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AEC 610/15

April 9, 1960

COPY NO. 49

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ATOMIC ENERGY COMMISSION

GAS CENTRIFUGE METHOD OF ISOTOPE SEPARATION

Note by the Secretary

The General Manager has requested that the attached report by the Acting Director of Research be circulated for consideration during the week of April 11, 1960.

W. B. McCool
Secretary

Approved 1609 4/12

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ATOMIC ENERGY COMMISSION

GAS CENTRIFUGE METHOD OF ISOTOPE SEPARATION

Report to the General Manager by the Directors of Classification, International Affairs, and Research

THE PROBLEM

1. To determine the method and scale of proceeding with the development of the gas centrifuge method of isotope separation, including possible control and collaboration with The Netherlands, West Germany and the United Kingdom.

SUMMARY

2. On November 5, 1954, an Ad Hoc Committee appointed by the General Manager to study the Gas Centrifuge Process recommended an orderly development program be carried forward to resolve certain key technical problems. The Ad Hoc Committee recommendations were never implemented and the Commission has hitherto not acted to establish policy on the development of the gas centrifuge process. Recent developments in this program are reported in AEC 610/5 - 610/13.

3. The lack of foreseeable U. S. production need for a gas centrifuge plant, estimates that this process was economically non-competitive with gaseous diffusion, and budgetary limitations have combined to limit the U. S. effort in this process during 1954 - 1960 to a modest experimental program at the University of Virginia, where, however, some significant advances in the technology have been made. Part of a captive German group which

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developed a short tube contrifuge in the USSR during 1946-1954 has duplicated the USSR work at the University of Virginia since 1958. The simplicity of their presently developed unit, along with materials improvements developed in missile programs, indicates the feasibility of design of a short tube unit showing considerable potential for isotope separation. Information on foreign work in the USSR, Germany, and The Netherlands has become available. The German program is considered to be the most extensive and most complete gas centrifuge program in the world at this time.

4. Informal discussions have been held with Dr. Boettcher, Director of Research, DEGUSSA, Germany (see AEC 610/10), Professor Groth, University of Bonn, Germany, and Professor Kistemacher, Director, Laboratory voor Mass Spectrographic, Netherlands (see AEC 610/7, 610/9) concerning their technical programs and the desirability of collaboration. As yet, official proposals to collaborate on a development program have not been received from the German and The Netherlands governments.1/ The United Kingdom has shown renewed interest in the gas centrifuge isotope separation process, and classified discussions permitted under the present bilateral agreement were held with representatives of the UKAEA, Risley, at the University of Virginia in November. The process appears attractive to them in view of the notable advances achieved since they discontinued work on this process in 1948. Other reasons which arouse their interest in the process is a U.K. decision to base their next round (1963-1965) of power reactors on enriched (1.5 - 2%) U-235, plus the fact that gaseous diffusion is a more expensive process with them than with us.

1/ The Secretary of State recently called Chancellor Adenauer's attention to the implications of Germany's work in this field. The Chancellor indicated that he would look into the matter.

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5. A technical and economic evaluation of the short bowl gas centrifuge process has recently been completed by the General Electric Company under a contract with the AEC. Their study reveals that, following a three-year development program, the U. S. could then build a gas centrifuge plant which would produce separated U-235 at a price competitive with the present AEC price schedule. Their study also reveals that such a plant requiring primarily mechanical engineering skills could be built at a cost of about $17 million, following a 2-3 year development program, which could produce 500 kgs/year of 95% U-235 and have a power requirement of approximately one megawatt. Except for the preparation of feed materials, the skills needed to design and construct such a plant are available to some 20-30 countries.

6. The potential of the gas centrifuge process in contributing to the Nth power problem has also been evaluated in a study by Union Carbide Nuclear Company. It is believed that the centrifuge route, as compared with the reactor route, studied by Hanford Operations Office, would be the easier to pursue both covertly and overtly.

7. In order to prevent gas centrifuge information and equipment from becoming available to other countries and permit them to use the gas centrifuge process in the production of weapons grade materials, agreements for classification, export controls, and collaboration should be explored with the United Kingdom, Germany, and The Netherlands. Collaboration would be technically and strategically desirable. Although serious procedural difficulties are recognized in establishing the agreements with Germany and The Netherlands, the problems are under exploration with the Department of State, (see Appendix D). In the meantime,

information developed as a result of U. S. work in this area is no longer being declassified.

8. An expanded U. S. development program costing about $6 million over three years should proceed expeditiously and independent of the negotiation, implementation, or rejection of an agreement with Germany and The Netherlands. A program, costing about $2 million a year over a three year period, is outlined which the staff believes would place the U. S. back into a position of technological leadership in this area of isotope separation, a subject of considerable military and commercial concern. The incentives for such an expanded program are:

a. Impact on economy of economic commercial power.

b. Military security through plant dispersion.

c. Reduced power consumption.

d. Cheaper incremental production.

e. Separation of commercial and military economy.

f. Maintain knowledge of sources and capabilities of foreign production of fissionable materials.

g. Retain U. S. leadership in forefront of isotope separation technology.

The recent work which has been done on the centrifuge method of isotope separation and its relevance in connection with the Nth power problem was brought to the attention of the White House, Departments of Defense and State, and the Central Intelligence Agency at a meeting on February 6, 1960 (AEC 610/13). On February 11, 1960, the Joint Chiefs of Staff were also briefed. The General Advisory Committee at its last two meetings, February 1-3, and March 17-19, 1960, considered the centrifuge process. Their comments and recommendations are included in Appendix "E". The JCAE was notified of the implications of this process to the Nth

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power problem in a letter dated 2/12/60 from the Chairman to Senator Anderson (Appendix "F").

STAFF JUDGMENTS

9. The Divisions of Finance, Intelligence, Military Application, Office of Operations Analysis and Forecasting, Office of the General Counsel and Production, concur in the recommendation of this paper.

10. The Division of Reactor Development notes that successful demonstration of low capital cost isotope separation plants can have major impact on the growth and development of industrial atomic energy. To the extent that low prices for enriched uranium may result, it would have an obvious effect upon achievement of economic nuclear power, both in this country and throughout the world. It would make possible real simplification of AEC problems such as those discussed by the Commission at meeting 1596 on February 26, 1960, on the subject of sale of special nuclear material, toll processing in Government diffusion plants and related matters. Lastly, the beneficial effect of making possible a completely private chain from ore through the entire fuel cycle, with the possible exception of ultimate waste disposal, cannot be overemphasized. The introduction of private industry at each phase of the cycle will bring into being cost-cutting incentives not otherwise available in the program and should significantly advance the date of low cost nuclear energy.

11. The Division of Production agrees that additional effort, over and above the current level, on gas centrifuge development is desirable but believes that such additional effort should be directed primarily to the resolution of the current technical

and economic uncertainties as to performance of a group of centrifuges operating as a cascade. The Division of Production believes that this feature of the proposed program should be emphasized in favor of accelerating the development of more efficient or advanced centrifuge units. Emphasis in the direction suggested above would permit proper evaluation of the Nth power problem at the earliest practicable date and would provide a realistic basis for anticipating the effects of further technological advances in individual centrifuge units.

12. The Division of International Affairs concurs in the recommendation that prompt discussions should be held with the Europeans on the feasibility of controlling gas centrifuge process technology, but notes that the serious policy problems associated with classified cooperation in this area referred to in paragraph 40 of Appendix "A" may be difficult to overcome. The Department of State has been asked to furnish its views on the international aspects of this problem.

13. The Office of General Counsel notes that the provisions of Section 144a of the Atomic Energy Act would be applicable to the proposed international exchanges of classified information. Thus, any international cooperation involving the exchange of classified information would require authorization by the President and the existence of an agreement for cooperation within Section 123 of the Act.

CONCLUSION

14. a. The U. S. should proceed with an expanded research and development program on the centrifuge process at an estimated cost of approximately $2,000,000 per year for three years, as described in detail in Appendix "B".

b. Suitable agreements concerning the control of gas centrifuge information, materials and equipment should be sought promptly, if the Department of State agrees, with Germany, The Netherlands, and the U. K.

c. Classified cooperation with Germany and The Netherlands would appear to be desirable from a technical standpoint but may be politically impractical.

d. Classified cooperation with the U. K. should continue.

RECOMMENDATION

15. The General Manager recommends that the Atomic Energy Commission:

a. Approve an expanded U. S. research and development program on the gas centrifuge process as set forth in Appendix "B";

b. Note that total funds estimated to accomplish this program are six million dollars for an approximate three year period.

c. Note that funds to initiate and conduct this program through FY 1961 will be obtained by reprocessing funds now budgeted for the Division of Research and the Division of Production.

d. Agree that the prompt initiation of exploratory discussions with the German, Dutch, and U. K. governments to seek control of all gas centrifuge information, equipment, and materials in light of the Nth power problem is desirable;

e. Agree that classified cooperation with the Germans and Dutch would be desirable from a technical standpoint;

f. Note that the Department of State has been informed of the potential of the gas centrifuge process in the context of the Nth power problem, that it will be informed of this action, and that the Department's views have been requested on (a) the desirability of our seeking agreed controls among the states where gas centrifuge research and development is being carried out and (b) desirability and feasibility of classified collaboration with these countries;

g. Note that the Commission will be promptly informed as soon as the views of the Department of State are received.

h. Note that classified collaboration in this area, which has been initiated with the United Kingdom, will be continued within the limits provided by the U.S.-U.K. Civil Uses Agreement for Cooperation;

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i. Note that the expanded U. S. development program should proceed independent of the negotiation, implementation, or rejection of any proposed agreements with Germany and The Netherlands that may develop;

j. Note that successful operation with gas centrifuges have far reaching implications in development of a privately-owned atomic energy industry in the United States, which subject will be covered in other papers under preparation;

k. Note that the JCAE has been informed of the potential of the gas centrifuge process to the Nth power problem by the letter in Appendix "F", and will be advised by appropriate letter of the planned expansion of the AEC's research and development program on the gas centrifuge process.

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APPENDIX "A"

BACKGROUND AND DISCUSSION

PRESENT POLICY

1. The Commission has hitherto not acted to establish policy, either domestically or abroad, in connection with the gas centrifuge process except in the area of classification. The present Classification Policy Guide (AEC 27/136) provides that the gas centrifuge program be a classified program but that experimental work on the detailed mechanical design for the centrifuge method of isotope separation may be declassified. There is, however, a restrictive paragraph attached to the topic which requires that such information be held classified when it becomes apparent that it could reasonably be used for the production of large quantities of U-235.

HISTORY OF THE PROBLEM

U. S. PROGRAM

2. The history of the AEC posture relative to the centrifuge process is outlined in the AEC 610 series. Pursuant to recommendations in a November 5, 1954 report by Ad Hoc Committee appointed by the General Manager to evaluate the gas centrifuge process, the Division of Research solicited bids from four companies to manufacture a prototype unit based upon as realistic an extrapolation of the war-time Westinghouse experience as possible. However, contract negotiations were halted and it was determined that the Research Division support should at that time be limited to the basic problem of spinning long thin tubes at the University of Virginia.

3. This classified program at the University of Virginia, now supported at a level of $300,000 per year, has had as a long-range goal the development of a high-speed, long-tube centrifuge and the application of such a centrifuge to the separation of isotopes. Emphasis in the early phases of the program was devoted to attacking basic mechanical problems associated with bearings, seals, drive systems, etc. In 1957, the Virginia group solved a major problem in successfully spinning a long tube through a series of critical vibrations, a problem inherent in high speed rotation.

4. Since that time emphasis has been placed on the problems of providing tubes of higher strength materials for higher rotational speeds and the problems of introduction and extraction of gases.

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5. An unclassified program has also been supported at the University of Virginia since the summer of 1958. The work is being carried out by Dr. Gernot Zippe, an Austrian scientist who assisted Steenbeck in the development of a short tube (subcritical)

centrifuge while a prisoner in Russia following World War II. Dr. Zippe has completed the construction of several of the units, has subjected them to lifetime tests, and is currently conducting isotope separation tests with UF_6. The simplicity of these units is impressive. Total AEC funds provided to this project are $108,000.

6. A contract with the General Electric Company was executed in June, 1959, to provide the Commission with a technical and economic analysis of both the long and short tube methods and to define the over-all problems. The study of the short tube method (GEL 0708)[1] has now been completed, and indicates that the United States could build in two years (preceded by a three year development program) a gas centrifuge plant.[2] This plant would be based on a short tube design and could produce enriched uranium at a price competitive with the present AEC price schedule.

7. The AEC has licensed Thor-Westcliffe Development, Inc., of Santa Fe, New Mexico, to import seven gas centrifuges from Germany for use in that Company's studies to determine the commercial feasibility of this process for the production of enriched uranium. The AEC is considering an application to permit construction of an experimental cascade. This activity is currently unclassified, but future work may have to be conducted on a classified basis. Discussions with Mr. Lohbeck of Thor-Westcliffe are reported in AEC 610/8.

FOREIGN PROGRAMS

8. Since World War II, the German, and later the Dutch, effort in this field has been greater than that in the U.S.; and

1/ On file in the Division of Research
2/ 75,000 Kg U/yr at 2%, 500 Kg U/yr at 95%

in recent years, the rate of growth of the German-Dutch effort has been substantial. On the grounds that (1) they should not blindly adopt a U-235 separation process chosen by the U.S. in 1943 under the pressures of war; (2) that they should carefully study all competing processes from the point of view of technical merits, flexibility and economy; (3) that they are seriously considering plants considerably smaller than those in the U.S. (for which the centrifuge has a greater chance of being fully competitive) and that they consider it advantageous to be able to divide the operation into several smaller plants at diverse locations, the Germans and the Dutch have parted ways with the French who have chosen the path of gaseous diffusion.

9. During World War II, the gas centrifuge was the method selected for study by the Germans for separation of uranium isotopes. The group of scientists who led the war-time program (Groth, experimental; Beyerle, instrument development; and Martin, theory) are now working on a program carried on by the GFKF (Society for Nuclear Research). This non-profit corporation is supported by the state of North Rhine-Westphalia, the Federal Government, and private industry. The gas centrifuge units are designed and constructed by Professor Beyerle in a GFKF laboratory in Aachen. The mechanical parts are manufactured by SARTORIUS Instrument Company, Goettingen, and the electrical drive and control equipment is provided by the AEG (German General Electric) Frankfurt. At the University of Bonn, Groth leads the experimental group which is now located in the Institute for Physical Chemistry; he is aided by collaboration with Professor Martin of the University of Kiel who has been provided with a centrifuge unit in order to test his theoretical predictions. The characteristics of the centrifuge units developed

by this group are given in the following table, which was published in Chemie-Ingeniur Technik, 31,

	Year Circa	Length cm	Radius cm	Length Diameter	Peripheral Speed m/sec	Separative Work Kg U/yr	Specific Power Kwh/Kg U	Specific Investment S/Kg U/yr
UZ I	1946	40	6.0	3.33	302	0.502	12,050	4,200
UZ IIIB	1952	63.5	6.7	4.74	302	0.935	8,380	2,860
ZG 3	1957	66.5	9.25	3.60	302	0.97	6,300	2,460
ZG 5	1959	113.0	9.25	6.11	302	1.64	3,710	1,460
ZG 6		240.0	20.0	6.0	302	3.5	1,750	685
					340	5.32	1,150	450
ZG 7	1960	316.0	22.5	7.03	302	4.77	1,285	500
					340	7.25	845	330

10. The Bonn/Aachen group plans to assemble 50 to 100 centrifuges at Julich. This cascade would have three stages of centrifuges and enrich uranium to about 2% U-235, and the type of centrifuge to be used will be determined as a result of the testing of the various centrifuges at Bonn.

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11. The program supported at Frankfurt by DEGUSSA-AEG was reported on by Dr. Boettcher, Director of Research, DEGUSSA, at a meeting held at the AEC (see 610/10) to discuss DEGUSSA activities in the field of the gas ultracentrifuge method of isotope separation and the question of U.S. - West German cooperation in this field. Boettcher reported that DEGUSSA and AEG are "cooperating without contract" to develop the gas centrifuge for isotope separation. Their project is under the direction of Scheffel, who is reproducing the device which he together with Steenbeck and Zippe had developed in the USSR.

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12. The Netherlands centrifuge program is several years old, although as of this time, only two publications have been issued. They have performed an economic analysis of the centrifuge process, but their estimate does not appear to be soundly based. It is not known whether they have separated any isotopes by this method.

13. An extensive review of the German and Dutch activities is contained in a report, K-1425,[1] by G. A. Garrett and S. A. Levin. These authors conclude that the West German program is the most extensive and most complete gas centrifuge program in the world and that the work is competent, relatively far advanced, and of such a nature as to lead to centrifuges that can be directly incorporated into a production plant. The costs to be expected from this production plant would be in the range of about $2000 to somewhat less than $1000 per kilogram U of separative work. Their development program probably costs of the order of one million dollars per year including the industrial participation. This level cannot be considered a crash program. Manpower and dollar levels, and the technical status of the European gas centrifuge activities for the period, 1941-1958, which substantiate the above, are on file in the Division of Research.

14. The French have determined to go the route of gaseous diffusion for U isotope separation. A report on the evaluation of their program is given in the report K-1409 by Dr. G. A. Garrett.[2] However, Dr. Boettcher reported that the French were interested in the gas centrifuge and offered to assist in its financial support,

1/ On file in the Division of Research
2/ Ibid

and he believes that they will consider using it to replace the top stages of their gaseous diffusion plant.

15. Brazil has purchased three ZG-3 units from the West Germans (Sartorius). It is reported that they are planning to purchase more units and are having two of their people trained in the operation of these units in Groth's Laboratory.

16. At the meeting on November 4, 1959, Dr. Boettcher of DEGUSSA reported that he had learned that the USSR had reinitiated their activities on the gas centrifuge process. Boettcher thinks that they are attracted to it by the possibility of decentralization for reason of military security or that they are interested in the separation of plutonium isotopes.

DISCUSSIONS WITH FOREIGN GROUPS

17. Informal discussions have been held with Dr. Boettcher, Director of Research, DEGUSSA, Germany (AEC 610/10). Professor Groth, University of Bonn, Germany (FVR-50)[1], and Professor Kistemacher, Director, Laboratory voor Mass Spectrographie, Netherlands (AEC 610/7)-(AEC 610/9) concerning their technical programs and the desirability of collaboration. As yet, formal proposals to collaborate on a development program have not been received from the German and Netherlands governments. However, the Division of Research has been advised by Dr. Boettcher that the question of collaboration is under consideration in several departments of the German ministry. These discussions were held prior to the evaluation of the centrifuge process by General Electric and prior to the safeguards studies in light of the Nth power problem.

18. Classified discussions permitted under the present bilateral agreement with the U.K. were held with representatives

1/ On file in the Division of Research.

of the UKAEA, Risley, at the University of Virginia in November, 1959. The process appears very attractive to them in view of the notable advances achieved since they discontinued work on this process in 1948. Other reasons which arouse their interest in this process are a decision by them to base their next round (1963-1965) of power reactors on enriched (1.5 - 2%) U-235, plus the fact that gaseous diffusion is a more expensive process with them than with us. They believe that they now have a unique opportunity to study another method of isotope separation before proceeding to the design of a plant.

ECONOMICS AND POTENTIAL

19. The economics of the gas centrifuge process in comparison with that of gaseous diffusion were evaluated in 1957 by three different groups; AEC staff (610/3), Dr. Manson Benedict (610/4), and Union Carbide Nuclear Company (K-1368). These studies, based on the technology available at that time, concluded that the gas centrifuge process did not compete economically with our gaseous diffusion process in the large scale separation of U-235.

20. The General Electric Company, under contract with the AEC, has taken a fresh look at the over-all centrifuge program (both domestic and foreign) and has again examined the economics of the process. Their Phase I Report (GEL-0708) presents a detailed study of the short tube unit. Their study is continuing with an examination of the long tube unit. Results of their study indicate that, due to significant advances in the centrifuge technology and with a 2-3 year period to develop foreseeable improvements in the technology, it is likely that the United States could construct a small gas centrifuge plant which would produce enriched uranium at a price competitive with the present published AEC price list. The plant described in the

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General Electric study would cost approximately 17 million dollars, would be capable of an annual production of 500 kilograms of U-235 at 95% enrichment, and would have a power requirement of approximately one megawatt of electricity. Such a plant could, with minor design changes, be so arranged as to produce larger quantities of U-235 at corresponding lower enrichment. For example, the $17,000,000 plant referred to above could be so arranged as to produce 75,000 Kg 2% U-235.

21. The gas centrifuge method of isotope separation has been considered by the General Advisory Committee at the February 1-3, 1960 and March 17-19, 1960 meetings. Their comments and recommendations are contained in Appendix "E".

SAFEGUARDS STUDIES

22. Sir William Penney, U.K., in conversation with Chairman McCone, expressed great concern over the development in Germany or the separation of U-235 by gas centrifuges. The Chairman requested a study of the possibilities of using the centrifuge process for the production of a small number of atomic weapons, either overtly or covertly, by nations not now having a major weapons program. For comparison, two approaches to the matter of the production of atomic weapons on a small scale were studied; the natural uranium reactor route for plutonium production, by Hanford Operations Office; and the high speed centrifuge route for U-235 production, by Union Carbide Nuclear Company (UCNC).[1]

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The capabilities of various type countries for building centrifuge

1/ Reports on file in the Division of Production

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plants have been analyzed for three degrees of capability - classed as X, Y, or Z where: a class X country would need no outside assistance; a class Y country would probably have to import also some of the auxiliary equipment; a class Z country would probably have to purchase pre-fabricated centrifuges and almost all the auxiliary equipment from foreign vendors and, in addition, would need technical advisors from the outside to aid in the construction and operation of the centrifuge plant.

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24. The results of the Hanford and UCNC studies are further summarized and analyzed in a safeguards report (Appendix "C") which also takes into account the GE study. This safeguards study concludes that the centrifuge route would be the easier to pursue both covertly and overtly, and that it would require less

specialized personnel, of fewer disciplines, than the reactor route. The principal liability of the centrifuge route as against the plutonium route lies in the fact that centrifuge technology is yet to be proven and the designs of the more advanced centrifuge units have not as yet been published nor have the units been tested.

DISCUSSION

25. The U.S. can ill-afford to lose technological leadership in this area of isotope separation. The gas centrifuge process as indicated in the GE study already shows the potential of producing U-235 at a cost which is competitive with the costs as reflected in the AEC price schedule. Moreover, there are other long standing arguments in favor of an expanded U.S. program. Separations for which the gas centrifuge method has particular advantages and for which the process is likely to find application include:

a) Separation of plutonium isotopes especially in view of the utilization of high exposure plutonium generated by the growing nuclear power industry.

b) Topping of the gaseous diffusion plants.

c) Separation of U-236 from U-235 (reactor fuel "Clean-up").

d) Separation of particular stable isotopes when required in large quantities.

26. The Division of Production sees little incentive for developing a highly efficient gas centrifuge plant on an accelerated schedule from the standpoint of U.S. needs. They feel that there is only a very slim possibility that centrifuges could ever be competitive with the current or anticipated cost of separative capacity in our large diffusion plants. There is, further, no need for additional separation capacity for at least ten, and more likely, fifteen years.

27. Should the U.S. determine not to move forward on the development program and merely to continue the limited work at the University of Virginia, it is likely that it would become increasingly difficult for the U.S. to hold together this group and its research return can be expected to diminish. Such a course would also weaken the present and future U.S. position in seeking internationally agreed controls over the process in light of the Nth power problem.

28. In AEC 27/135, as revised, the Commission adopted a new Classification Policy under the terms of which gas centrifuge work would be conducted as a classified program with the information produced being declassified until such time as a breakthrough might occur. One factor that influenced the determination to classify the program in this way was the fact that at least two other countries (Germany and The Netherlands) were (and still are) vigorously pursuing studies in this field, that they have advanced their technology to the point where it was equal to or better than ours, and that, moreoever, they were publishing the results of their work. This situation still prevails.

29. The research project at the University of Virginia concerning the spinning of long tubes has been conducted in a physical security area on a classified basis. The other research project there, under Dr. Gernot Zippe, an Austrian scientist, on the reproduction of the short tube unit developed for the USSR, has been conducted on an unclassified basis in an open area. Progress reports prepared by Zippe and issued under the AEC contract have been given distribution by TISE at Oak Ridge.

30. Since the drafting of the gas centrifuge classification policy adopted in AEC 27/135, not only the German and Dutch work,

but the U.S. work, as well, has progressed considerably. The Germans have now already so far progressed in their development of the gas centrifuge method that it appears that they could, without any further advancement in their technology, build a working plant for the mass production of U-235. The table of the Groth-Beyerle centrifuge in paragraph 9, Appendix "A", showing steps in the development of their program, indicates very clearly that in a period of approximately 14 years they have been able to increase the separative potential of their machines by better than an order of magnitude, while at the same time reducing total plant costs also by more than an order of magnitude. The U.S. work has also progressed to the point where it would appear that in the very near future, using the long thin tubes developed by the University of Virginia, a plant could be built for the mass production of U-235.

31. There are other important advantages of the gas centrifuge method of separating isotopes. One of these is its very low power consumption, as compared with the gaseous diffusion method. One might say that for an approximately equal total outlay in dollars (that is, power plus plant), one could build equally productive plants. However, to a nation short on power, the low power-consumption for the gas centrifuge method could make possible a production plant at a time when a gaseous diffusion plant would still remain a desirable but impossible goal. Another advantage is the relatively small size of the gas centrifuge plant as compared with gaseous diffusion in producing 95% U-235. This factor would enhance the position of military security by means of plant dispersion as well as permit an operation in a clandestine manner.

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32. Because the "breakthrough" mentioned in topic 2-741 of the Classification Policy Guide (OC Doc-68) has taken place, the importance to the national defense of the gas centrifuge method of isotope separation is now considered great enough to warrant classifying existing and future U.S. work and to request the Department of State to explore the possibility of entering into discussions with the West German and Dutch governments in an attempt to obtain the cooperation and the agreement of these governments to keep the results of their work in this field classified.

33. Clearly, however, the purpose to be served by any classification action the Commission might take could be vitiated if the German activities were to proceed on an unclassified basis. It appears, therefore, that it is important to determine whether the German government could and would classify their work in gas centrifuge technology.

34. The alternatives that present themselves in this matter are, of course, dependent on the views expressed by the Department of State and negotiations with the several states involved.

35. There are several problems which could make a classification action difficult. The German development to date has been undertaken almost exclusively by private parties interested in ultimate commercial exploitation. The German Atomic Ministry has no classified programs due in part at least to Germany's commitments under the Brussels Treaties. Any modification of this position could perhaps have serious political repercussions in Germany. It is unclear both from the standpoint of Treaty provisions and policy as to whether Germany could or would take a classification action in this area that would prevent dissemination of the technology to her EURATOM partners, although limitation of the

technology to the EURATOM members would obviously constitute a degree of information control substantially greater than a completely unclassified development. The problem as regards The Netherlands, is not treated separately, but the EURATOM aspects would be similar.

36. The Office of General Counsel believes that the subject matter of the proposed cooperation would probably be considered by EURATOM as outside the purview of its treaty. In any event, they suggest that this is a matter which should be determined in the first instance by the EURATOM member nations involved.

37. Notwithstanding these problems, the safeguarding of ultracentrifuge technology by agreed procedures for the control of this information among the several states in which centrifuge work is being carried out is important and should be explored. It would further appear that such exploration should take place with the German and Dutch governments.

38. Moreover, regardless of whether these governments or EURATOM could classify their present and future gas centrifuge work, agreement should be sought to control the export of gas centrifuges and related equipment and to subject such export to safeguards. Agreement on such controls taken together with the controls the U.S. is seeking among uranium supplier nations, would mitigate to some extent at least the likelihood of an Nth power exploiting the process.

39. As a related matter, it is recognized that technical cooperation in centrifuge research and development with the Germans and Dutch may be desirable. While such cooperation is not essential to achieving the stated objectives of the proposed U.S. developmental program, it is reasonable to assume that it would

contribute to the rate and probability of their achievement. In addition, it would permit an immediacy of association with European development. The Europeans also may have a strong interest in pursuing such cooperation from their standpoint.

40. If it proves feasible, therefore, for the Dutch and Germans to establish control over existing and future gas centrifuge information, the possibility of cooperating with these two countries on a classified basis should be examined. However, it is important to note that there are a number of serious policy problems associated with pursuing classified cooperation with the Germans and Dutch in this area. These include: (1) whether it would be politically feasible for the U.S. to enter into new classified agreements with two member states of EURATOM without also agreeing to transmit the Restricted Data involved to EURATOM and the other member states, including France; (2) the need to define the role of EURATOM in any agreement that might ensue; (3) whether any such cooperation would directly or indirectly assist the French military program; and (4) the possible inconsistency between our willingness to cooperate, on a classified basis, with the Dutch and Germans on the centrifuge process (if separate agreements with these countries are feasible) and our refusal to transmit Restricted Data on the gaseous diffusion process to France and the U.K.

41. Finally, if agreement cannot be reached with the Germans and the Dutch to control gas centrifuge information, then there may be serious question as to whether a real purpose would be served in classifying our own work. Should we, therefore, as a result of our inability to secure German and Dutch agreement to control centrifuge information, decide to declassify our own work;

it would appear possible to work out an arrangement for unclassified technical exchange with the Germans and Dutch under the ambit of EURATOM if this should prove desirable; and, probably without modification of our existing agreements for Cooperation either with EURATOM or the member states.

APPENDIX "B"

U.S. EXPANDED DEVELOPMENT PROGRAM

1. A three year U.S. development program is proposed at a total estimated cost of $6 million. The program would include simultaneous undertakings of experimental and theoretical studies of basic centrifuge problems, the design, manufacture, and testing of a prototype, and the design, construction, and operation of an experimental cascade.

2. These areas of development are delineated below and are presented on a following time-scale chart:

a. Supercritical centrifuges

(1) Mechanical development
Bearings, gas seals, drives

(2) Hydrodynamic development
Internal circulation

(3) Process testing of UF_6

DELETED DOE 6.2(a)

(1) Alternate means for internal circulation

(2) Process testing on UF_6

c. Cascade development

DELETED DOE 6.2(a)

(2) Analogue computer study of large cascade

d. Hydrodynamic studies

(1) Combined theory of thermal plus Coriolis effects

(2) Glass centrifuge experiments

(3) Phenomena of turbulence, scoop design, and effects

DELETED

DOE 6.2(a)

(1) Design

(2) Fabricate two units

(3) Mechanical and process testing

f. Advanced mechanical studies of higher speed machines

(1) Bearing characteristics

(2) Material fabrication

3. The development program as outlined should serve to accomplish the following objectives:

DELETED

DOE 6.2(a)

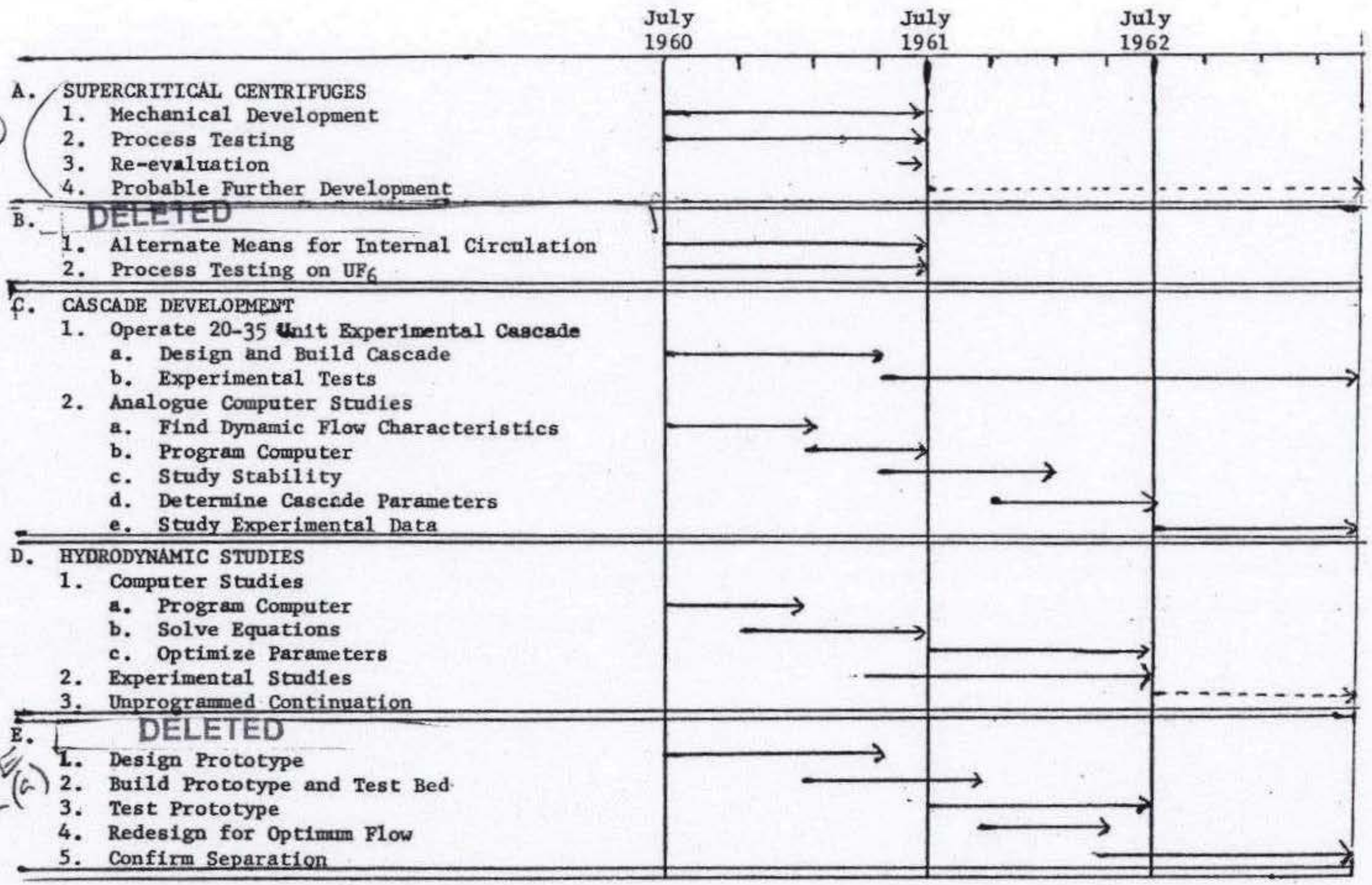
b. Demonstrate an operating experimental cascade.

c. Establish a sounder basis for theoretical projections of the centrifuge process, including cascade behavior.

d. Determine potential for further improvement of the centrifuge process.

e. Improve the accuracy of the economic projections

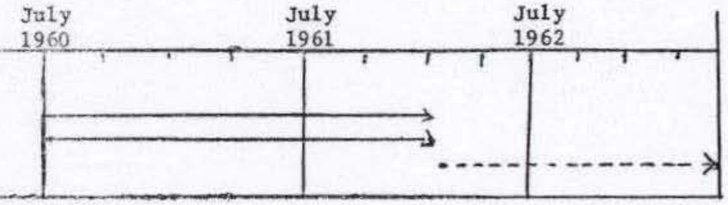
GAS CENTRIFUGE DEVELOPMENT PROGRAM



Appendix "B"

GAS CENTRIFUGE DEVELOPMENT PROGRAM
(continued)

F. ADVANCED STUDIES OF HIGHER SPEED MACHINES
1. Bearing Characteristics
2. Material Fabrication
3. Unprogrammed Continuation



APPENDIX "C"

CONTRIBUTION OF THE GAS CENTRIFUGE PROCESS TO THE Nth COUNTRY PROBLEM

SUMMARY

1. In an attempt to delineate the potential contribution of the gas centrifuge process to the Nth country problem, special studies have been undertaken by Hanford and Oak Ridge, (graphite reactors - gas centrifuges). In addition, the General Electric Corporation has recently completed a broad technological review on the subject of gas centrifuges for the AEC.

2. These studies indicate that the reactor approach has the advantage of a proven operability and readily available technological data. On the other hand, the gas centrifuge route has the advantage of smaller manpower requirements and a lesser degree of specialization required in the manpower for construction and operation; more readily available materials, equipment and components; a lower inventory of uranium; an ease of fission weapons fabrication from the product material; and the potential for the construction of thermonuclear weapons. Finally, in terms of costs, electrical requirements, and time, the gas centrifuge route based on present technology is comparable to the production reactor route. It is therefore concluded that at present the gas centrifuge route is the more attractive and perhaps easier route for an Nth country.

3. Controls and safeguards therefore need to be exercised over the gas centrifuge process. The forms of control which should be sought are not substantially different from those already encountered in connection with the efforts to establish similar controls over other types of nuclear production facilities

and materials. Strategic technological information should be controlled on a classification basis. Gas centrifuge plants or important components and materials of such plants, if not classified, should only be exported when committed to peaceful uses and subject to safeguards. Finally, controls should continue to be exercised over the supply of feed materials (natural uranium).

INTRODUCTION

4. Recent advances in the technology of isotope separation via the gas centrifuge route warrant an evaluation of this process in terms of its potential contribution to the production of atomic weapons by nations not now having a major weapons program. In analysis of this problem special studies have been undertaken by Hanford and Oak Ridge. (Reports KB-789 and KOA-662). Summaries of this work are attached as Annex I. The Hanford study treated the present production potential of plutonium via the natural uranium-graphite reactor route, while the Oak Ridge studies examined the gas centrifuge method based on technology known to date as well as commenting on the gaseous diffusion process. In addition, the Division of Research recently completed its comprehensive review of the gas centrifuge field to determine the potential of the method based on forseeable technological advances (Report GEL 0708).

5. Basic to the consideration at hand is the realization that the decision by any country to acquire a military capability will be a political decision taken at a time when the country believes it has the means to do so. These means include the utilization of any type of production facilities and the acquisition of any necessary materials or equipment by any procedures, providing that the objective is obtainable through the combination of resources of money, manpower, and materials.

6. Three production methods might be considered, (a) plutonium via the reactor route, (b) Uranium-235 by the gaseous diffusion method, and (c) Uranium-235 by the gas centrifuge process. The example of France would seem to indicate that the first choice might be the plutonium reactor route. Further, the lack of availability of complete technical information on the gaseous diffusion method, and the lack of the ready availability of components together with the magnitude of effort and investment required, represent serious obstacles to the pursuit of this course. In present circumstances it would seem that the initial choice by the Nth country might be narrowed down to the reactor and centrifuge methods. For the purposes of this study the comparison is so limited.

7. The specific points which would be likely to be examined by a nation in reaching a decision between the two routes are as follows:

a. The potential and proven capabilities of the method.

b. Skills and numbers of personnel required for the design, construction, and operation of the necessary plants and processes.

c. The availability of the necessary technical information.

d. The availability of the necessary components and materials without restrictions on their use, if the country is largely dependent upon the import of such equipment and materials.

e. The time required to achieve a military nuclear capability.

f. Capital costs and operating costs.

g. Electrical power requirements.

h. Availability of the feed materials and inventories of these materials in the process.

i. Willingness to demonstrate overtly the military intentions of the program.

j. The relative ease of using the final product, whether Uranium-235 or plutonium. Considerations here are toward (a) the effectiveness of the materials in fission or thermonuclear weapons, (b) the quantities required to achieve the objectives, (c) the skills and equipment required for fabrication of the weapons, (d) the ready availability of necessary technology, and (e) the hazards involved in fabrication.

EVALUATION

8. The studies presented in Annex I compare the production of 10 kgs of plutonium per year by reactor with the production of 50 kgs of U-235 per year by centrifuge. These two methods are evaluated in terms of these foregoing factors in the following sections. In addition, attention will be given to the Division of Research review of the gas centrifuge problem.

9. The potential and proven capabilities of the two methods differ widely. Reactor production of military quantities of special nuclear material has existed for many years. The technology associated not only with the reactor portion of the complex but also with the feed material preparation and chemical separation aspects of the system have received wide unclassified dissemination. On the other hand the gaseous centrifuge process is yet untested. To date experimentation and development has been limited to the evaluation of single centrifuges, and no multiple cascade arrangement has been examined.

10. Evaluation of the two methods in Annex I indicates that the manpower requirements for the design, construction, and operation of both kinds of facilities, differ with fewer personnel required if a Nth country were to pursue the gas centrifuge route (reactor 3,411 - gas centrifuge 1,653). These numbers might still be further reduced by having personnel serve dually in the construction and operation phases. In addition, the skills required to proceed with these processes differ considerably. If

the nation desired to pursue its military objective through a reactor complex, a specialized series of skills in feed material preparation, reactor technology, and chemical separation techniques are necessary. For the most part, these skills differ from normal mechanical, chemical, and civil engineering practices. The gas centrifuge method, on the other hand, offers a nation the possibility of proceeding on a military nuclear program relying predominately on mechanical skills with the exception of the feed material portion of the complex. For example, it appears that a nation skilled in machine tool manufacture or large scale appliance production could readily proceed to fabricate and assemble a gas centrifuge plant. This point was emphasized in the General Electric study where it was pointed out that a possible prospective supplier of gas centrifuges is their Hot Point Appliance Division. Further, the gas centrifuge method does not present safety problems of the magnitude associated with the reactor route, where specialized skills would be required in handling and treating highly radioactive materials.

11. There exists a wide difference in availability of the necessary technical information required to construct and operate the two types of facilities. The nuclear technology for civilian power reactors and chemical separations has been given wide dissemination not only by the U.S. but by the nuclear powers. There is little difference between this technology and that involved in producing plutonium for military uses. The information on centrifuges, however, is still relatively closely held in the Western world, i.e. limited, it is believed, to the U.S., Germany, U.K. and the Netherlands. In these cases only a small number of individuals are intimately associated with the projects. However, the technological information to date is limited to the centrifuge per se, and little or no work has been devoted towards

the plant control and cascading problems associated with the operation of many centrifuges in unison. Commercial sales of gas centrifuges, which it is understood are contemplated by the German group, would make present technology readily available.

12. A study of the important component parts and materials required in construction and operation of reactors shows them to have many especially designed or prepared features, i.e., nuclear grade graphite, nuclear instrumentation, and control rod drives. The reactor route also requires specialized equipment to fabricate and process the fuel material before and after reactor irradiation. The gas centrifuge method, on the other hand, provides potentially less difficult fabrication techniques. This route would permit a nation to concentrate a major portion of the total effort on the construction of a centrifuge plant rather than on a variety of plants from fuel fabrication through reactors to chemical separation.

13. Purchase of a plant or the principal components would, in the case of some countries, make the problem substantially easier. At present, by law, U.S. exports of reactors and other production and utilization facilities require an export license issued by the Atomic Energy Commission in connection with an appropriate agreement for cooperation. This control could also apply to gas centrifuges if they are designated as a production facility or as important components of such a facility. The U.K. has in being its mechanics for a similar control. Germany does not.

14. The results of the special safeguards studies indicate that the time required for nations to independently achieve a nuclear capability by either route is approximately the same (reactor 51 months - gas centrifuge 49 months). It would seem

from this that a nation has little choice on this basis here in determination of the route to be followed.

15. Examination of Annex I in the terms of the capital and operating cost of comparable production facilities indicates a further similarity (capital costs, reactors 38.7 million - gas centrifuge 38.8 million; operating costs, reactor 7.6 million - gas centrifuge 6.7 million). There are two additional factors that should be noted in this connection. The first of these is that for an additional million dollars the assumed reactor complex could increase production by a factor of 4 or 5. The Hanford study shows this to be achievable by addition of more. heat exchanger facilities to the reactors, thus allowing an increase in the reactor power output. The second point is that gas centrifuge costs could be sharply reduced if the General Electric conclusions concerning the short range potential of the centrifuge process are correct. On the basis of these conclusions, the costs of the gas centrifuge route could be reduced by perhaps as much as a factor of four. It may then be concluded that these two further points tend to cancel and no further distinction between the two approaches can presently be developed on a cost basis.

16. One factor that has been to the disadvantage of the gaseous diffusion route for the separation of uranium isotopes for many of the less industrialized countries is its large requirements for electrical power. The General Electric study on the gaseous centrifuge route, however, indicates that the power requirements for this method are nominal (a few megawatts) and comparable to those of the reactor route. This factor would then permit ready consideration of this method of isotope separation by a power-poor country.

17. In considering the availability of feed materials for either process, it is important to examine the inventory of material necessary to produce either 10 Kgs. of plutonium or 50 Kgs. of Uranium-235. The special studies conducted, indicated that for the reactor route 100 tons a year of natural uranium were required, while in the gas centrifuge method only 25 tons a year of natural uranium were required. This may be a very important difference for a nation without indigenous natural uranium or possessing only a small quantity.

18. In considering whether a nation would be willing to demonstrate overtly its intention, little choice exists between the routes. Clearly a reactor ostensibly for the civil purpose of producing power could be used to produce plutonium and a gas centrifuge plant might be constructed ostensibly for the purpose of producing very slightly enriched uranium for power purposes or very small amounts of highly enriched uranium for research and test reactors. If the military production program is carried out covertly a gaseous centrifuge plant might be more easily hidden than a reactor complex, simply because of the smaller size, the lack of associated radioactivity, and the possibility of breaking up the facility into sub units.

19. In analysis of the final weapons fabrication and assembly of the produced material, consideration must certainly be given to the radioactivity hazard associated with plutonium and the limited amount of unclassified technology presently available on plutonium metallurgy. Further, it might be simpler to fabricate the uranium weapon since a gun barrel approach might be utilized, in contrast to the implosion techniques required for plutonium. On the other hand, plutonium has the advantage of requiring substantially less material for a given fission weapon size, as presently reflected in the ground rules of the study,

equating 10 kilograms of plutonium and 50 kilograms of uranium. Another factor that needs be considered in this light, is that if it is desired to maximize the weapons effect of the special nuclear material on hand, the thermonuclear weapons route may be chosen. In this instance, Uranium-235 would be necessary since the utilization of plutonium would require an extremely advanced degree of weapons technology. In an over all sense, though it would seem reasonable to conclude that, if a nation possessed either plutonium or Uranium-235, a weapon could be constructed, although the Uranium-235 would seem to be favored in terms of simplicity of weapons design and construction, together with a maximum potential of weapon yields.

CONCLUSIONS

20. In summary, then, of the factors influencing a nation in a choice of the two methods it can be seen that in terms of cost, electrical power requirements and time there is probably little to be gained by either method. The reactor route has in its favor proven operability and readily available technological data. On the other hand, the gas centrifuge plant is attractive because it needs smaller manpower requirements and a somewhat lesser degree of specialization in the manpower required for construction and operation; requires more readily available materials, equipment, and components; and requires a lower inventory of uranium. The reactor route has to its disadvantage the fact that the equipment, component, and materials required are at least in part specialized, and if a nation is dependent upon import of such items safeguards would normally be attached. In a similar manner, the gas centrifuge route suffers from the unproven aspects of this means of isotope separation, although this disadvantage should be removed within the next few years if the projected programs proceed.

21. It might, therefore, be concluded that a nation desiring a military nuclear capability might choose the gas centrifuge method in preference to the reactor route. The method is at present the more attractive of the two for reasons noted above, and if its potential is fully realized, probably the easier route to pursue.

22. It is, therefore, urgent that attention be given at this time to the means of control and safeguards applicable to gas centrifuge utilization by other countries. It appears that the problems involved are not substantially different from those already encountered in connection with efforts to establish similar controls over other types of nuclear production facilities and materials required for their use. An important question is whether any potential Nth country could manufacture all the equipment and components required to construct and operate a gas centrifuge complex. It appears that this question cannot with assurance be answered in the negative, since countries having highly developed capabilities for the engineering and manufacture of industrial equipment, could proceed with such a plant in the near future. The estimates of the Oak Ridge study groupp (KOA-662) as to the representative nations possessing the potential capability for such a production plant are given in Annex II.

23. Two forms of control may be imposed over gas centrifuges and their related technology. These are security control and safeguards. In a manner similar to that adopted for the gaseous diffusion method of isotope separation, the centrifuge technology and important components of centrifuges utilized in the process may be classified and subjected to rigid security controls. This form of control for gas centrifuges cannot be complete since considerable detailed information on the process has already been divulged

through normal commercial channels by the German and Dutch groups. However, it may potentially be possible with the cooperation of Germany, The Netherlands, and the United Kingdom to restrict, through classification, the dissemination of any further technological advances in the gas centrifuge process.

24. The second form of control that might be exercised over gas centrifuges and their related technology is safeguards. This sort of control would only be applicable to the unclassified exports of gas centrifuges. This system of control should involve agreements among the countries having the present capabilities to manufacture isotope separation centrifuges and their components to export such devices only when committed to peaceful uses and subject to the application of safeguards. Since such centrifuges come within the definition of a production facility in the meaning of the Atomic Energy Act and AEC regulations they would be exported only by the U.S. under an agreement for cooperation. The U.K. and Canada in accordance with their practices concerning other nuclear production facilities could be relied upon to acquire safeguards for the export of centrifuges in similar circumstances. The Federal Republic of Germany does not have the mechanics for controlling the exports of reactors or isotopes separation centrifuges except when these devices might be destined for Soviet bloc countries. There are indications, however, that West Germany would institute export control mechanics and require safeguards, if the U.S. so requested, and there could be achieved a similar agreement by other potential exporters and production devices.

25. While no specific studies have been made of the safeguards techniques which would be required for application to the centrifuge isotope separation plant and complex, it appears that

the problems would not be substantially different from those which would be encountered in a gaseous diffusion complex. The techniques and effort required of this latter type of complex have been the subject of a study. It appears on the basis of this work that effective safeguards could be devised.

26. In addition to direct controls applied to gas centrifuge information and components and devices associated with the gas centrifuge method, controls on natural uranium needed for operation of the plant would also prove important to an effective control system. Controls on natural uranium would not only assist in deterring the utilization of centrifuges as well as other production methods for military purposes, but at present appear to be essential to the application of any meaningful international safeguards.

~~S E C R E T~~

ANNEX I TO APPENDIX "C"

SUMMARY RESULTS - COMPARISON OF COST, TIME SCHEDULE AND MANPOWER REQUIREMENTS; PRODUCTION OF 10 KG PU VIA NATURAL U REACTOR ROUTE VERSUS PRODUCTION OF 50 KG OY VIA GAS CENTRIFUGE ROUTE

Item	10 Kg Pu (and 10 Kg Pu/yr)	50 Kg Oy (and 50 Kg Oy/yr)
Capital Cost ($MM)	38.7	38.8
Operating Cost ($/yr)	7.6	6.7
Time Schedule (Months)		
Design and Construction	44	36
Operation (Reactor or Cascade thru Weap. Feb.)	21	13
Over-all	51	49
Manpower Requirements:		
Design and Construction		
Professional and Scientific	355	68
Skilled	575	179
Other	1940	969
Total	2850	1216
Operations		
Professional and Scientific	55	57
Skilled	309	225
Other	197	155
Total	561	437
Grand Total Manpower*	3411	1653

* Uncorrected for personnel who conceivably could serve sequentially in construction and/or operations, if only one year of production

ANNEX II TO APPENDIX "C"

REPRESENTATIVE NATIONS POTENTIALLY CAPABLE OF UTILIZING THE GAS CENTRIFUGE METHOD

United States

Union Soviet Socialist Republics

United Kingdom

Austria

Belgium

France

Japan

Netherlands

Sweden

Switzerland

West Germany

SECRET

APPENDIX "D"

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON 25, D. C.

February 19, 1960

MEMORANDUM FOR: Mr. Philip J. Farley
Department of State

SUBJECT: CONTROL OF AND COOPERATION IN GAS CENTRIFUGE RESEARCH AND DEVELOPMENT TECHNOLOGY

The attached background paper summarizes the current state of the art both domestically and abroad in the gas centrifuge method of U-235 isotope separation. It notes that as a result of recent developments here and in Germany, the process now shows significant promise of producing U-235 at a cost bracketing the AEC published price schedule. The capital costs, power requirements, and technical skills necessary to build and operate a production scale plant may shortly be within the capabilities of as many as 20 to 30 foreign countries if development meets expectations and the technology remains unclassified. The implications of this on the Nth power problem are obvious. The staff is now preparing recommendations for Commission consideration as to (1) the future scope of our own gas centrifuge program; (2) control of the gas centrifuge process including information in the light of the Nth power problem; and (3) cooperation with the Germans, Dutch, and possibly others in this area.

Because of the complexity and interdependence of the foreign and domestic aspects of this problem, we would appreciate the views of the Department as to the several questions raised in the attached paper.

Members of my staff are, of course, available to discuss this matter in further detail and provide such additional technical background information as may be of assistance to you.

A. A. Wells, Director
Division of International Affairs

~~SECRET~~

ENCLOSURE TO APPENDIX "D"

CONTROL OF AND COOPERATION IN GAS CENTRIFUGE RESEARCH AND DEVELOPMENT TECHNOLOGY

The Commission has for a number of years supported a modest experimental program at the University of Virginia in the separation of U-235 isotopes by the gas centrifuge process. Most of this work has been done on a classified basis and has not been pursued as a matter of priority due principally to the lack of a foreseeable need for expanded United States U-235 production and the relatively high efficiency of our present diffusion plant.

Within Germany a gas centrifuge research and development program has gone forward with groups working at the Universities of Bonn and Kiel, the Max Planck Institute at Aachen, and at DEGUSSA and AEG. All of the German work has been done on an unclassified basis and aimed primarily at developing the process for commercial exploitation. In addition, a Dutch group has been working under the FOM (Society for Fundamental Studies on Matter) at several different sites on a basis which appears to be partially classified. Although the Dutch interest is undoubtedly partly commercial, the possibility of using the process for developing a native U-235 capability for national purposes such as naval propulsion was noted in our recent discussions with the Dutch Naval Group.

Until recently, the state of the art both domestically and abroad did not suggest that the economics of the gas centrifuge process were sufficiently attractive to justify consideration of building a centrifuge plant. As a result of developments in Germany and in the United States, it now appears possible that a gas centrifuge plant could be designed, built, and put into operation within the next five years in the United States that would produce U-235 at a cost roughly equivalent to our published prices. The basis for this assumption is a detailed study that has already been prepared for the Commission by the General Electric Company. It should also be noted that the building of such a plant in Germany is judged by the General Electric study group to be within the capability of the Germans. It does not appear, moreover, that successful conclusion of such a project either in the United States or Germany is dependent upon cooperation since the state of technological advancement is roughly equal in both countries, with the Germans, if anything, enjoying a slight lead.

At the present time, the information which has been published on the German centrifuge effort (the ZG-III model developed by Professor Beyerle of the Aachen Group) if used as the basis of a separations plant, would result, according to our estimates, in the production of U-235 at a cost approximately ten times that of our published price schedule. A refined model of this centrifuge (the ZG-VII) is also unclassified and is currently an article of commerce. (The Commission has issued a license to Thor-Westcliffe to import seven of the ZG-VII centrifuges into the United States. We understand Thor-Westcliffe plans to construct an experimental cascade for purposes of studying the economic potential of the

process.) Complete information, however, has not yet been published on the ZG-VII. According to our estimates, a plant designed around this unit if built could produce U-235 at a cost of two to four times our published price.

The General Electric study referred to above would require a $6 million research and development program to advance present technology to the point where a plant could be built to produce U-235 at a competitive price.

We have reviewed these developments in light of the potential of the gas centrifuge process for contributing to the Nth power problem. Our preliminary conclusion is that this potential is significant and that the process now may, in some circumstances, be equal to or slightly more attractive than the plutonium reactor route. Some of the more significant factors underlying this conclusion as useful to an appreciation of the problem. The hypothetical plant described in the General Electric study would cost from 17 to 24 million dollars, would be capable of producing 500 kgs of U-235 at 95% enrichment annually, and would have a total annual power requirement of approximately one megawatt of electricity. Except for the preparation of feed materials, the skills needed to design and construct such a plant are primarily in the area of mechanical engineering and are available to perhaps some 20-30 countries.

The principal liability of the centrifuge route as against the plutonium reactor route today lies in the fact that centrifuge technology is yet to be proven and the designs of the more advanced centrifuge units have not as yet been published, nor have these units been tested. Because of our concern with the attractiveness of the process to a potential Nth power we are studying what steps might be taken to control centrifuge technology both in this country and abroad. It should be noted that independent of this study, the staff has under consideration a recommended research and development program designed to advance gas centrifuge technology within the United States to a point where it could produce U-235 at a cost competitive with our published price schedule. The principal justification for adopting such a program would be to maintain U.S. leadership in isotope separation technology rather than to fulfill any currently forecast requirement for expanded U.S. production capacity.

In view of the potential of this process for contributing to the Nth power problem, our current intention would be to carry out such a program on a classified basis in order most effectively to safeguard the technology.

Clearly, however, any classification action the Commission might take could be vitiated if the German activities were to proceed on an unclassified basis. It appears to us, therefore, that it is important to determine whether the German Government could and would classify its work in gas centrifuge technology.

We are mindful of several problems in this regard which could make such an action difficult. The German development to date has been undertaken almost exclusively by private parties interested in ultimate commercial exploitation. To the best of our knowledge, the German Atomic Ministry has no classified

programs due in part at least to Germany's commitments under the Brussels Treaties. Any modification of this position could perhaps have serious political repercussions in Germany. It is unclear both from the standpoint of Treaty provisions and policy as to whether Germany could or would take a classification action in this area that would prevent dissemination of the technology to her EURATOM partners, although limitation of the technology to the EURATOM members would obviously constitute a degree of information control substantially greater than a completely unclassified development. The problem as regards the Netherlands is not treated separately here but we would assume that the EURATOM aspects would be similar.

Notwithstanding these problems, we believe that the safeguarding of ultra-centrifuge technology by agreed procedures for the control of this information among the several states in which centrifuge work is being carried out is important and should be explored. It would further appear to us that such exploration should in the first instance be with the German and Dutch Governments.

We believe, moreover, that regardless of whether these governments or EURATOM could control their present and future gas centrifuge information by classification or otherwise agreement should be sought to control the export of gas centrifuges and related equipment and to subject such export to safeguards. It is our impression that agreement on such controls could probably be successfully negotiated, and taken together with the agreed controls we are seeking among uranium supplier nations would mitigate to some extent at least the likelihood of an Nth power exploiting the process.

As a related matter, the Commission staff recognized the technical desirability of cooperating in centrifuge research and development with the Germans and the Dutch. While such cooperation is not essential to achieving the stated objectives of the proposed U.S. developmental program, it is reasonable to assume that it would contribute to the rate and probability of their achievement. In addition it would permit an immediacy of association with the European development which in itself could enhance control. If it proves feasible, therefore, for the Dutch and Germans to establish control over existing and future gas centrifuge information, the possibility of cooperating with those two countries on a classified basis should be examined. We recognize that classified cooperation with the Germans and the Dutch raises certain problems with respect to EURATOM, including the concurrence of the Community in the negotiation of new bilateral instruments and the feasibility of the German and Dutch governments' segregating their work from their EURATOM partners. In this regard the possibility of considering a classified agreement with EURATOM to permit exchange of gas centrifuge information deserves examination as a means for cooperating with the Germans and the Dutch even though we recognize the policy problems that such an Agreement would present to both the Europeans and ourselves.

Finally, if agreement cannot be reached with the Germans and the Dutch to control gas centrifuge information, then there may be serious question as to whether a real purpose would be served in classifying any of our own work. Should we, therefore, as a

result of our inability to secure German and Dutch agreement to control centrifuge information, decide to declassify our own work, it would appear possible to work out an arrangement for unclassified technical exchange with the Germans and Dutch under the ambit of EURATOM if this should prove desirable, and, probably without modification of our existing Agreements for Cooperation either with EURATOM or the member states.

The staff is now preparing recommendations for Commission consideration as to (1) the future scope of our own gas centrifuge program; (2) control of the gas centrifuge process including information in light of the Nth power problem; and (3) cooperation with the Germans, Dutch, and possibly others in this area. Because of the complexity and interdependence of the foreign and domestic aspects of this problem, we would appreciate the views of the Department as to:

a. Whether an approach to the German or Dutch Governments to seek their agreement on classifying or otherwise controlling present and future work is feasible and desirable from an over-all U.S. foreign policy standpoint; and

b. Whether the German Government to your knowledge, could or would, in view of its Treaty and foreign policy commitments, be likely to agree to such an action.

On the basis of your consideration of these questions we would appreciate your views regarding the general desirability of cooperation in this field including your specific comments as to:

a. Whether, if the German and Dutch Governments could agree to the control of gas centrifuge information it would be desirable from a U.S. foreign policy standpoint to cooperate with them bilaterally on a classified basis in a research and development program; and, if not, whether it would be possible or desirable to seek to do so with EURATOM under a classified agreement.

b. Whether, if it is not possible for the Dutch and Germans to agree to control gas centrifuge information it would be desirable from a foreign policy standpoint to cooperate with the Dutch and Germans either bilaterally or through and with EURATOM.

~~S E C R E T~~

APPENDIX "E"

GENERAL ADVISORY COMMITTEE COMMENTS AND RECOMMENDATIONS

1. The General Advisory Committee at its February 1-3, 1960 meeting was briefed on the gas centrifuge method. Their comments and recommendations as contained in their report, dated February 29, 1960, to Chairman McCone are presented below:

> "Dr. McDaniel of the Division of Research and Dr. Jesse Beams of the Committee described recent developments in the gas centrifuge separation studies, both at the University of Virginia and abroad, particularly in Germany and Holland. Although the Committee has followed this program rather closely during the past few years, through Dr. Beams, it is now felt that it has reached the point where it demands serious and careful consideration. Recent experiments and achievements are not only exciting but promising for the gas centrifuge separation process.
>
> "It is recommended that we co-operate with the United Kingdom, the Netherlands, and West German programs so that we may be fully informed of the progress that is being made in this endeavor. At the same time, we should establish in the United States a substantial program that would lead to the development of a pilot plant. The program should be carried out in co-operation with industry, particularly in those phases that demand engineering skills necessary for the development of the pilot plant. Furthermore, it was suggested that a detailed study of the program and its potentialities might be made by the K-25 group at Oak Ridge."

2. The General Advisory Committee was further briefed by G. E. Garrett and his associates at Oak Ridge at the March 17-19, 1960 meeting. Dr. Garrett presented the Oak Ridge paper studies of the potential possibilities of the centrifuge method for the separation of uranium and other isotopes. Also, he compared the Oak Ridge estimates with those made by the General Electric Company.

3. The General Advisory Committee comments and recommendations on the centrifuge process as expressed at the March 17-19, 1960 meeting are given below:

S E C R E T

"It is believed that the centrifuge method has certain characteristics that may make it attractive especially where small separation plants are required or where power is scarce as is the case in many foreign countries.

"In order to assess these potentialities, we wish to reaffirm our recommendation at the last meeting to the effect that a research and development program be carried on with the view of exploring further the possibilities of the method. Also, we wish to recommend that the following specific programs be undertaken.

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DOE 6.2(a)

b. "This subcritical machine should be operated as a single unit with uranium-hexafluoride until an efficiency of at least 60 per cent of theoretical is obtained.

c. "A small cascade should then be constructed of a sufficient number of these centrifuges to determine the characteristics of their operation in a cascade.

d. "The supercritical centrifuge has greater potential possibilities than the subcritical type, but the art is not as far advanced. In view of this, we recommend that laboratory research be continued on the supercritical centrifuge."

~~S E C R E T~~

APPENDIX "F"

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON 25, D. C.

February 12, 1960

Dear Senator Anderson:

The first phase of a technical and economic evaluation of the gas centrifuge method of isotope separation being performed under contract to the Atomic Energy Commission by the General Electric Company has now been completed. The attached study (GEL 0708) reveals that, following a three year development program including the operation of an experimental cascade, the U. S. could build a gas centrifuge plant which would produce U-235 at a price which might be competitive with the published AEC price schedule. This study was based on the short bowl (subcritical) units and is being continued to factor in the long bowl developments being carried out at the University of Virginia.

The plant described in the General Electric study would cost about 17 million dollars, would be capable of an annual production of about 75,000 Kgs of U-235 at 2% enrichment or about 500 Kgs of U-235 at 95% enrichment. It appears that only about one megawatt of electricity would be required to operate such a plant. Except for the preparation of feed materials, the skills needed to design and construct such a plant are primarily in the area of mechanical engineering and are available to many smaller countries which heretofore have not been considered as being capable of producing weapons materials. Much of the basic information underlying this process has been developed outside the United States and can be considered to be generally available to all countries.

The Commission is currently considering this problem and has begun discussions with the Department of State and Department of Defense on those aspects of the problem of concern to those agencies. We shall, of course, keep you fully informed on this matter.

Sincerely yours,

/s/ John A. McCone

Chairman

Honorable Clinton P. Anderson
Chairman, Joint Committee on
Atomic Energy
Congress of the United States

~~SECRET~~

APPENDIX "G"

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON 25, D. C.

December 7, 1959

TO : A. A. Wells, Director
Division of International Affairs

FROM : C. L. Marshall, Director
Division of Classification

SUBJECT: COOPERATION IN THE FIELD OF GAS CENTRIFUGE

SYMBOL : C:CLM

As you know, a topic of the new AEC Policy Guide provides that experimental work on the detailed mechanical design for the centrifuge method of isotope separation may be considered declassifiable to date. There is, however, a restrictive paragraph attached to the topic which requires that we classify that work when it becomes apparent that it could reasonably be used for the production of large quantities of U-235.

One of the factors that influenced the determination to classify this program in this way was the fact that at least two other countries (West Germany and The Netherlands) are vigorously pursuing studies in this field and that they have, moreover, advanced their technology to the point where it is equal to or better than ours.

In considering the proper classifications to be assigned to this program, not only now but in the foreseeable future, a number of facts inevitably made themselves felt. Important among them is the fact that the Germans have now already so far progressed in their development of the gas centrifuge method that they could, without any further advancement in their technology, build a working plant for the mass production of U-235. The attached table, which represents steps in the development of their program, indicates very clearly that in a period of approximately 14 years they have been able to increase the separative potential of their machines by better than an order of magnitude, while at the same time reducing their costs also by more than an order of magnitude.

Another of the important aspects of this method of separating isotopes is its very low power consumption, as compared with the gaseous diffusion method. One might say that for an approximately equal total outlay in dollars (that is, power plus plant), one could build equally productive plants. However, to a nation short on power, the low power-consumption for the gas centrifuge method could make possible a productive plant at a time when a gaseous diffusion plant would still remain a desirable but impossible goal.

~~S E C R E T~~

We all, I know, realize that a large-scale plant for the separation of heavy isotopes is an important part of a weapons program. Therefore, a method of separating isotopes, which would make such a program possible for an unfriendly nation, is clearly one which should be classified.

The presence of China among the nations inimical to the United States gives that view both point and substance. This re-awakening nation of several hundreds of millions of people is already significantly increasing its industrial potential, with the help of the Soviet Union. It should be expected that as soon as possible China will attempt to embark upon a weapons program that, significantly, may be without Soviet help. When one considers that the Chinese built an advanced civilization many years before our so-called Western civilization existed, the probability of their succeeding in such a venture must not be under-estimated. China is, however, still power-poor and probably will be for some time to come. The gaseous diffusion process for separating heavy isotopes is not, therefore, within their grasp for many years to come. The gas centrifuge method, however, with its low power consumption, is not nearly that far in the future, if one remembers, as I pointed out earlier, that present technology would already permit the construction of a working plant. It is not impossible, therefore, that in a relatively short time China could, unless steps are taken to prevent it, purchase on the open market a producing isotope-separation plant for heavy isotopes.

In imposing classification on information and material in the field of the centrifuge separation process, it is not sufficient to think only in terms of U. S. work since, as I have said before, both Germany and the Netherlands are known to equal or excel our own state of the art in this field. In order to insure that such nations as China would not be allowed to accelerate their weapons programs by the use of this isotope separation method, it would be necessary also to prevent them from obtaining the information or the material from other knowledgeable nations.

I therefore recommend that immediate consideration be given to amending the classified bi-laterals with West Germany and the Netherlands to include full cooperation in this field with both nations on a classified basis. Because, I am sure, full cooperation with both these countries will depend, at least in part, on economic considerations which might involve the purchase of the fruits of German and Dutch labor, and because of other powerful considerations involving our relations with the British, of which I am sure you are well aware, I would also strongly recommend that the bi-lateral existing with the United Kingdom (and possibly that with Canada in the future) also be amended to permit the same full cooperation. This would not only help to maintain our friendly relations with the U. K. and increase substantially the potential market for Dutch and German products, but, by helping to obtain the cooperation of the West Germans and the Dutch, would enhance the security of the nation by denying to unfriendly nations, such as China, information and materials which would enable or assist them to establish a nuclear weapon program.

Enclosure:
Table, as stated

ENCLOSURE TO APPENDIX "G"

	Year Circa	Length cm	Radius cm	L/R	Peripheral Speed m/sec	Separative Potential Kg U/yr	Specific Power Cost Kwh/Kg U	Specific Investment DM*/Kg U/yr
UZ 1	1946	40	6.0	3.33	302	0.582	12,050	17,200
UZ 3B		63.5	6.7	4.74	302	0.935	8,380	11,950
ZG 3		66.5	9.25	3.60	302	0.97	6,300	10,300
ZG 5		113.0	9.25	7.03	302	1.64	3,710	6,100
ZG 6		240.0	20.0	6.0	302	3.5	1,750	2,860
					340	5.32	1,150	1,880
ZG 7	1960	316.0	22.5	7.03	302	4.77	1,285	2,100
					340	7.25	845	1,380
Gaseous Diffusion							9,000	2,350

* German marks

Enclosure to Appendix "G"