Appendix

A

Document transcriptions: The liquid thermal diffusion uranium isotope separation method.

Contents

1940, September 9	Letter of George B. Kistiakowsky to Lyman Briggs, Director, U. S. Bureau of Standards.
1942, July 27	"Extract from report of Dr. H. C. Urey dated July 27, 1942."
1942, December 12	Letter from W. [Warren] K. Lewis, Massachusetts Institution of Technology; National Defense Research Committee of the Office of Scientific Research and Development; member of the Uranium Committee of S-1, to J. B. Conant, Chairman, National Defense Research Committee.
1942, December 14	Letter of James Conant to W. K. Lewis.
1942, December 31	Letter of Vannevar Bush to Rear Admiral William R. Purnell.

1943, January 15	Letter of H. T. Wensel, Technical Aide, National Defense Research Committee, to Rear Admiral W. R. Purnell.
1943, January 19	Letter of James Conant to Lyman Briggs, Director, National Bureau of Standards.
1943, January 23 (1)	Letter of Special Subcommittee of the S-1 Executive Committee: Lyman J. Briggs, Chairman; E. V. Murphree; Harold G. Urey.
1943, January 23 (2)	Letter of Special Subcommittee of the S-1 Executive Committee, Lyman J. Briggs, Chairman E. V. Murphree; Harold C. Urey.
1943, January 25	Letter of E. V. Murphree, Standard Oil Development Co., New York, NY, to Lyman Briggs.
1943, January 28	Letter of Harold C. Urey, Columbia University, to Lyman Briggs.
1943, January 30	Letter of Lyman Briggs, U.S. Department of Commerce, National Bureau of Standards; Chairman, Special Sub-committee to James Conant. Subject: Liquid Thermal Diffusion Plant.
1943, February 13	Memorandum for Admiral Purnell from Vannevar Bush.
1943, February 19,	“Program for experiments to be carried out on the thermal diffusion method,” E. V. Murphree and H. C. Urey.
1943, February 23	Letter of Lyman Briggs to James Conant, including:
1943, February 24	Letter of James Conant to General Groves.

1943, May 11	Letter of James Conant to Rear Admiral William R. Purnell.
1943, June 19	Letter of Lyman Briggs to Colonel T. C. Crenshaw, Manhattan District Office, Corps of Engineers, New York, NY.
1943, July 10	Letter of General L. R. Groves to James Conant.
1943, July 10	Letter of James Conant to Rear Admiral William R. Purnell.
1943, July 30	Letter of James Conant to Rear Admiral William R. Purnell.
1943, September 3	Memorandum from Chief of the Bureau of Ships, signed by H. A. Ingram by direction of Chief of Bureau, to Commander in Chief, U.S. Fleet. (Attention Rear Adm. W. R. Purnell).
1943, September 9	Letter of Ruth E. Jenkins [secretary to James Conant] to Harold Urey, Columbia University.
1943, September 15	Letter of James Conant to Rear Admiral W. R. Purnell.
1944, March 4	"Paraphrase of teletype" of J. R. Oppenheimer to James Conant.
1944, March 4	Letter of James Conant to Rear Admiral William R. Purnell.
1944, March 8	Letter ["Dictated—not read–not signed"] of General Groves to James Conant.
1944, March 17	Letter of Rear Admiral W. R. Purnell, Navy Department, Office of the Chief of Naval Operations, to James Conant.

1944, March 20	Letter of Ruth E. Jenkins to Dr. J. R. Oppenheimer, Box 1663, Santa Fe, New Mexico.
1944, April 20	Letter of James Conant to Lyman Briggs.
1944, May 6	Manuscript note of James Conant to Vannevar Bush.
1944, June 3	Letter of General Groves, War Department, Office of the Chief of Engineers, Washington, to James Conant.
1944, June 3	Memorandum of Mssrs. W. K. Lewis, E. V. Murphree and R. C. Tolman to Major General L. R. Groves. Subject: "Possible Utilization of Navy Pilot Thermal Diffusion Plant."
1944, July 25	Memorandum of Chief of the Bureau of Ships [Vice Admiral Edward L. Cochrane] to Rear Admiral W. R. Purnell, U.S.N. (Op-05).
1944, July 27	Manuscript of James Conant, "Historical note on introduction of the Abelson-Gunn process."
1944, September 15	Letter of James Conant to Lyman Briggs.
1944, September 21	Letter of Lyman Briggs to James Conant.

Document transcriptions

1940, September 9
Letter of George B. Kistiakowsky to Lyman Briggs, Director, U. S. Bureau of Standards.

"Dr. R. Clark Jones, the co-author with Furry and Onsager of the theory of thermal diffusion which has proved itself very well in the past, has discussed the advisability of further theoretical work in connection with the Uranium isotope separation work with E. H. Land of the Polaroid Corporation by who he is temporarily employed. Mr. Land telephoned Dr. Vannevar Bush and the letter suggested that Jones talk the matter over with me. This letter is a result of our conversation.

“It appears that Jones and Furry and developed general expressions which cover the case of concentric cylinders as well as a wire inside a cylinder and that when numerical solutions become available, it will be possible to calculate theoretically the best type of apparatus (including cascade systems) for each particular problem and to know in advance the rate of establishment of equilibrium and the concentration factor to be expected. Jones and Furry, however, have not been able to obtain algebraic solutions notwithstanding extended work and Jones proposes now to use the Bush differential analyser of M.I.T. for this purpose. Professor P. M. Morse of M.I.T. has promised the machine for two months if technical help can be found to run it during this time. The necessary help means an expenditure of $600. to $1000. and Mr. Jones asked me to find out whether the necessary funds could not be made available from defense appropriations.

“Although I am personally somewhat skeptical about the ultimate usefulness of the thermal diffusion method in separating Uranium isotopes, I am quite convinced that we should have complete information on the possibilities of the method and that [the] calculations in question would be of great utility in this connection. Therefore, I want to urge a grant of $1000. for the hiring of men needed to run the differential analyser machine.

“If you believe that the matter should be handled confidentially, may I suggest that the contract for the work be given to Professor E. B. Wilson, Jr. of Harvard who has been appointed a consultant of the National Defense Research Committee, who is willing to oversee the work and who is well qualified to do so in virtue of his theoretical training.

“Another matter which I should like to mention is the question of withholding from publication an article by Furry and Jones on the thermal diffusion which has been sent to Reviews of Modern Physics and which contains enough new information to be of considerable interest.”

1942, July 27
"Extract from report of Dr. H. C. Urey dated July 27, 1942." SECRET. [The complete text of this July 28, 1942 report in reference has not been located.]

"I understand that the Naval Research Laboratory is having some success in separating the uranium isotopes. From remarks that Dr. Gunn made some time ago, they are probably using the electrolytic mobility method in fused salts. Dr. Nier tells me they are securing 10% changes in the ratio of the isotopes with 25 gram samples, or thereabouts. This work has not been correlated with the other work of the Committee [the Uranium Committee of S-1], for reasons that I do not understand, but efforts should be made by Dr. Conant, or Dr. Bush, probably, to be sure that the work of that laboratory ties in with the general purpose of this committee.

"Since giving me the above information, Dr. Nier has been requested by the Naval Research Laboratory, not to transmit information of this kind to the Columbia people [i.e., Harold Urey]. He will respect this request in the future. However, this information has come to me, and I feel that I am duty bound to pass it on to the committee."

1942, December 12

Letter from W. [Warren] K. Lewis, Massachusetts Institution of Technology; National Defense Research Committee of the Office of Scientific Research and Development; member of the Uranium Committee of S-1, to J. B. Conant, Chairman, National Defense Research Committee. CONFIDENTIAL.

"With reference to the trip made by our committee to the Naval Research Laboratory yesterday, it is unfortunate that the work is in such an early stage of development and particularly that the Laboratory has not been able so far to envisage at all definitely its ultimate potentialities. On the way home last night I finally got the picture sufficiently clarified in my own mind so that I was able to make an estimate of the number of stages required for a product of high purity. The figure was only eighty of the present units in series. While the estimate is highly tentative, it is certainly of such interest that the development work ought to be continued intensively.

"During the conversation the workers expressed their desire for the help of suitable experts, particularly physicists, in consultation. I suggested that I would do anything I could to make such men available through the NRDC. If they write to you along this line, you will understand the background of the request. On thinking the matter over, I feel sure that men like Sherwood and Hottel of this Department or Chilton of DuPont are even more likely to be of help than a physicist. They have worked in fields which I am sure are parallel.

"If I can help the Laboratory in any way in consultation on the matter (and I think I can) it would be a delight to try to do so."

1942, December 14
Letter of James Conant to W. K. Lewis.

"Thank you very much for writing to me about the Naval Research Laboratory. I appreciate your suggestions and your willingness to help. I will see if anything can be done along these lines."

1942, December 31
Letter of Vannevar Bush to Rear Admiral William R. Purnell. SECRET. [The Atomic Bomb Military Policy Committee was established 23 September 1942; Vannevar Bush was appointed chairman of the committee; Adm. Purnell was appointed to represent the Navy.]

"The Executive Committee on S-1 at its last meeting entered the following statement in their minutes: 'The Committee expresses the hope that the work of the Naval Research Laboratory can be expedited so that a comparison can be made with other processes and that, to further the end, the S-1 Executive Committee will do all it can to help.'

"When we recently listened to the members of the Reviewing Committee they expressed the feeling that the Naval Research Laboratory needed further facilities and manpower on this particular aspect of the problem in order to carry out a very difficult piece of experimentation. The also felt that it would be well to have the experiments carefully repeated.

"I would feel much gratified if you found it possible in some way to aid the Naval Research Laboratory to proceed on this matter to better advantage. While our Reviewing Committee at the present time did not recommend any extensive work along these lines, I feel that no possibility should be overlooked, and it also appears that while the method being studied at the Naval Research Laboratory has certain disabilities, it also has certain advantages, and the whole possibilities of that particular approach ought to be rendered more clear and again evaluated.

"My Office, of course, will be glad to aid in this in any way possible. Dr. Briggs has already undertaken to assure than any information that we have that can be of service to NRL in connection with their research program along these lines is made available to them. There may be other ways in which we could assist as, for example, by aiding in seeking for appropriate additional personnel. I take this up directly with you, however, rather than with Admiral Van Keuren,* as it is a matter concerned with this special secret program."

[* Rear Admiral Alexander H. Van Keuren, until 2 November 1942, Chief of the Bureau of Ships; succeeded by Vice Admiral Edward L. Cochrane. However, as late as 31 May 1944 Admiral Van Keuren, a naval architect, was still involved in the development of the liquid thermal diffusion method. See the document below: 1944, June 3. Memorandum of Mssrs. W. K. Lewis, E. V. Murphree and R. C. Tolman to Major General L. R. Groves, paragraph 5.]

1943, January 15
Letter of H. T. Wensel, Technical Aide, National Defense Research Committee, to Rear Admiral W. R. Purnell.

“Dr. Conant has asked me to inform you that the two reports, which the Naval Research Laboratory has sent to him for transmittal to you, are being held for approximately ten days to permit their study by a subcommittee especially appointed by Dr. Conant for this purpose.

“This subcommittee has been instructed to submit a report not later than January 25th based on their studies of these reports and of other data in regard to the Naval Research Laboratory project. Dr. Conant felt that you would prefer to have a definite recommendation from such a subcommittee, along with the report, even though this will delay the transmission to you for the time indicated.

“In the event that this procedure does not meet with your full approval, I trust you will so notify us. The time indicated above was as short a time as possible, in the opinion of the members of the subcommittee, which would be required for a study of the report[s] adequate to permit a definite recommendation to be formulated.”

1943, January 19
Letter of James Conant to Lyman Briggs, Director, National Bureau of Standards.

“Dr. Bush has expressed the hope that you and the members of your subcommittee (Murphree and Urey) will make an actual visit to the Naval Research Laboratory and discuss with the people there the work that they are doing. He feels this will be important both from the point of view of your obtaining all the information and in order to improve the relations between the S-1 Committee and the Navy. I concur in his views.”

1943, January 23 (1)
Letter of Special Subcommittee of the S-1 Executive Committee: Lyman J. Briggs, Chairman; E. V. Murphree; Harold G. Urey. SECRET.

"At the last meeting of the S-1 Executive Committee, on January 14, the undersigned were appointed as a Subcommittee to review reports prepared by the Naval Research Laboratory, covering work they have carried out on separation of the uranium isotopes by liquid thermal diffusion. The Naval Research Laboratory reports are Nos. 0-1977 and 0-1981 and are dated January 4 and January 7, respectively. The Subcommittee has been assisted in its investigation by Dr. Karl Cohen and Dr. W. I. Thompson. Discussion of the reports and of the work at the Naval Research Laboratory has been held with members of the Naval Research Laboratory staff. The thermal diffusion pilot plant at the Naval Research Laboratory has been visited by the Subcommittee and Doctors Cohen and Thompson.

"The Naval Research Laboratory has made excellent progress in the separation of the isotopes by liquid thermal diffusion and they are to be congratulated on their work. In the process used, the uranium is in the form of uranium hexafluoride. The diffusion column consists of an inside nickel tube, jacketed by a copper pipe, which is in turn jacketed by a steel pipe. The uranium hexafluoride is charged to the annular space about 0.25 mm clearance between the nickel and copper pipes and held under a higher pressure than that of the vapor pressure of the uranium hexafluoride at the hot surface. Steam at the pressure required to give the working temperature desired is used as the heating medium inside the nickel tube. The outside of the copper pipe is cooled by water. With this combination, there is a rapid flow of heat from the nickel tube to the copper tube, resulting in a rapid diffusion of the uranium hexafluoride. The columns used in the Naval Research Laboratory are about 36 feet long. With this equipment and with a steam temperature of about 238°C on the inside of the nickel tube and with cooling water temperature of about 65°C, under total reflux conditions, equilibrium values have been obtained indicating an enrichment of the light uranium isotope of as high as 31% at the top of the diffusion column and impoverishment of the light uranium isotope as high as 28% at the bottom of the tube. These are not actual experimental results, but represent an extrapolation of such results.

“Last September, some earlier results of the Naval Research Laboratory were reviewed by the S-1 Committee. In obtaining these earlier results, somewhat lower temperature was used at the hot surface and the enrichment obtained was not as high as shown by the more recent work.

“In all the work to date of the Naval Research Laboratory, no appreciable amount of material has been withdrawn, either from the top or the bottom of the diffusion apparatus, so results are not available under steady production conditions, such as would exist in any cascade built up with thermal diffusion units. The Naval Research Laboratory has, however, measured the change in concentration at the top and bottom of the thermal diffusion apparatus as a function of time. From this work, it is possible to make an estimate of what would occur under steady production conditions and hence to make estimates as to the size of the cascade required and time required to reach equilibrium. The method of making these calculations is outlined in a memorandum dated January 22, attached to this letter. In this memorandum, the methods of calculation were worked out by Doctors Cohen and Thompson. Dr. Urey has made independent calculations, using a simplified method and obtained results closely approximating those of the memorandum.

“The results of calculations made on certain experiments carried out by the Naval Research Laboratory are given in table one, attached to this letter. [Note: table one (Table I) is reproduced below the Appendix text]. Three cases are considered. The first column is based on the early results obtained at the Naval Research Laboratory, which were given to the S-1 Committee last September [1942]. The second column is based on an extrapolation of actual experimental results obtained recently at the Naval Research Laboratory. The third column is based on a different extrapolation of the recent experimental results. It will be noted from the table that in the enriching section of the plant, with the newer results, about 20,000 36-foot diffusion columns will be required.

Diffusion columns of greater length than 36 feet may be used with a corresponding reduction in the number of columns. This compares with around 38,000 for the earlier results. The newer results indicate an equilibrium time of about 600 days, compared with somewhat over 800 days for the earlier results. It should be realized that the figures given here represent a considerable extrapolation of the actual experimental data. As pointed out above, the actual experimental data obtained was on a column operating under total reflux with no appreciable product withdrawal, whereas, in the calculation, columns producing product continuously are pictured. Further, in the recent data the number of experimental determinations of the composition at the top and bottom of the column as a function of time are very limited. Moreover, in the experimental work, a reservoir of normal uranium hexafluoride was connected at all times to the bottom of the column in such a way that circulation to the bottom of the column may have occurred. This leads to results difficult to interpret. For these various reasons, the calculations given in table one should be considered very approximate. The equilibrium time calculated in the table one is quite optimistic, since no allowance was made for hold-up of material in the expansion joints which will be required, and, furthermore, no allowance was made for any hold-up of material in connecting piping. In a commercial plant, corrections for these items may lead to an increase in equilibrium time of approximately 25%.

"Table one gives estimated figures of steam requirements, cooling water, and electric power. The estimated requirements of electric power may be somewhat high. Estimates of the quantities of copper and nickel required are also given in table one. For the quantity of steam involved in column two, which is estimated at 12,00,000 pounds per hour, an investment in steam production facilities of $30,000,000 is indicated. Based on figures given in Naval Research Laboratory report 0-1977, the cost of the thermal diffusion tubes proper would be around $12,000,000. Considerable additional expenditure would be required for steam and water piping, structural steel, buildings, and the like. A very rough guess at the cost of the complete plant to produce one kilogram per day of U235 at 90% purity, would be $75,000,000. This puts the estimated cost in the same region as other separation projects.

"The high equilibrium time indicated in table one represents a drawback to the project. It has been estimated that if the U235 were produced in 10% concentration, the equilibrium time would be considerably reduced, possibly to about one-third or less that given in table one. In this case, other processes would be required to bring the concentration to the desired 90% strength.

"It is felt that the Naval Research Laboratory has developed a simple and positive means of separating the uranium isotope and this method, at least qualitatively, has been well demonstrated. There would appear to be no major mechanical problems to be solved. The thermal diffusion process as developed has the very great advantage of mechanical simplicity. The system is completely closed without stuffing boxes and moving valves and should have no contamination of the product. It is felt that the process may be appreciably improved by future developmental work. For example, the results given in report 0-1981 show a decrease in equilibrium time to about 50%, due to raising the hot wall temperature of the diffusion tube from 213EC to 238EC. This change in equilibrium time is, of course, reflected in a decrease in the size of the plant. The Naval Research Laboratory feels that by the use of still higher temperatures on the hot side of the diffusion tube, even more favorable results will be obtained.

"The future development work was discussed with the Naval Research staff. At present it is planned to obtain experimental data with steady product withdrawal, under conditions so far found to be optimum. This will probably involve the use of two 24 foot diffusion tubes, one to be operating as a stripping section and the other as an enriching section. Further, the Naval Research Laboratory plans to explore the advantages to be gained by using a higher hot wall temperature. It is planned to do this first by the use of higher pressure steam and next by the use of Dowtherm [a Dow Chemical Co. biphenyl/diphenyl oxide blend eutectic heat transfer fluid applicable to either liquid phase or vapor phase heating] as a heating medium. It has been suggested that, in the single tube diffusion experiments, with no product withdrawal, a reservoir with circulation to the bottom of the tube be installed so that the experimental results may be more easily interpreted. The Naval

Research Laboratory has estimated that the experimental work outlined may be completed within two months.

"The time required to construct a one kilogram per day liquid thermal diffusion plant will depend on the degree of priority the project would have. Taking the estimated cost of $75,000,000, it would appear that some eighteen months may be required for the erection of the plant, although this could be reduced by better priorities on materials. The eighteen months period should be considered as starting April 1, of this year, at which time it is hoped that sufficient experimental data may be available for plant design. The figure given in column two of table one, for equilibrium time is approximately 600 days, or twenty months. Rounding off the construction and equilibrium period to a total of three years would give April 1946 as the time the plant would started delivering product. It is felt very likely that further development work at the Naval Research Laboratory will lead to an appreciable reduction in the plant size, which would give a corresponding reduction in equilibrium time and should also result in a decrease in construction time. It should be realized that the figure of approximately 600 days, given in Figure [table] I, represents an optimistic interpretation of the actual experimental data.

"The Subcommittee feels that large-scale application of the thermal diffusion process, as developed by the Naval Research Laboratory, will be accelerated by having some large commercial concern work with the Naval Research Laboratory from the standpoint of carrying out preliminary engineering studies which later could be readily expanded to engineering work on actual plant design. Similar arrangements have been made in the past in connection with other projects of this general type."

1943, January 23 (2)
Letter of Special Subcommittee of the S-1 Executive Committee, Lyman J. Briggs, Chairman E. V. Murphree; Harold C. Urey. SECRET.

“In addition to the technical discussion of the liquid thermal diffusion project at the Naval Research Laboratory by the Subcommittee of Section S-1, this Committee believes that it would be well to bring to your attention possible developments on this method that may have taken place in Germany.

“The thermal diffusion method was discovered by Clusius and Dickel, who first applied it to gaseous diffusion. Wirtz and his co-workers have discussed thermal diffusion of electrolytes in water solutions and the separation of carbon tetrachloride and hexane by thermal diffusion. In the Annalen der Physique, Vol. 36, 1939 Debye and Wirtz discussed the theory of thermal diffusion in liquids. Wirtz ends his article with the remark, ‘There is at present too little material for a comparison of these results with experiment. In this Institute corresponding experiments are in progress.’ This is dated July 30, 1939. In the Zeitschrift für Elektrochemie, Vol. 45, 1939 Wirtz and Korsching describe experiments showing the separation of carbon tetrachloride and hexane. Also, in the Zeitschrift für Angewante Chemie, Vol. 52, p. 499, 1939 the same authors mention the separation of the hydrogen isotopes to a slight extent when the method is applied to pure water. The effect on the hydrogen isotopes is small, and may have led them to believe that the method could not be applied to the uranium isotopes.

“As stated above, this method is the discovery of this group of German scientists, and it would seem to us most probable that they would apply it to our problem. In 1939 they had had experience on the thermal diffusion of electrolytes in water solutions, and they would not be obliged to do further experiments, as Dr. Abelson was, to become acquainted with the method.

“This Committee can only estimate a possible time schedule for the German development along these lines. We will assume that they started immediately after the War started, that within 16 months, namely, by the end of 1940, they had arrived at a place where the plant could be constructed. This is somewhat better than our schedule, but we are being somewhat optimistic because of their great experience with the method in general. Assuming that it would require 36 months to built the plant and bring it to equilibrium, namely, the same assumption we are making, from April first for our own possible development, this plant would come to production by January 1, 1944.

"We must allow some months for the production of material and hence this might become an effective weapon during the first half of 1944.

"This Committee believes that it may be possible to improve the diffusion process so that the time to come to equilibrium might be reduced to one year in place of 18 months, assumed before. At the same time it is felt that with very high priorities on materials it might be possible to construct the plant within one year. On this basis the total period for erecting the plant and coming to equilibrium would be two years, which would mean that production might start January 1, 1943. Therefore, it seems possible that this material might become an effective weapon in their hands during the first half of 1943.

"Recommendations

"The Committee recommends that active steps be taken immediately to discover plants in Germany which may be designed and used for this purpose. In the first place, this method could be modified to make multiple plants possible; thus it may be necessary to look for a number of smaller plants rather than one large one. The plant or plants would be placed in a coal mining region where some five or ten thousand tons of coal a day would be available. Some 30,000 kilowatts of electrical power would be required for the total of all the units. These plants must be placed either on a river to furnish the necessary cooling water or else they will have water cooling towers. The plants will undoubtedly be heavily camouflaged and might conceivably be built into the side of a hill. The construction would hardly have been begun before January 1, 1941, but of course they might have been begun at any time after that. The plants will contain a large number of steam generation units and hence many smoke stacks.

"The thermal diffusion units may be housed in buildings, in which case they will be large and tall, perhaps 50 to 100 feet high. On the other hand, if the thermal diffusion units are placed outside, they may present the appearance of many rows of vertical pipes housed at the top and bottom. I. G. Farbenindustrie would be a reasonable company to undertake this work. Elaborate precautions to prevent bombing will be taken because the long time to come to equilibrium would make interruption by bombing especially disastrous.

"This Committee would be glad to study photographs of any plants which are being built in Germany."

1943, January 25
Letter of E. V. Murphree, Standard Oil Development Co., New York, NY, to Lyman Briggs. SECRET.

"On further considering the work of the Naval Research Laboratory, I am wondering if our report stressed strongly enough the possibility of using the Naval Research Laboratory process as an alternative to the [gaseous] diffusion process, at least for the lower part of the separation plant.

"In the lower part of a separation plant, the length of time for the thermal diffusion process is by no means as serious as for the upper part of the plant. Dr. Urey brought out this point in our discussion Saturday and the point was mentioned in our report. On thinking the matter over further, it seemed to me that the enrichment in the thermal diffusion process was about as well demonstrated as for the [gaseous] diffusion screen process and that the thermal diffusion process has considerable less unsolved mechanical problems. There is a lack of sufficient experimental data on the thermal diffusion process and this lack is more serious than in the screen diffusion process because the theory of the thermal diffusion process has not been as well established. The thermal diffusion process suffers from the further disadvantage that no adequate engineering survey has been made to determine what the approximate cost and materials required for the plant would be.

"Considering the basic simplicity of the thermal diffusion process and the demonstration that has been made at the Naval Research Laboratory of its operability, it is my recommendation that consideration should be given to it as an alternate to the diffusion screen operation for the bottom of the plant. To bring this question to a head, it will be necessary first to obtain further experimental information, particularly on a continuous flow operation. Such work was discussed with the Naval Research Laboratory people and it was our understanding that they would do it. I do feel that every effort should be made to see that this work is done promptly. In our discussion with the Naval Research Laboratory people, it was further understood that the possibility of higher hot wall temperature would be investigated to see if the process could be improved. This is also quite urgent and must be done promptly.

“I don’t feel that we really have any adequate picture of the equipment required for a thermal diffusion process. The rough figures that we made Saturday probably are not of too great significance. Some engineering group should immediately undertake a study of the process, using as a basis a somewhat optimistic interpretation of present results. This would give then a rough comparison of the cost and materials requirement of the thermal diffusion process as compared with the screen diffusion process. With this information and the experimental information mentioned above, it should be possible to decide whether the thermal diffusion process should be used as the lower part of a separation plant. I believe if prompt action is taken it may be possible to reach a conclusion on this within two or three months and possibly sooner.”

1943, January 28
Letter of Harold C. Urey, Columbia University, to Lyman Briggs. SECRET.

“I am in complete agreement with the letter of Mr. Murphree to you as of January 25, 1943. I had felt that the report brought out a usefulness of the thermal diffusion method in the lower part of any plant that we might consider. The time to come to equilibrium may prove to be too long for the use of this method for the whole process, but still it may be possible to use the process for the lower part of the plant. The method seems to be remarkably free from many of the troubles that we experience in the other methods.

"I should like to emphasize what Mr. Murphree says in his last paragraph. I certainly do not think that we have an adequate picture of the equipment required for the thermal diffusion plant, nor of the possible troubles that we may have. I believe that some chemical firm should be given the job of studying this with the Naval Research Laboratory. The results of their study would be very interesting indeed.

"I have been unable to get Thompson today, and hence can tell you no more than I knew the other day. I will try again tomorrow and if the situation is any different from what it was I will telephone you. The report which I received through Dr. Cohen was that the equilibrium time for the plant should be 850 days instead of 600."

1943, January 30
Letter of Lyman Briggs, U.S. Department of Commerce, National Bureau of Standards; Chairman, Special Sub-committee to James Conant. Subject: Liquid Thermal Diffusion Plant. SECRET.

"The following report supplements and summarizes the one made to you under date of January 23, 1943 by the special sub-committee appointed to consider the above subject.

"(1) We recommend that immediate consideration be given to the liquid thermal diffusion process as an alternate to the diffusion screen operation, particularly for use in the bottom part of the plant. This recommendation is made because of the basic simplicity of the thermal diffusion process. By this procedure, the material is processed in a sealed system, thus avoiding contamination. No pumps to move the process material or valves with moving parts in the sealed system are necessary. Flow can be stopped when necessary by freezing the material in a pipe. The operation of individual columns has been satisfactorily carried out at the Naval Research Laboratory. That enrichment can be obtained by the thermal diffusion process has been demonstrated about as conclusively as for the diffusion screen process. The unsolved mechanical problems of the liquid thermal diffusion process are considerably less than those of the diffusion screen process. The time required to reach working equilibrium becomes much less serious when the thermal diffusion process is used only in the lower stages of the plant.

"(2) We recommend that further experimental data on the thermal diffusion process be obtained by the Naval Research Laboratory with all possible speed. This information is urgently needed because the theory of the thermal diffusion process is not as well established as that of the screen diffusion process. It is particularly important to obtain further experimental information on continuous flow operation. Higher hot-wall temperatures should also be investigated to see if this improves the process. An effort should be made to reduce the hold-up in the ends of the columns and in the communicating pipes between the columns. All of these points have been considered by the staff of the Naval Research Laboratory and work on some of them is already underway. Further information on these subjects is urgently needed as the final design is dependent upon it.

"(3) We recommend that some competent engineering group should be employed at once to undertake a study of the process, with particular reference to its use in the bottom part of the plant. This would provide a basis for making a better comparison of the thermal diffusion process and the screen diffusion process as regards cost and materials required. We consider this an urgent matter. It will help to speed up the program.

"Letters from Dr. Murphree and Dr. Urey relating to this supplemental report are enclosed.

[Manuscript notations at the bottom of this letter read: 1. "Letter to L. J. Briggs from Urey dated Jan 28, and letter to L. J. Briggs from Murphree dated Jan 25 confirmed by conversation with Miss Kingsbury by phone to have been correct attachments. R. J." (Ruth Jenkins, Conant's secretary) 2. "Gen. Groves has copy of this letter. Confirmed by phone conversation with Mrs. O'Leary (Gen. Groves' secretary) 4/28/44. R. J."]

1943, February 13
Memorandum for Admiral Purnell from Vannevar Bush.
SECRET.

"Conant and I looked over the attached. There are a large number of incomplete or incorrect statements, but I do not believe that it is necessary for us to point these out since you have access to the whole matter. We have, as you know, urged that the Naval Research Laboratory be given support in its experimental program.

"The Engineering Panel has just completed a further review of the proposed NRL process of separation. General Groves will undoubtedly present this at the next meeting of the Military Policy Committee on this subject. I judge that at that time you will wish to discuss this further with the group."

1943, February 23
Letter of Lyman Briggs to James Conant. SECRET.

"I enclose herewith a special report prepared by Dr. Murphree and Dr. Urey at the request of S-1. This report outlines an experimental program which it is hoped the Naval Research Laboratory will be willing to carry out as promptly as possible. These experiments will help to determine the way in which the liquid thermal diffusion process may be used most effectively in the cascade.

[This "special report," dated 19 February 1943, "Program for experiments to be carried out on the thermal diffusion method," is transcribed below.]

"I have reviewed this program and it meets with my approval. I suggest that it be transmitted through appropriate channels to the Director of the Naval Research Laboratory."

1943, February 19
"Program for experiments to be carried out on the thermal diffusion method." SECRET. Signed, Murphree and H. C. Urey; copies to: L. J. Briggs (3), A. H. Compton, J. M. Conant, E. O. Lawrence, E. V. Murphree, H. C. Urey. SECRET.

"The writers were asked to give recommendations as to a detailed program to be carried out to establish the application of the thermal diffusion method for separation of uranium isotopes. The program proposed is divided into two parts. The first part deals with unsteady state experiments and is primarily drawn up to determine the reproducibility of separation tubes. These experiments will also give information that can be used in calculating a cascade of thermal diffusion units to obtain a given separation from a given amount of material. The second part of the experiments suggested are steady state experiments which may more definitely establish the length of diffusion columns required in a separation plant. In particular the steady state experiments will serve as a check on the theory that has been used to extrapolate unsteady state experiments over to steady state conditions.

“Unsteady State Experiments:

“In order to build a plant making use of the thermal diffusion plan, it will be necessary to be sure that the individual units constructed behave closely in the same manner. So far experiments made by the Naval Research Laboratory indicated that with a variety of spacing between the hot and the cold tubes, a regular curve for the over all fractionation is secured. This regular curve indicates that it is possible to construct these tubes in such a way that they are reproducible, though the fact that the fractionation factor secured in these experiments follows a smooth curve may be fortuitous, and in any case gives us no estimate as to how closely it is possible to duplicate the performance in tubes of this kind. The following experiments should therefore be run in order to test the question of reproducibility of these tubes.

“The Naval Research Laboratory is building 48' tubes with spacings of 0.25 mm, though they have built in the past 36' tubes, and also have talked of 24' tubes. The experiments outlined below should preferably be done with 24' tubes. If these are not available, then with 36' tubes and, again, if these are not available, with 48' tubes. The reason for this choice is that the experiments can be done much quicker with the short tubes, while the fractionation factors secured are quite adequate for analytical purposes.

“The volume of the 48' tubes within the tube itself is, according to the best information available, about 1,600 grams of hex [uranium hexafluoride] The experiments should be done with a holdup at the top of the tube (i.e., the holdup in the expansion joint) of 200 to 500 grams, preferably 200, again because the time of the experiments would be decreased. In any case the holdup at the top of the column must be accurately known. A circulating holdup at the bottom of the tube should be about 25 kilos in order that the entire volume of the tube is only a small fraction of the reservoir at the bottom of the tube, this being desirable from the standpoint of the theoretical interpretation of the results.

“Experiments performed by the Naval Research Laboratory indicate that a 36' tube comes half way to equilibrium in about one day. Experiments should therefore be run, taking samples every six hours for a period of about four days. If the concentration curve with time at the top of such a column is approaching equilibrium, the experiment could be stopped, otherwise it must be continued. The samples taken every six hours period should not be over 1 or 2 grams so that the material withdrawn from the top of the column is only a small part of the total holdup at the top of the column, thus resulting in only a small upset of the operation of the column. Care should be taken to get a representative sample at this point.

“Such experiments should be run on a number of tubes, perhaps four, in order to see whether successive tubes made in the manner which they are using, are reproducible. It is impossible to expect that they are exactly reproducible, but it is important to know what deviation there is between tubes of this kind in order that one can estimate the performance of a plant constructed of such tubes. It is not possible to construct a plant assuming that the best performance observed can always be repeated, unless experiments are made to demonstrate this.

“Steady State experiments:

“A single test on a thermal diffusion unit, or a pair of thermal diffusion units, even though operated under steady state conditions will not definitely determine the minimum number of thermal diffusion units required in a cascade. Tests under at least two conditions, and preferably three, are required. In the program proposed below steady state experiments on a pair of columns are proposed, using three product withdrawal rates. The first of these product withdrawal rates, which is considered near the optimum, is 0.36 kg. per day. This experiment may establish the number of diffusion units required in a cascade to within about 40% of the minimum. In order to get a closer approximation to the minimum number of units required, and also to obtain an overall check of the data, runs at product withdrawal rates of 0.2 kg. per day and 0.7 kg. per day are proposed.

“For the data previously reported at unsteady state conditions in 36' columns, it is proposed that a pair of 24' columns be connected together with a feed reservoir between them. One of these 24' columns would serve as an enriching stage and the other as a stripping stage. When the column is operated under steady state conditions equal amounts of material would be withdrawn at regular intervals from the top of the enriching stage and from the bottom of the stripping stage. For the equipment proposed it is estimated the annular space of the 24' column would have a holdup of 600 grams of hex, and that the expansion joints of each unit would have a holdup of 500 grams of hex. The holdup in the expansion joint must be accurately known.

“In order to make the units symmetrical the expansion joint for the enriching tube should be at the top of the column and the expansion joint for the stripping tube at the bottom of the column. If it is not possible to put the expansion joint for the stripping unit at the bottom of the column then a small circulating reservoir having a holdup equivalent to an expansion joint should be installed at the bottom of the stripping tube.

“In order to be sure that the composition of the hex between the enriching and stripping sections is approximately that of the feed, it is felt that a circulating reservoir of 25 kg. capacity should be used. This reservoir will serve to charge the columns and furnish the material to be withdrawn.

“It is important that the material withdrawn from the columns at any one time be limited in amount so as not to upset the conditions within the columns. For the runs at product withdrawal rates of 0.2 kg. and 0.36 kg. per day, equal samples of product and waste should be withdrawn at two-hour intervals. For the run at a product withdrawal rate of 0.7 kg. per day, product and waste should be withdrawn at intervals of one hour.

"In the runs proposed during the initial part of the operation the composition of the material withdrawn from the column will be changing and will eventually approach constant composition. In order to get a reasonable approximation of this constant composition the run should extend over a period of seven days. Analyses by the mass spectrometer should be made on samples representative of the material withdrawn from the top and bottom of the column pair at twelve-hour intervals. That is, information will be available on the composition of the material at the top and bottom of the diffusion pair at every twelve hours of the seven-day run. Analyses should be made on a sample representative of the material in the reservoir between the two columns at twenty-four hour intervals."

1943, February 24
Letter from James Conant to General Groves. SECRET.

"I am transmitting to you herewith a special report prepared by two members of the S-1 Committee dealing with the experimental program at the Naval Research Laboratory. This report has been reviewed by another member of the Committee, Dr. Briggs, and meets with his approval.

"The S-1 Committee hopes that you will transmit this report to the Director of the Naval Research Laboratory. The proposed experimental program recommended by this group we believe to be of considerable importance. The results of these experiments will provide the information which will be most helpful in determining the over-all advantages of the thermal diffusion process as a part of the cascade system. I need not say that it is desirable that this information be secured at the earliest possible date."

1943, May 11
Letter of James Conant to Rear Admiral William R. Purnell. SECRET. [Reference is made in this letter to a book, which book Conant returns to Adm. Purnell. The title of the book nor identification of the chapter in reference is provided by this letter.

"I have had a photostat made of the important chapter in this book and have forwarded it to Dr. H. C. Urey, who is the expert on this matter.

"I am returning the book to you with my thanks, thinking you will probably want to forward it to our friends in the Naval Research Laboratory."

1943, June 19
Letter of Lyman Briggs to Colonel T. C. Crenshaw, Manhattan District Office, Corps of Engineers, New York, NY. SECRET.

"I am enclosing a copy of a letter to Dr. P. F. Alexander directing him to turn over to your Office two tons of uranium oxide belonging to the National Bureau of Standards. This material was purchased from funds provided by NDRC and its transfer without charge to your Office for use in the war effort meets with the approval of the NDRC.

"An acknowledgment in due course of the receipt of this material will be appreciated."

1943, July 10
Letter of General L. R. Groves to James Conant. SECRET.

"I feel that the progress at the Naval Research Laboratory, on the problem with which we are concerned, has reached a point where it will be desirable to have this situation reviewed by the S-1 Committee.

"It is possible that you would prefer to have this done by a Committee appointed by you, but not necessarily members of the S-1 Committee.

"Would you be kind enough to take charge of this review and render a report."

1943, July 10
Letter of James Conant to Rear Admiral William R. Purnell.
CONFIDENTIAL.

"I have been asked by General Groves to appoint a subcommittee of the S-1 Committee to review the present status of the work at the Naval Research Laboratory on the S-1 program. It was his idea that this subcommittee would compare the present prospects of that process with the other plans which are now being developed under the Military Policy Committee to see if there was any way in which the Naval Research Laboratory program could be advantageously fitted in to the general scheme which is now in progress of development.

"I am proposing to appoint a committee composed of W. K. Lewis, Chairman, and Drs. Urey, Murphree and Briggs.

"I am writing to inquire whether or not the Naval Research Laboratory group would be willing to receive such a committee and give them all the information it would be necessary for the committee to have to form a judgment and make a report through me to General Groves. I hope the Naval Research Laboratory would not regard such a visitation as an intrusion but rather as one more indication of the desire of the S-1 Committee to be of any assistance they could to the group which is doing such interesting and excellent work."

1943, July 30
Letter of James Conant to Rear Admiral William R. Purnell.
SECRET.

"I am transmitting herewith a copy of a portion of a memorandum submitted through Dr. Harold C. Urey which deals with NRL Report No. 0-2047, by N. Rosen, dated April 17, 1943. I should be indebted to you if you would transmit this memorandum to those concerned in the Naval Research Laboratory.

"Enclosure. 1 copy only made of Memo to Dr. Urey from Karl Cohen dated July 16, 1943 on NRL Report No. 0-2047 - Theory of Liquid Thermal Diffusion. Sections 1 thru 4 copied. Sections 5 and 6 not sent to Admiral Purnell."

[NRL Report No. 0-2047, "Liquid Thermal Diffusion Research Theory of Isotope Separation," dated 17 April 1943, has not been located. NRL Report No. 0-2047 was apparently written by N. Rosen. The memo "which deals with NRL Report 0-2047" was apparently written Karl Cohen and dated16 July 1943; that memo has not been located.]

1943, September 3
Memorandum from Chief of the Bureau of Ships, signed by H. A. Ingram by direction of Chief of Bureau, to Commander in Chief, U.S. Fleet. (Attention Rear Adm. W. R. Purnell). SECRET.

"Subject: NRL Report No. 0-2127 - Fourth Partial Report on Liquid Thermal Diffusion Research [30 July 1943].

"Reference: (a) NRL sec. ltr. S-S41-5U(448), Serial #1647, of 13 Aug. 1943.

"Enclosure: (A) Two copies of NRL Report No. 0-2127.

"1. In accordance with the suggestion of reference (a), two copies of the subject report are forwarded herewith, one copy to be further transmitted to Dr. Karl Cohen, Columbia University, New York, New York."

1943, September 9
Letter of Ruth E. Jenkins [secretary to James Conant] to Harold Urey, Columbia University. SECRET.

"At Dr. Conant's request, I am sending you herewith NRL Report No. 0-2127, dated July 30, 1943 and entitled 'Fourth Partial Report on Liquid Thermal Diffusion Research,' for transmission to Dr. Karl Cohen."

1943, September 15
Letter of James Conant to Rear Admiral W. R. Purnell. SECRET.

[The September 8, 1943 report, in the form of a letter, cited in paragraph (1) has not been located. Probably the report, in the form of a letter, cited in paragraph (1) was the result of General Groves' request to Conant of 10 July 1943 and Conant's inquiry to Admiral Purnell, also of 10 July 1943.]

> "(1) I am forwarding herewith to you as a member of the Military Policy Committee a report dated September 8, 1943, from a committee composed of Dr. L. J. Briggs, Dr. H. G. Urey, Dr. E. V. Murphree and Dr. W. K. Lewis, Chairman, dealing with the work on liquid thermal diffusion being done at the Naval Research Laboratory. This report is in the form of a letter dated September 8, 1943 addressed to me. I shall greatly appreciate it if you would forward this document to the Naval Research Laboratory through the appropriate channels.
>
> "(2) This report was discussed at a recent meeting of the S-1 Committee at which General Groves was present. It was the strong opinion of this group in accepting the report of the subcommittee to which I have just referred that it would be most unfortunate for the entire effort if any further expansion of the work at the Naval Research Laboratory in this field were to result in the drawing away of personnel now being employed on other aspects of this program. In particular, we had in mind such men as Drs. Beams, Nye, Armistead, Snoddy and Ham of the University of Virginia. It was the opinion of both the subcommittee and the whole Committee that the most useful way in which the work referred to in the first paragraph of page 2 of the report could be carried out by the Naval Research Laboratory would be by careful study on a small scale of the problems referred to in this report.
>
> "(3) We understand that there is still available at the Naval Research Laboratory approximately 80 pounds of hex, made up of several lots of different known composition. If this material, together with the analyses of the several samples, can be made available to those now engaged on the project under the general direction of the Military Policy Committee for experimental purposes, the favor will be deeply appreciated, and an equivalent amount of base material will be supplied

in exchange. The arrangements for this would be made through General Groves' office.

"cc: Brigadier General L. R. Groves (together with copy of Report) shown only on Gen. Groves' copy and file copies."

1944, March 4
"Paraphrase of teletype" of J. R. Oppenheimer to James Conant. SECRET.

"It is believed by [Joseph W.] Kennedy that thermal diffusion methods may be effective in our problem of purification of X ten [plutonium] product. It seems probable that some of the experimental work on separation carried out at NRL may be relevant. If such is the case could you arrange for most pertinent reports sent to us. Reference YC-227. Parsons suggests this might be cleared with Purnell. Paul Fine (Dr. Tolman's office) can arrange details."

1944, March 4
Letter of James Conant to Rear Admiral William R. Purnell. CONFIDENTIAL.

"Dr. Oppenheimer, who you know is in charge of the experimental work at Y on the S-1 project, would like to have his men look at the reports from the Naval Research Laboratory on the thermal diffusion method, feeling that the technique they have developed might be of some use to them in some problem of purification. Needless to say, they do not propose to set up a separation plant at this spot in connection with the main problem.

"I have in my possession copies of the third and fourth partial reports on this process dated April 17, 1943 and July 30, 1943, numbered NRL-0-2047 and NRL-02127, respectively. I should not wish to send them to these men, however, without your permission. My own feeling is that the chances that they will find anything of use is slight, but I hesitate to turn down any request from that hard-pressed area. If I were to send these two reports and they on reading them found anything of interest, it would then be possible perhaps through you to obtain copies of the first two, but at the moment no action on your part would be needed except to let me know whether or not I would have permission to send these reports to Y solely for their use."

[Note at bottom of letter page, "NRL No- 0-2047 dated April 17, 1943 and NRL Report No. 0-2127 dated July 30, 1943 sent to Dr. J. R. Oppenheimer 3-20-44 upon receipt of telephoned approved from Admiral Purnell to Dr. Conant. Confirmation by letter to be mailed to Dr. Conant."]

1944, March 8
Letter ["Dictated—not read–not signed"] of General Groves to James Conant. SECRET.

"Here is an item that I meant to speak to you about today but it got lost in the shuffle.

"Nichols told me that he had gotten a rumor that Gunn at the Naval Research Laboratory was responsible for a story that they would be producing 10 grams of 90% material by July 1 and that the cost of the plant would be only $1,000,000.

"Do you have any ideas as to how the truth of this affair can be found out? I personally am suspicious of any cost figures unless we have been completely misinformed in the past by all of our scientific investigators who have looked into the process. There is one possibility, however, —that he is using surplus steam from a Navy yard and is not charging himself anything for it."

1944, March 17
Letter of Rear Admiral W. R. Purnell, Navy Department, Office of the Chief of Naval Operations, to James Conant. CONFIDENTIAL.

I can see no objection to forwarding the report of the Naval Research Laboratory, on the thermal diffusion method, to Dr. Oppenheimer.

Accordingly, permission is granted to forward the reports of April 17, 1943 and July 30, 1943, numbered NRL-0-2047 and NRL-0-2127, respectively, to Dr. Oppenheimer."

1944, March 20
Letter of Ruth E. Jenkins to Dr. J. R. Oppenheimer, Box 1663, Santa Fe, New Mexico. SECRET.

On Dr. Conant's behalf and in answer to your teletype of March 4 (Reference YC-227), I am forwarding to you NRL Report No. 0-2047 dated April 17, 1943 and NRL Report 0-2127 dated July 30, 1943.

If on reading these reports you find anything of interest, please let Dr. Conant know, and he will endeavor to obtain through Admiral Purnell copies of the first two partial reports on this process.

"Enclosures:

"Report No. 0-2047, April 17, 1943, 'Liquid Thermal Diffusion Research Theory of Isotope Separation by Thermal Diffusion, – I. Single Column.'

"Report No. 0-2127, July 30, 1943, "Fourth Partial Report on Liquid Thermal Diffusion Research."

1944, April 20
Letter of James Conant to Lyman Briggs. SECRET.

"I was very much interested in your remarks yesterday about the origin of the work on liquid phase separation now being carried on at the Naval Research Laboratory. Am I right in understanding that the first work on this method was done by Mr. Abelson at the Bureau and sufficiently promising results were obtained by him while there to warrant the NRL going ahead with the project vigorously when Mr. Abelson transferred to NRL? What was the approximate date of Mr. Abelson's transfer?

"I would greatly appreciate your dropping me a line on these matters, as I want to have my facts straight about this bit of history."

1944, May 6
Manuscript note of James Conant to Vannevar Bush.
PERSONAL.

"I uncovered a rather strange and to my mind a rather unpleasant bit of past history in S-1 the other day. In a conversation with Smyth [Princeton physicist Henry DeWolf Smyth, author of *Atomic Energy for Military Purposes*, 1945] & myself Briggs was led to recount the origin of the Naval Research Lab's method. According to his story Abelson (of Carnegie) was working at the Bureau of Standards in the earlier days of the Briggs committee and either invented or developed the idea of separation by thermal liquid diffusion and obtained results indicating that there was a chance that it would work. Gunn a member of the Briggs committee but apparently no one else became a party to this knowingly and prevailed upon Briggs to let Abelson go to the NRL where they had a lot of steam necessary for the purpose. Gunn & Abelson continued working on the Thermal Diffusion Process at NRL and kept Briggs informed of progress. Briggs felt himself under pledge not to tell anyone else. This continued till Briggs was smoked out by some questions of Urey in the summer of 1943 (my interpretation!). Briggs said that finally he felt he must get a release from the NRL and reveal to the S-1 Executive Committee NRL progress.

"I rather led Briggs on in an innocent way to tell this story. From my point of view it is very damaging to Briggs. Whether he realized it or not I don't know but I wrote the enclosed letter [20 April 1944] and have received no reply after two weeks.

"I'm not particularly anxious to accuse Briggs of double dealing nor Gunn either. But I could get very mad in retrospect about his behavior. It is necessary to make a record now to show why the S-1 committee never pushed the Thermal Diffusion method, namely because they were never informed of it?

"In particular shall I forget the letter I wrote to Briggs though to me his failure to reply is pretty much an admission of guilt?"

1944, June 3
Letter of General Groves, War Department, Office of the Chief of Engineers, Washington, to James Conant. SECRET.

"I am inclosing a copy of the report by Messrs. Lewis, Murphree and Tolman with the suggestion that you take it with you to Tennessee and discuss the question insofar as necessary with the people at the site. If you could then give me your advice it would be very much appreciated.

"As yet Mr. Murphree and Mr. Lewis have not signed the report but I understand that they are agreeable to it.

"Incl.: Report 6/3/44"

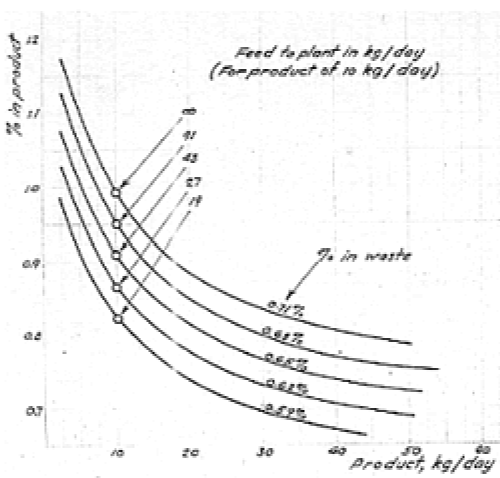
1944, June 3
Memorandum of Mssrs. W. K. Lewis, E. V. Murphree and R. C. Tolman to Major General L. R. Groves. SECRET.

Subject: "Possible Utilization of Navy Pilot Thermal Diffusion Plant."

"In accordance with the request in your letter of 31 May 1944, we have examined into the possible utilization of the Navy pilot thermal diffusion plant. Our conclusions are given in the following paragraphs which are numbered to correspond to the paragraphs in your letter. [This 31 May 1943 letter has not been located.]

"1. The installation of a 100 tube plant at the Philadelphia Navy Yard is well advanced, and operation is expected to begin about July 15, 1944. The plant is provided with two high pressure boilers of sufficient capacity for operating a total of 300 tubes, and is to be provided with a low pressure boiler for operating auxiliary equipment. The Navy's tentative program for the operation of this equipment is to set aside some of the 100 tubes for special experiments on individual tubes. The remainder of the 100 would then be connected up as a cascade, with 7 stages of enrichment and 1 stage of stripping, which is estimated would give a production of about 100 grams of 25 [U^{235}] per day, at approximately 6% concentration, with a hold up of about 100 days.

“2. The estimate mentioned in your letter that the Navy plant, with 100 tubes connected in parallel, would produce 12 kilograms a day of 1% material is optimistic. The attached curves, “Feed to plant in kg/day (For product of 10 kg/day).” Curves giving the anticipated possible production of the Navy thermal liquid diffusion plant with 100 tubes connected in parallel] give the anticipated possible production of the Navy plant, with the 100 tubes connected in parallel, based on the data presented in Columbia Report No. 4-R-104 for tubes and operating conditions at NRL most nearly comparable to those to be used at Philadelphia. These curves give the plant production in kilos of metal per day, plotted against the percentage concentration of 25 in the product. Each curve corresponds to a specific concentration of 25 in the depleted material to be rejected from the plant. The feed requirements in kilograms of metal per day indicated on the plot apply on to the case of a daily production of 10 kilos of enriched material. (The corresponding figures can be readily computed for other daily outputs.)



“From these curves it can be seen that the maximum attainable production of 1% material would be a trifle under 10 kilos per day, and this would involve a very large quantity of feed material, with a very high concentration of 25 left in the reject. Probably it would be unwise to try to lower the concentration of 25 in the rejected material below

0.68%. This corresponds to the production of about 7.4 kilos per day of 1% material, with a consumption of 75 kilos of natural metal. With the same concentration in the reject material, the 100 tube plant would produce 10 kilos of 0.95% material, with a consumption of 91 kilos of natural metal. A plant of 300 tubes would obviously produce three times as much product with three times the metal consumption.

As already mentioned, the curves given are based on the assumption that the 100 tubes would be connected in parallel, and for getting quantities of product of the order of 10 kilos per day this is the most effective method of utilizing the present equipment.

“3. The two main boilers mentioned above, plus the auxiliary boiler, would be adequate for the operation of an additional 200 tubes. However, the Navy would like to obtain information on the operation of the present 100 tubes, before making decision as to details of the remaining 200. They estimate that the installation of the additional 200 could be made two months after decision to go ahead was reached. If it seemed wise from a military standpoint to push for the earliest possible maximum production of approximately 1% material, we feel that no great uncertainties would be involved in this program in going ahead with 200 more tubes of the present design. Nevertheless, this would inevitably delay the sound development of the ultimate possibilities of the thermal diffusion method.

“4. Attention should be called to the fact that 300 tubes could produce 30 kg of 0.95% concentration, with a discard of 0.68% concentration, and a daily consumption of 273 kilos of natural metal. It may also be mentioned that although a temporary utilization of the Navy plant for production would delay the investigation of the ultimate potentialities of the thermal diffusion method, useful information would nevertheless be obtained during production operation. We are of the opinion that the ultimate potentialities of the thermal method should in any case be investigated at the proper time.

“5. The information on which this report is based was obtained from a conference which we had on 31 May 1944 at the Naval Research Laboratory with Admiral A. H. Van Keuren, Captain T. A. Solberg, Commander R. H. Gibbs, Dr. Ross Gunn, and Dr. P. H. Abelson, and on a conference on 1 June 1944 at Philadelphia with Captain C. A. Bonvillian and Dr. Abelson. At both conferences we were assisted by Mr. W. I. Thompson and Dr. Karl Cohen. We desire to inform you that we found the Navy very cooperative in furnishing the information which we needed, and hope that you will express to the Naval Research Laboratory our appreciation for this cooperation."

1944, July 25
Memorandum of Chief of the Bureau of Ships [Vice Admiral Edward L. Cochrane] to Rear Admiral W. R. Purnell, U.S.N. (Op-05). SECRET.

"Subject: Special Project - Name of Method.

"Reference: (a) Dir. N. R. L. SECRET ltr. S-S41-5(U) (200) Ser. 3459 of 13 July 1944.

"1. The Chief of the Bureau of Ships concurs in the recommendation of reference (a) that the thermal diffusion process for isotopic separation which originated at the Naval Research Laboratory and is shortly to be put into operation at the Naval Boiler and Turbine Laboratory at Philadelphia be given the name Abelson-Gunn Process, in recognition of the two scientists, Dr. Philip H. Abelson and Dr. Ross Gunn, who have developed this process to its present state.

"Copy to:

Dir. NRL

Dr. James B. Conant, N.D.R.C.

Maj. Gen. L. R. Groves"

1944, July 27
Manuscript of James Conant, "Historical note on introduction of the Abelson-Gunn process."

"Pursuant to attached letter of June 3 from Gen. Groves, JBC [James B. Conant] and W. K. L. [Warren K. Lewis] Discussed with E. O. L. [Ernest O. Lawrence] & the top [Oak Ridge] Tennessee people the relation of the NRL process (later to be called the Abelson-Gunn process) to the electromagnetic process. It was agreed that the use of the expanded Phila. [Philadelphia] plant to produce 0.70% feed was of first importance and by itself would increase the output before July 1, 1945 appreciably. The question was also raised of building a NRL plant to operate on the [boiler] house of the [gaseous] diffusion plant at Tennessee. It was pointed out that for small enrichment this process was economical but for large enrichment almost impossible because of coal consumption and long hold-up time. It was recommended to Gen. Groves that a plant be built at Tennessee to feed in the electromagnetic plant enriched material thereby perhaps doubling the output of providing insurance against failure of the [gaseous] diffusion plant to come in on time."

1944, September 15
Letter of James Conant to Lyman Briggs.
CONFIDENTIAL.

"In going over my records in connection with summing up the present status of the S-1 work, I find that I do not have an answer to a letter I addressed you on April 20 concerning the origin of the Naval Research Laboratory work.

"I am wondering if I could trouble you to let me know if I am right in assuming in my summary to Dr. Bush that the first work on the NRL method was done by Mr. Abelson at the Bureau and that sufficiently promising results were obtained by him while there to warrant your transferring the work to the NRL with the understanding they would prosecute it vigorously. I take it the date of the transfer of this work was some time during the summer of 1941.

"This has all become a matter of ancient and mostly academic history now, but I am trying to record a few facts as I am clearing up a portion of my files."

1944, September 21
Letter of Lyman Briggs to James Conant. SECRET

"This is in reply to your letter of September 15th. The S-1 work was initiated by the President, as you may recall, in October, 1939, and was at first supported by small allotments from the Bureau of Ordnance of the Navy and the Bureau of Ordnance of the Army. In April, 1940, I learned of Admiral Bowen's active interest in the matter. He was at that time in charge of the Naval Research Laboratory and was prepared to give some real support to the project. This support resulted in an enlargement of Fermi's work at Columbia and the initiation of the centrifuge work at the University of Virginia and at Columbia. Nier was given funds to separate a larger sample of 25 with the mass spectrograph. Meier was asked to study the separation by diffusion. Urey was given a grant for the separation of heavy hydrogen. At this time, also various other methods for separating the isotopes were studied, including separation by thermal gaseous diffusion. In the course of this work, Dr. Abelson thought he saw possibilities in the thermal liquid diffusion method. Accordingly, in September, 1940, on my recommendation, a grant was made by the Naval Research Laboratory to the Department of Terrestrial Magnetism [Carnegie Institution, Washington, D.C.] for this purpose. The facilities of the Department of Terrestrial Magnetism were not, however, altogether adequate for this type of work and accordingly I invited Abelson to come to the Bureau of Standards where he set up and operated columns about 10 feet long, with different clearances between the concentric tubes. The results of these experiments were encouraging, but Abelson was convinced that we should employ larger thermal gradients, which necessitated much higher steam pressures than were available at the Bureau. Accordingly, at Dr. Gunn's suggestion, that phase of the work was transferred to the Naval Research Laboratory in the summer of 1941 where higher steam pressures and greater shop facilities were available.

"Dr. Abelson was never on the rolls of the Bureau. The work was supported throughout this preliminary period by the Naval Research Laboratory except for such laboratory facilities and help as were contributed by the National Bureau of Standards. The move to the Naval Research Laboratory took place as I recall about July 1, 1941.

"It was the understanding, as you say, that the work would be pursued diligently and that the Committee would be kept advised of the progress that was made. Dr. Gunn and Dr. Abelson kept me fully informed regarding the work and I have in my files a letter from Dr. Gunn expressing his willingness to release the results to the Committee during the earlier stages of the work. Admiral Bowen, of the Naval Research Laboratory, requested that the project be left in the hands of the Naval Research Laboratory until its possibilities had been more definitely established. I think he feared that the method, despite its promise and simplicity, would not be looked upon with favor by the Committee because of the high operating costs. You will recall that this was exactly what happened when the process was examined by the S-1 Committee."

Following pages reproduce:

Memorandum of W. I. Thompson, "Analysis of separation data from liquid thermal diffusion experiments," dated January 22, 1943; 5 pp pages, including "table one [Table I]."

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M E M O R A N D U M

ANALYSIS OF SEPARATION DATA FROM LIQUID THERMAL DIFFUSION EXPERIMENTS

A number of experiments have been carried out at the Naval Research Laboratories on separation of isotopes by thermal diffusion in the liquid phase. The results are given in reports numbers O-1977 and O-1981. The following is an analysis of these data from the standpoint of plant size, equilibrium time and requirements of power and strategic metals.

The experimental results now available have been obtained on single 36-foot columns consisting of an inner nickel tube and an outer copper tube. The material to be separated is contained in the annular space between the tubes and is subjected to a large temperature gradient by condensing steam in the inside tube and cooling water around the outside tube, undoubtedly setting up appreciable countercurrent flows. The best results were obtained with an annular clearance of about 0.25 mm. on the radius. The procedure has been to fill the column from the bottom from a comparatively large reservoir. During the run this reservoir is connected to the base of the column but does not circulate with the base. That is, the base is allowed to drop in composition as the top becomes richer. This type of operation makes the analysis a little indefinite but it is felt that reasonable allowances can be made for these conditions.

Table I shows the results calculated from three different sets of data. The first is for a column with a spacing of 0.21 mm. The second is for a column with 0.25 mm spacing and somewhat higher temperature difference. The third is for this same column, using values of the enrichment ratio which the experimenter feels are more in line with other results. The minimum size plant is composed of 20,000 36-foot columns and has an equilibrium time of 580 days. The steam consumption is estimated at 12.0 MM pounds per hour and the water circulation at 1.60 MM gallons per minute.

METHOD OF CALCULATION

The rate of approach to equilibrium of a single countercurrent column may be expressed approximately by the following expression (see paper by K. Cohen, attached, Eq. 4.23. It is assumed that ρ is roughly equal to C_1):

$$\frac{N_t}{N_f} - 1 = \left(\frac{N_t}{N_f} - 1\right)_{equil.} \left(1 - e^{\frac{-nB^2L\,F(nB)T}{H}}\right) \qquad (1$$

In this expression n is the number of plates, 1 + B = α which is the ratio of the concentration in one stream to the concentration which would be in equilibrium with it in the other stream, L is the flow in each stream, H is the column holdup, T is time and the function F(nB) is plotted in Fig. 4 of the attached paper (nB is equivalent to 2σ). In this expression, the value nB may be determined from the relation

$$nB = \ln\left(\frac{N_t}{N_f}\right)_{equil.} \qquad (2)$$

and the value F(nB) may be read from Fig. 4. The time for 50% of equilibrium is obviously the time for which the exponental term equals 0.5, or the exponent of e is -0.692. Equating the exponent of e to -0.692, the following relation is obtained.

$$nB^2L = \frac{0.692\ H}{T\ F(nB)} \qquad (3)$$

in which T is the time for the column to reach 50% equilibrium.

It may be shown that the number of countercurrent columns in a large plant, each with n plates, a flow in each stream of L and an equilibrium separation factor of 1 + B is

$$\text{Number} = \frac{4\ P\ Y_p}{nB^2L} \qquad (4)$$

in which P is the product rate and Y_p is a function of the product concentration, which for 90% product equals 130. The equilibrium time for such a cascade may be defined as the amount of light isotope present in the plant at producing conditions in excess of that present at feed concentration divided by the net production of the light isotope under steady conditions. Since the average net composition of material in a plant to produce 90% product is 3.57%, the time defined in this way may be shown to be

$$\text{Time} = \frac{.0357 \times 4\ P\ Y_p\ H}{nB^2L\ P \times 0.9} = 20.6\ \frac{H}{nB^2L} \qquad 5)$$

- 3 -

where H is the total holdup per column.

To summarize, the value nB may be obtained in a given case from the maximum separation value by the use of equation (2). Using the time for 50% equilibrium (experimental) and evaluating F(nB) from Fig. 4 of the attached paper, the quantity nB^2L may be calculated by the use of equation (3). The number of columns required is determined for a given product rate and product composition from equation (4) and the equilibrium time from equation (5).

The relations given above for a single column refer to the case where the bottom of the column is maintained at the feed composition. In the examples to be analyzed, the bottom composition was allowed to drop below feed composition. In order to apply these relations to the data, it is necessary to estimate a "neutral" point in the column, which point may be considered as the bottom of a column which satisfies the required conditions. Actually, of course, no such point exists since the point in the column actually at feed composition probably moves somewhat as the column concentrations are built up. However, it seems reasonable to suppose that it soon comes to a fairly definite position. If the concentration distribution at equilibrium is linear (a fair approximation at low enrichment since $e^{nB}=1 + nB$ for small values of nB), the final "neutral" point is located such that the distance from each end is proportional to the enrichment. Thus in a 36-foot column with a final enrichment of 1.136 at the top and stripping of 1.060 at the bottom, the final neutral point is located 25 feet from the top and the column may be calculated as a 25-foot column with the base held at feed concentration. These numbers correspond to the first case in Table I.

A further correction is required for the fact that a portion of the holdup in the enriching section is located at the top of the column rather than distributed uniformly throughout the column. A rough correction on the time for 50% equilibrium has been applied on the basis of some numerical calculations of Dr. Cohen for the countercurrent centrifuge.

It should be pointed out that the plant designs refer to arrangement of the columns in banks. The tops of the columns in one bank will be constantly or periodically mixed with the bottoms of the columns in the next bank. In order to prevent flow up one column and down the next in parallel by a thermosyphon action, it would be necessary to restrict this mixing circulation to alternate banks at any one time. This would require some sort of periodic operation with a large

- 4 -

number of automatic valves. However, since the relaxation time for individual columns in a cascade of this type might be the order of days, the cycle of valve changing could also be of the order of days so that valve difficulties might be not too great. The equilibrium times given in Table I include only the material in the annular spaces of each column. When a definite design is made up, it will be necessary to allow for holdup in lines and possibly inter-stage storage.

Another type of arrangement of columns is possible which involves the use of two single columns arranged as a pair. The feed is introduced between the columns, an enriched stream is removed from one column and a stripped stream from the other. These pairs are arranged in a cascade much as flow-through centrifuges. This is inherently a less efficient type of arrangement than the type described above. For example, a plant composed of pairs of 36-foot columns and based on the data for the second column of Table I, would require 29,200 36-foot columns and would have an equilibrium time of 840 days. As a matter of interest, it appears that the optimum production for such a pair of columns would be about 0.3 Kg/day of each stream.

W. I. THOMPSON

WIT:HCW

January 22, 1943

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TABLE I.

Report No.	0-1977	0-1981	0-1981
Paragraph No.	22	6	9
Width of Annular Space - mm	0.21	0.22	0.22
Temp. - Hot Side, °C	210	237.5	237.5
Cold " "	64	65	65
Enrichment Ratio - Top = N_t/N_f	1.136	1.149	1.307
Enrichment Ratio - Bottom = N_f/N_w	1.060	1.281	1.281
Holdup at Top of Column - H_t-KG.	0.50	0.50	0.50
Holdup - enriching section - H_e-KG.	0.62	0.42	0.63
Holdup - stripping section - H_s-KG.	0.28	0.78	0.57
Enriching Section of Experimental Column			
Time for 50% equilibrium - days	0.56	0.69	2.00
Time corrected for disproportionate holdup at top - days = T	0.34	0.35	1.21
$nB = \ln (N_t/N_f)$ max.	0.127	0.139	0.268
F(nB) (see text)	145	121	31
$nB^2L = \frac{.692\ (H_e + H_t)}{T\ F(nB)}$	0.0157	0.0150	0.0208
Large Scale Plant for 1 KG/D U235 @ 90% (enriching section only)			
No. 36' columns for 1 KG Plant $= \frac{860}{nB^2L} \times \frac{H_e}{H_e + H_s}$	37,700	20,000	21,800
Equilibrium time for plant - days $= 20.6\ \frac{H_e}{nB^2L}$	815	580	625
Economics (20% is added to the number of columns above to allow for a stripping section)			
Steam, MM#/hr.	22.6	12.0	13.1
+ Investment - MM $	56.6	30.0	32.6
++ Operating Cost - M $/Day	110	56.5	62.6
Cooling water, MM-GPM	3.18	1.69	1.85
Power for circulating - MKW	51.1	27.2	29.6
Strategic Metals (columns only)			
Copper - Tons	2940	1550	1700
Nickel - Tons	2940	1550	1700

\+ For steam above @ $2500/1000 #/hr.
++ For steam above @ $0.20/1000 #

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Memorandum of W. I. Thompson, “Analysis of separation data from liquid thermal diffusion experiments,” dated January 22, 1943; 5 pp pages, including “table one [Table I].” Source: Author’s files.

“Feed to plant in kg/day (For product of 10 kg/day).” Curves giving the anticipated possible production of the Navy thermal liquid diffusion plant with 100 tubes connected in parallel. From: 1944, June 3. Memorandum of Mssrs. W. K. Lewis, E. V. Murphree and R. C. Tolman to Major General L. R. Groves; Subject: “Possible Utilization of Navy Pilot Thermal Diffusion Plant.” Source: Author’s files.