear power in Great Britain. This programme shorts with the comstruction of two gas-cooled, graphite-moderated stations, each with two reschere, and these should be in production in 1960 or 1961. By 1966 there should be twelve stations in operation, which a total generating superity of around 2,000 mm. 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 impertant problems which lie in the way of producing useful power from medear energy.

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

Unfortunately there is no known way of converting melear energy into your without going through a heat graie. It follows therefore that is evaluable from our the maximum thermal efficiency we must use the heat which is available from our fis alon energy at the highest possible temperatures. This can only be does if our fuel elements can be operated at high emperatures. Hereover, in event to get the greatest occorry in capital cost, it is necessary to remove as much heat enpossible from every ton of suchear fuel that we put into the receiver. It empiricabe over emphasised that whereas the dimensions of the ever of a mellow receiver are detarained primarily by malear physical considerations, the perdecible

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rate of hast 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 firstle 0235 is diluted by non-flasila U238 and because of this reasonably respondent piles can be built with moderate heat releases yer ton of fuel. But as we make 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 liss 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 unterial which encloses it. To my wind the limiting problem in reaster design for many years to came will be the design of the fuel element; the reastors 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 some first

A nuclear reactor presents a potential basard occause of the accumulation of highly active fission products within the fuel. Any accident with a reactor, in the way of a fire or uncentrolled 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 alternativaly 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 ascident to a reaster. In the case of thermal reactors the core contains both mederator and evaluat in addition to the fuel element. If the coolant is more effective as an absorber of medrums than it is as a moderator, any less of coolant from the core may result in an increase of the reactivity of the pile. This is because the medrums that have previously been absorbed in the coolant now become available to come further fission and so increase the activity. Such a reaster, for instance some designs of graphite or heavy water understed piles using ordinary light water as coolant, may be inherently dangerous. On the other hand a graphite-moderated pile with air, \Im_2 or halium cooling is interently safe because loss of coolant will not increase the member 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 suddem increase of reactivity on occur.

In the case of the more highly rated thermal reactors which can be built

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when enriched uranism 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 coelents; if for any reason circulation of the coolent coases, the best especity of the ears is so small that the temperature would rise sufficiently quickly to emme structural disintegration of the core and vapourisation of the liquid metal which might then eatch fire and cause dispersal of fission products. The result of such an accident can be contained by brazing the reactor in a suitable vessal which will stand the calculable pressure which may arise. This is being done on our fast reactor at Deservery by housing the core of the fast reactor in a steel uphere.

It would be a mistake to suppose that the probability of an accident need be any higher in the case of a malear 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 reaster 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 HHPO and Miniscals piles. We have an active core in the form of a sylinder of approximately 20 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 ari.e 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 shannels in the graphite mederator. Such an arrangement is convenient so far as the design of the coalast circuit is comcorned 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 shannels the latter difficulty disappears but the design of the graphite structure becomes much more submard. In either case there is difficulty in arranging a suitable mechanism for charging and discharging the fuel elements. If a separate hele through the shall of the promotes we wasel is provided for every channel the design problem is extremely avecand. 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 coolast circult by means of motor-driven blowers and the cutlet temperature of the gas leaving the reactor is in the neighbourhood of 350°C. The heat exchangers or bullers are situated outside the main biological shield surrounding the reactor itself and the turbo-alternator plant is of conventional design.

The similar stages of the graphito-moderated gas-cooled reader are its inherent safety and stability and the large thermal capacity of the care. Heat realizes..... Page Despirition Esser

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are quite modest, in the range between 1 and 2 MM per toges of uranium, and this means that the capital investment of uranium is large. The main dicadvantages of this type of reactor are the large investment of uranium required, the meed to use high-purity graphite, and the difficulty of constructing the pressure shell. However, the graphite-moderated gas-e-coled 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 unit over optimistic.

If this competitive price can be achieved in the first muchar power stations, it should be possible, with the development of techniques, to make considerable improvements and to generate electrical energy from macher power at prices lower than those which can be achieved by the use of conventional faels. 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 properties 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 stems 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 steen power station was over \$2,000 - in the middle 1990's this cost per horse-power had fallen to about \$4.0.

Every technical consideration suggests that the unit cost of smalear 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 predmeticm 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 im 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 inigher ratings; in the long run. This will reduce costs and reactors with high Page Desp. No Energi

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ratings are essential to enably us to burn up the plutomium produced as a byproduct in gas cooled reactors.

Heavy Water Noderstad Natural Urasium Heaster

From a physicist's point of view, heavy water is the bast understor for a thermal reactor since it gives the best newiron 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 occlant 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 inherestly dangerous reactor. It is there-fore desirable to choose heavy water for use as coolant as well as understor. We should now be able to go to ratings in the range between 5 and 10 MM per tonne of urakium.

The estimated cost of power generation from a heavy water mederated 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 everyme 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 Headtor Veine Enriched Uranian

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

The use of light water should give greater freeden 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 reastors is to dispense with the moderator altogether and to use a highly enriched fuel. The core of such a reastor, in which the fission process would be carried on by intermediate or fast (as opposed to thermal) neutrons, would contain a fael having a relatively high proportion of one of the fissile elements or isotopes, UZ33, UZ35 or PuZ39 together with one of the fertile elements, i.e. an element which can absorb nontrons to form a fissile muturnal such as ThZ32 or UZ38.

It is a reactor of this type that we are building at Dourreay. The absence of moderator results in an active core of very small volume. This volume can efcourse be increased by dilution of the fissile alement with a greater questity of the fertile element or alternatively by the addition of some other dilutes to the ourse. Kither course of action, however, introduces materials which absence moutron and therefore increase the investment of fissile material messency to

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give a critical assembly. Since the expital cost of the fiscile meterial in the core is the major item in the companie of this type of reactor, we must therefore face the problem of designing a core of very small clos, say a cylinder of 2 ft. diameter and length with a heat rating of perhaps 100 MV.

This is a difficult problem but there are strong reasons for facing it because probably fast reastors can be made to bread more fiscile material them they consume and so, while generating power, they can increase our stock of fiscile material. Hereever, if a large number of thermal reastors 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 contered on the small size of the core. It is not so much the heat transfer from the surface of the field elements to the coolant that is the stumbling block, although this is difficult enough since we may be asking for a heat flux around 3×10^9 HU/hr per sq.ft.

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

In sutlining some of the problems of the fast reactor I have implied that the reactor core would be of estivational design in having solid-astal fuel elements. Because of our limited knowledge of the physics and engineering of other systems, this is the only form of construction which see be followed at the present time but ane inevitably searches for a better and redically different derign. One would like to superate the heat-transfer problem from the smaleer physics of the dure, and, in fact, to transfer the heat outside the eare. One would like to provide fur continuous removal of gaseous finding products. One would like an arrangement in which the fuel is already light so that the problem of malting of the fuel elements, in the event of disturbance of the coolant flow, would disappear. Any such sahame which would involve circulating a liquid fual through the reactor brings up a host of chemical, physical, and sutallurigical problems. As regards best trensfer, as eveperative system would be better them a liquid coolant arrangement. A homogeneous reactor core conditing of a solution of the fissils meterial in some solvent, which would be allowed to beil 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 unalour emergy.

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Lecture - No. Jaioptists

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

In presenting lectures on the work we have done in developing our statis energy programs I an usually speaking to a group of exientists or engineers with specific interests. Ans 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 andience, I understood that today I should be speaking to scientists generally and not to exientists with one essents 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 emergy programme, and I hope that you will find this useful.

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

The Atomic Energy organization in Great Britain was established in 1946 and our insudicts objective was the manufacture of plutonium for defense purposes. I briefly outlined in my first lecture the extraction process at the Springfields factory where the aranium fuel elements are fakticated. The most stage was to hull a reaster and at that time our incolledge of reaster technology was not sufficient to eachle us to design a dash purpose pile where we could use the heat generated in the reactor core as wall as manufacture platening. Therefore, in the Windowske piles, the reactor is could by a current of sir which is passed out to atmosphere through a 400 ft. chimmy and the heat of firster is wasted.

In order to generate power from heat it is necessary that the heat shall be available at a high enough temperature and research work as 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 seactors 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 coelant in view of its low cost, ease of availability, neutron absorption cross section, and low chemical reactivity under pile emditions. The gas is circulated from the reactor through a hest embanger, where the heat is used to form super-heated steam to drive conventional turbo-alfornator generating sets.

The British programme for the development of nuclear power starts with the construction of two or probably three gas-cooled graphite-anderated 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 inte 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 ebseld show an improved performinge, purticularly in heat rating. By 1965, ----

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twelve stations should be in operation and this group should supply between 1,500 and 2,000 meganette of electrical power. The first reastors of this group will be of the gas-coaled graphite-mederated type but the last two or three may be of the liquid-coaled type which may then have been developed sufficiently to be economically satisfactory.

Our planning of the development of the industrial uses of stamic energy in Expland has largely been conditioned by the coal supply situation. Our present usage of coal for generation of electricity is about 36 million here a your and, without nuclear power, it is estimated that by 1975 we should be using 100 million tons per annum. Coal is becausing increasingly difficult to obtain 55 that the price will rise and reliance on coal alone as a source of power would mean that eost of electricity would increase considerably and repidly.

In the position of urgently requiring power from atomic energy we have placed our reliance firstly on the gas-cooled graphite-understed reactors. While these have abort-comings, they have the advantages of being inherently safe, of being simple in engineering design and of using materials and toduciques of construction which are well established - no great difficulties are expected in getting them into operation. They are, moreover, expedie of great improvemer⁴; but in our second stage of development they will have to be supplemented, and perhaps ultimately superveded, by reactors which are capable of high retings. These will certainly be measury to burn the two product platesters in wher construction in the method. To this and a protetype fast reactor is wher construction in the method of Sostland - this type of reactor is very highly rated uses concentrated mellear fuel and is capable of creating user finally material than it destroys. We are also vorking on the design of thermal reactors which are capable of high ratings.

Our long-term programs may therefore be summarized as follows. We sim first of all at securing a reliable catput of power from remoters of the Calder Hall type, we aim must at improving these reactors to make them more scancellen, and we aim must to develop scientific knowledge, materials, and techniques, to emable 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 suclear physical research which is necessary the use of experimental reactors is coossilial and these which are used can be divided into two general types

- (a) reactors built and operated as research tools in which irrediction of materials is carried out or measurement of muches 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 buildering sholes of types. In order to earry out irrediation quickly and obtain early results, the scientist demands a reactor with a high moutrom intensity in the sore.

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Irrediction of melear fuel is conveniently expressed in KdD/T or persent burn-up; 10,000 Min/T is about 1 persent burn-up. For communic resocue we need to achieve about 0.3 percent imm-w in a reactor using astyral or acar-matural U; probably 1 percent with wrenium a wiebed 3.5-2 times and perhaps 5 or 10 percent in a fast reactor having 10-25 percent fiscile enterial in the fact. H REPO the first Harvall experimental sile has a flux of 1 or 2,10 as per en BEPO the first Harvell experimental pile has a finx of 1 or 2.19" per see. and will give a burn-up of 0.1 percent of materal wrandom in 16 years. One might use, say, 5 Commenter for motallurgical experiments on fuel and reduce this to 3 years but evidently no very workal experiments of this art our be done in a reactor of this type. Finte has a fing about 100 times as great and can produce 1 percent burn up in test-specimens in 3 er 4 months; it is therefore very weeful for this sort of work. When irradiating other meterials one meeds to displace, by fast neutron collision, say 1 percent of the stans to set significant results. Assume a target area of 10 turns per stan. This is 10^{-23} cm². The anterial must therefore experience on integrated fast perform flux of 10^{21} ns per cm², ⁷ If this is to be achieved in 1/5 of a year (10⁷ seconds) one meds, once again, a neutron flux of 10¹⁴ms per cm² 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 member 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 furticities - he meets results from a reactor in which the core has a sufficient volume to give a statistically adequate number of experiments. SEPO 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 reastor on the industrial scale with big capital cost, hig burn up of feed and hig operating costs. I know of no royal read to the solution of this problem. Except by making the programme for the construction and operation of intervial reactors may 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 programs since the reactors built combine high flux values with a large volume and much valuable statistical data can be derived from their normal operation.

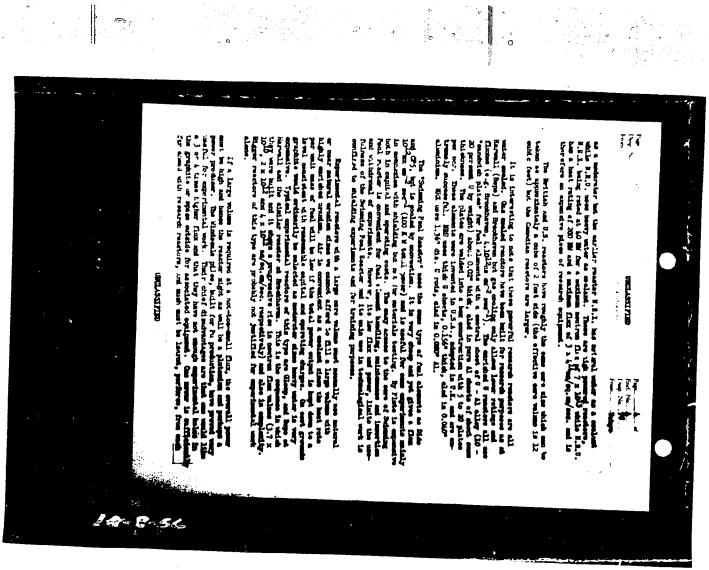
A full research programme must however include sume provision of high neutron flux research reactors of which the following are emergies-

1. Dido and Pluto reastors in the U.K. with a maximum mentrum flax of 10⁻⁴ ns/cm²/soc. and 10 Mf heat rating. These reastors use heavy water moderation and cooling.

2. M.T.R. and GP5 reactors in the U.S.A. These are different in type from one another. GP5 may be regarded as a smaller version of the Dide-Flute reactors with heavy vater moderator and coolant, and a maximum movelens flux of 1.7×10^{-3} ns/sq.cs/sec. at a power of 1 MM. 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 10¹⁴ ns/sq.cs/sec. at a heat rating of 30 MM. It is therefore a powerful and useful research reactor:

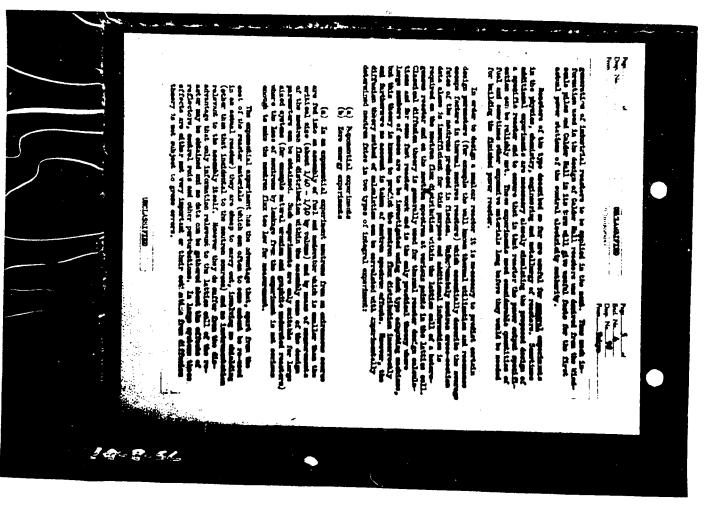
3. N.R.I. and M.R.U. reactors are used in Canada. Both have beavy under

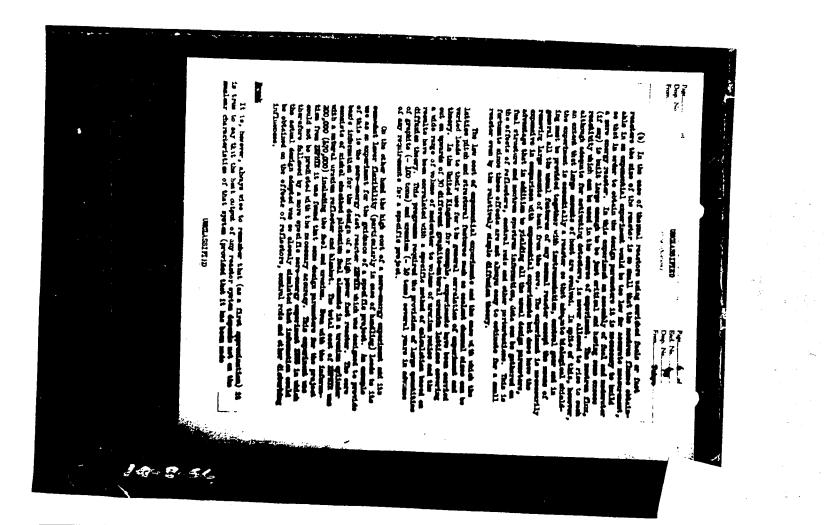
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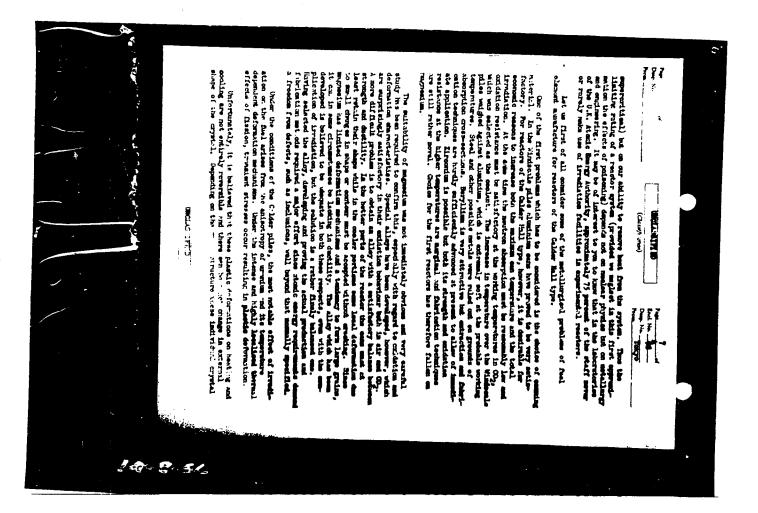


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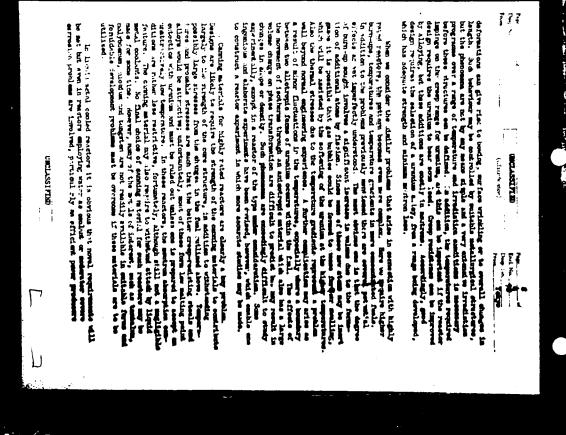
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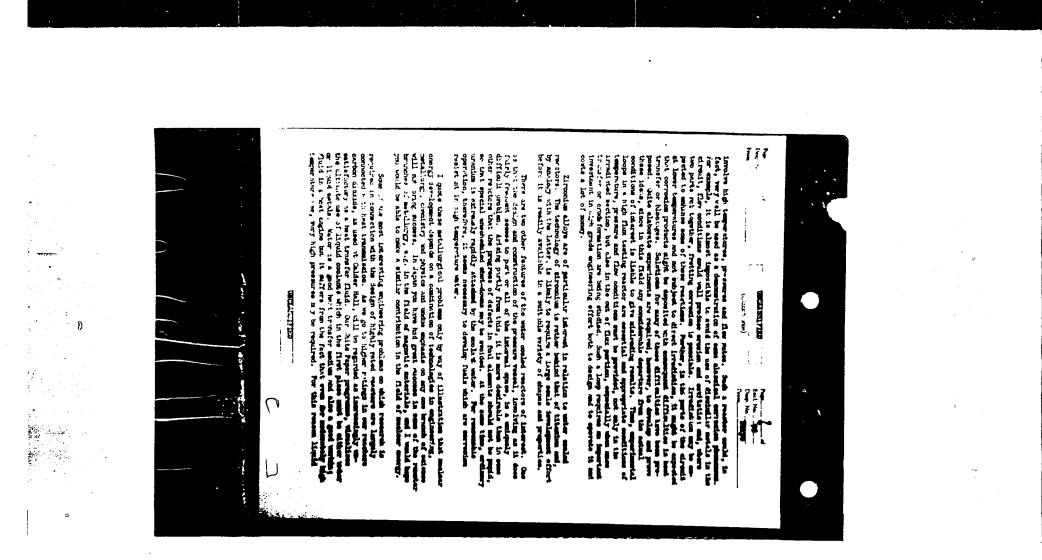
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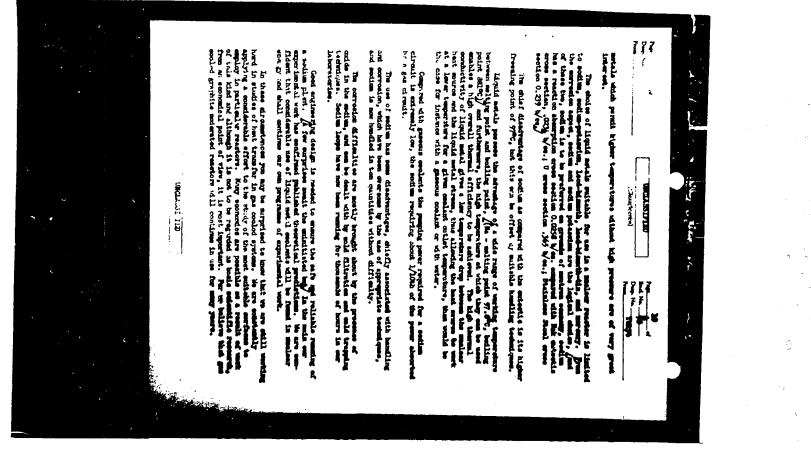
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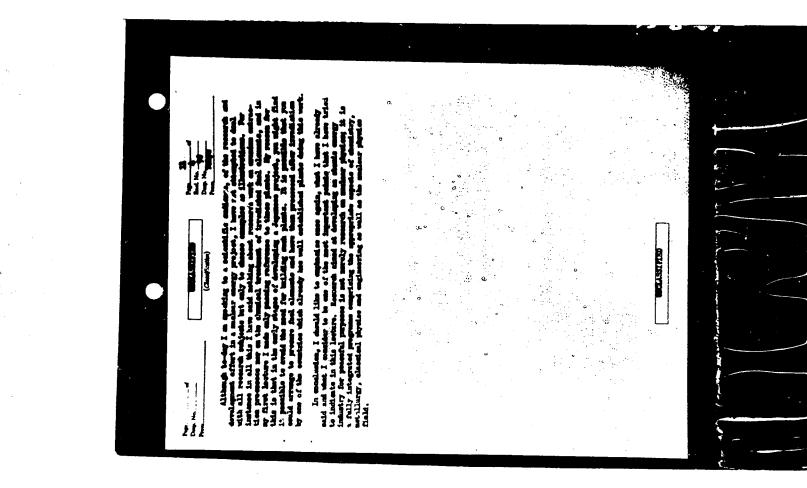
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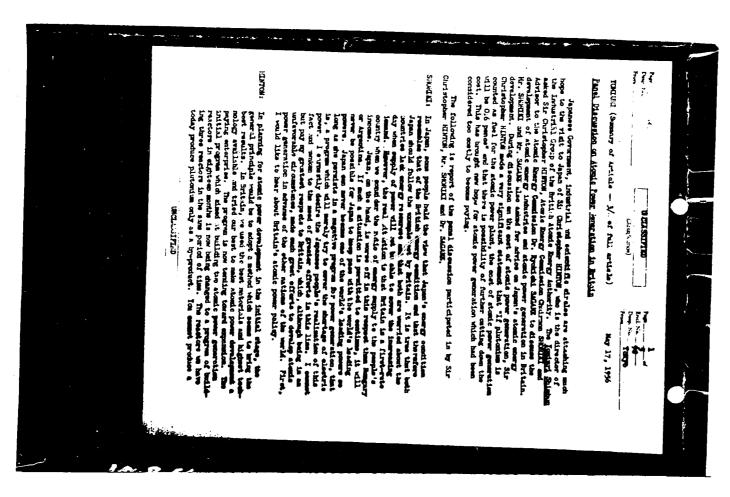


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A H H H H H H H H H H H H H H H H H H H	ther which we take to make the second of the	- SMOUNT I suppose you were confronted with charges of wanting State funds and eritistant this the project was durgeress, that it was still too early to lawned into and a project, etc. More did you enverses these oppositions?	HINDER There were no difficult problems in Britain. It was because, in Britain, state energy we first derabaged for utiliary purposes and then more thorned large-scale proceed use of states every. In the initial state, we had gained confidence issued secret. It was not until after we had gained confidence issued. States for while suffice after you propose that accuse energy developent as revealed to the poople. In this respect, we were fortunated	NAUR: Do the British people feel aste about stonds energy developments (GUNM: As I said but nov, the pople ware not told about stonds emergy develop- ment during the war, so they had mathing to werry about. After the and of the war, we have taken every apportantly to inter the papel that is not during threas. I, don goodshift has an ann around the analysis.	celling the people that there are to danger, and that introd, stands every vill benefit the projle. However, there is no module which is there is no module with its projle. However, there is no module which is the densited. The shall then that although there may be seen danger is the storic resolver which we have half it there is a loss danger is the storic resolver which we have built iters is lossed popula granewily resolved from the other modules. The lossi popula granewily preder front from the preder power power presention. The material weeks granding from the predericy ands.	SkückEi Iou seem to have perfect confidence thre stands parer paremention at Calder Rull will be sconnarial from the beginning. Mill yes give us the premats for your confidence?	MUNTUM: The storic resolver being built at Childer Foll is primarily the the production of plutomium with power gener tion as a serie of hyperband. In Britchin bodhy, the secief rocate power generation is alightly have then one pense primariant. This price deer generation is alightly have from the plutomium produced As A by erroduct. If we fix the price of plutomium at alightly lawer bin the inverger of the Mighers price of east ched urmation with price of fullual urmating, the secief of them power generation will be built to fix plusted.	Sacuto: The quartion of atomic power jonner-iion cost is a very section when and if you will explain a little further		
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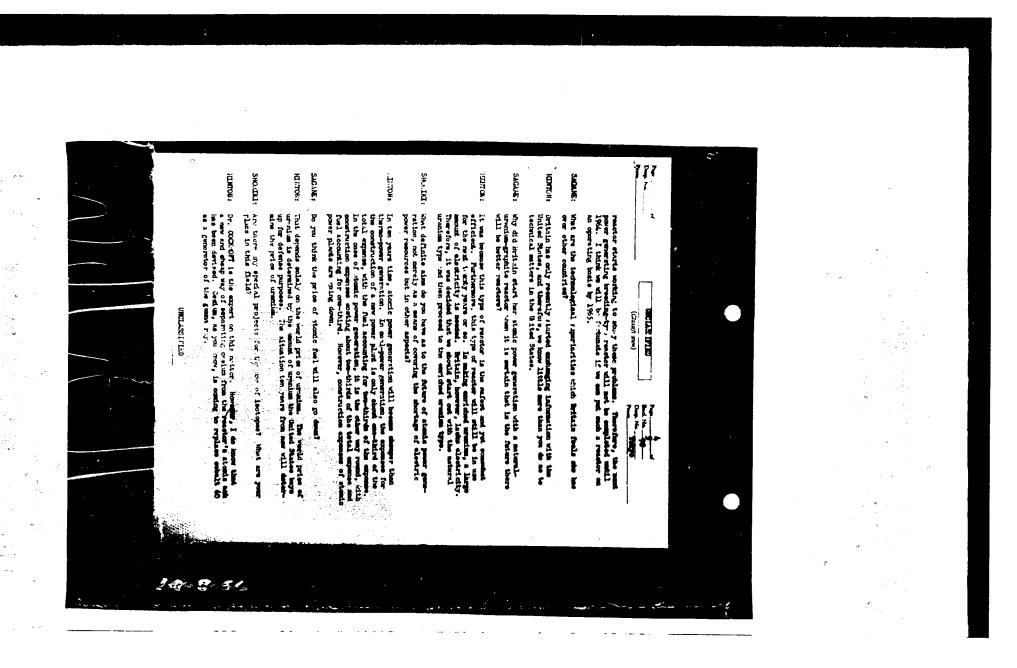
		HINDAY Let us explain about the breading-type reactors. Metain has, or is in the process of completing, three breading-type reactors. Here, the of them to not produce energy. The third one now being constructed mill have considerable power generating compatible and will dear upsenting in 1950. Henever, there are difficult problems, and here to indeed energy of of the reactor, what offices the worker power will be a mergy of of the reactor, what offices the worker power will be a mergy of of the reactor, what offices the worker power will be a the stands that controlly. It will take about the power after the out stands and frequently. It will take about the power after the	SAGARE: in what supert, in comparison to the other antions of the weeds, does British have the greatest confidence? What are the greatedt hopes in British attached to sizet poor generation? What are Britisha's press for the future development of breading-type reactory?	HINTOK: Tism differ as to how stonds reactors will damage in the most five years. We expect considerable improvements to be made in the type of reactors we have now, that is, the type which uses materal words and graphite cooled by gas. We may get reactors which uses water as a coderator and with a water-cooling system. There may be reactors with uses made in the one-lag system. All these will be madered with uses made in the one-lag system. All these will be madered with uses made in the one-lag system. All these will be madered with uses made in the one-lag system. All these will be madered with uses which is not materialle. In the years these, I as em- fident that these will be used for indestrike. Atomic power temperatum will before the question is store power development. It will become better and better. The question is, when can we made a highly efficient and paying stomic power reactor.	Shirilki: What are your prospects for stands power generation, technically and economically, for the next five years?	WINDH: Of course, the cost includes all such expenses. When us take pluvaels into consideration, the present cost will be abase 0.6 passe. How, is about three or Bur years, the restor which us will order must journary starts operating, the cost will prebaby be lowered be about 0.5 er 0.4 pence. If we can asks better readers in the fabure, we will be able to est domn the cost further. The price of call may go up, but will mave go dome. That is way the future prospects for storals pence presention are very hepeful.	SAGANE: Does the cost that you mentioned take into consideration the expenses for the plunning and construction?	ELTOF: Of course it is. Although it salls for a complicated operation to expansio plutostim from the cludges of matural wraching, plutostim should be taken into account as it is important book for willing pur- poses and as fuel for studic readers.	entidention. The reactor which will be endered must January will probably out down the cost further. SuGiME: Is it matural to take plutonium into ensideration?	HUITUMI The cost is lass thin one many sitter into the lass that the lass that the lass that the lass that the lass the	
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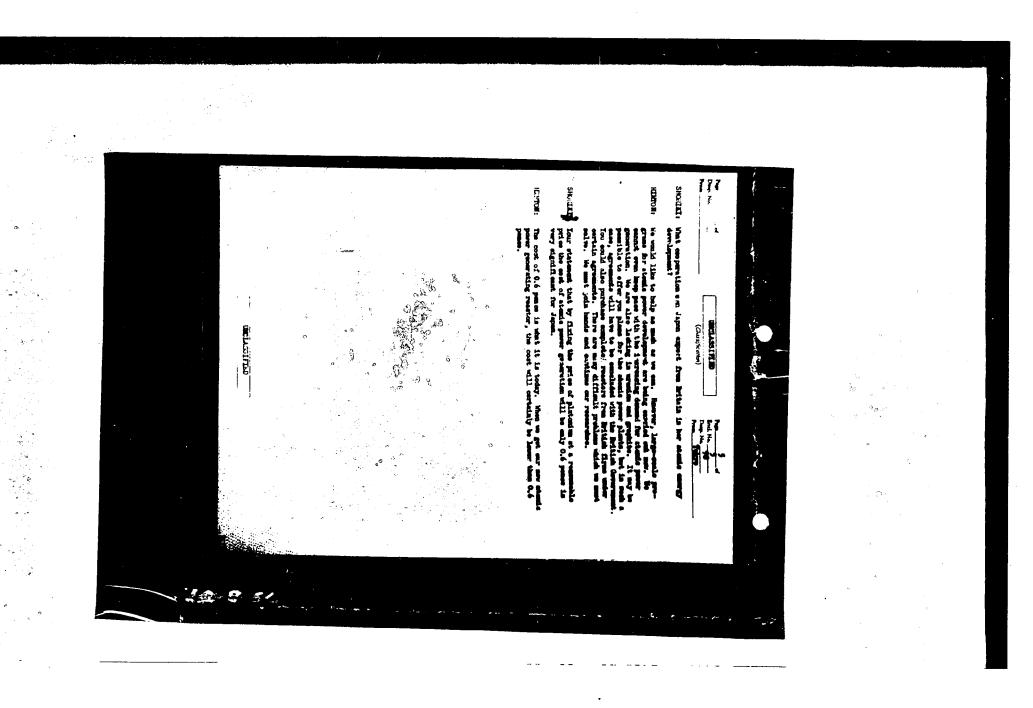
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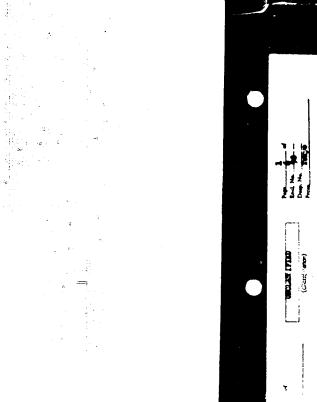
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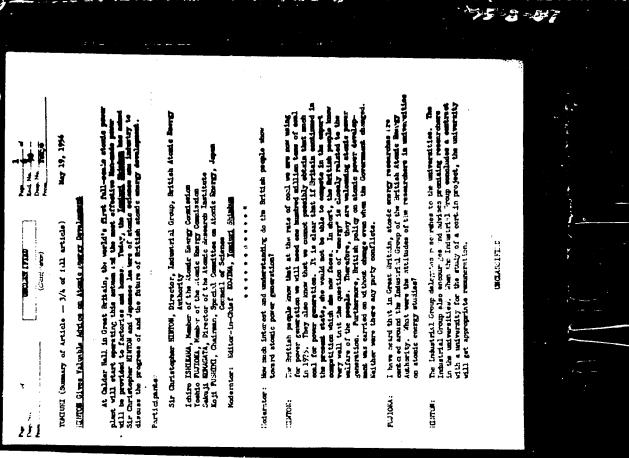
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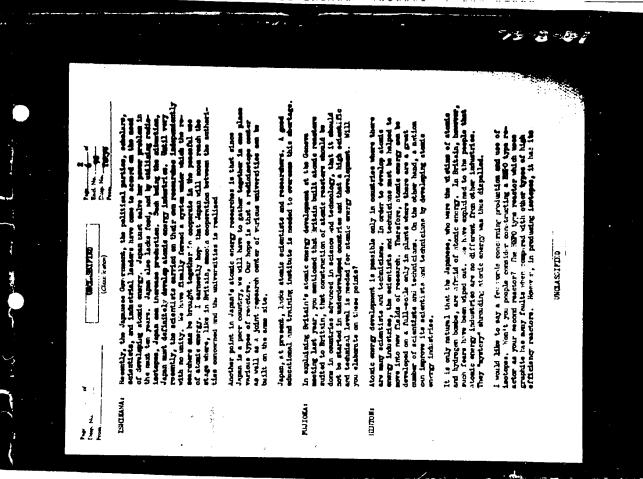
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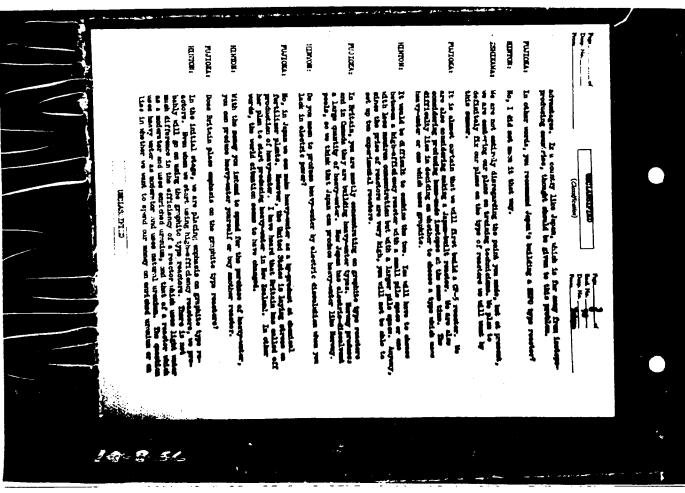






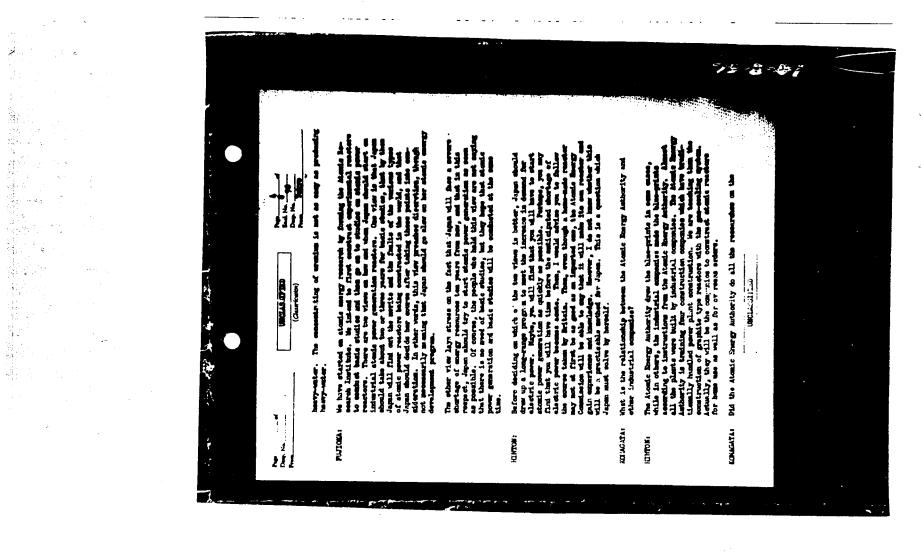




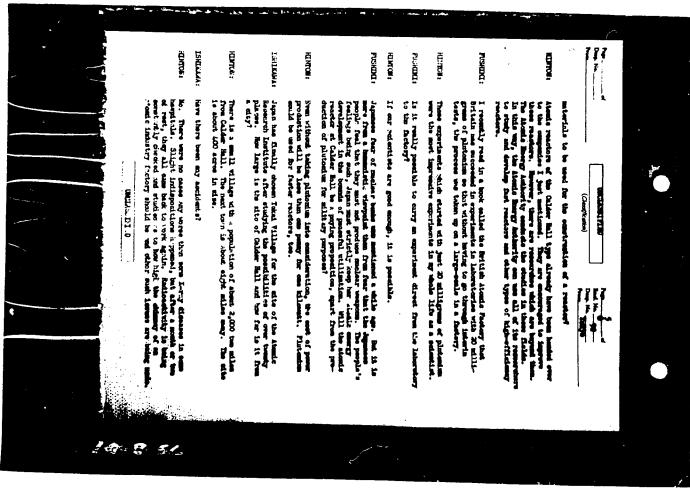


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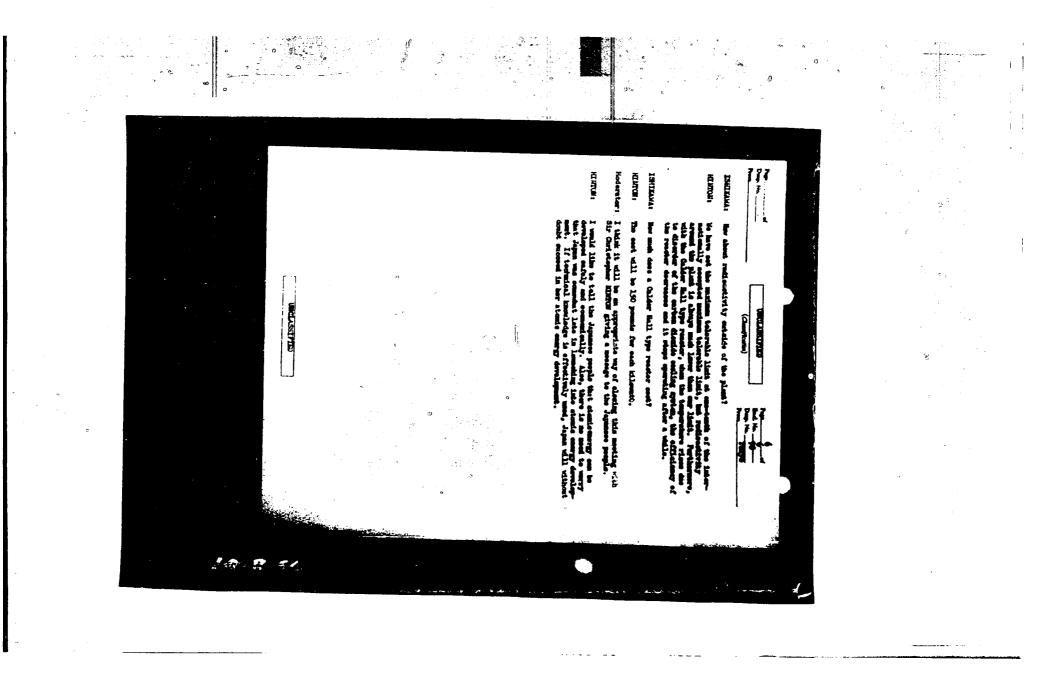


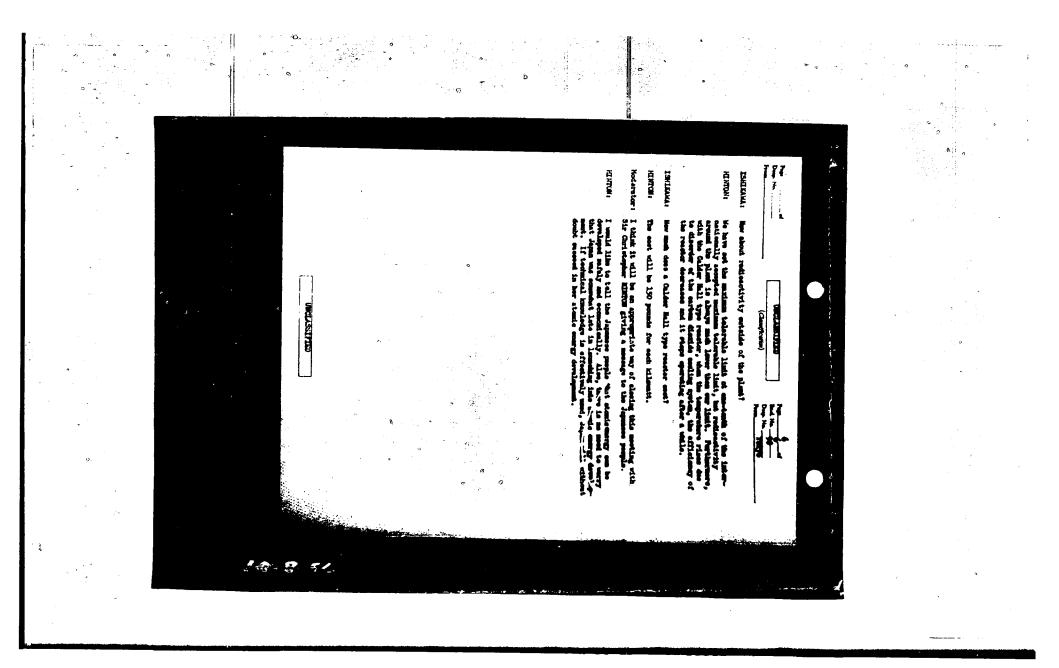
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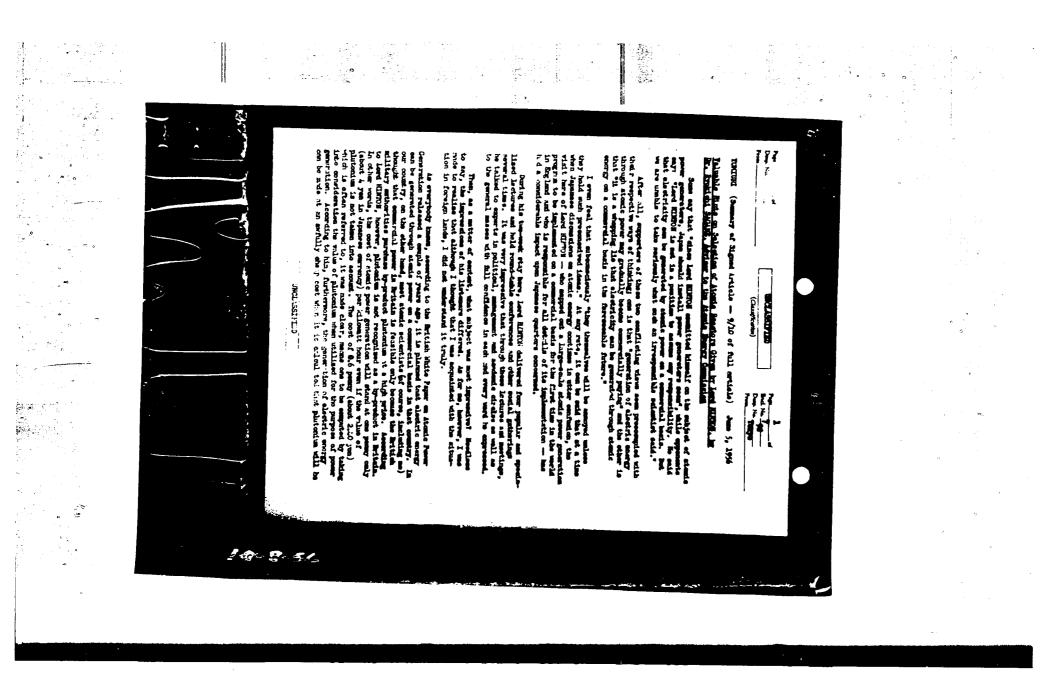


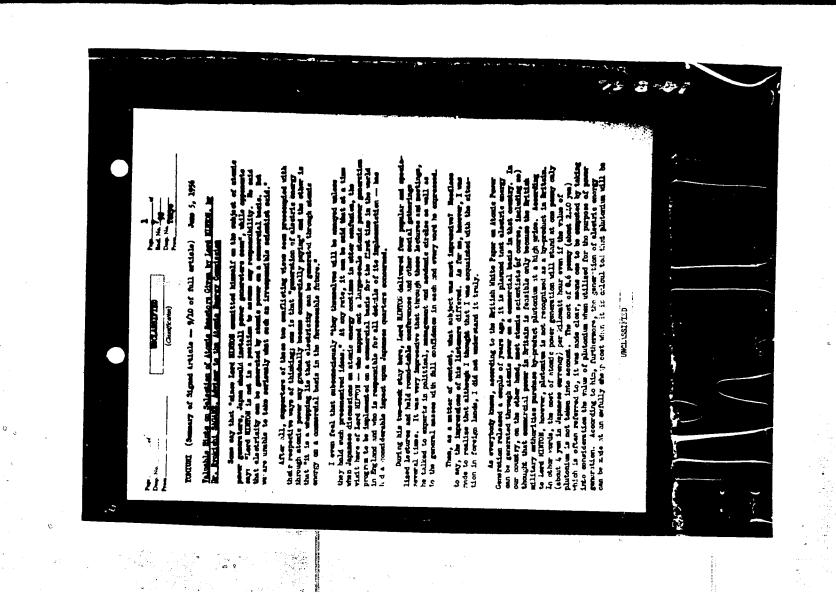
I chick it will be an appropriate my of alering this meeting with Sir Chickopher Albitist civing a meeting to the dependent people. ٦ I would like to tail the Japanese people that stationary deviloped anthly and community. Aim, there is no an that Japan as essential lists its static as but it commission insurface is effectively used, depen-dents accound in her static energy devilopment. aller onter the televolis lists at moving the televolis lists, ha n - ma love the or list about redisectivity estable of the plant? The east will be 150 younds for each kilomath. Her much done a Childer Hall type reactor on all type reader, the sector se ALL DE LE DE (maximo) UNCLASSING Ş i i i i . to have not the publicantly accept around the plane with the culture is discriment of the Ĵ 1 28 2 Noderator : ISHIKANA **TSHERANA** HINTOUL HENDORIA HCHTOM:

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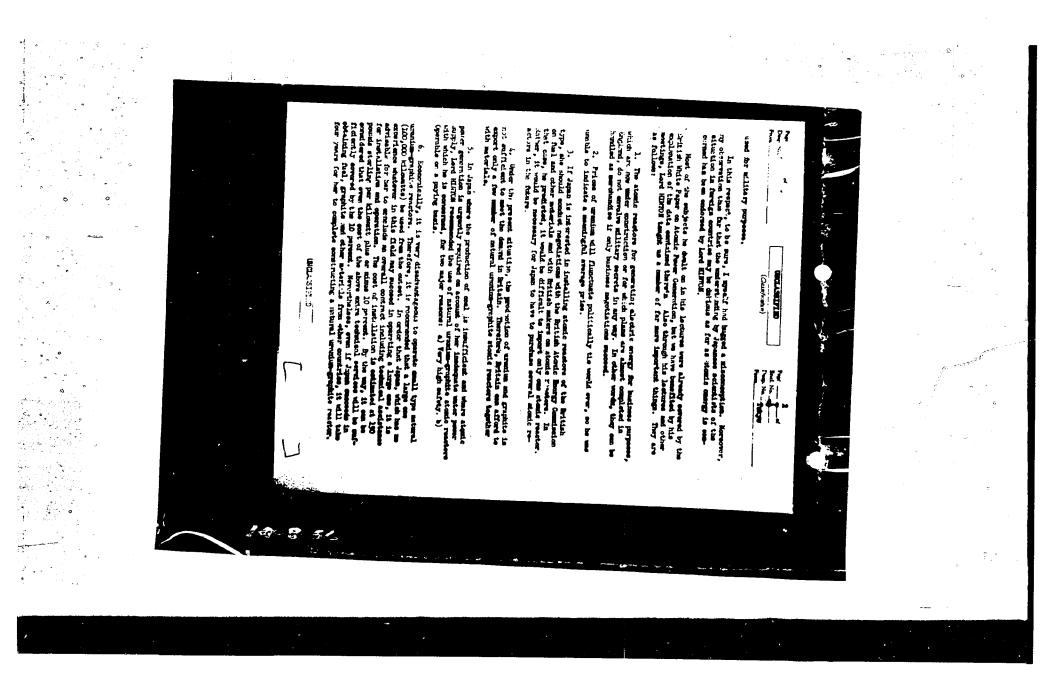


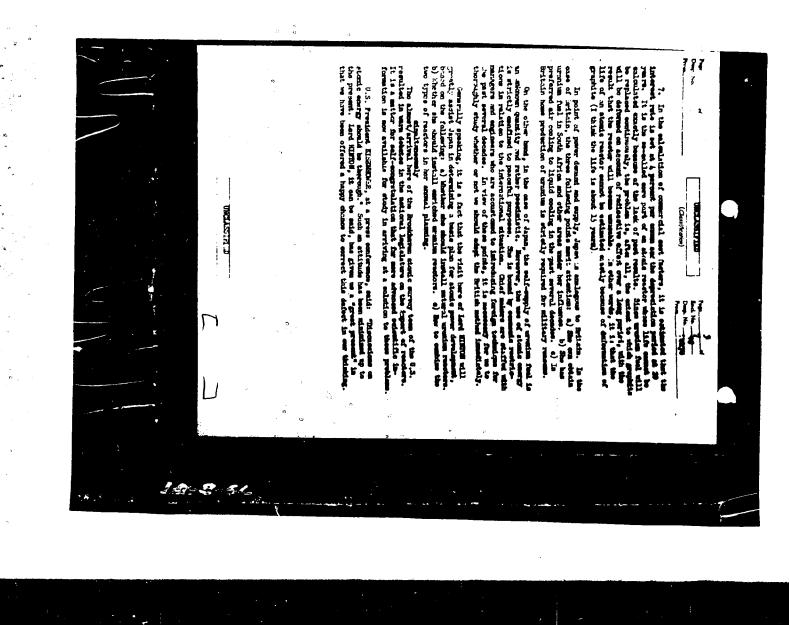


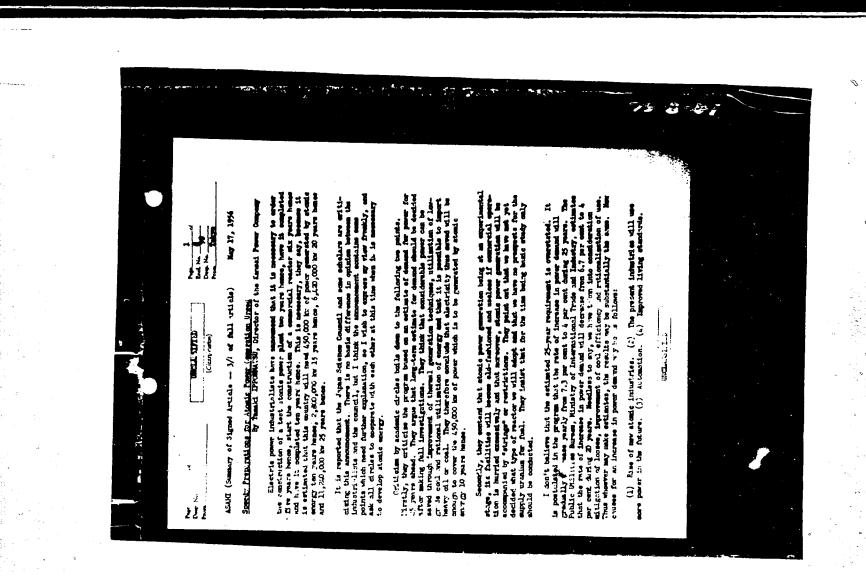


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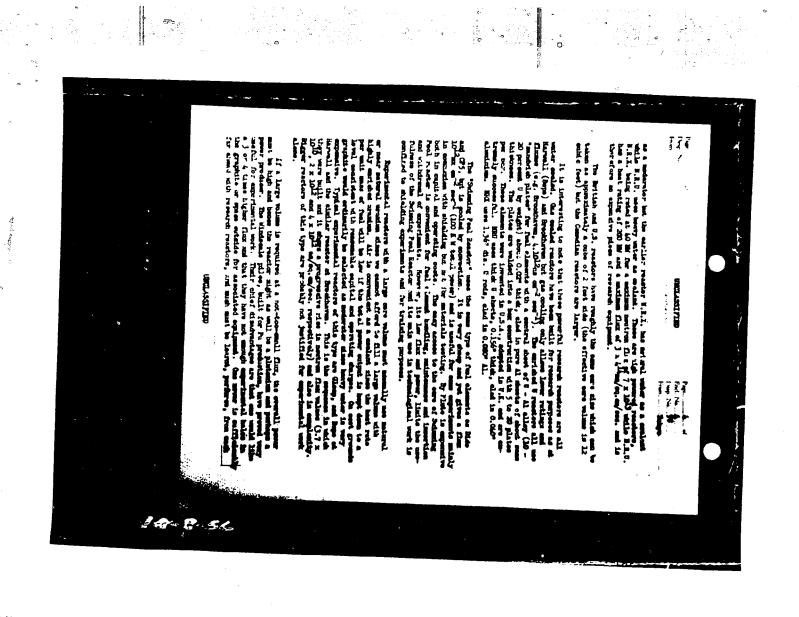
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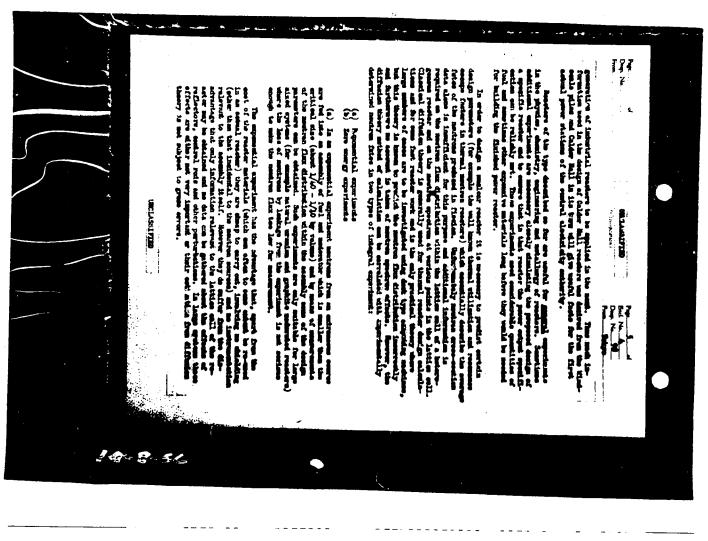
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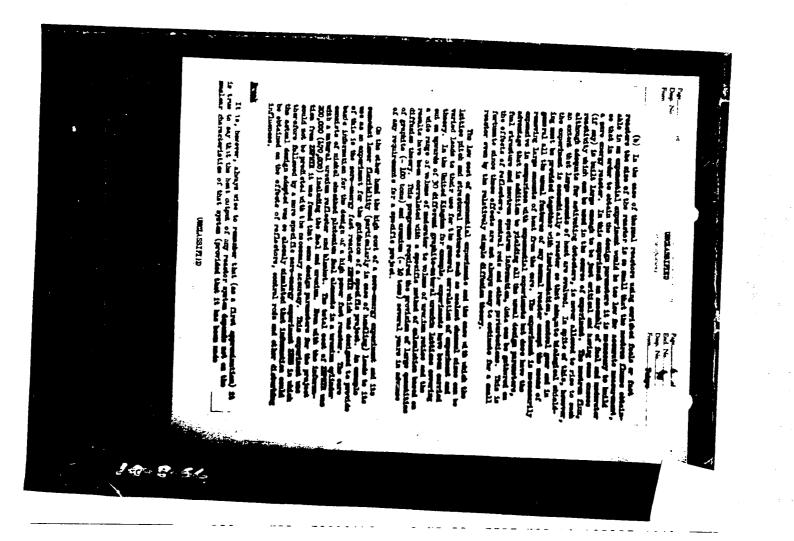
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a s 6 The mainability of magnetic was not insudicially obvious and very sareful study has been required to confirm this, especially with mean develope, hence, which are surprisingly satisfactory in their solution bearings, hence, which are surprisingly satisfactory in their solution bearings which is dreamed Op. A more difficult problem is to electing an alloy with a satisfactory builds be the strength and developed is to electing an alloy with a satisfactory builds be increased in their solution of the same and of least retrin that shape or confirm marks to account that a same constant was limited deformation methanism and a taken developed it can be satisfacted deformation methanism and a taken be been supported in a limited deformation methanism and a taken of the same placetion of introduction, but the solution is a rather thank which as an introduction of introduction, but the solution is a rather thank which as introduced the align dargeting and proving the standard which are placetion of introduction, but the solution is a rather thank which as introduced the align dargeting and proving the standard production and introduced the solution of a rather thank which are introduced to be introduction to a rather thank which are introduced to be align dargeting and proving the standard which are introduced to be a solar offert show standard with meanly which and a freedom from defects, and as inclusions, will beyond that meanly workfield. One of the first problems which has to be considered is the decise of sensing nuterial. In the Similarla plan aluminian case have proved to be very active factory. For reactors of the Galar Hall type, however, it is decisable fal-socond to reason to increase both the matimum set to preveate and the total inrediction. At the set the balance Hall type, however, it is decisable conduction resistance may be activitient to working temperature in Oor which was selected as the sector. The increase in temperature to Oor which was selected as the sector. The increase in temperature over the Winner-phie weights against induction, which is extravaly nork at the presents of the temperatures. Steal and other possible merits were valued and as provents of absorption cross-sections. Beryllin the way attentive be defined as the set applications are breakly softwared at present to allow of increa-se applications at the both is both to define the mathematic resistance at higher temperatures are anythed by the therefore faller as are still rather noral. Godes for the first reactors has therefore faller as **117** Under the conditions of the C:lder piles, the most notable effect of irredu-sion on the fuel arises from the anisotropy of urredum to the temperature dependent deformation measurement. Under the intense and highly issuifand thermal effects of firstion, treasient stresses occur resulting in plastic deformation. f experiential) but on our addity to remove heat free the system. These the limitize ruling of a remotor system (provided we majors in this first approach-section the effects of pulsesing) depends not on mealure physics list on medilinegra-and engineering. It may be of interest to you to know that in the laboratorial of the U.K. Atomic Barny Authority, approximately 75 percent of the staff move of rurely main use of investigation fieldities in experiment-1 resolver. let us first of all consider some of the metallurgical problems of fuel at austicture for reactors of the Calder Hall type. i, **GLADER D** C.141. SYTDMD (Clease) uner) 14- 8-51

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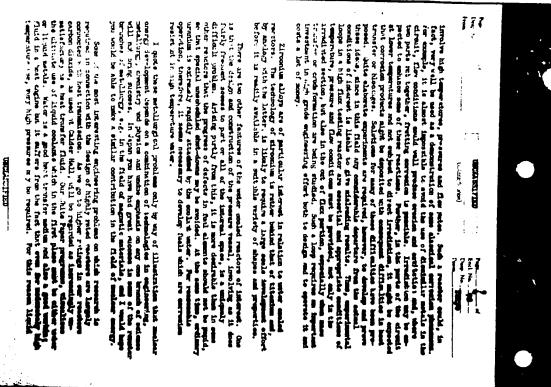
When we consider the digits problem that acies in accreation with highly rever restrantures and responsing eventually in more comparison fullo-tor-reger, temperatures and responsing evaluation in more comparison fullo-tion dilition to the possiblem periodualy services in more comparison. Thus, it diditions to the possiblem periodualy services in more comparison fullo-stication of additional problem periodualy services in a state of the depen-sion of additional problem periodualy services in a state of the depen-sion of additional problem periodualy in service and the formation with stall be marked by the softwards of the service and the formation of the distribution for additional problem on the service of the service which stall be marked by the softwards of the service and the distribution formal distribution. Since works and the formation with beyond normal sequences for the temperatures predime regions a state distribution for a service of the second and the formation and the distribution formal events for the temperatures, concluding the the distribution formal experiment for marked as marked as any service the structure of production are difficult to predict the temperature of the second and indicates the second and the formal of a struc-ture structure of production are difficult to predict the second product and theorem and subscripted the second distribution. Second formalism additions that have second a burdent for a shore structure and allowed the superisent have been distributed and the subscripted distribution and allowed the superisent have been distributed and the structure the structure apperiated the second the second beaution at the shore structure and theorem apperiated have been distributed and and and the structure apperiated the more second beaution at the shore structure and the structure apperiated the structure distribute and beaution at the structure apperiated and and addition the structure distribute and beaution at the structure apperiated at the structure distribute and beauti Caming aderials for Highly rited reactors are closely a key produc-leading aderials for require the strugger and and reliable to estimate leading an regular stresses for a construction is addition to estimating possibly large stresses for an energy in the full reliable to estimating possibly large stresses for and that the beiter crosperedicting possible structure that antirizing under the beiter crosperedicting possible statistics with a structure. In these restores, the methan lar militag point estimates for the restores are and that the beiter crosperedicting possible statistics without beiter crosperedicting possible and estimates and the structure. In these restores, the methan lar militag point estimates and contains and and on employed the structure and fullows are rather lass restriction, fortunately, attempts faill as a subject fullows are rather lass restriction, fortunately, attempts faill as a subject fullows are rather lass restriction, fortunately, attempts faill as a subject fullow are rather lass restrictions, fortunately, attempts failed as four double stresses attempts are not restly attempts for any four double stresses are to orrected for these structure by four double stresses are be orrected for these structure are be found able structure and be orrected for these structure are be found able structure and be orrected for these structure are be found able. deformutions and give rise to bondry, our fees wrinkling or to evenil dranges is langth. But behaviour may so extremine by suitable metallungued drangeres but the phenomena are not by any means signa and a very extending in the structure programme over a rege of beginning and investigation satisfication is a meaning buffore these thructures and investigation satisfication is a meaning buffore the urbiture to hear soon jost. Greep restatates is a best draign requires the urbitue to hear soon jost. Greep restatates and ingree is required to the solution of a urbitue is a first and the solution is a draign requires the urbitue to hear soon jost. Greep restatates and ingreed is rightly on these addaction at a urbitue and the addactes and buffer draid draign requires the subjection of a urbitue without hear. Same and the second ì CHILDREN THE (יינַשאר אירשער) N. シ えき差

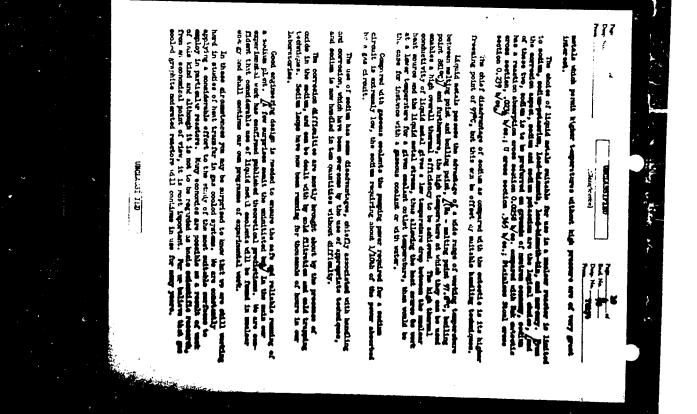
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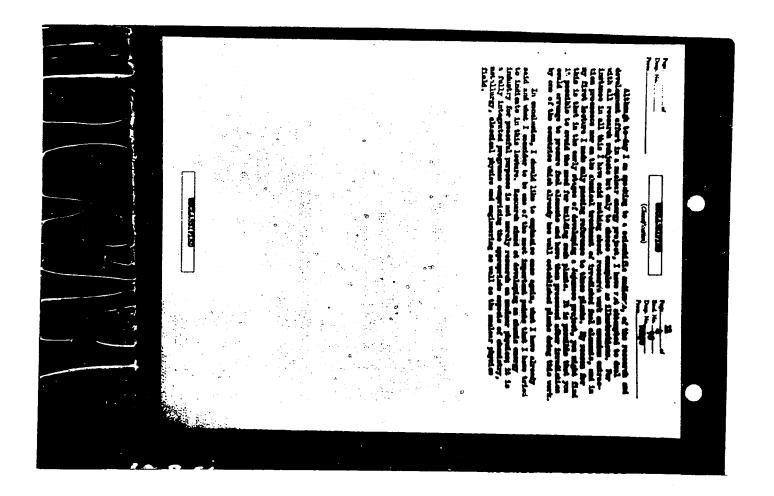
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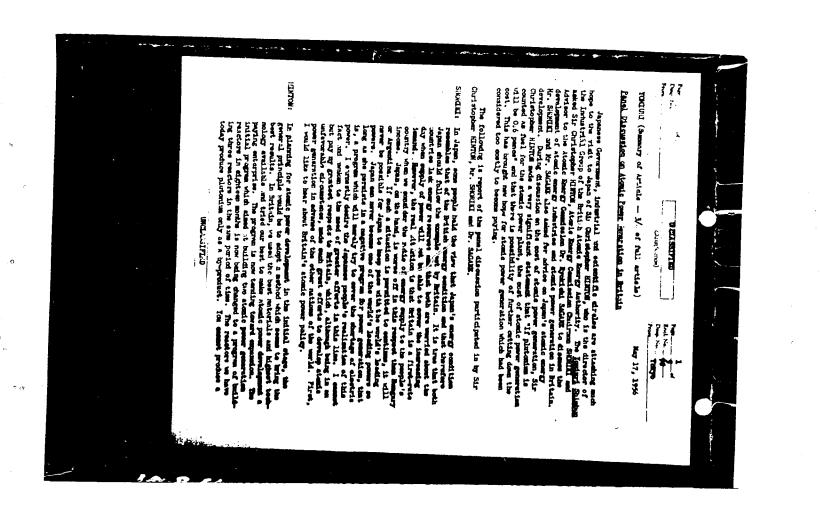


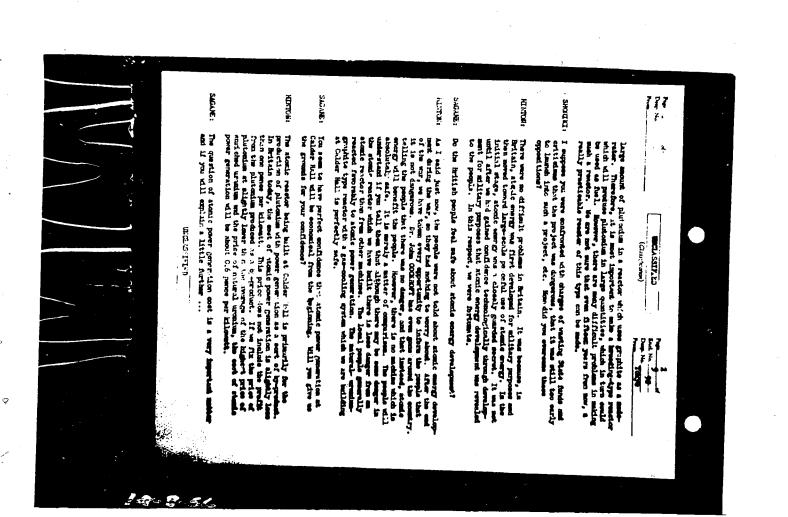


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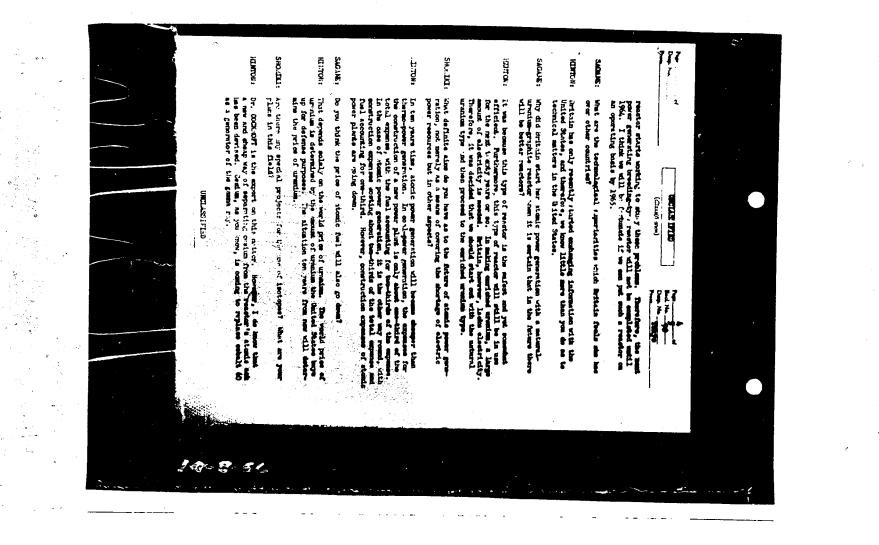
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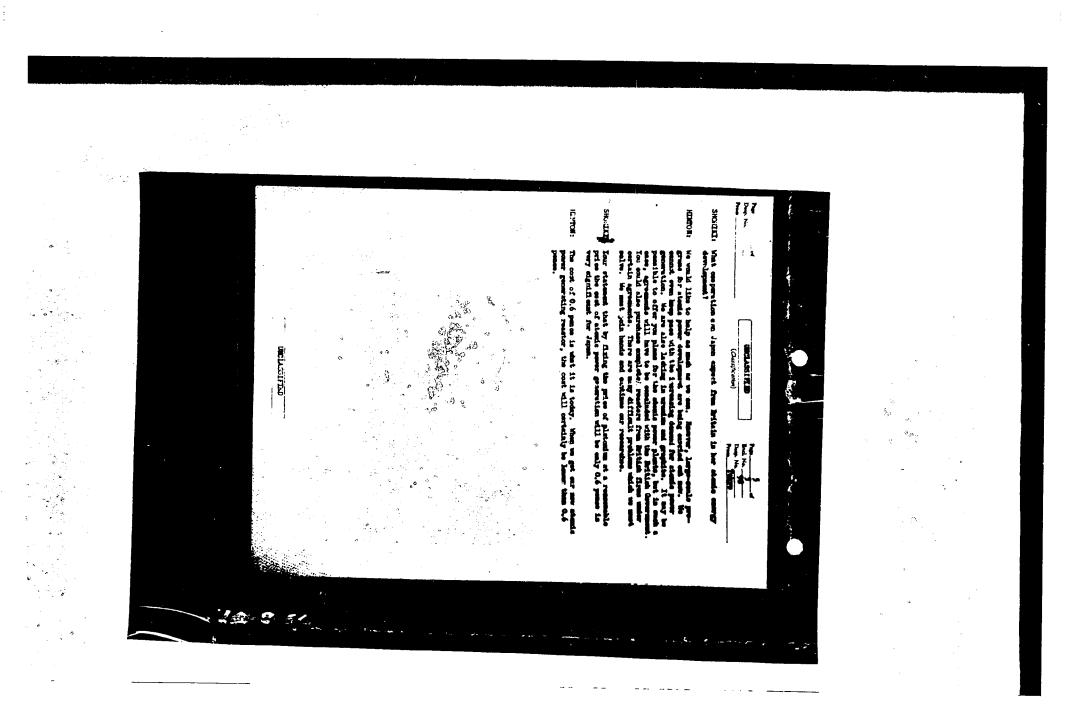
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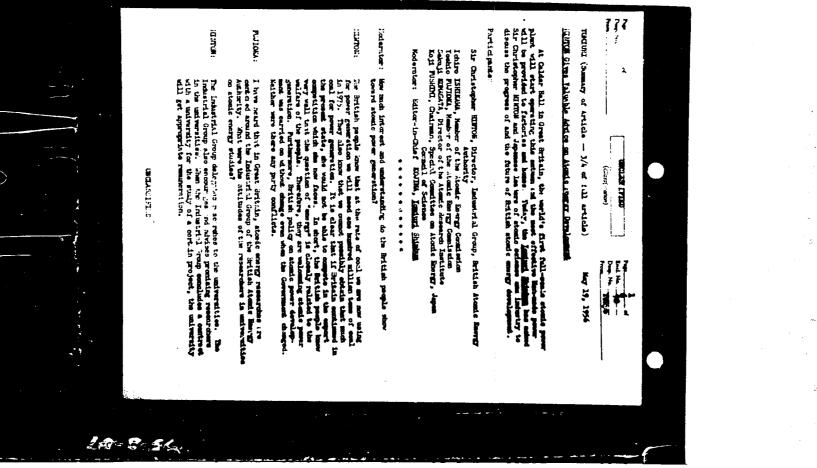
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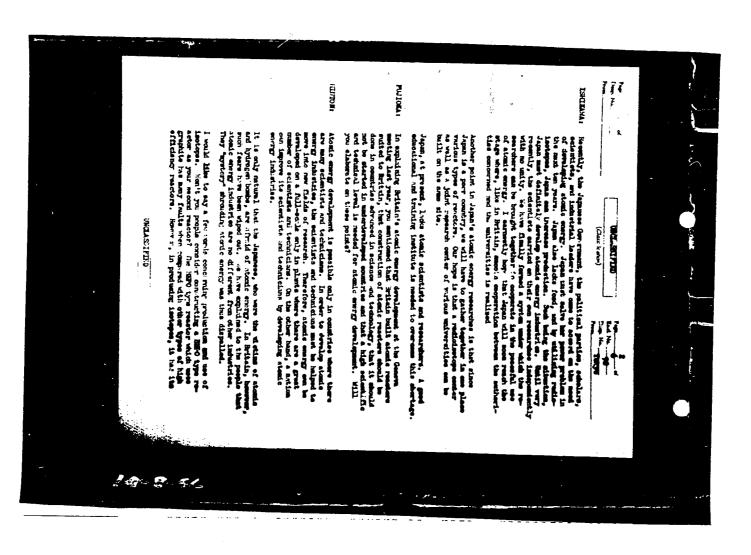
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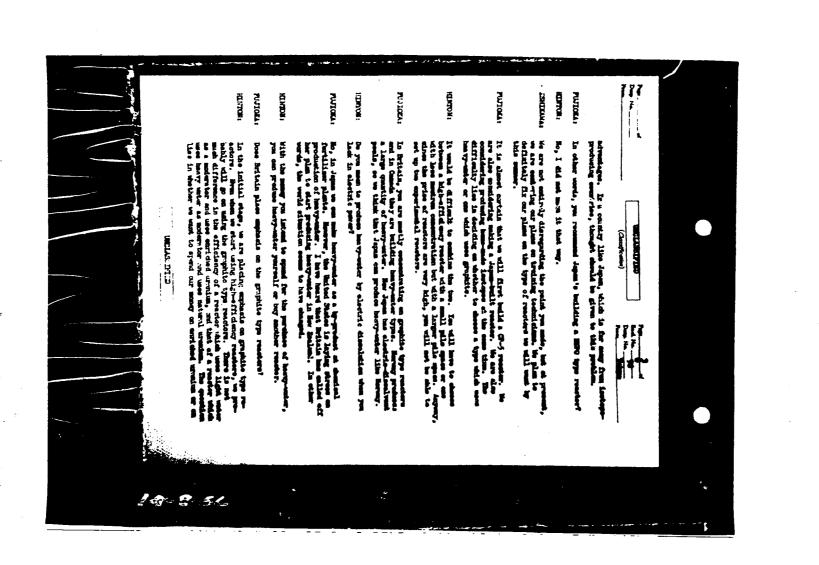
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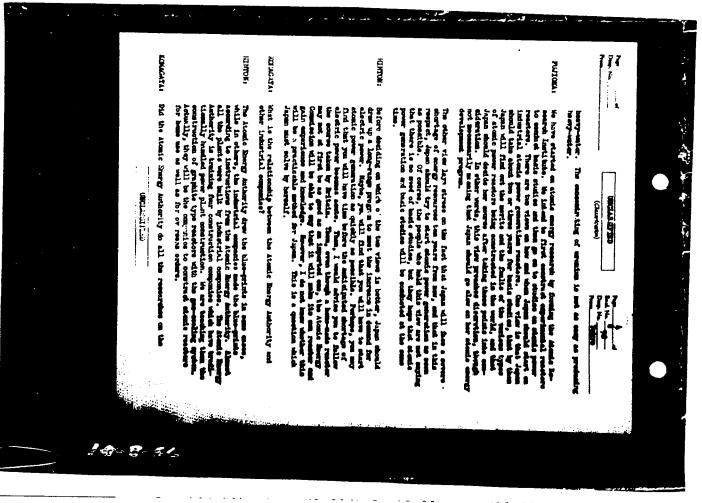


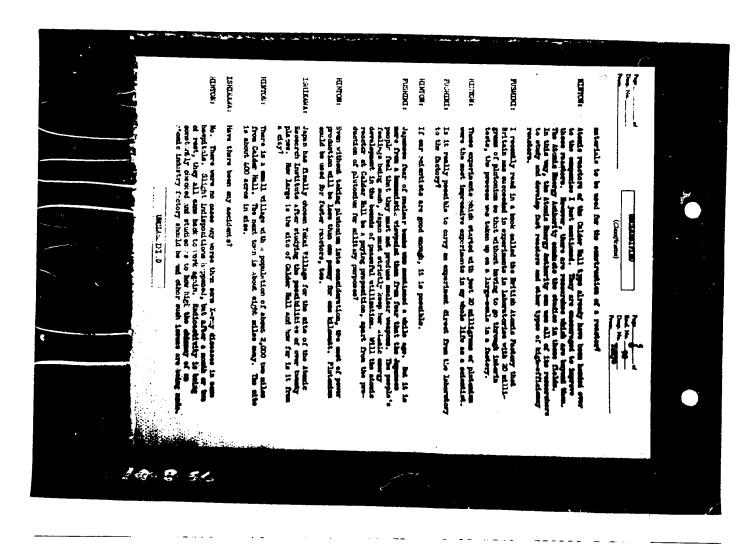
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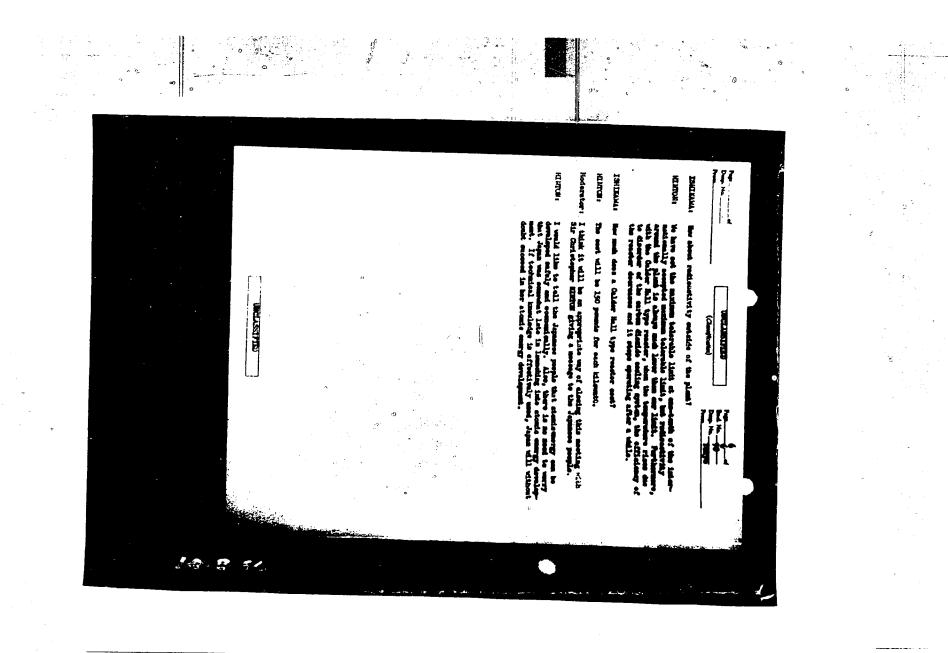




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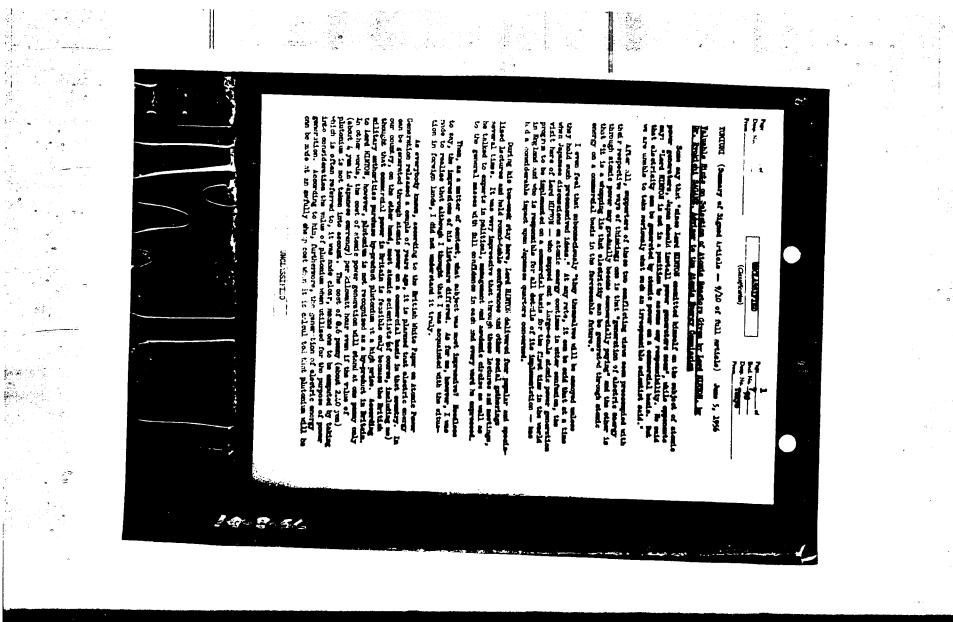


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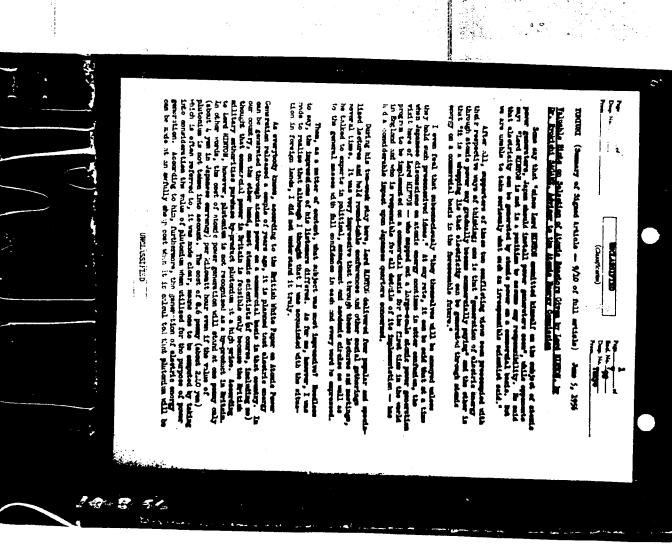
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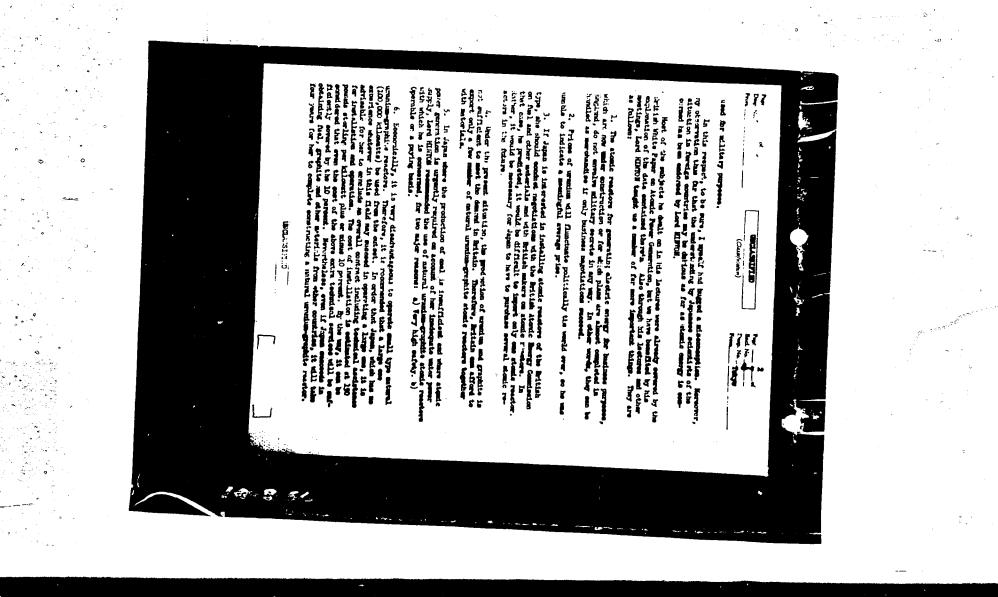
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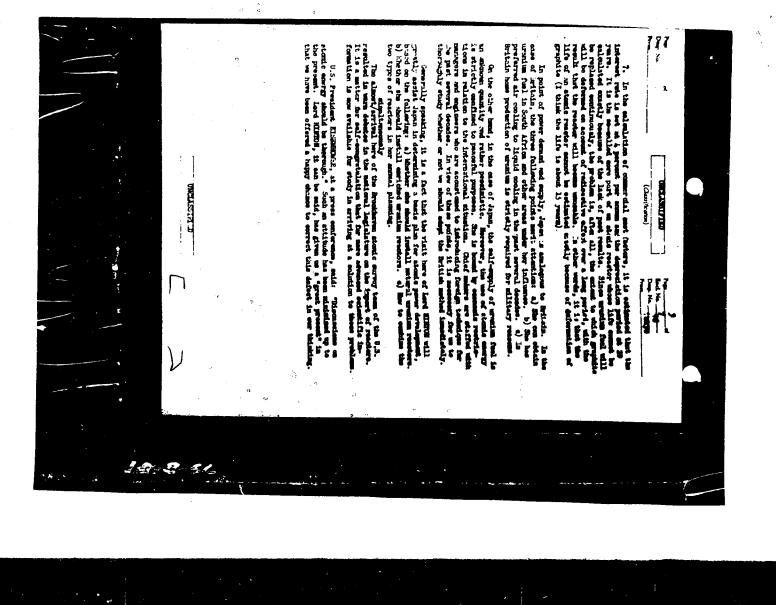


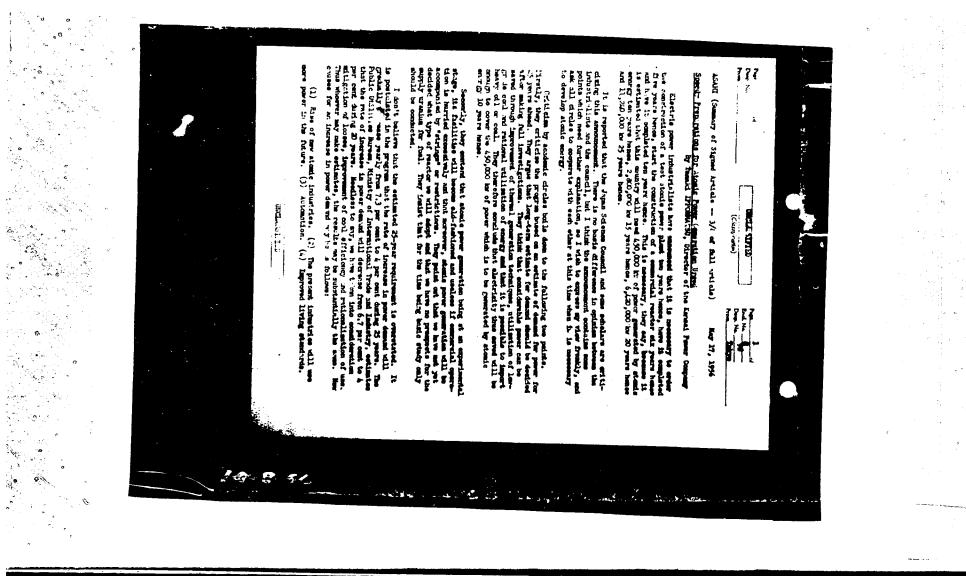
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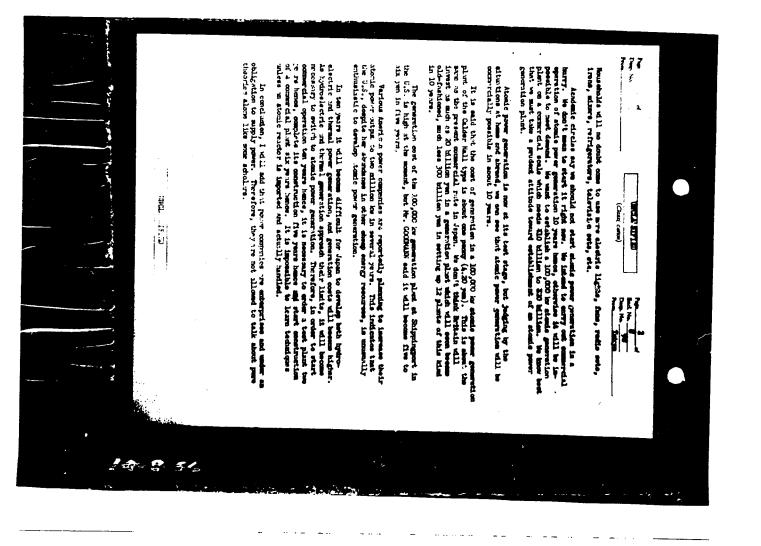
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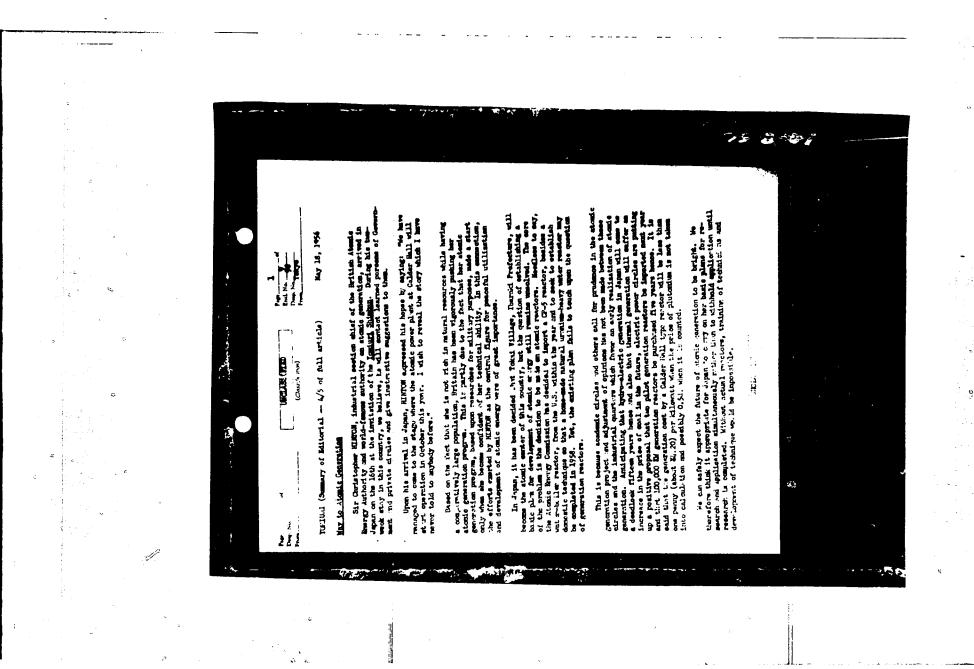
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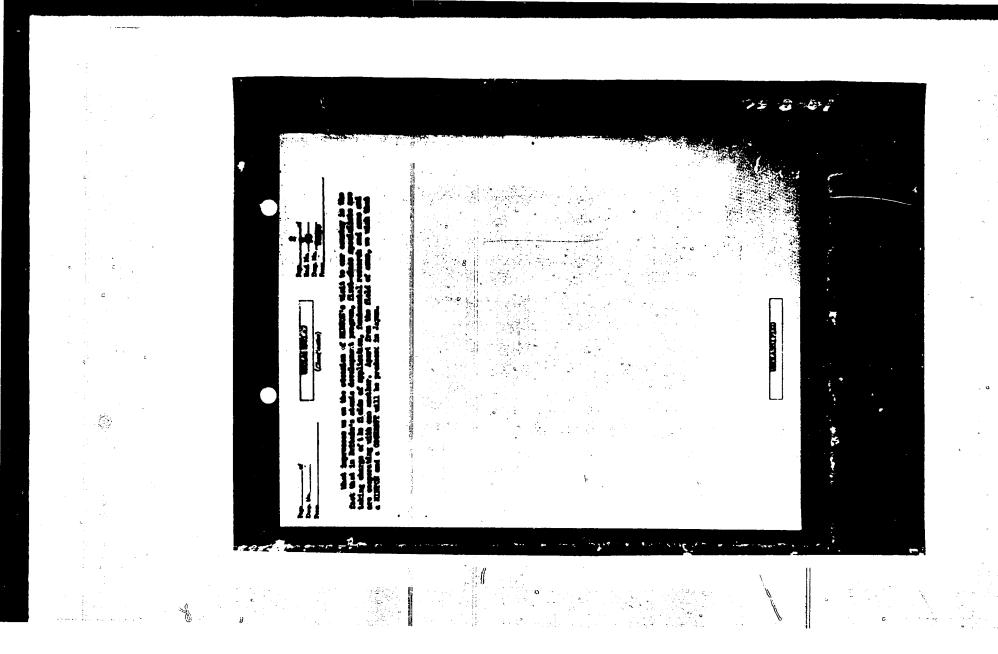


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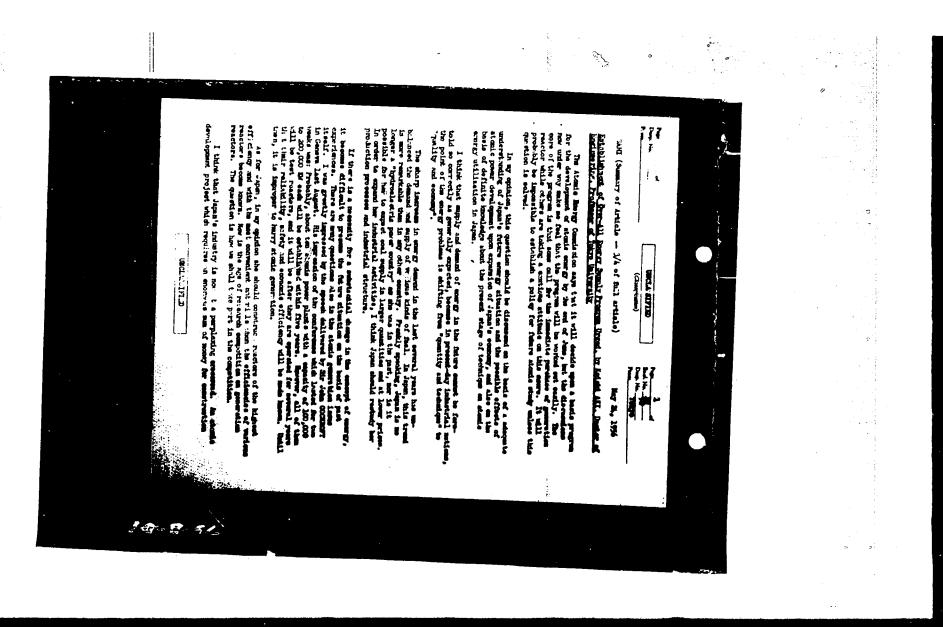
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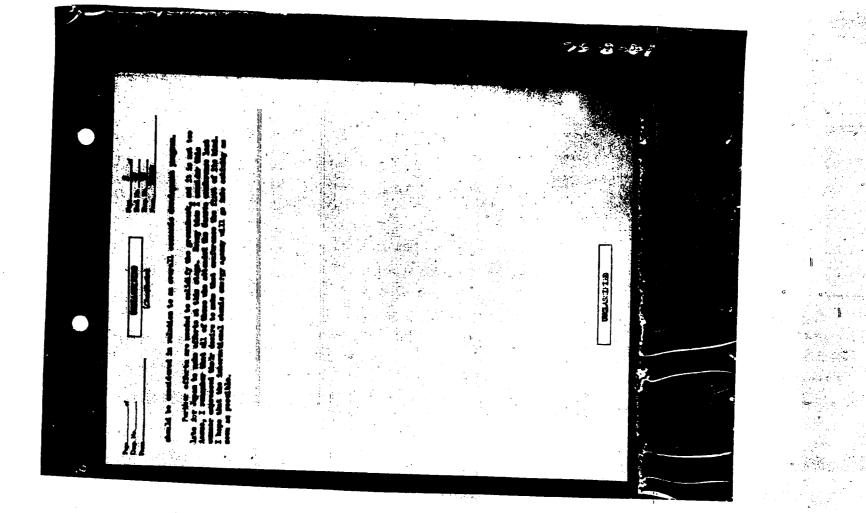




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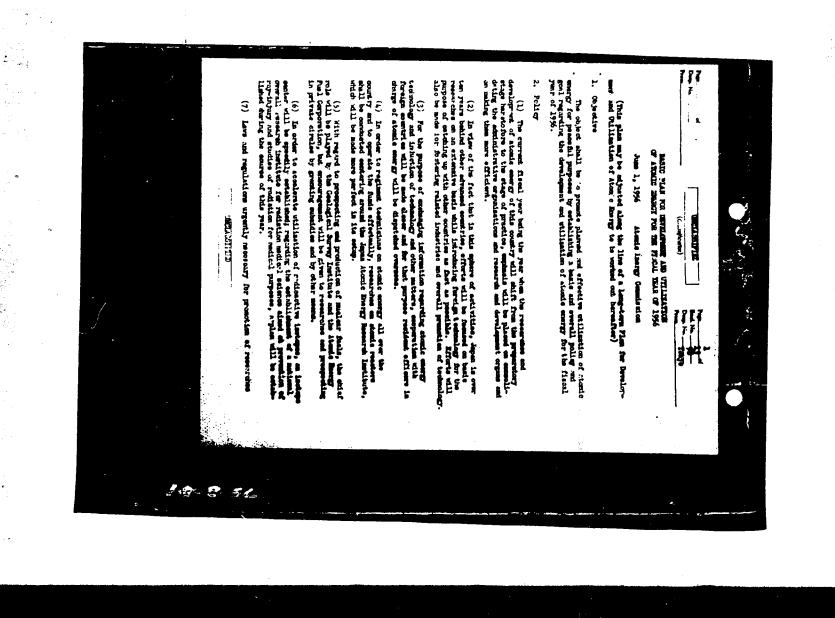
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1. In order to Judge when Japan will need stands generation, 14 is necessary to obtain a correct foremark on Anture communic development, particularly in the fields requiring allocatic power. However, when the present circumstance, and how-range foremark in the future ensert but he a rough one beaut upon any assumptions. 2. Electric power demand in 1965 and 1960 is estimated at LS times and 3.7 times as that is 1955. Considering that the U.S., Mattedn and Prese are as assuming that 20 years hence it will be 4 to 4.5 times as large, the above estimation is by no means achorticart. 3. Jean has hydro-aloctric energy equivalant to Z₀(U) kilometta is protectic power, but 60 perment of 11 has already been developed. As for each protection is jugar, the contacted 11 aloct is meaned are the start is be 50 for 14 percent of 43 million toom accountly protected. From 12 theory contacted for 14 percent of 43 million toom accountly protected. From 12 theory contacted for 14 percent of 43 million toom accountly protected. From 12 theory contacted for 14 percent of 43 million toom accountly protected. From 12 theory contacted for 16 percent of 43 million toom accounts the 10 million toom is accounted for the contacted of and through district fluctuate of the quantity of each when the requiring you are taken into account, the 12 million toom. In the mean and percurbing on the statistical inter theore is argued at the but is 15 million toom. In the mean they is usuable percubane receives are obtained with the too is imperied every year. The Fourd Magne Aregenici (Federides of Electric Manageriese) on the 20th and a superial anomenon in antitical of Electric Manageriese) on the 20th prove expected anomenon and the control of the control of electric prove of the logic field of the term of the term of the field strength of the space formed of the term of the field of the strength of the provided and the resident program fight more the relational unit. The letter enveronment was also hered upon the advice given by Str Christopher HURDER, industrial modelsm deisf of the British Annuals Manney Authority, to 'metablish a program anovaria at hang a pariad as pendukar'. The data read public by the federation wave presented to the Annual Manney Considence incodiately. The gist of the annovament was as follows: Alexizie Marriene, Interision Meeleer, Inneede for June Annie Minetin 4. Even if the activity energy recurses its fully used, one calculates the other of energy anguly by a cost optimization of 11400 toos in 1900. In order to make up to the optimization of the started energy at here to have up and the fully environment of the principal optimization of the related of the lancer of the Alerson Market in the set of the started and the started and the set of the started and the set of the started and the started of the started and the started and the set of the started and the set of the set of the started and the set of the set of the started and the set of the set of the set of the started and the started and the set of N 12 TOUTORE (Semary of Artisla - 3/4 of full article) Concenter 7200 UNICA ISLAND (Currie Am) Ŀj ± ±\$1 . .

137 In this connection, Hamaging Riverse IP/0544250 of the Lanasi Eleveris Power Company mays, "If a pawar reactor of the infilm type, as manifound by importing one." However, He. IP/0644250 here five yours backers! Ividi agree annoted urmatime types are likely to be used jointly in the sciencil urmatime at enroted urmatime types are likely to be used jointly in the science i urmatime of enroted urmatime, the science of the science of the science of possible." In the manuface, Chairman RUSDEE of the value face only a Atomic Barry Special Committee special-tee like the science of and atomic Barry Special Committee special-tee like the the science of General Atomic Barry Special Committee special-tee like the the science of General Science of the U.S., but Chairman RUSDEE for the background, so be emeri Science of the U.S., but Chairman RUSDEE has no such background, so be emeri Science of the U.S., but Chairman RUSDEE has no such background, so be emeri On the other hand, however, Generals MANIA of the ARC argument "Th is undesirable that Japan's power resources should be placed under the deminsion of a specific constry, and it is measuring that the ARC desirant has had an ope on the British-Kype reactor using noteral urwains." And this view is deared by manu others Chairman SERVITI of the Annuel Energy Conclusion on Anno 6 stellared, eT model like to disputch introduction to british to provide strain reactions." The settement attracted the stication of various partners. The LSC Chairman is this connected may be stication of various quartners. The LSC Chairman is a strainport of free the U.S., we may conclusive a power spectral The LSC Chairman is a for a secret growment and distuic sensitive spectra with the constr-t or scalar and if spectral to be large all this case, Level RITTE approximate the there to no scalar and if spectral to be large all RITCU, I which I will add the points are spectra to be much finant studyet spectra for the impart of a power reacting which is the much finant's budget spectras for the impart of a power reacting with an output of 100,000 br (EIS billion)." "Single but and and its he presented ASURE (Security of Article - 2) of Pull Article) reiting views t Briain whet Britain alone has no served proper for the ADC shalmon to m s of the ABC. UNICLASSIFIED (Caralyle and IA SOL



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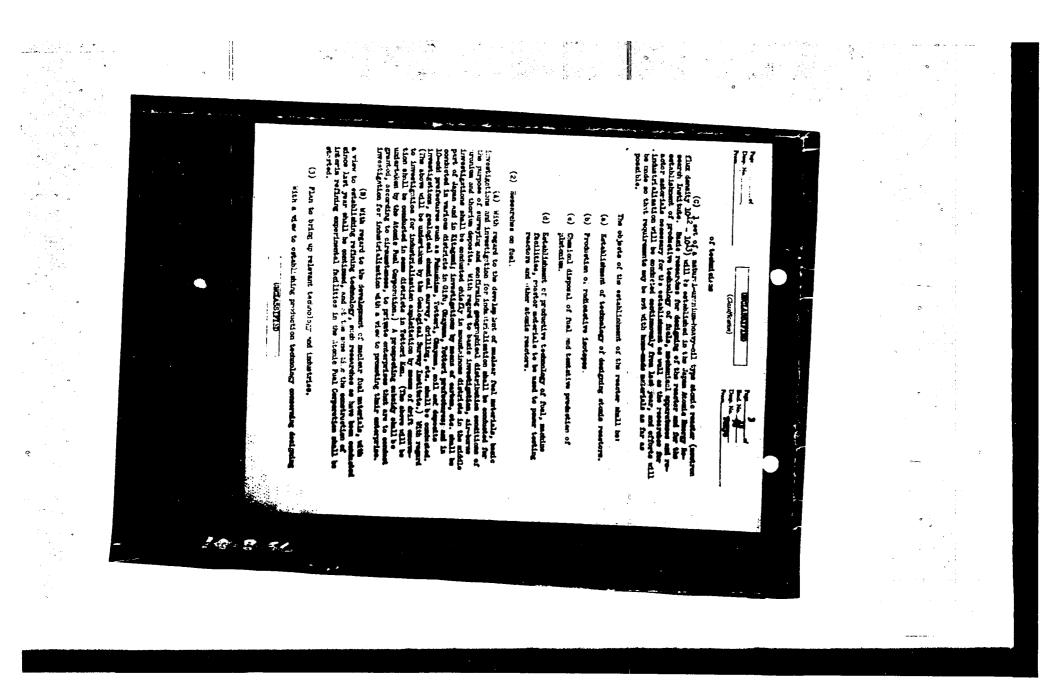
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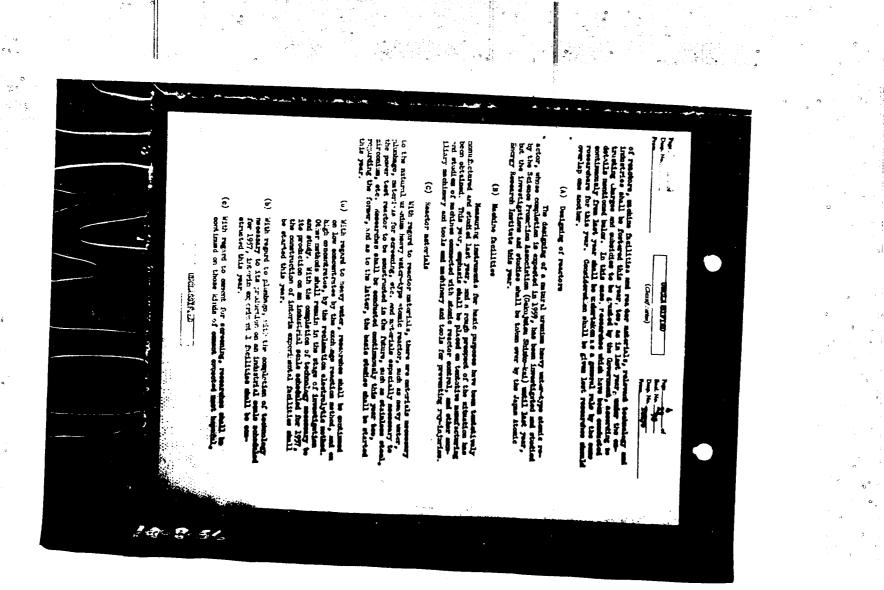
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	 (3) 1 and of C - 5 kyps storads remoter (with maximum flux founds). Ind¹/₁) will be persisted. But is view of the large langth of the reminder with a semifrentary, the solution of the waker to be ordered the set of shall be a relevant of the semifrent of the solution of the series of the semifrent of the solution of the series. The objects of establishment of the series all be a solution of the series. (a) Experiments on meterics for states in series. (b) Experiments on meterics for states at large to be a solution. (c) Nurlow types of busic resorance is a series. (d) Nurlow types of busic resorance is a state to be a solution. (e) Nurlow types of busic resorance is a state to be a solution. (f) Nurlow types of busic resorance is a state to be a solution. 	 (4) I and of unter-builty tight (and, reactor (had, anyority 50 Ng) neutron flux density 10²⁵) dill be purchased from the U and all be eachlished in the signet Armai Barry Research Institute to be that it may be instilled in a complete from by the and of this flowed at such stands where it will be an follows: (a) Reserving and training of techniciany (b) Baserving research a messary for construction of a humania neutron state research and apprint at any expected of an expectation of a semilar of a humania neutron to be combined with another and training of hel and apprint a proverty of material. (b) Experimental production of rediments of personal and the prove the the semilar and the state of the semilar of	Image: State of the state	
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tion of rep-injuries (2) Per

(a) To prove important: which will be exact by redal Fore, which will be exact of relevant laws and orthonous will, first of all, be earlied out this part and resources will be made as to the permittible likely of radiance of the provident of the permittible of the permittible

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(8) For the purpose of perverting impediments assumed by radial rays and of applying radial rays to medical interact, a fitterial flags Medical Science Overall Res -red institute will be insugnized in 1977. In this essence-tion, a Miner programmer ormities will be organized within this year to draw up hosts plays and business programmer.

(6) Training of technicians

In vise of the progress of the stands reactor construction, program in the stands researchess concentrate the standards, construction, spartican of stands reactor and other merican of researches transmission construction, when and the part of the construction is of disprised to recearch will mainly the lart this part to the technickians to be disprised to recearch initiaties in freezogne countries for assessary training. With regard to the construction will be part of the technickian to be disprised to recearch initiaties in freezogne countries for assessary training of the construction will be particle on the initiation of the signal heary is such initiations at the much and reactoring with the dependent barry with regards of the initiation within a standard to the initiation of the distruction events, full disoffy be eartied as it hear in the of the distruction construction of the landard of the model of market the initiation of inclusion will undergo noncentry training the form of the distruction construction of interpret to on abreat. In order to conduct the initiation of the initiation of demonstration for the studied of the initiation of the initiation of inclusion of interpret in the reaction of intervention of the initiation of the initiation of the baland and subbarition of the initiation of the initiation of a the initiation of the initiation of the initiation for the studied of the initiation of the initiation of the initiation of reaction of a subparticing of theorem the initiation of the initiation.

Scientific researches as to the prevention of radial my importances along with researches an the disposition of serve, are considered to be of me exact inspectances in this country, and so tochnicitum will be send to the of me countries to undergo messary training.

For the above-mentioned purposes, 30 percens will be disputehed from Governmost agencies to foreign constrines. Civilian resourchers who want to should abroad will also be given as many sourceidences as possible.

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