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Manhattan District History

Book II - Gaseous Diffusion [K-25] Project

Vol. 1 - General Features

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 1 - GENERAL FEATURES

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FOREWORD

This introductory volume presents a general discussion of the main features of the Gaseous Diffusion (K-25) Project. The purpose of the Project, authorization, theoretical foundations, preliminary planning, safety and security aspects, costs, and administrative organization are treated, and a brief overall description is given, with an indication of scope and magnitude, as well as a statement of problems posed by the decision to utilize the method of gaseous diffusion. The various aspects, as listed below, are dealt with briefly. In general, when greater detail is desired, reference should be made to succeeding volumes of Book II as follows:

Volume 2 - Research
Volume 3 - Design
Volume 4 - Construction
Volume 5 - Operation

Activities described in Volume 1 extend from the earliest OSRD contracts, negotiated in July 1941, for the study of the diffusion process, to 31 December 1946, at which time all basic phases of the K-25 program of research, design, and construction had been effectively completed, the gaseous diffusion plant existed as an operating entity, and administrative responsibility passed from the Manhattan District to the United States Atomic Energy Commission. The term, "K-25 Project" is used throughout in the broad sense, and is synonymous with "Gaseous Diffusion Project". The K-27 plant addition is viewed as a supplementary portion of the K-25 process plant. No new basic principles are involved in K-27, and its discussion is interlocked with that of the original phases of the Project throughout the course of Book II.

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A number of appendices are attached to illustrate the text of this volume by means of maps, organization charts, and a personnel list. References indicated by parentheses as (App. A3), (App. B1), etc., refer to Item 3 of Appendix A, Item 1 of Appendix B, etc.

The Summary contains an abstract of every major subject treated in Volume 1. Paragraph numbers in the Summary correspond to section numbers in the main text.

A detailed descriptive account of the K-25 Project with special emphasis on design and development has been prepared by the Kellex Corporation: "Completion Report on the K-25 Gas Diffusion Plant" (Contract No. W-7405-eng-23) January 1, 1946 - H. B. Levey, J. F. Hogerton, and J. H. Arnold. This report has provided an outstanding source of reference during the preparation of the present work. More extensive treatment of the design and engineering underlying many of the subjects discussed in Book II may be found by consulting the Kellex report.

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 1 - GENERAL FEATURES

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SUMMARY

1. Introduction. - The goal of the Gaseous Diffusion (K-25) Project was the large scale, multi-stage separation of Uranium-235 from the more abundant non-fissionable Uranium-238 by utilization of the principle of molecular effusion. The complete novelty, both of the manufacturing process, and of the process material, made necessary a major program of fundamental research, development, engineering, design, construction, and operation, involving a large number of university and industrial contractors. Basic authorization was obtained from the President. With the general approval of the S-1 Committee of the Office of Scientific Research and Development (OSRD), and the Military Policy Committee, Major General L. R. Groves directed the general policies under which the Manhattan District carried on the work.

2. Basic Theory. - In 1938 O. Hahn and F. Strassmann discovered the phenomenon of nuclear fission in uranium. It was subsequently realized that the fission reaction was due to the uranium isotope of atomic weight 235, and that the reaction could probably be made to sustain itself as a chain reaction with the rapid release of tremendous quantities of energy. The problem was therefore presented of concentrating Uranium-235, which exists in natural uranium only to the extent of 0.714 per cent. The task is complicated because of the small difference in the atomic masses of U-235 and U-238, which difference must form the basis of the operating process. The method of gaseous diffusion is based upon the experimental finding of Thomas Graham in 1829 that the rate of effusion of gases through small apertures is inversely pro-

portional to their molecular weights. The only known feasible working substance for the process was uranium hexafluoride, UF_6, which can be easily volatilized. The process equipment installed at K-25 consists of a lengthy series or "cascade" of diffusion stages. The "converter" of each stage is subdivided into a cooler and "diffuser". The diffuser is a tank-like piece of equipment which encloses the "barrier". The barrier is the heart of the process, and consists of a thin, porous, metallic membrane containing billions of submicroscopic openings per square inch. The stage "B pump" supplies the converter continuously with undiffused gas from the stage above, mixed with diffused gas from the stage below. The cooler removes the heat of pumping and maintains a constant operating temperature. Conditions are so arranged that half of the gas fed to the converter diffuses through the barrier, becoming slightly enriched in concentration of the lighter component in accordance with Graham's Law, and is delivered by the stage "A pump" to the next higher stage. The remaining half leaves the converter, passes through the control valve, which maintains a constant converter operating pressure, and enters the suction of the next lower stage "B pump." Product material is withdrawn from the "top" of the cascade. Depleted waste leaves at the "bottom".

3. Planning of the Project. - In July 1941, OSRD contract OEMsr-106 was awarded to Columbia University, providing for investigation of the method of gaseous diffusion as applied to uranium isotope separation. Contract OEMsr-406 was next awarded to the M. W. Kellogg Company for further experimental and engineering investigation. After the preliminary production plant program had been reviewed by the OSRD S-1

Executive Committee and the Reassessment and Reviewing Committee, it was decided to construct a 4600 stage plant to produce 1 kilogram per day of U-235 at a concentration of 90 per cent. Arrangements for the work were concluded in secret letter contract W-7405-eng-23 awarded to the M. W. Kellogg Company on 14 December 1942. For security and accounting reasons, Kellogg created a totally-owned subsidiary, The Kellex Corporation, which was to be wholly devoted to the K-25 undertaking. Fundamental research was carried on at the SAM Laboratories of Columbia University under OSRD contracts OEMsr-106 and OEMsr-412, and, after 1 May 1943, under Manhattan District contract W-7405-eng-50. On 1 February 1945, responsibility for the SAM Laboratories was transferred to the Carbide and Carbon Chemicals Corporation under a modification of contract W-7405-eng-26. The Kellex contract W-7405-eng-23 also called for extensive research and development, as well as stipulating that that corporation have overall responsibility for planning, engineering, design, and development of the Project. A number of specific phases of the research program were assigned to various other laboratories as subcontractors. A large number of additional firms participated in the immense design and engineering program, under general Kellex supervision. British assistance was also obtained on various theoretical and design problems. After a thorough review of all phases of the Project from the standpoint of cost, completion dates, performance, and capabilities of possible plants, it was decided on 18 August 1943 to construct a plant to produce material at an isotopic concentration of 36.6 per cent U-235, and on 31 March 1945 the "K-27 Plant", a side feed addition plant, was authorized, in order to increase the production capacity of K-25.

Diffusion plant construction was accomplished principally by the J. A. Jones Construction Company (contract W-7421-eng-11), and Ford, Bacon, and Davis, Inc. (contract W-7407-eng-19), each under the supervision of Kellex, and each assisted by numerous subcontractors. Operated principally by the Carbide and Carbon Chemicals Corporation under contract W-7405-eng-26, the plant has been in production since March 1945.

4. Description of the Project. - The K-25 production plant is located at the northwest corner of the Clinton Engineer Works military reservation. The process area includes the main cascade of 2892 stages, housed in a series of 51 contiguous buildings arranged to form a single large "U"-shaped structure. Each building is subdivided into from three to fourteen six-stage "cells" which are the smallest individually operable units. Auxiliary facilities include systems for feed purification, purging, surge and waste handling, process gas recovery, and product removal. Service installations are also provided for maintenance facilities, and for supplying compressed air, specially dried air, cooling water, and special coolant, in accordance with process requirements. The conditioning area includes principally the conditioning building, in which a large number of cleaning, fluorinating, and maintenance operations are carried on. A sizeable florine generation plant is also located within this area, together with a disposal unit for spent conditioning gas, a nitrogen vaporization system, and a 270,000 pound per hour low pressure steam plant. The power plant area includes a boiler house for three 750,000 pound per hour coal-fired units designed to produce steam at 1325 pounds per square inch and 935°F, a turbine room for 14 turbo-generators with a combined rating

of 238,000 KW, a storage yard for 250,000 tons of coal, and suitable switch house and pump house facilities. The administration area includes miscellaneous office buildings, laboratories, station houses, a cafeteria, a dispensary, and a laundry. The K-27 Area is a strucurally separate annex to the main process area, consisting of a 540-stage cascade complete with auxiliary facilities, and so connected with the main buildings as to form a "cascade of cascades". Sometimes referred to as "the largest physico-chemical process in the world", the K-25 plant represents the fruition of a research, development, design, and manufacturing program which was spread throughout the nation. The greater plant area encompasses some 5000 acres. The cascade "U" is one mile in perimeter and one quarter mile across. The size of the installation, which had required 60,000 carloads of equipment and supplies as of 1 January 1946, is typified by the following: the plant contains 7,500,000 square feet of geometric barrier area, 8,700 process and coolant pumps, 100 miles of process piping, 130,000 specially engineered instruments, and 500,000 valves. Auxiliary facilities include one of the largest dry air installations ever constructed and a 170,000,000 gallon per day cooling water plant. The power plant is the largest steam-electric station ever constructed in a single operation, and a 200,000 gallon plant inventory is maintained of specially developed process coolant.

5. <u>Major Problems.</u> - A host of problems of unparalleled scope and complexity were inherent in the K-25 program. Outstanding amoung these were the evolution, development, and large scale production of barrier, a totally novel and highly specialized material. DELETED DOE b(3)

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The factor of corrosion was a dominant consideration throughout the course of the program. In order to minimize the effects of barrier plugging, process gas consumption, process stream contamination, and equipment deterioration, elaborate precautions were taken at the K-25 plant, and at many of the points of equipment fabrication. The aggressiveness of the process gas was multiplied by the large volumes to be handled at elevated temperature, and by the tremendous exposed surface areas within the plant. Cleaning and conditioning procedures, set up to prevent contamination of the process stream, were based upon specifications approaching those of a hospital surgery ward. Leakage of atmospheric air into the process system would be of such disastrous effect in terms of UF_6 consumption, stream dilution, and barrier plugging by the non-volatile reaction products of UF_6 with atmospheric moisture, that it became necessary to insure that absolutely no atmospheric air could find its way into the system. Unique tightness features had to be incorporated in all process equipment, including special leakproof welding, a specially designed triplex pump seal, and a dry air enclosure around the entire process system of 6,000,000 cubic feet volume. Special pumps, convertors, valves, and instruments were required in large quantities, and a number of special highly fluorinated, inert chemicals had to be newly developed. In order to carry an estimated design load of 193,000 KW, it was required that a highly reliable and uninterrupted source of power be available, distributed among a number of specified frequencies, each variable and subject to close control. The special hazard introduced by the fissionable nature of the substance in process called for careful and thorough safety checks on designs of equipment and methods of procedure in order to eliminate completely any possibility of approaching the critical mass. Finally, the preparation of the plant site called for the levelling of many acres of hilly terrain. The method of "compacted fill" was selected. It is a relatively new concept for building construction, and involved careful analysis, adjustment, and control of uniformity of moisture content in some 2,800,000 cubic yards of cut and fill.

6. Safety and Security. - Strict and thorough security, safety, and medical programs were set up and carried out in accordance with standard District procedures.

7. Costs. - As of the end of the fiscal year 1946, total costs attributable to the K-25 Project amounted to $552,466,926, and the current estimate for total costs at completion of contracts was $643,703,601.

8. Organization and Personnel. - The K-25 Project was headed by an Officer-in-Charge, or Unit Chief, reporting to the Manhattan District Engineer. Reporting to the Unit Chief were the New York Area Engineer, who administered design contracts, the Columbia Area Engineer, who administered research contracts, and Construction and Operations Officers stationed at the site. The New York Area was assisted by three sub-areas located in Decatur, Illinois; Detroit, Michigan; and Milwaukee, Wisconsin. The Madison Square Area, reporting directly to the

District Engineer, and serving all District projects, supplied feed material and special chemicals.

MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 1 - GENERAL FEATURES

SECTION 1 - INTRODUCTION

1-1. Purpose. - The purpose of the Gaseous Diffusion (K-25) Project was to accomplish the concentration of Uranium-235 on a large scale. A production plant was to be engineered and built to handle a volatile, uranium-containing process material in the gaseous state, and utilize the principle of molecular effusion so as to effect the separation of U-235 from the more abundant, non-fissionable, U-238, through the use of a long series of diffusion stages, in each of which a slight enrichment in concentration was achieved.

1-2. Scope. - In order to accomplish this objective, a major program of fundamental research, development, engineering, design, construction, and operation was undertaken. Industrially, gaseous diffusion represented an entirely new and untried unit operation. Moreover, the process material was a new chemical never previously handled except in small quantities on a laboratory scale. Research and development activities were centered in various university and industrial laboratories, chiefly Columbia University, Princeton University, Ohio State University, California Institute of Technology, and the laboratories of the Kellex Corporation, the Linde Air Products Company, the Bakelite Corporation, the Western Electric Company, and the Interchemical Corporation. Design and engineering were the responsibility of the Kellex Corporation and were carried out by its own staff with the cooperation of ninety-six contractors from whom major items of equipment were procured. The major portion of the K-25 plant at Oak Ridge was constructed by the J. A. Jones Construction Company, Inc., with the aid of about sixty subcontractors. The other principal prime construction contractors were Ford, Bacon and Davis, Inc., the William A. Pope Company, the A. S. Schulman Electric Company, and the Combustion Engineering Company, Inc. Each of these was assisted by several subcontractors. Plant operation is carried on by the Carbide and Carbon Chemicals Corporation.

1-3. Authorization.

a. Basic Authorization. - All action in connection with the institution and prosecution of the K-25 Project was taken, and the necessary funds appropriated, in accordance with certain acts of Congress which are described in Book I, Volume 1. Under the authority vested in him by these Acts, the President issued orders and authorizations which are also described in that volume.

b. Military Authorization. - Major General Leslie R. Groves directed or authorized the general policies and directives under which the Manhattan District carried out the work. The S-1 Committee of the OSRD, and the Military Policy Committee, registered their general approval of the basic decisions involved.

1-4. Administration. - As with other projects of the Manhattan District, the bulk of the work done within the K-25 Project was carried on under War Department contracts. Major prime contractors arranged for the performance of subsidiary or specialized portions of the work under subcontracts which were let with the approval of the District.

K-25 contracts were administered by various Manhattan District offices set up in the field and at the diffusion plant site, each headed by an authorized representative of the Contracting Officer. The administrative organization is described in Section 8. Further details are presented in subsequent volumes.

SECTION 2 - BASIC THEORY

2-1. Nuclear Fission. - With the momentous discovery by the German scientists, O. Hahn and F. Strassmann, in 1938, of the phenomenon of nuclear fission in uranium, a turning point in the course of modern physics was reached. The effect was one in which the element uranium was converted or transmuted into different elements, mass was converted into energy according to the predictions of Albert Einstein, new elements of transuranic atomic numbers were synthesized, and a tremendous reservoir of hitherto unleashed power was uncovered. With the subsequent realization that the breaking up of a uranium atom was initiated under proper conditions by the impact of a neutron, and further that several neutrons were released at high speed among the fission products, it was realized that this vital reaction might be made to sustain itself as a chain reaction. In other words, the conversion of part of the mass of a nucleus into energy could be multiplied billions of times within a very small fraction of a second. The fission phenomenon was subsequently shown to be due to the Uranium-235 isotope, and scientists turned their attention to the study of methods for separating this isotope from the more abundant Uranium-238.

2-2. Concentration of Uranium-235. - The element uranium exists naturally in the form of various compounds all of which contain the metal as U-238 - 99.28 per cent, U-235 - 0.714 per cent, and U-234 - 0.006 per cent. This third component, present in such a small amount, will be disregarded in further discussions, and the concentration problem may be visualized as one of separating U-235 from U-238. The goal of the Manhattan District was to make available for military use the atomic energy released as a product of the fission reaction. The scope of the K-25 Project includes the enhancement on a large scale of the isotopic concentration of U-235 in uranium by means of the process of Gaseous Diffusion.

a. <u>Separation of Isotopes.</u> - The task of separating isotopes is well known to be complicated by the very nature of the problem. Thus isotopes of an element are identical as far as atomic number, and therefore chemical properties, are concerned. The distinction is one of structure and weight of the nucleus. Attempts at separation must be based upon differences in atomic weight. Methods employed must be physical rather than chemical, and further, they must make use of a difference between isotopes which is very slight; that is, the atomic weights of elements ordinarily differ by only a small number of mass units. The problems are particularly difficult in the case of uranium, which is the heaviest of all atoms in the classical periodic table. Thus a difference of three mass units between the atom of U-235 and that of U-238 amounts to only 3 parts in 238 (using the more abundant isotope as a basis for calculation) or 1.3 per cent. Slight as this difference is, it is significant, and within the Manhattan District, the separation has been effected by means of Thermal Diffusion (Book VI), by the Electromagnetic Method (Book V), and by the Gaseous Diffusion Method, which is the object of the K-25 Project.

b. <u>Gaseous Diffusion.</u>- A more accurate designation would be "molecular effusion" since the method is based upon the effect noted by Thomas Graham in 1829 wherein molecules in the gaseous state tend to flow or "effuse" through narrow apertures at rates which under given conditions of temperature and pressure, are inversely proportional to the square root of the density or molecular weight. Thus, if a mixture of gases is confined within a container possessing a small opening, the lighter molecules will tend to escape more rapidly than the heavier ones, and a means is available for separating molecules according to mass. It is important to note that the size of the aperture must be of the same order of magnitude as the distance travelled by individual molecules between collisions with one another. Larger openings would permit ordinary "viscous" flow of the fluid mass without any separative effect.

2-3. Application of Theory.

a. Process Material. - Elemental uranium is a dense, heavy metal. The process calls for a gaseous process material, and the first requirement is therefore to obtain a compound of uranium in such form that it will be susceptible to processing by this method. As will appear in more detailed discussion (Vol. 2), the material, uranium hexafluoride (UF_6), presented itself, not without a series of important disadvantages, but nevertheless as the only known uranium-containing substance which could be handled in the gaseous state. Since the atomic weight of fluorine is 19, the molecular weight of $U^{235}F_6$ is 349, and the molecular weight of $U^{238}F_6$ is 352. It is important and fortunate that the situation is not complicated by variation in the atomic weight of fluorine, i.e., fluorine possesses no isotopes of its own. Thus the difference of three mass units between the atoms of U-235 and U-238 results in a difference of three mass units between the molecules of $U^{235}F_6$ and $U^{238}F_6$. Having chosen UF_6 as the working substance, however, this difference now amounts not to three parts in 238, which is already discouragingly small, but to three parts in 352, or 0.85 per cent. Another disadvantage of the use of a fluorine-containing compound is the extreme corrosiveness of the substance. The problems introduced by this factor are discussed in Paragraph 5-3.

b. Process Equipment. - Having settled on a suitable process material, the best means must be chosen of exploiting the Gaseous Diffusion phenomenon on a practical scale. At the K-25 Plant, as now in operation, the basic unit of operation is the diffusion "stage". A stage is made up of four elements as illustrated in Figure 1: diffuser, cooler, pumps, and control valve. The diffuser is a piece of mechanical equipment which includes, supports, and encloses the "barrier". The barrier is a porous, metallic membrane containing billions of sub-microscopic openings per square inch. The cooler is built integrally with the diffuser, and the complete unit is called a "converter". The cooler removes the heat of compression caused by pumping, and maintains the process temperature at the specified point. The function of the control valve is to regulate process flow and pressure at the desired values. It is emphasized that Figure 1 is highly schematic, and is intended to aid in the visualization of process principles only. Detailed description of the various items, as well as reasons for selection and arrangement, are left for Volume 3.

c. Arrangement. - Since only slight enrichment can be accomplished in one stage, it is necessary to connect a great many in series to form a "cascade", a schematic representation of which is presented in Figure 2. The stage "B" pump supplies the converter with diffused gas from the stage below, mixed with undiffused gas from the stage above. The "A" pump moves diffused gas or "diffusate" leaving the converter to the suction of the "B" pump of the next higher stage. That portion of process gas which does not pass through the barrier is recycled to the next lower stage. Process feed to the plant is introduced at a point located about one tenth the distance from the bottom to the top of the cascade. The operation is a continuous one; with respect to time, the pressure, temperature, flow rate, etc. are constant at any point in the plant. At each stage, pressures and flow rates are so maintained as to allow one half of the process gas entering a converter to diffuse through the barrier and leave as enriched diffusate. The remaining, undiffused, half leaves as partially depleted material. It follows that the amount of material entering each stage becomes progressively less in stages further removed from the point of feed introduction. For this reason, the size of equipment should, in theory, vary continually from stage to stage. Rather than make each stage a trifle smaller or larger than the preceding one, necessitating thousands of sizes of pumps, converters, and other items, together with suitable spares, four standard sizes of equipment were chosen, the plant divided into "sections", and equipment size made uniform throughout a section, but smallest in those sections farthest from the feed point.

d. Nomenclature. - To avoid confusion in subsequent discussions it is well to lay down certain conventions at this point. The term "A-stream" (Fig. 2) is used to denote the flow of material which is advancing toward the top of the plant, consisting of "diffusate" or that fraction of the process gas fed to a converter which finds its way through the barrier before leaving the unit. The "B-stream" is the remaining portion which passes through a given converter without diffusion through the barrier. It flows toward the bottom of the plant. In this connection, "top" refers to the end of the plant at which desired product, rich in U-235, is drawn off, and "bottom" refers to the opposite end, where depleted material, or waste, is withdrawn. "Enrichment" and "enhancement" are used interchangeably to denote the increasing in concentration of U-235.

SECTION 3 - PLANNING OF THE PROJECT

3-1. Beginning of the Project.

a. Preliminary Work under OSRD. - Various investigators, particularly a group at Columbia University, did much to develop the theory of the gaseous diffusion process between January 1939 and July 1941, at which time the first of the OSRD contracts (OEMsr-106) was executed for the investigation of this method as applied to the separation of uranium isotopes. These investigations were supplemented by other OSRD contracts, including one (OEMsr-406) with the M. W. Kellogg Company for engineering studies and experimental investigation. Utilizing the fundamental data obtained at the Columbia University installations, in addition to their own experimental findings, the Kellogg Company designed a diffusion pilot plant, devised a process flow diagram for a large scale production plant, and made preliminary designs of principal mechanical equipment. This work is summarized in a report entitled "The Diffusion Plant-First Progress Report" (Vol. 3).

b. Selection of Process. - The construction of the production plant was later authorized on the basis of these studies. On 12 November 1942, the Military Policy Committee recommended that the Kellogg Company should proceed with the construction of the pilot plant and that, subject to the concurrence of the OSRD S-1 Executive Committee, and of General Groves, they should be authorized to engineer a production plant the size of which was tentatively set at 600 stages. Before a final decision was made, however, General Groves appointed a Reassessment Reviewing Committee on 21 November 1942, to review the gaseous diffusion process as to its own potentialities and merits, in contrast to the electromagnetic method for separating isotopes of uranium, and the pile process for producing plutonium. Their recommendation was to proceed immediately with the design and construction of a 4600-stage diffusion plant with a capacity of 1 kilogram per day of U-235 at a concentration of 90 per cent. Acting on this report, the Military Policy Committee authorized General Groves to arrange for the construction of a 4600-stage diffusion plant, with the M. W. Kellogg Company as engineers. These arrangements were concluded in secret letter contract W-7405-eng-23 executed 14 December 1942, for design, development, and procurement services for a plant to enrich U-235 in uranium hexafluoride to 90 per cent by gaseous diffusion. For security and accounting reasons, the Kellogg Company created a totally-owned subsidiary organization, called The Kellex Corporation, which was to be wholly devoted to the K-25 undertaking.

c. Selection of Plant Site. - Immediately following the decision to build the production plant, consideration was given to the selection of a suitable site. The selection of the Clinton Engineer Works (App. A1) as the location for the diffusion plant is described in Volume 3. The first internal site inspection (Vol. 4) for the purpose of locating the several areas of the Gaseous Diffusion Project was made on 18 January 1943 by representatives of the Manhattan District Engineer, the Kellex Corporation, and the Carbide and Carbon Chemicals Corporation, which ~~had been~~ were to be engaged to operate the plant. Factors affecting the selection of suitable sites within the Clinton Engineer Works were topography, safety distances, dispersion of plants, rail service, water, and power facilities. Nineteen possible sites within the area were considered. The final location is shown ~~in an enclosed~~ on an outline map (App. A2) of the Clinton Engineer Works.

S-2. Research and Development. - Fundamental research (Vol. 2) was concentrated in the SAM Laboratories of Columbia University, originally under OSRD contracts, OEMsr-106 and OEMsr-412, and after 1 May 1943, under Manhattan District contract W-7405-eng-50. This work included theoretical studies of large scale production, and experimental investigation of process gases, corrosion properties of materials satisfactory for use in equipment such as pumps and seals, etc., and methods of manufacturing a suitable diffusion barrier. On 1 February 1945, responsibility for the SAM Laboratories was transferred to the Carbide and Carbon Chemicals Corporation under Supplemental Agreement No. 4 to contract W-7405-eng-26. The Kellex Corporation was also committed to an extensive research and development program under contract W-7405-eng-23. The Bell Telephone Laboratories (Western Electric Company) studied the preparation of powdered nickel barriers under contract OEMsr-1125. The preparation and purification of fluorocarbons were investigated at Ohio State University under contract OEMsr-554. These OSRD contracts were later replaced by Manhattan District contracts, and the program expanded to include research by Princeton University, the Interchemical Corporation, the California Institute of Technology, and certain other industrial laboratories. Assistance was also obtained from British sources.

S-3. Design and Engineering. - The Kellogg-Kellex-War Department contract stipulated that Kellex have overall responsibility for planning, engineering, design, and development of the Gaseous Diffusion Project (Vol. 3). Because of the immensity of the Project, the work was performed in part by a large number of firms under the supervision of the Kellex Corporation. In many cases, problems were solved by the joint effort of several contractors. Assistance was also obtained on various theoretical and design problems from a group of British scientists and engineers.

a. Policy Changes. - The original plan to design a plant for the production of 90 per cent U-235 was conceived before all equipment problems had been solved, and before the respective capabilities of the various isotope concentration methods were clearly realized. In August 1943, General Groves requested the Kellex Corporation to report on the probable cost and completion dates for 5, 15, 36.6 and 90 per cent production plants. Based upon these data, the construction of a 36.6 per cent production plant was authorized by General Groves on 18 August 1943. Although interest in higher concentrations was shown early in 1945, this idea was abandoned on 16 March 1945 after intensive study of the performance and capabilities of the electromagnetic and gas diffusion plants. On 31 March 1945, the District Engineer authorized a side feed addition to the 36.6 per cent plant, which greatly increased its output of this product for use in the electromagnetic plant. This addition was known as the "K-27 Plant". K-27, like K-25, is a gas diffusion plant designed to concentrate U-235, its function being to provide K-25 with an enriched feed. K-27 is practically a duplicate of one of the sections of K-25. Only those changes were made which were absolutely necessary or which could be made without delaying the progress of the construction. The K-27 addition should be considered as a part of the K-25 Project. Succeeding volumes will accordingly treat of the various development, engineering, and construction phases of this portion of the Project at appropriate points throughout the body of the text.

3-4. Construction. - The Kellex Corporation was responsible for engineering supervision and overall job progress direction. Construction (Vol. 4) was to be handled by two principal cost-plus-fixed-fee prime contractors, the J. A. Jones Construction Company, and Ford, Bacon, and Davis, Inc., who served also in a supervisory capacity. Under contract W-7421-eng-11, dated 18 May 1943, the J.A. Jones Construction Company, with their own forces and subcontractors, in cooperation with three other prime contractors, were to build the facilities in the power house area. These other three prime contractors, William A. Pope Company, A. S. Schulman Electric Company, and Combustion Engineering Company, were awarded smaller contracts, and their activities were coordinated and supervised by the Jones Company. The J. A. Jones Construction Company, with their own forces and subcontractors, also built the facilities in the process area and the administration area. The other principal prime contractor, Ford, Bacon, and Davis, Inc., with their own forces and subcontractors, built the conditioning area facilities under contract W-7405-eng-19. Electrical power lines into the Project were built by the Tennessee Valley Authority under cost-plus-fixed-fee contracts. The site for the power house was approved by the Manhattan District on 3 May 1943, and for the process and conditioning facilities on 24 June 1943. The J. A. Jones Construction Company also constructed the K-27 plant.

3-5. <u>Operation.</u> - The principal operator chosen for the gaseous diffusion plant is the Carbide and Carbon Chemicals Corporation under contract W-7405-eng-26 dated 18 January 1943 (Vol. 5). They were assisted by Ford, Bacon, and Davis, Inc., builders of the conditioning plant, who contracted to operate this facility through May 1945, when Carbide could assume this task. The fluorine plant was operated by its designer, the Hooker Electrochemical Company, until 1 February 1945.

SECTION 4 - DESCRIPTION OF THE PROJECT

4-1. Description of Site.

a. Location. - The gaseous diffusion plant is located within the Clinton Engineer Works, Oak Ridge, Tennessee (App. A1, A2, A3). The site is the northwest corner of the military reservation, near Poplar Creek, and due west of McKinney Ridge.

b. Main Features. - The plant site is fairly level and possesses good drainage and foundations. It has natural ridge protection and is sufficiently distant from other C.E.W. plants to satisfy dispersion requirements as a safeguard against possible enemy bombing action. The Clinch River and Poplar Creek provide a source of water for process and power purposes. The relative proximity of the Southern Railroad, and the accessibility of the TVA, readily permitted the construction of a railroad spur for freight, and the installation of emergency power lines.

4-2. Description of Facilities. - The diffusion plant is divided into four main areas, including, respectively, the main process buildings, conditioning facilities, power plant, and administration buildings. In addition the K-27 plant forms a supplementary process area, which was not originally contemplated, but which was authorized in the spring of 1945, and engineered and constructed after the bulk of the K-25 Project proper had been brought to completion.

a. Process Area. - A plot plan of the K-25 plant area is shown in Appendix A4. The process area includes the main cascade, certain auxiliary facilities, and a number of service installations.

(1) Main Process Buildings. - The diffusion process takes place within a series of 54 contiguous buildings arranged to form a single huge "U"-shaped structure. A total of 2,892 diffusion stages is provided. Each building in this cascade contains from three to fourteen "cells". The cell is the smallest individually operated unit of the cascade. It is a group of six stages contained within a single enclosed steel cubicle. Dry air is supplied continuously to the cell cubicles, and the internal temperature is controlled thermostatically at operating levels ranging from 90° to 120°F. A cell can be started up or shut down independently of the other cells of the plant, and can be added to, or removed from, the cascade at will. A building can also be removed or added to the cascade without interruption of the operation of other buildings. Thus, the continuous operation of the cascade is not dependent upon the continuous operation of every stage, every cell, or every building. There are six sections containing 2,622 stages above the feed point, and three sections containing 270 stages below the feed point.

(2) Auxiliary Process Facilities. - In addition to the cascade proper, there are five auxiliary process systems. These are: (1) the feed purification system, designed to purify, distill, and feed uranium hexafluoride to the cascade; (2) the purge system which removes light diluents from the cascade; (3) the surge and waste system which provides a means for damping process pressure fluctuation and removing depleted waste material, (4) the process gas recovery system, which permits of evacuation of process equipment to be shut down for repair, and (5) the product system for removing the final product of the plant.

(3) Service Installations. - Facilities were constructed in the process area for supplying dry air for instruments, pump seals, and all equipment enclosures, for furnishing dry compressed air for pneumatic instruments, for furnishing process cooling water, and for storing and purifying the special process coolant. Shops are available for the calibration, repair, and cleaning of the pneumatic and electrical instruments and equipment.

b. Conditioning Area.

(1) Conditioning Building. - The principal building in this area is the Conditioning Building, where major items of process equipment, such as pumps and diffuser units, are treated with fluorine gas to form a surface fluoride coat which is inert to process gas, thereby eliminating corrosive reaction between equipment and process fluid. This building also houses facilities for chemically cleaning, and vacuum testing process piping, valves, and various other pieces of equipment before installation, and a precision machine shop for repairing and adjusting process equipment.

(2) Fluorine Plant and Disposal System. - A plant for the electrolytic generation of fluorine gas for conditioning purposes is located in this area. Suitable facilities for purifying and bottling conditioning gas for use in the process area are provided, as are means for disposing chemically of waste and contaminated gas and acids from the conditioning building.

(3) Nitrogen Supply. - Dry nitrogen gas is distributed from this area through pipe lines to the process area. This material is received in liquid form and vaporized prior to distribution. It is

chemically inert to process gas, and is used to protect the interior of process equipment from contamination by air, as pump sealant, as a conditioning diluent, for purging purposes, and in certain instruments.

(4) Auxiliary Steam Plant. - An auxiliary steam plant is provided, chiefly for supplying heat to various buildings. It includes six forced draft boilers with a total capacity of 270,000 pounds per hour of steam at 175 p.s.i.g.

c. Power Plant Area. - The principal buildings located in this area are: (1) the boiler house, which houses the three coal-fired boilers and operating offices, each boiler being designed to produce 750,000 pounds per hour of steam at a pressure of 1,325 pounds per square inch and a temperature of 935°F; (2) the turbine room, containing 14 turbo-generators, with a combined rating of 238,000 KW; (3) The main switch house, containing electrical equipment for the regulation of power, and an auxiliary switch house for control of power plant operations; and (4) the pump house for supplying condenser water. Two coal dumps provide a total storage capacity of 250,000 tons.

d. Administration Area. - In this area are located office buildings, a fire and ambulance station house, guard headquarters buildings, a dispensary, a cafeteria, a laundry, and four laboratory buildings completely equipped for plant control and assay work on process material.

e. K-27 Area. - The K-27 plant (App.A5) constitutes a structurally separate annex to the main process area. Its function is to increase substantially the overall output of the greater K-25 Project by supplying preliminarily enriched feed to the main cascade. It is located just southwest of the original "U" structure, and is connected to it by means of process gas lines in such a way as to form a "cascade of cascades". It consists of a 540-stage cascade similar in all important respects to the main cascade. Certain specific differences in design are discussed in Volume 3. It is complete with its own set of auxiliary process facilities, including such items as a feed purification system, surge and waste systems, and purge and product facilities.

4-3. Size of the Project. - The K-25 process has been called "the largest physico-chemical process in the world". Payrolls of the operating company have reached a peak of 11,000 names. Construction personnel at one time totaled over 25,000. Since the present volume is intended as an introductory survey of aims, scope, and problems, a brief indication is made of the unusual magnitude of the Project, so that the reader may obtain the proper perspective before proceeding to subsequent volumes and more detailed accounts of progress of research, evolution of design, construction and procurement schedules, etc.

a. Geographical Distribution. - Mention has been made of the large number of participating institutions and manufacturing firms. It may be noted that proper supervision, control, and coordination of the various research, development, design, and manufacturing activities necessitated the maintenance of Manhattan District Area Offices in Decatur, Illinois; Detroit, Michigan; and Milwaukee, Wisconsin. Two separate units were maintained in New York City. A third office in New York City, as well as Area Offices in Tonawanda, Wilmington, and Cleveland, were not exclusively devoted to the prosecution of the gaseous diffusion portion of the Manhattan Project, but participated extensively in certain phases of the K-25 undertaking. The production plant itself is situated at Oak Ridge, Tennessee.

b. Size of the Plant. - The K-25 area is situated on a 5,000-acre tract of land, 60 acres of which are encompassed by the 54 contiguous buildings comprising the "U"-shaped structure which houses the main cascade and light diluent purging system. The "U" is one mile in perimeter and one quarter mile across. The process buildings of the main and auxiliary cascades are all four-story structures, and contain the process equipment including, in part, approximately 3500 diffusion stages with a total geometric barrier area of some 7,500,000 square feet, 8700 process and coolant pumps, 100 miles of process piping, and 130,000 instruments, the majority of which are specially engineered and developed to meet the requirements of the K-25 Project. About one half million valves are required to operate the gaseous diffusion plant. Among the auxiliary facilities is included one of the largest dry air installations ever constructed, which was designed for the purpose of maintaining without interruption some 6,000,000 cubic feet of enclosed volume at a dewpoint of -40°F or better. It has a capacity of 75,000 CFM of air at a dewpoint of -75°F. Included in the installation are 1,000 tons of refrigeration equipment. The K-25 inventory of special process coolant, a chemical (perfluorodimethylcyclohexane) especially developed to meet the unusual requirements of the process, exceeds 200,000 gallons and is valued at $20,000,000. Cooling water for process use is supplied by a pumping plant with a capacity of 170,000,000 gallons per day which is equivalent to the normal requirement of a city of 5,000,000 inhabitants. A 2,250,000 pound per hour boiler plant, generating superheated steam at 1,325 p.s.i. and 935°F, supplies a turbo-generator plant rated at 238,000 KW. The K-25 power plant is generally conceded to be the largest single steam-electric station ever built in one operation. Included within the plant area are approximately 80 miles of roads, 15 miles of railroads, 12 miles of storm sewer lines, 25 miles of sanitary sewer lines, and 58 miles of sanitary water lines. As of 30 September 1946, over 57,000 car loads of freight had been received at the site.

SECTION 5 - MAJOR PROBLEMS

5-1. General. - It is the purpose of this section to formulate briefly the outstanding problems encountered in the prosecution of the Gaseous Diffusion Project, and to indicate their number and magnitude, so that in the light of these problems the reader will be better able to follow and appreciate the many ramifications of the K-25 undertaking, as well as the reasoning applied, the decisions made, and the methods chosen throughout the course of the work as traced in succeeding volumes. In visualizing these difficulties, it should be borne in mind that all were faced under the intense pressure of wartime urgency, under the restrictions imposed by the obvious necessity of secrecy and security, and during a period of severe shortages of labor, materials, and technically qualified personnel. In the solution of these problems it became necessary to employ the development and manufacturing facilities of dozens of university laboratories, and hundreds of industrial concerns. In many cases the simultaneous prosecution of numerous interlocking phases of the research and design complicated the scheduling and accomplishment of the work by necessitating the release of plans and designs for certain portions of the Project, even though it was realized at the time that these decisions might be affected by other factors not yet fully developed. This made necessary extensive study and careful re-checking, under separate assumptions, in order to ensure the necessary degree of flexibility.

5-2. Barrier. - Since the barrier is the very heart of a gaseous diffusion plant, the evolution, development, and large scale production of this material was the number one problem throughout the course of the Project. It was required to develop and fabricate, on a large scale production basis, a previously unknown, structurally rugged, porous membrane containing billions of sub-microscopic openings per square inch. As shown in Volume 2, to be effective as a separating medium, the diameter of the openings must be on the same order of magnitude as the mean free path of the process gas molecules, the average distance travelled by a molecule between two successive collisions with other molecules. This results in a specification of aperture diameter at a dimension which is less than the wavelength of visible light. Moreover, in order to attain practical production rates, the barrier must contain li~~t~~terally billions of these openings per square inch.

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The workmanship and durability of product must be such as to avoid the formation of pinholes or invisible cracks which would permit the mass flow of non-enriched process fluid through the barrier. Finally, the nature of the material must not only be such as to resist attack by the violently corrosive process fluid, uranium hexafluoride, but it must also be able to withstand exposure to the conditioning gas to be used to form protective films on the internal surfaces of the converter, namely, fluorine gas, which is the most reactive element known.

5-5. Corrosion. - The factor of corrosion, as considered in connection with barrier requirements, played an equal role in determining the material of construction for any pipeline, valve, or piece of equipment which was to be used in contact with uranium hexafluoride or fluorine gas. It was realized from the outset that corrosion could result in any of four undesirable effects: contamination of the process stream, deterioration of equipment, and particularly plugging of the barriers, and consumption of precious process material. Within the diffusion plant, large volumes of process gas, at high temperatures and rates of flow, are recirculated many times through miles of piping, pumped through thousands of pieces of equipment, and passed across and through many acres of barrier surface. A rate of corrosion per unit area of exposed equipment surface which would ordinarily be considered moderate or low, when multiplied by the tremendous total exposed area within the K-25 plant would lead to such a high total rate of consumption of process fluid as to become prohibitive. Measuring consumption rates on a per-pound-basis of process material handled, the maximum numerical values permitted must be very low because of the huge volumes handled in comparison with the small amounts of product obtained per day. These considerations were intensified not only by the high monetary value of the process fluid, especially in the higher sections of the plant, but even more so by the critical wartime strategic value of the product. Detailed study and analysis of the problem were, in fact, to lead to specification of allowable corrosion rates at values below that of stainless steel in air. The immensity of the problem posed by this factor was quickly apparent in consideration of the fact that the material to be processed was a chemical never previously handled in industry even on a small scale, and one which has a tendency to react with extraordinary aggressiveness with nearly all known materials of construction.

5-4. Contamination. - Contamination by traces of foreign materials will cause many of the same harmful effects as interaction of process fluid with structural materials: barrier plugging, process stream dilution, and UF_6 consumption. In addition, a distinct and serious "special hazard" would be introduced by hydrogenous materials, e.g. moisture, finding their way into the system. Such an occurrence leads to an accumulation of hydrogen fluoride in the higher, more enriched sections of the plant. The possibility of a disastrous chain reaction setting in as a result is considered further in Paragraph 5-9. Cleanliness specifications were to become necessary approaching those of a hospital surgery ward. A fingerprint on a process surface would fail to pass these specifications. The vast program of cleaning, conditioning, and maintenance of cleanliness, which had to be set up, was complicated by the size of the Project, by the thousands of varying activities being carried on simultaneously by different crafts during construction and installation, and by the early realization that certain phases of the cleaning and conditioning would have to be handled and supervised at the point of manufacture of many items of equipment in factories scattered throughout the country.

5-5. Leakage. - The process is operated at pressures below atmospheric, but leakage of air into the system is absolutely intolerable. This is primarily because of the ruinous results of the interaction of the water vapor in the air with the process fluid. Such an occurrence would consume process material, and form non-volatile uranium oxyfluoride as a hydrolysis product, with consequent plugging of the barriers, and would contribute to the accumulation of hydrogenous material within the system. Air inleakage will also dilute the process stream with oxygen and nitrogen, thereby impairing operating efficiency. These effects are so intolerable that it became necessary to make sure that absolutely no atmospheric air could find its way into the process system. Problems posed included the fabrication of all process equipment in such manner that atmospheric leakage was nil. This was to be accomplished by development of new and unusually leakproof welding techniques, by incorporation of unique tightness features in all process equipment, and by providing a special, dry air enclosure around the entire process system, the total volume of which was finally to exceed 6,000,000 cubic feet. Finally, a vacuum technique had to be developed by means of which hundreds of thousands of routine leak tests and repairs could be made, both at the site and in the plants of many equipment manufacturers, at speeds approximately forty times that of any previous high vacuum testing, and using scientific instruments especially developed and designed for the K-25 Project.

5-6. <u>Special Equipment.</u> - The unprecedented nature of the operating process, the corrosive, toxic, and expensive aspects of the process material, and the sub-atmospheric features of the operations, combined to require, almost without exception, designs and arrangements of equipment which were totally new and previously untried. The design and procurement of some 6000 process pumps, capable of operating at sub-atmospheric pressures, at high temperatures, at supersonic tip speeds, with lowest possible holdup volume, and with zero inleakage of air at the shafts; the development and manufacture of pumps for fluorine service; of vacuum valves without leakage across the seat; and pneumatic and electrical instruments in huge numbers and unprecedented designs, were some of the many staggering tasks confronting K-25 equipment engineers.

5-7. <u>Special Chemicals.</u> - Book VII treats in detail of the various phases of the program relating to special chemicals. In this section, indication is made of the type of problem posed by this portion of the Project.

a. <u>Process Material.</u> - The process requires a stable, volatile compound of uranium in which the other atoms present do not present complications by reason of isotopic variation. The only suitable material known is uranium hexafluoride. It fulfills these requirements, but has the disadvantages of toxicity, extreme corrosiveness, and high freezing point.

b. <u>Conditioning Gas.</u> - In order to "immunize", as far as possible, the internal surfaces of process equipment against attack by UF_6, a method was developed which involves the formation of a protective fluoride film by exposure at elevated temperature to elemental fluorine. Except for a single pilot plant installation, no industrial utilization of fluorine had ever been undertaken prior to the K-25 Project. Estimated conditioning needs at the gaseous diffusion plant, led to the decision to construct a special facility at the site to produce 200 pounds per day of the substance. Since gaseous fluorine is the most aggressive element known, highly toxic, highly corrosive, and a violent supporter of combustion, the design and operation of this

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unit posed no small problem. It was necessary to work out safe methods of handling, compressing, and storing the gas

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Finally, an effective means was required for safe disposal of spent conditioning gas, contaminated, diluted, and still high in fluorine content.

c. Test Fluid. - It was desired to discover, develop, and make available for plant use, a non-hydrogenous, gaseous material which would be non-corrosive, and preferably non-toxic, for testing process equipment prior to use. The substance ultimately to be developed was n-perfluoroheptane, C_7F_{16}.

d. Sealant. - The problem of preventing inleakage of air, as well as escape of toxic and valuable process gas, at the shafts of the many thousands of process pumps, called for the selection of an inert, non-toxic, non-corrosive, sealing material. The choice and adaptation of dry nitrogen for this use, as well as for purging, instrumentation, and conditioning purposes, is discussed in Volume 3.

e. Coolant. - The possibility of inleakage ruled out the use of water or ordinary organic liquids in process coolers within the converters, since uranium hexafluoride reacts vigorously with these materials. A stable, inert, non-hydrogenous material was required, of molecular weight appreciably above or below that of UF_6, and preferably non-toxic. The boiling point would probably have to be between 40 and 260°F. The substance ultimately to be developed for this use was perfluorodimethylcyclohexane, C_8F_{16}. The chemical had never been

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commercially manufactured previously, but K-25 was to require an inventory in excess of 200,000 gallons valued at about $20,000,000.

f. Other Chemicals. - In the course of the Project it also became necessary to use large quantities of helium as a probe gas in leak detection work, and to devise lubricants, resilient valve seats, and impregnants which would be resistant to attack by fluorine and UF_6. These demands were to be met chiefly through the use of a number of especially developed highly fluorinated hydrocarbons.

5-8. Power Supply. - The operation of the K-25 plant, with its many thousands of electric motors, calls for a continuous and highly dependable supply of power. Moreover, efficient operation of process pumps was to lead to specification of a number of frequencies, differing from one another, each variable and capable of close control. The total design load was estimated at 193,000 KW. It was predicted that interruption of the power supply for more than a small fraction of a second would result in a complete plant shutdown, and that several days of lost production time would be required to restore process equilibrium necessary for plant operation. It became necessary to design and construct at the site a huge steam-driven turbo-generator plant, larger than any other ever built in a single operation, and with an extremely high reliability factor. A two-mile underground transmission duct bank was also required, as well as a distribution system including thousands of transformers, switches, relays, and circuit-breakers.

5-9. Special Hazards. - Handling the working substance of the atomic bomb presented obvious hazards which necessitated that large quantities and high concentrations be carefully controlled. Precautions taken against the possibility of a fission chain reaction are of two types: First, the capacity of every storage point, and the holdup volume of every process item containing liquid or solid UF_6 at high concentration of U-235, had to be checked to be sure that no approach would be made to the critical mass. Secondly, in consideration of the possibility of inleakage, the neutron-moderating properties of hydrogenous material, such as water and organic liquids, provided an additional reason for ruling out the use of these convenient substances for applications, such as cooling and lubrication, in regions adjacent to concentrated process material.

5-10. Preparation of Plant Site. - The reasons leading up to the choice of plant location within the Clinton Engineer Works are discussed in Volume 3. The site acquired was located in hilly country covered to a great extent with timber and underbrush. The difference in elevation between the top of the knolls and the bottom of the valleys amounted to as much as 45 feet. The nature of the plant is such that it would be impractical to attempt to arrange the equipment on a floor not entirely at one level. If the usual practice of leveling the site were followed, large areas would be covered with fill which would not be suitable for receiving footings because of subsequent settling under load. Attempt to carry footings down through fill to virgin soil would result in a network of columns of different lengths the design of which would entail a great amount of time, and the construction of which would be very difficult. It was accordingly proposed to use the method of "compacted fill". This is a recent development in the construction of dams and airfields which had not been previously used to any extent in building construction. The method required careful analysis of soil to be moved, in order to determine the exact mixtures and percentage of moisture which should be present in the fill when deposited and rolled. The fill would have to be placed in six-inch layers, water content carefully adjusted, and the deposited material carefully rolled and tamped in accordance with rigid specifications. The amount of cut and fill required was to reach an ultimate total of nearly 2,800,000 cubic yards.

SECTION 6 - SAFETY AND SECURITY

6-1. Introduction. - In addition to normal industrial hazards encountered, the toxic and corrosive nature of many of the chemicals and materials involved, and the potentially dangerous aspects of various operations and manufacturing procedures, necessitated the organization of a comprehensive safety program extending throughout the K-25 Project. The vital nature of the information obtained and handled similarly made it necessary to set up and prosecute an intensive security program. Discussion of these programs, as they pertain to research, design, procurement, construction, and operation phases of the work, is presented in succeeding volumes.

6-2. Safety Program.

a. Organization. - All major contractors were required to assign a Safety Engineer, supported by an adequate staff, to enforce safety regulations as specified by the District (Book I, Vol. 11). The Manhattan District Engineer has maintained a resident Safety Engineer at the plant site, since the start of construction, to supervise and assist these safety departments. Safety committees were frequently established to consider various anticipated hazards. One such committee was the New York Safety Committee (Vol. 3), which cooperated with various installations using process materials, in studying safe methods of handling these chemicals.

b. Safety Measures. - Employees of all contractors were instructed in the necessity and methods of safe operation as applied to their jobs. This was done by means of meetings, posters, bulletins, and other literature. For construction contractors, the handbook used as a criterion in safety and accident prevention programs was the Corps of Engineers publication entitled "Safety Requirements for Excavation - Building - Construction". Modern personnel protective equipment was provided; tools, equipment and facilities were inspected frequently for hazards and for compliance with safety regulations; and complete reports of all injuries were prepared. All District installations were provided with adequate first aid and medical facilities. As a result of this complete program, the safety record of contractors on the Gaseous Diffusion Project is outstanding.

6-3. Medical Program. - Because the process gas and fluorine were known to be extremely toxic, and since many of the special chemicals were suspected of being dangerous, the District inaugurated an extensive medical program designed to safeguard the health of personnel (Book I, Vol. 7). To supplement available information regarding the toxicity of process materials, contracts were negotiated with certain institutions for the performance of annual tests to determine tolerable concentrations of these materials. This work was not prosecuted directly in connection with K-25 activities; the investigations were carried out under the jurisdiction of the District Medical Section.

6-4. Security Program. -

a. District Organization. - In Book I, Volume 14, an account is presented of the development and establishment of the sections and offices charged with the responsibility for security administration within the District. As ultimately reorganized in February 1944, an Intelligence and Security Division was set up with

Branch Intelligence and Security Offices strategically located so as to cover all Manhattan District areas and contractors. An agent or officer from the local Branch Office was assigned to the staff of each Area Engineer.

b. Contractor Organization. - Each contractor appointed a Security Agent who enforced District security regulations, and reported to the local Intelligence Officer.

c. Security Measures. - At all facilities, educational programs were instituted to advise personnel of the necessity for absolute secrecy concerning Project affairs, and to instruct individuals as to the importance and proper methods of handling classified materials. All military and contractor personnel were investigated prior to clearance for access to classified information and restricted areas. Suitable plant protection measures were adopted at various installations, which included fencing of areas, establishment of a guard force, pass and badge control, and fire protection. In general, the plan was followed for establishing security controls as outlined in the "Protective Security Manual" dated 1 February 1943 (Book I, Vol. 14). As a result of such measures, no instance of sabotage or serious violation of security has been encountered.

SECTION 7 - COSTS

7-1. Introduction. - This book presents a discussion of all costs attributable to the Gaseous Diffusion Project (including K-27) with the exception only of costs incurred under the special chemicals development and procurement program. The latter costs are treated in Book VII.

7-2. Source. - Original and modified contract estimates presented in succeeding volumes are taken directly from each contract. All other figures are taken from the annual statement of the Manhattan District Cost Section for the fiscal year 1946.

7-3. Presentation. - The method of cost presentation used in Book II may be explained by comparison with that of the Manhattan District Cost Section, which has set up the following three main classifications, each of which includes both capital and operating costs:

a. Main Plant Program.

b. Research Program.

c. Special Operating Materials.

The first class includes design, engineering, and procurement costs which are discussed in Volume 3, construction costs which are discussed in Volume 4, and diffusion plant operation costs which are discussed in Volume 5. The second class includes research costs which are discussed in Volume 2. The third class includes the special chemicals costs which are covered in Book VII.

7-4. Cost Breakdown. - Detailed cost breakdowns according to

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TABLE 1. - COSTS

	CONTRACT PAYMENTS TO DATE	FIXED FEE PAYMENTS TO DATE	MATERIAL FURNISHED BY GOVERNMENT TO DATE	TOTAL CONTRACT COSTS TO DATE	ESTIMATED TOTAL COSTS FOR COMPLETED CONTRACTS
Research	$ 14,544,964	$ 0	$ 471,960 (credit)	$ 14,073,004	$ 15,811,663
Design, Engineering and Procurement	245,598,661	9,039,913	966,401 (credit)	253,672,173	275,449,699
Construction	193,808,333	1,494,267	7,798,933	203,101,533	207,004,739
Operation	68,648,698	1,558,030	11,413,488	81,620,216	145,437,500
TOTAL	522,600,656	12,092,210	17,774,060	552,466,926	643,703,601

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prime contracts are presented in succeeding volumes, and allocated as indicated above.

7-5. Cost Summary. - As of the end of the fiscal year 1946, the total costs attributable to the K-25 Project amounted to $552,466,926. This includes early research work (Vol. 2) done under the auspices of the Office of Scientific Research and Development. As of the same date the current estimate for total costs at completion of contracts was $643,703,601. A complete summary is presented in Table 1.

SECTION 8 - ORGANIZATION AND PERSONNEL

8-1. General. - This section outlines the K-25 portion of the Manhattan District administrative organization. Details regarding the organization of the various area offices, as well as of the major contractors, are presented in subsequent volumes.

8-2. K-25 Administrative Organization.

a. Original Organization. - The K-25 Project was originally under the supervision of an Officer-in-Charge, or Unit Chief, who reported directly to the Manhattan District Engineer. The Unit Chief was aided by the New York Area Engineer, who administered design, engineering, and equipment procurement contracts; by the Columbia Area Engineer, who administered contracts for fundamental research and development; and by Construction and Operations Officers stationed at the plant site to supervise the contracts of construction and operating contractors. Appendix B1 shows a typical organization chart (effective 31 March 1945) representing line of authority from the District Engineer to the site and area offices, together with the phases of work involved. It will be noted that the New York Area was assisted by three sub-areas located in Decatur, Illinois; Detroit, Michigan; and Milwaukee, Wisconsin. This charts also shows the relationship between the K-25 Project and the Madison Square Area and its sub-areas. The Madison Square Area supplied feed material and special process chemicals to the Gaseous Diffusion Project. Organizationally, the Madison Square Area was independent of the K-25 Officer, reporting directly to the Manhattan District Engineer and serving all projects of the District (Book VII).

b. Reorganization. - On 1 May 1946 the K-25 administrative organization was headed by a Division Chief, and the position of K-25 Construction Officer was discontinued, duties of this officer being assumed by the Chief of the K-25 Construction Section reporting to the Chief of the Construction Division. Appendix B2 shows the latest detailed K-25 Division organization chart.

c. Personnel. - Officers occupying key positions in the K-25 organization are listed in Appendix C1. On 7 January 1943, Lt. Colonel J. C. Stowers assumed the dual position of Officer-in-charge and New York Area Engineer. On 18 January 1945, he was succeeded as Officer-in-charge by Colonel W. J. Williams who served in this capacity until the organization change of 1 May 1946. Since that date, Lt. Colonel R. W. Cook has served as K-25 Division Chief. Lt. Colonel Cook had been serving as Operations Officer since 3 October 1944, having succeeded Major J. J. Moran at that time. The post of Construction Officer was held by Lt. Colonel W. P. Cornelius from 31 July 1943 until 28 February 1946, at which time Major Noland Varley assumed this position. All personnel shown on the organization chart of Appendix B2 (which was drawn up as of 1 November 1946) are holding these positions at present.

MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 1 - GENERAL FEATURES

APPENDIX "A"

MAPS

No.	Title
1.	Map of Clinton Engineer Works and Vicinity.
2.	Map of C.E.W. Reservation, showing location of K-25 Plant.
3.	Plot Plan of K-25 and K-27.
4.	Plan of Process, Conditioning, and Administration Areas.
5.	Plan of K-27 Area.

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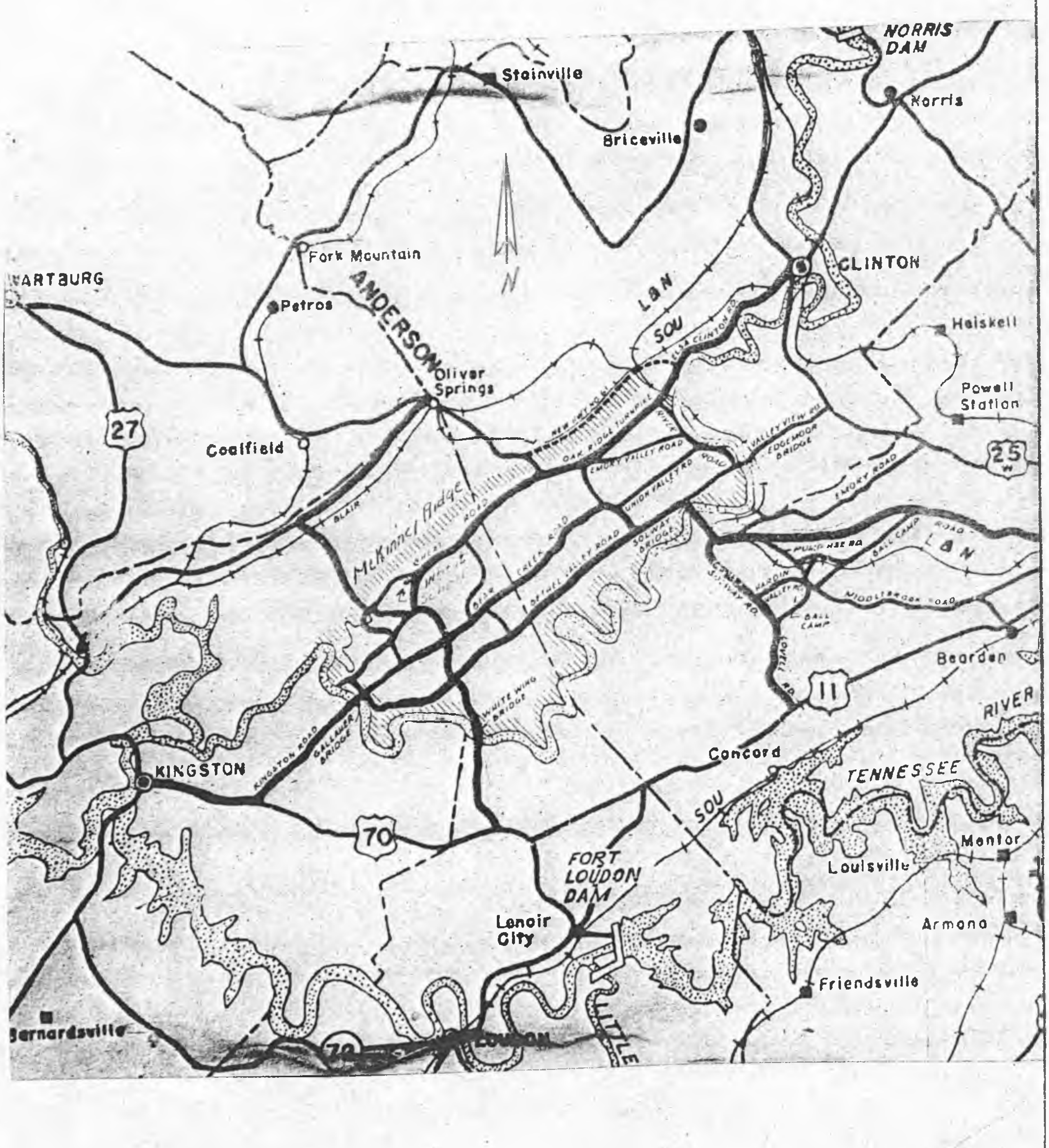

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SECRET

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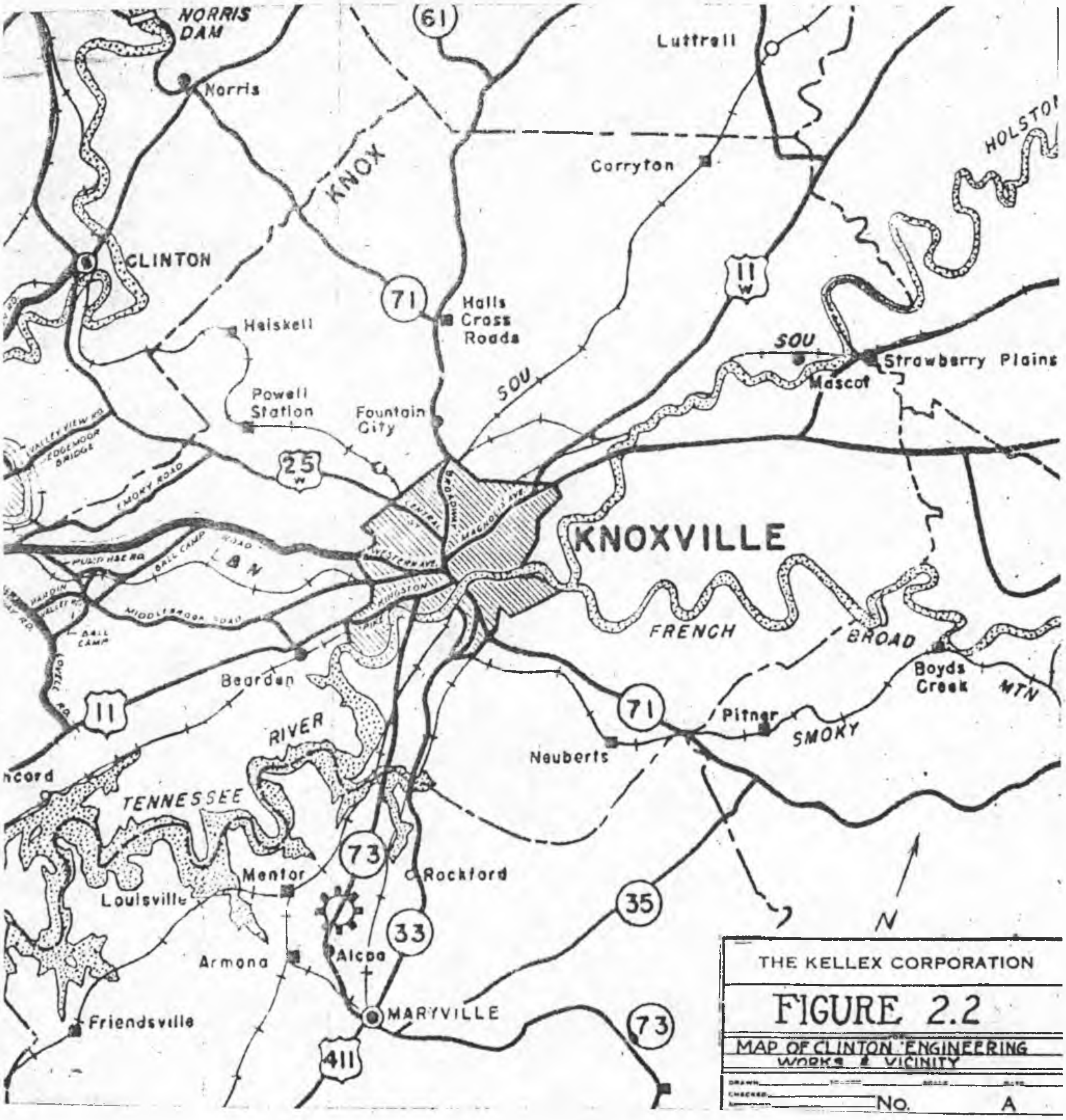

THE KELLEX CORPORATION

FIGURE 2.2

MAP OF CLINTON ENGINEERING WORKS & VICINITY

NO. A

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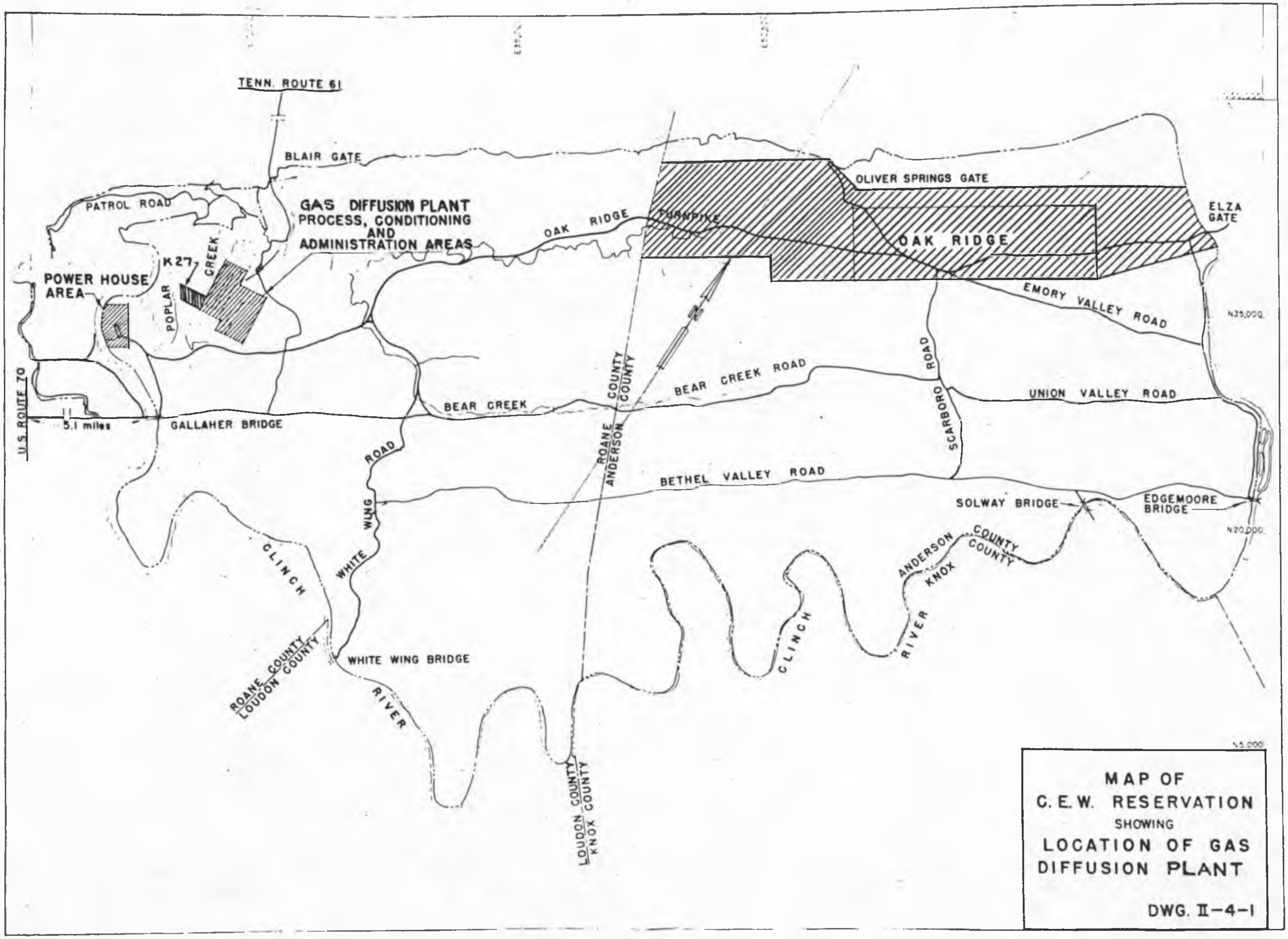

MAP OF
C. E. W. RESERVATION
SHOWING
LOCATION OF GAS
DIFFUSION PLANT

DWG. II-4-1

A3-1

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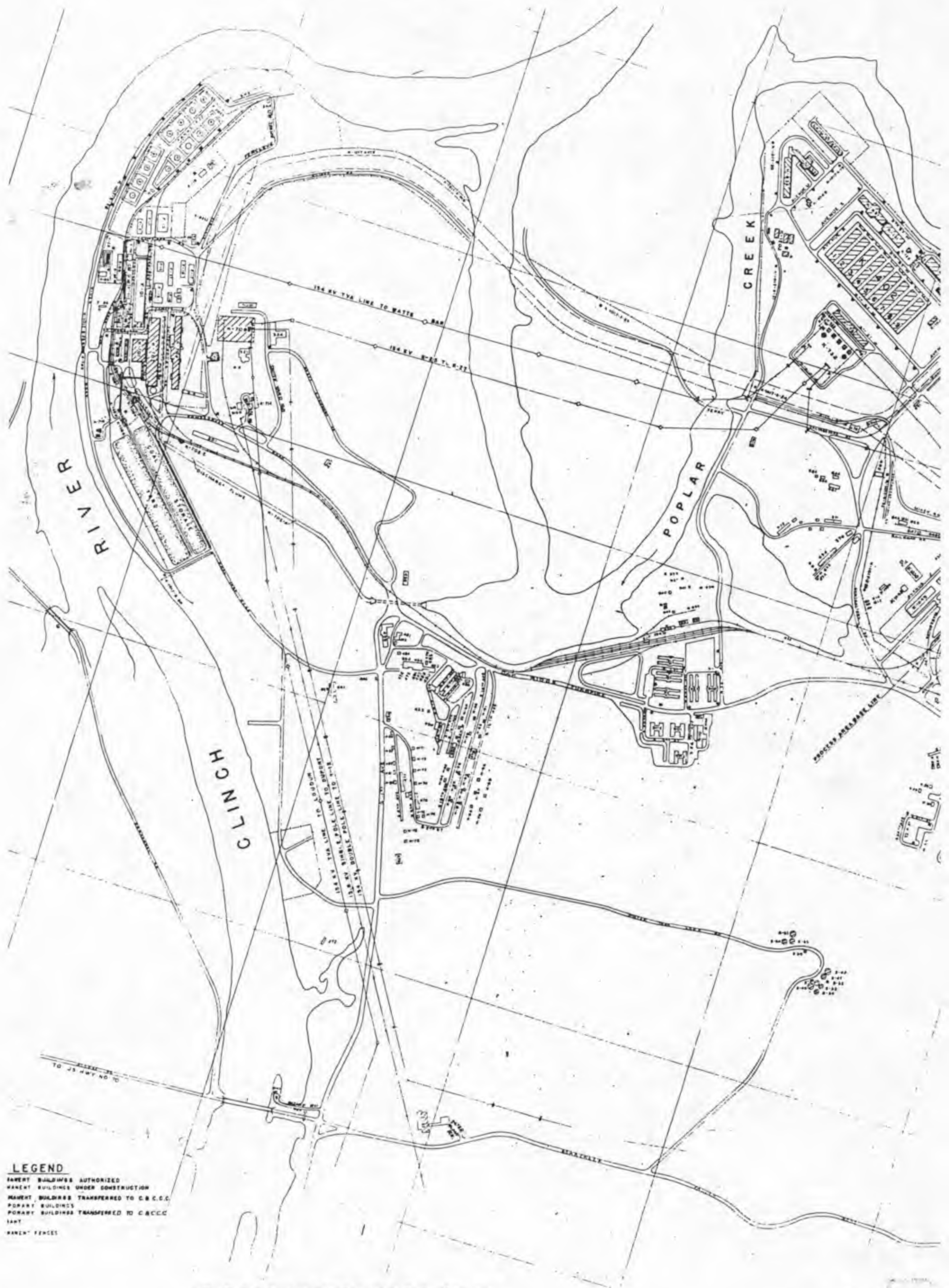

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A

SECRET

A3-2

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RESTRICTE

THE KELLEX CORPORATIO

K-25 & K-27

PLOT PLAN
&
STATUS OF CONSTRUCTION

SCALE

DATE FEB. 27, 1944

DRAWN BY: LONGFELLOW

DWG. NO. FD-01-A

NO.	DESCRIPTION	DATE
9	ADDED MAR. CONSTR.	3-31-44
8	ADDED FEB. CONSTR.	[illegible]
7	ADDED JAN. CONSTR.	[illegible]
6	ADDED DEC. CONSTR.	[illegible]
5	REDRAWN	[illegible]

REVISIONS

A3 SECRET

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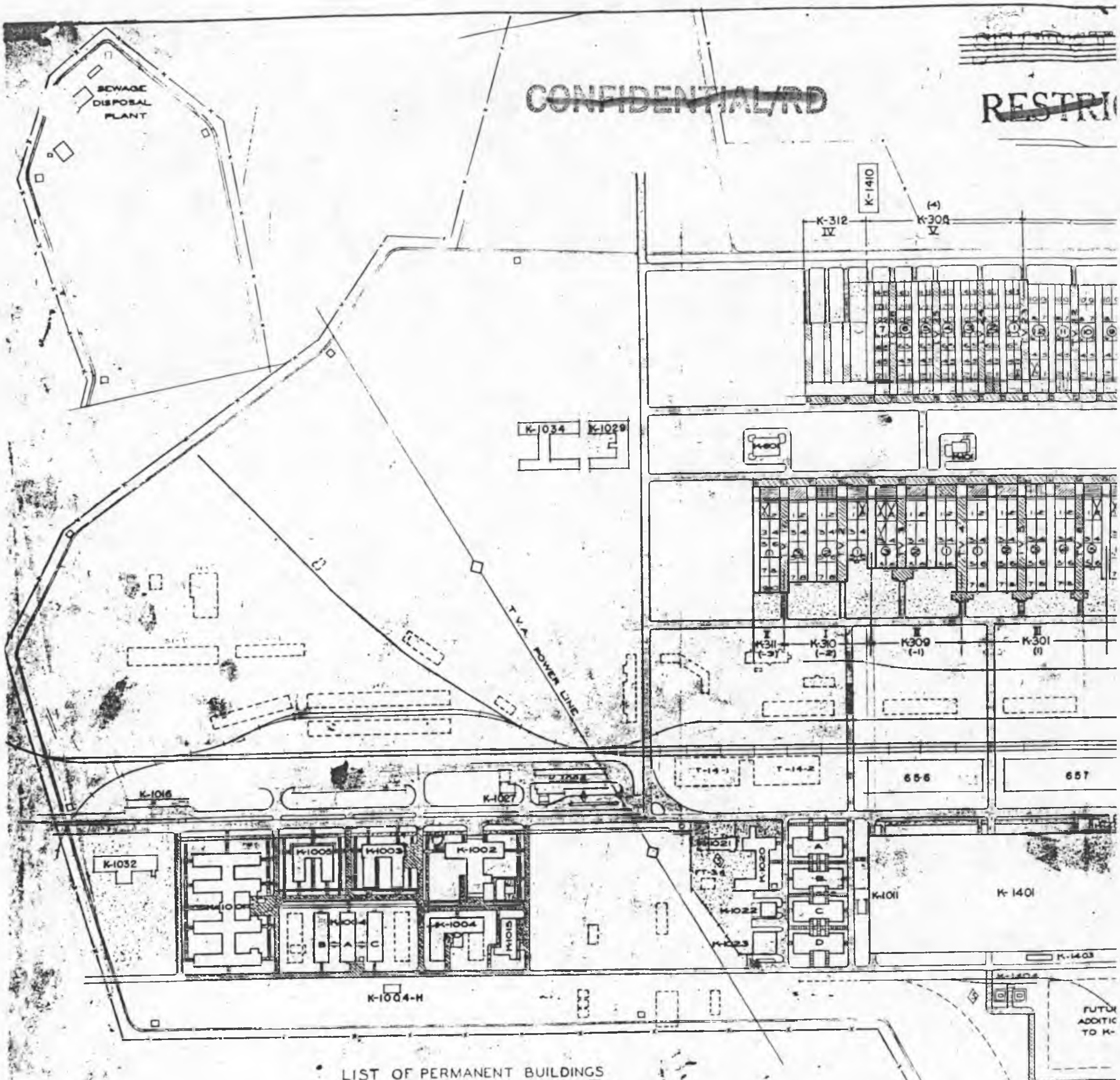
RESTRICTED



LIST OF PERMANENT BUILDINGS

K-101 Feed Purification Building
K-301 1 thru 5 Process Bldg.
K-302 1 thru 5 " "
K-303 1 thru 10 " "
K-304 1 thru 5 " "
K-305 1 thru 12 " "
K-306 1 thru 7 " "
K-309 1 thru 3 " "
K-310 1 thru 3 " "
K-311 ?1 Stage " "
K-312 Nitrogen Separator 3 Units
300-C Coolant Storage & Drying Plant
300 Light Product Recovery
K-601 Waste Disposal System
K-801 Intake Water Pump House
K-802 Recirculating Water Pump House
H-801 Cooling Tower A
H-802 Cooling Tower B

K-1001 Administration Building
K-1002 Cafeteria
K-1003 Dispensary
K-1004 Laboratories (A thru H)
K-1005 Payroll & Safety Building
K-1008 Change Houses (A thru D)
K-1015 Laundry Building
K-1011 F. B. & D. Clock Alley & Timekeepers' Office.
K-1020 Gate House #2 with Guard Building
K-1021 Ambulance Garage & Fire House
K-1022 Maintenance Office & Tool House
K-1023 Car & Truck Repair
K-1024 Instrument Building
K-1025 Whse for Drum Storage
K-1101 Air Conditioning Building
K-1201 Compressor House
K-1301 C-216 Building

K-1302 C-216 Storage
K-1303 C-216 Bottling Plant
K-1401 Conditioning Building
K-1402 Control House
K-1403 Fan House
K-1404 Acid Storage
K-1405 & K-1406 C-216 Disposal
K-1407 Acid Neutralization Plant
K-1408 Nitrogen Plant
K-1409 Change House
K-1501 Heating Plant
K-1102 Transformer Housing (K-1102, KA-1102 & KB-1102)
K-1410 Regeneration Building
K-1016 Bus Loading Platform
K-1026 Bus Terminal
K-1027 Bus Repair Garage
K-1030 Electrical Repair & Maintenance
K-1029 Joint Field Office
K-1052 Industrial Relations
K-1034 K-27 Office Bldg.

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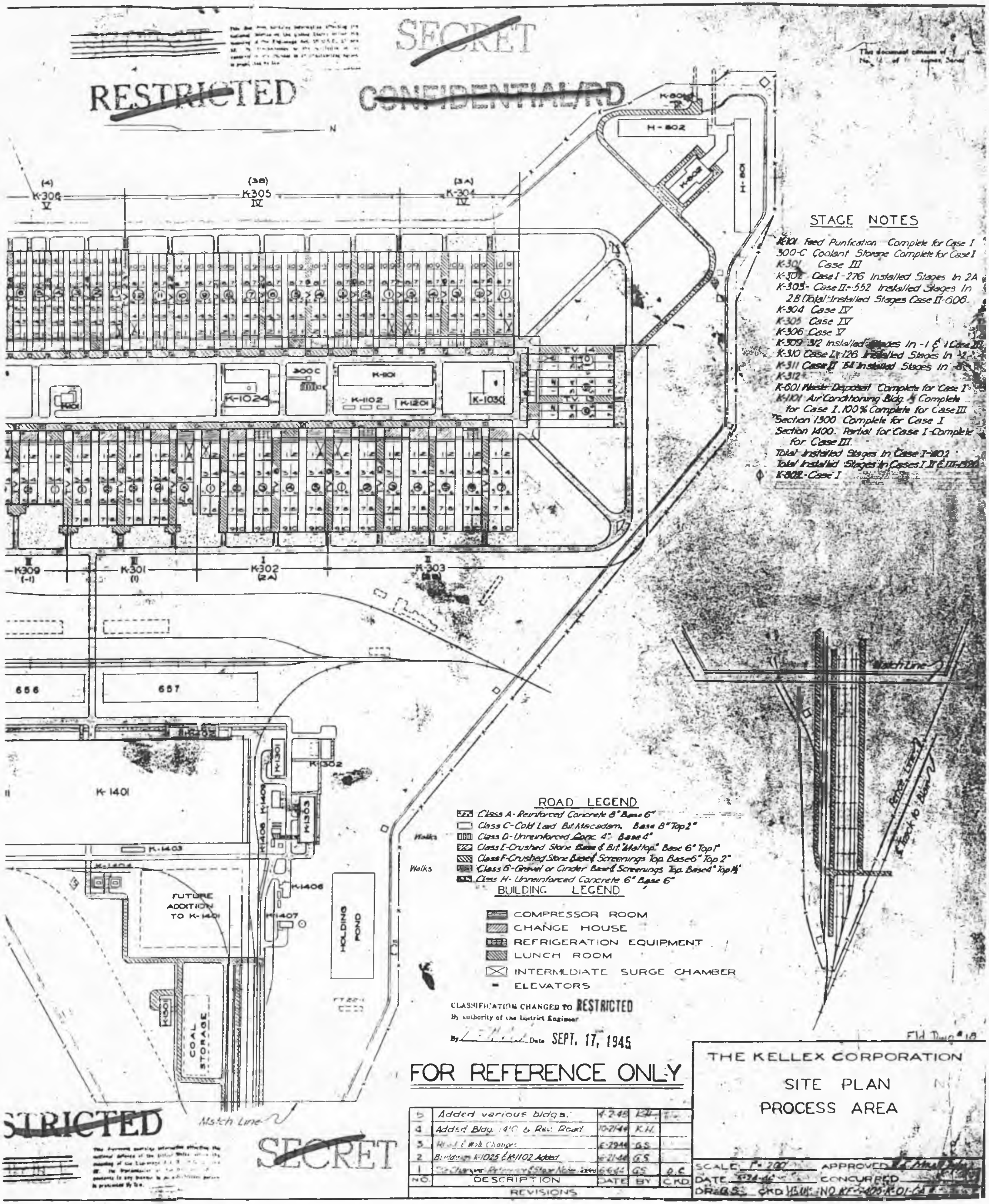

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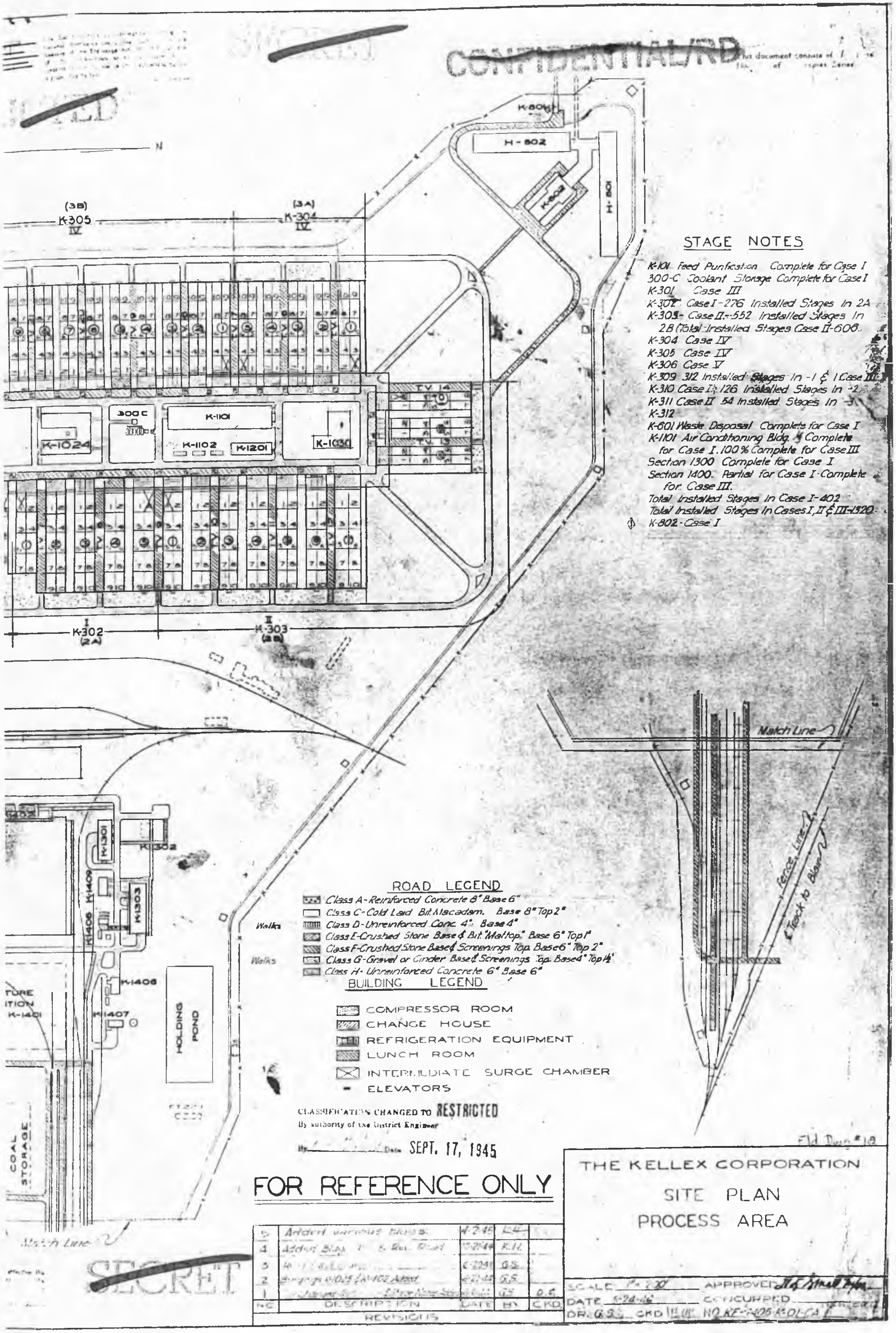

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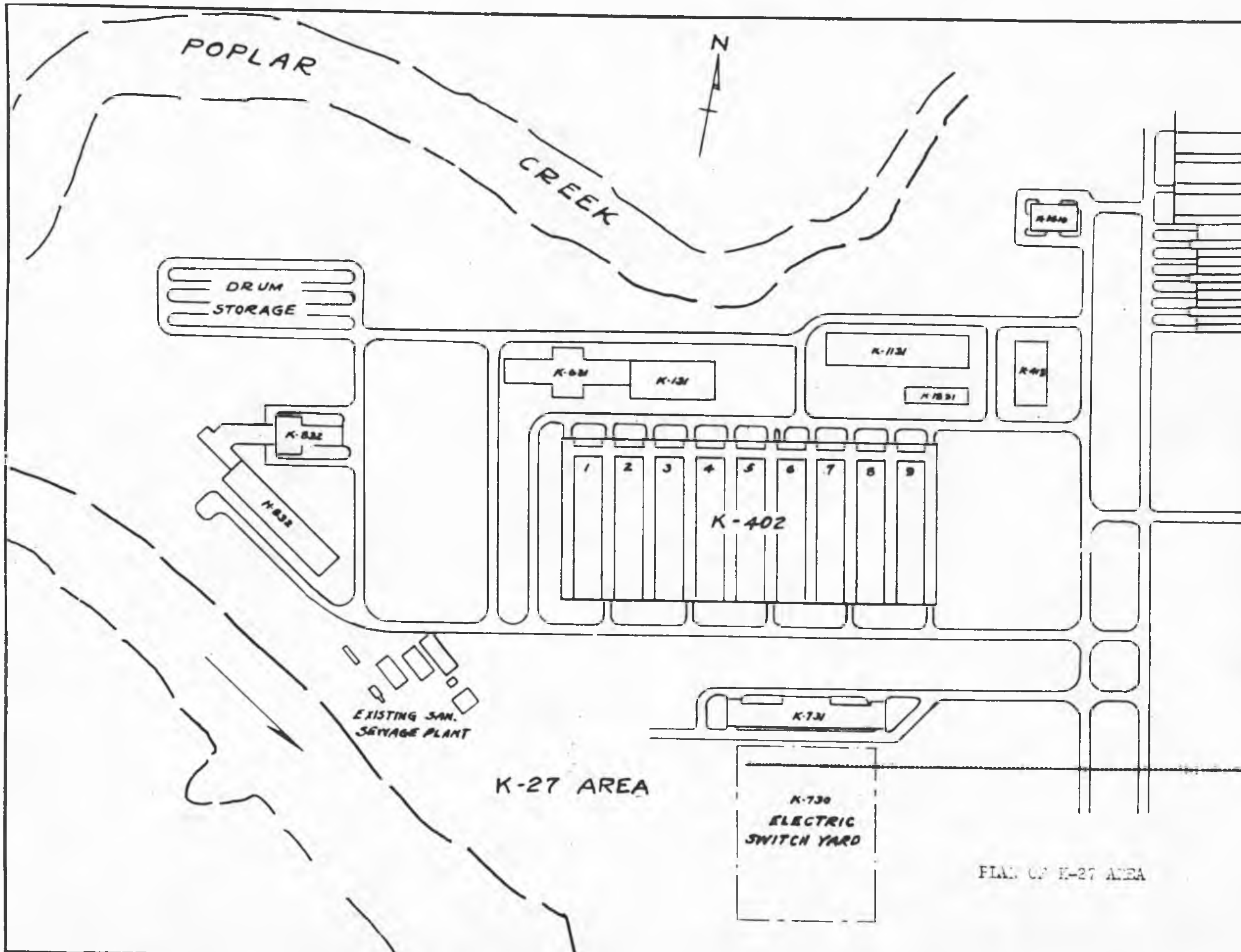


PLAN OF K-27 AREA

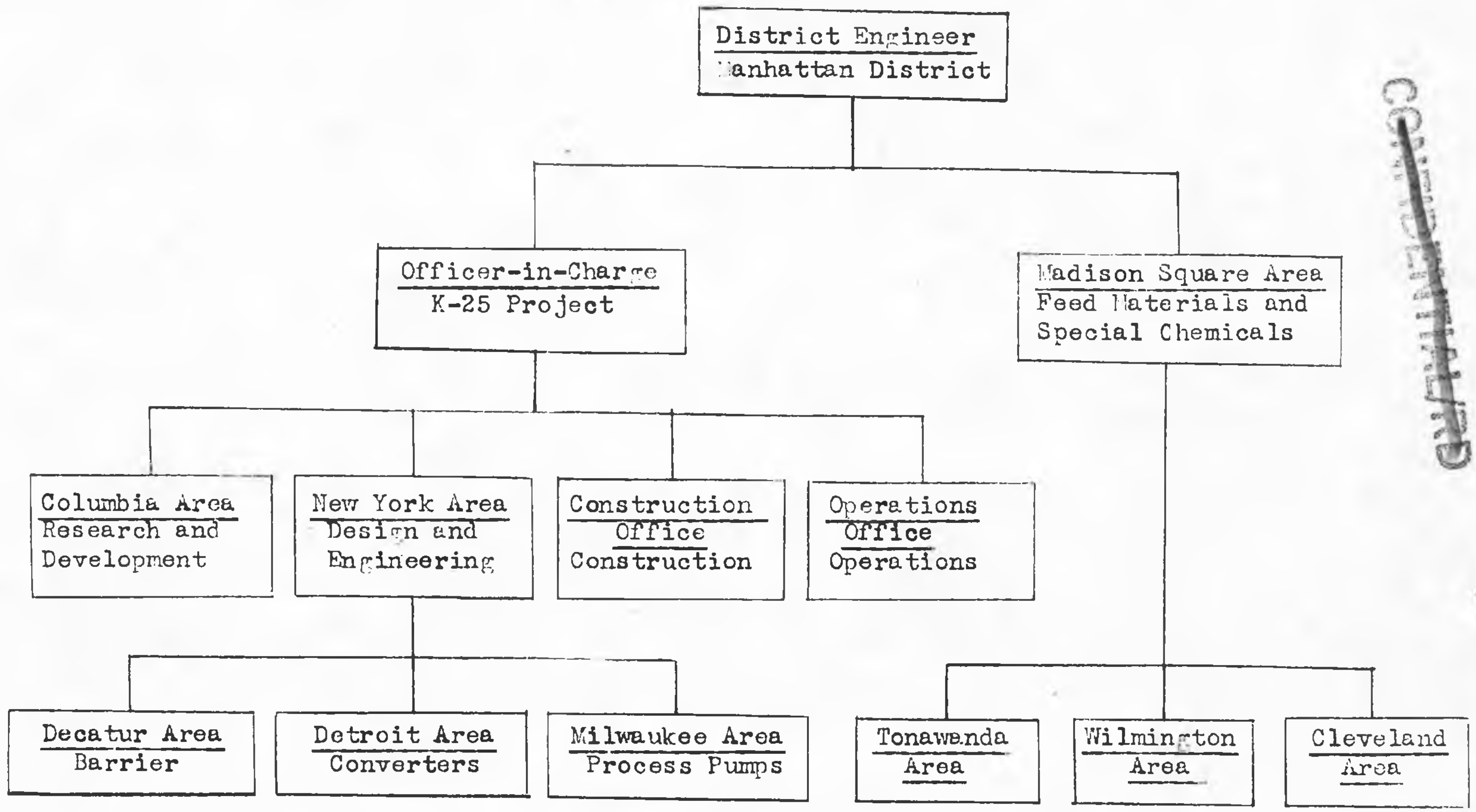
MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 1 - GENERAL FEATURES

APPENDIX "B"

CHARTS

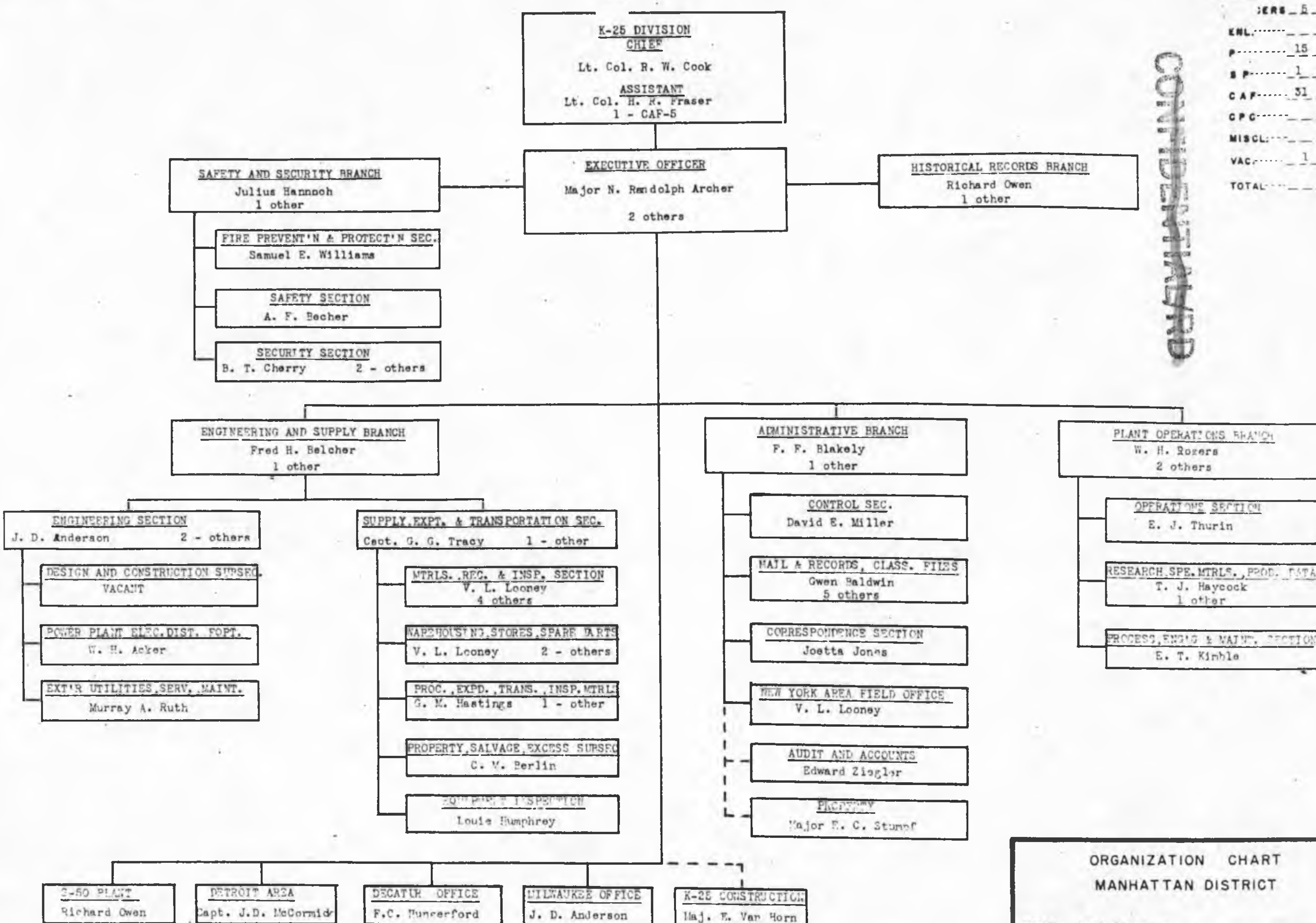


ORGANIZATION CHART

K-25 PROJECT

31 MARCH 1945

PERSONNEL
OFFICERS 5
ENL.
P 15
S P 1
C A F 31
C P C
MISCL.
VAC. 1
TOTAL



ORGANIZATION CHART
MANHATTAN DISTRICT

UNIT K-25 Division
SUBMITTED ____ DATE ____
RECOMMENDED ____ DATE ____
APPROVED RWCook DATE 1 Nov 194[illegible]

EIDM FORM 424

SHEET NO. ___ OF ___ SHEETS

MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 1 - GENERAL FEATURES

APPENDIX "C"

LISTS

KEY PERSONNEL, K-25 ORGANIZATION

Williams, Col. W. J. - Officer-in-Charge, K-25 Project from 18 January 1945 to 30 April 1946.

Cook, Lt. Col. R. W. - K-25 Operations Officer from 3 October 1944 to 30 April 1946. K-25 Division Chief from 1 May 1946 to present.

Cornelius, Lt. Col. W. P. - K-25 Construction Officer from 31 July 1943 to 28 February 1946. Chief of District Construction Division 1 March 1946 to present.

Stowers, Lt. Col. J. C. - New York Area Engineer from 7 January 1943 to 28 February 1946. Officer-in-Charge, K-25 Project, from 7 January 1943 to 17 January 1945.

Tammaro, Lt. Col. A. - Detroit Area Engineer from 21 July 1943 to 15 November 1944.

Belcher, Major F. H. - Detroit Area Engineer from 16 November 1944 to 31 January 1946.

Campbell, Major W. C. - New York Area Engineer from 1 March 1946 to 23 August 1946.

Choate, Major C. E. - Decatur Area Engineer from 10 October 1944 to 5 December 1944.

Hough, Major B. K., Jr. - Columbia Area Engineer from March 1943 to January 1944.

McCormick, Major J. L., Jr. - Milwaukee Area Engineer from 6 August 1944 to 14 November 1945.

Moran, Major J. J. - K-25 Operations Officer from 22 February 1944 to 2 October 1944. Decatur Area Engineer from 12 December 1944 to 15 December 1945.

Varley, Major Noland - K-25 Construction Officer from 1 March 1946 to 30 April 1946. Chief of K-25 Construction Section from 1 May 1946 to 31 July 1946.

Anderson, Captain J. D. - Milwaukee Area Engineer from 15 November 1945 to 30 July 1946.

Brannan, Captain J. H. - Decatur Area Engineer from 20 July 1943 to 9 October 1944.

<u>Crawford, Captain R. L.</u> - Decatur Area Engineer from 15 December 1945 to 1 July 1946.

<u>Grotjan, Captain L. L.</u> - Columbia Area Engineer from January 1944 to 1 July 1946.

<u>Hill, Captain R. C.</u> - Milwaukee Area Engineer from 15 July 1943 to 5 August 1944.

<u>McCormick, Captain J. D.</u> - Detroit Area Engineer from 1 February 1946 to present.

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