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GASEOUS DIFFUSION PLANT (U)

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PREFACE

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K-25, the gaseous diffusion plant at Oak Ridge, has been described as "the largest continuous chemico-physical process in the world". With a total of 63 process buildings, sprawling over 600 acres and costing a half billion dollars, the project up to January 1946 had required approximately 60,000 carloads of materials and equipment.

The developing of a diffusion plant of this magnitude from techniques considered previously only on a laboratory scale led to many unusual problems and their solutions; problems ranging from spectroscopic analyses to generation of enormous quantities of variable frequency electrical power; from the production of millions of square feet of diffusion barrier having on the order of hundreds of millions of pores per square inch to the assembly of hundreds of thousands of pieces of equipment into a single vacuum-tight system having an internal volume in excess of 600,000 cubic feet; from the control of flow of a few cubic inches of gas per day to the movement of millions of gallons of water; from the mounting of delicate instruments to the installation of probably the greatest collection of complex apparatus ever assembled in one place.

Because of the size and complexity of the plant, this paper does not attempt to treat the individual phases of operation in detail but will discuss the salient features of operation in general terms.

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PURPOSE

The gas diffusion plant was designed and constructed to concentrate the uranium 235 isotope from feed of natural uranium containing only 0.714 atom percent of the light isotope. At the time the K-25 plant was authorized in its present extent it was contemplated that the plant would process 960 kilograms per day of normal uranium hexafluoride to produce 4.05 kilograms per day of uranium hexafluoride having an isotopic concentration of 36.6 atom percent of uranium 235, equivalent to 1.0 kilograms per day of uranium 235 metal. This corresponded to a yield of approximately twenty-two percent of the uranium 235 in the feed. Actually, the diffusion plant has been producing since the first portions of the plant started operating in March, 1945, and production has continued at increasing purity until full operation was attained on 15 August 1945. The entire product from the K-25 plant has been transferred to the Y-12 electromagnetic separation plant for further enrichment. During several months of operation, the uranium hexafluoride product from the S-50 thermal diffusion plant, averaging about 0.85 atom percent in isotopic concentration of U-235, has been fed to the K-25 plant for further enrichment.

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ADMINISTRATION

The K-25 project has been carried out under the authority and direction of the War Department, represented by the Manhattan District, U. S. Engineer Office. Research, development, design, engineering, procurement, supervision of construction, and consulting services have been discharged by The M. W. Kellogg Company and its subsidiary, The Kellex Corporation, as architect-engineer. The main construction contractors were the J. A. Jones Construction Company, Inc., builders of the main plant, the power plant, and most of the auxiliary installations, and Ford, Bacon & Davis, Inc., builders of four of the auxiliary plants. The operation contractor is the Carbide and Carbon Chemicals Corporation.

Numerous other organizations were prominent in the K-25 project, particularly in the fields of research and development, and equipment manufacture. Some of these organizations, such as the Columbia Laboratories, The Bell Telephone Laboratories, the Princeton Laboratories, the Chrysler Corporation, Allis-Chalmers Manufacturing Company, Houdaille-Hershey Corporation, General Electric Company, and Westinghouse Electric Corporation, worked in close collaboration with Kellex. Other organizations conducted independent investigations.

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SITE

The K-25 plant site is located in a valley due west of McKinney Ridge near Poplar Creek in Roane County, Tennessee. Midway between the Watts Bar and Norris Dams, it is in the heart of the Tennessee Valley Authority.

The plant occupies a 5000 acre tract of land in the northwest corner of the Clinton Works, approximately 15 miles from the townsite of Oak Ridge. Bordered on the west by the waters of the Clinch River, the site is hemmed in by thickly wooded ridges which are characteristic of this terrain. The western half is crisscrossed by Poplar Creek as it follows a winding course to join the Clinch. The elevation varies between 750 and 900 feet above mean sea level, the highest places being 200 or 300 feet below the crests of the surrounding ridges.

At the time the site was selected it was thought that the necessary power could be obtained from TVA. However, since most of the available TVA power at the time was being used by other consumers and the nature of the process required large amounts of extremely reliable power of variable frequency, it became necessary to build a power plant.

The site selected for the power house was on the Clinch River on the western extremity of the bend just prior to its intersection with Poplar Creek. This site was chosen for the availability of condensate water from the Clinch River and the discharge of same into Poplar Creek, plus the availability of rail facilities and coal storage.

THEORETICAL ASPECTS [redacted]

As has been stated before, the purpose of the K-25 gaseous diffusion plant is to separate two gaseous isotopes of uranium UF_6 with the ultimate goal of obtaining a product concentrated in U-235.

To understand more clearly the operation of the plant, some of the theoretical aspects of gas separation will be discussed.

The two gaseous istotopes of UF_6 (U-235 and U-238) are separated by means of tubes made of porous metal -- that is, the metal tubes have very small holes through them. The purpose of these holes is to separate the two gases by allowing a partial seepage of gas through the holes.

Now it would be very simple to make such a separation if it were possible to make up tubes containing holes just large enough to filter out the larger gas particles. Unfortunately, this is practically impossible. Gas particles are so very small that it would be impossible to make holes small enough or accurately enough to let particles of one size through and hold back larger particles.

There is one peculiarity of gas particles, however, which makes it possible to make a separation in this manner. All gas particles are in motion at all times. Further, all gas particles have the same amount of kinetic energy at a given temperature. In plain words heavy gas particles move more slowly than do light gas particles. For a comparison, imagine putting the same size motor in a ten ton truck as is in a jeep. The jeep can be driven much faster with that size motor than could the ten ton truck.

THEORETICAL ASPECTS (Continued)

With this reasoning in mind, suppose you have a gas tight box containing two types of gas particles - one heavy and one light. These particles are bounding about inside the box, striking the walls, bouncing off, striking each other and bouncing off. Because of their higher velocity, though, the lighter particles are making more collisions per second against the walls of the box than are an equal number of heavier particles. Now suppose a small hole is made in one wall of the box. A gas particle will escape through the hole only if it strike that particular spot. Since, the lighter particles strike the walls more often they have a better chance of passing through the hole.

It is in this manner that we make a separation of two gases - one heavy and one light. This separation of two gases is not accomplished by the use of a box with one hole but by a large series of porous metal tubes having billions of holes. The increase in concentration per set of tubes (converter) will be very slight if the speeds of the particles are nearly the same. That is the case in this process. Because the speeds are so nearly the same a great number of converters are necessary to make a complete separation.

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DA BARRIER

Barrier, since it accomplishes the isotope separation, is in a sense the most important part of the cascade. It is a highly specialized material, developed by an intensive program of over three years duration and manufactured by new plant facilities built and equipped within a period of a year.

Various types of barrier, all of them ingenious and thoroughly novel, and in a variety of material, were developed as forerunners to the "DA" barrier finally selected for installation in the plant. Among others, these included; (1)

(2) etched copper, made by dissolving the manganese from thin sheets of a special alloy containing 70% copper and 30% manganese,

None of these barriers gave satisfactory separating efficiency nor were they suitable for the continuous manufacture of the large quantities of barrier necessary for the gaseous diffusion plant. Therefore, work was begun to develop a more satisfactory barrier, with "DA" barrier the result. The following steps show the method of producing this barrier - a material having pores of an average diameter of three (3) millionths of an inch and in the order of 40 billion of these holes per square inch.

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respectively, including three different types, with the greatest amount being of the type described above. A consideration of the magnitude of the program and its successful completion may be gained by noting that the decision to produce "DA" barrier was made in January 1944 and the first tube shipped in August of that year. By May, 1945, over 6 million tubes had been produced.

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THE CONVERTER

Since the individual converter is essentially the "heart" of the entire process, it might be appropriate to consider briefly some of the more pertinent details regarding this rather vital piece of equipment, of which there are nearly 3000 throughout the process area.

There are 5 types of converters, 4 of which are alike except for physical sizes, while the fifth is of the flat diffuser type and very small in size. The various dimensions and distribution is shown in the following table.

TABLE I
SIZES OF CONVERTERS AND THEIR LOCATION

Number	Diameter	Length	Tube Length	No. of Tubes	Location (Section)	Bldg.
1	5' 8½"	11' 3"	7' 5-3/8"		-1, 1	309, 301
2N	5' 8½"	10' 8"	7' 5-3/8"		-2, 2A, 2B	302, 310
2 (Plain)	5' 8½"	11' 1½"	7' 5-3/8"		2B	303
3	4' 2"	8' 4"	5' 2-3/8"		-3, 3A, 3B	311, 304, 305
4	3' 8"	5' 6"	3' 2-3/8"		4	306
5	1' 4"	6' 7/8"	Flat Plates (Stripping)			312

The external shell is fabricated of nickel-clad steel and mounts three reinforcing flanges which provide added rigidity as well as convenient points of suspension. Of 6 external connections, the 3 large ones are the process gas connections, the 2 two-inch connections at the front of the converter are the coolant inlet and outlet connections, and the small one-inch connection on top is for pressuring up with G-74 during welding procedures. Refer to diagram.

Within the conveter is found the "Fin Tube" section at the front in which the coolant is contained and circulated and over which all process gas entering the converter must pass in order that excess heat may be removed from the gas. The remainder of the converter contains the numerous

5/8" porous, metallic tubes, supported by a tube sheet at each end and suitably baffled so that this tube section is divided into three concentric sections with the result that the process gas makes three passes in negotiating a converter. Material penetrating the tube walls, passes out of the converter at the center connection and is considered the "A" or light fraction. Material passing the length of the tubes without penetrating the walls leaves the converter at the side connection and is considered the "B" or heavy fraction. Components inside the converters are constructed chiefly of either monel or nickel-clad stainless steels; except for the tubes

The tube sheet at the front of the converter is fastened to the shell while the rear sheet is not fastened to the shell but is supported on a guide ramp which permits a longitudinal sliding motion of the entire tube assembly, and in this manner overcomes effects of thermal expansion and contraction.

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SPECIAL CHEMICALS

It is appropriate to mention at this time the necessity for developing a new group of chemicals to be used for various functions in contact with UF_6 (uranium hexafluoride).

The UF_6 which is used as process gas readily undergoes reaction with metals, water vapor, and with other compounds containing hydrogen.

The name "Special Chemicals" is applied to the various compounds which have been developed for use on this project or which have been used extensively by the project. These include:

C-816 - The coolant used in converters.
MFL - Lube oil used in pumps which handle UF_6 or fluorine.
C-2144 - Lube oil used in pumps which handle UF_6 or fluorine.
C-616 - Uranium hexafluoride.
MFP-10 - Fluorinated plastic used in valve seats.

Pertinent facts about special chemicals:

(1) UF_6

Uranium hexafluoride can exist in three phases.

1. Colorless crystalline solid of high refraction.
2. Colorless liquid.
3. Colorless gas.

The molecular weight of UF_6 is 352 and its density as a liquid at 147.3° F is 229 lbs. per foot^3, 2.67 times the density of water.

Upon contact with the atmosphere UF_6 vapor is immediately hydrolyzed by the moisture present to form a dense white fog of UO_2F_2 particles and a corrosive colorless gas HF (hydrogen fluoride).

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(2) C-816.

C-816 is a completely fluorinated saturated fluorocarbon. When pure it is a colorless liquid with a faint but distinctive odor.

The molecular weight of C-816 is 400, heavier than UF_6, and has a boiling point of 216° F.

(3) Lube oil.

C-2144 and HFL are high molecular weight fluorocarbons containing a very small per cent of hydrogen. C-2144 has the empirical formula $C_{21}F_{44}$, whereas HFL is a polymerized derivative of freon 113 and is a blend of varying-length chain molecules. Both oils are required to meet exacting specifications on extremely low acidity and moisture content as well as high resistance to the corrosive action of fluorine and uranium hexafluoride.

(4) HFP-10.

HFP-10, like HFL, is a derivative of freon 113 but is more highly polymerized.

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PROCESS AREA

All of the operations directly connected with the isotope separation are carried out within the Process Area. That part of the Process Area which houses the diffusional equipment is known as the Main Process Area and the buildings which house this equipment are known as the Main Process Buildings.

The raw material is received at the area as refined UF_6. It is vaporized from the shipping drums, filtered, and charged to the main cascade (Section 300) at a point about one-tenth the way up from the bottom to the top of the cascade. Product is withdrawn from the top of the cascade and waste from the bottom.

The diffusional separation is accomplished in approximately 3000 separate steps, each step being carried out in an operational unit called a "stage". The gas that has diffused through the barrier of a stage, thereby being enriched in U_{235}, (commonly called A stream) is directed up the cascade to the next stage. The gas that flows through the stage without diffusing through the barrier, (commonly called B stream) thereby becoming depleted in U_{235}, is directed downstream to the next stage below. The stages are connected in series as a simple cascade.

The stages above the feed point of the cascade are called the enriching stages. Those below the feed point are called the stripping stages.

The stages are grouped in blocks, or "cells", of six. The cell is the smallest unit of the cascade that can be operated individually. Thus a stage cannot be cut into or out of the cascade by itself;

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this can be accomplished only by cutting out the cell in which the stage is located. The main cascade contains four hundred eighty-three typical cells, not including a number of special purpose cells known as intersectional cells.

Each stage is composed of four principal parts - (1) the converter, (2) the gas cooler, (3) the pumping units, and (4) the control valve.

The enrichment takes place in the converter - a tubular unit of intricate design and construction, somewhat similar in shape and arrangement to a shell and tube heat exchanger. Each of the largest converters contain tubes made of the finely porous barrier material, providing a working surface of approximately square feet.

The gas cooler, a circular bundle of finned tubes built within the converter, removes the heat of compression and controls operating temperature.

The booster and blower pumps circulate the process stream through the barrier and from stage to stage.

The control valve maintains constant pressure on the tube side of the diffuser. Regulation of this pressure on each stage constitutes the control of flow throughout the plant.

In brief, the process stream enters the converter, is passed through the gas cooler (known as the absorber) and flows into a bundle of permeable tubes. Half the gas (the A stream) diffuses through the walls of these tubes into a low pressure chamber from which it is exhausted by the booster pump and advanced to the suction of the blower feeding the next higher stage. The other half of the gas (B stream) flows through the tubes and out the high pressure outlet of the converter, passing through a pressure control valve into the suction of the blower feeding the next lower stage. The process stream is circulated in this manner throughout the cascade.

Six stages are inter-connected and installed as an operating unit called a cell. It is the cell and not the stage that is connected to the main circulating lines with facilities for by-passing. Thus, when a stage must be taken off the process stream, the other five stages of the cell must come off with it. In general, the cell can be said to be a self-contained operating unit with its own control board, cooling system and other auxiliaries.

The cells have been grouped and housed in the Main Process Buildings, with ten cells to a building on the average. However, the term building is used here in a sense that is broader than just a "housing". The building is the operating unit next up the scale in size and complexity from the cell.

The structure and arrangement of the building are of ingenious design with facilities for housing or carrying all of the many auxiliary systems required for the operation of the stages and the cells. It is interesting to note that many of these auxiliaries were not even conceived, and, in fact, the design of the stages themselves not fixed when the buildings were designed, due to the necessity of releasing the building designs while some development work and studies were still under way.

The building has four levels - (1) basement, (2) cell floor, (3) pipe gallery and (4) operating floor.

The stages, grouped into cells, are installed on the cell floor in two parallel rows extending the length of the building.

The pipe gallery carries the main building process gas lines, called cell by-pass lines, as well as many auxiliary lines. The cells are connected to the cell by-pass lines so that any cell may be taken off stream without affecting the others.

The basement houses auxiliary equipment such as lubricating oil system, coolant equipment, ventilating fans and switch gear.

The top level is primarily the operating level and carries the instrument panels with most of the indicating, recording and control instruments, as well as the electrical control equipment. The handwheels for the valves used for by-passing the cells are located above the operating floor, where they can be reached readily by the operators.

Ample driveways called "withdrawal alleys" are provided alongside the rows of cells at truck bed height below the cell floor on which equipment is transported by special truck into and out of the building.

There are 51 main process buildings laid out under a common roof in the shape of a massive "U". Four stories high, nearly a quarter of a mile across and over a half a mile long, the "U" encompasses an area of 60 acres. The individual buildings, varying somewhat in length and width but similar in arrangement and structure, are arranged side by side under one roof, with the front of the buildings facing the inside of the "U". Thus, except from the operational standpoint, there is in effect one huge building housing all of the main process equipment.

A system of headers, carrying the process streams and interconnecting the buildings, runs along the inside of the "U". These headers, which are the main arteries of the plant, are equipped with motor

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operated valves, making it possible to isolate buildings or even sections from the main stream. This automatic valving is one of the many precautions which have been taken to prevent localized operational disturbances from interrupting the operation of the cascade as a whole.

There are two streams of uranium hexafluoride flowing through the cascade, one travelling toward the top, which becomes progressively richer in U_{235}, and the other traveling toward the bottom which becomes progressively richer in U_{238}. These two streams meet at each stage, are mixed and passed through the converter. Half of the gas fed to the converter passes through the barrier and is fed upstream slightly enriched in the light isotope; the other half, which passes through the converter and is slightly leaner in the light isotope, is fed downstream. Thus, each step up the cascade brings the concentration nearer to the goal until the top is reached and the gas is taken off and condensed as product.

The diffusional separation of the isotopes of uranium must be carried out at subatmospheric pressures. This required that thousands of pieces of equipment and miles of piping having a total gas volume of more than a half million cubic feet be hermetically sealed.

This requirement made necessary the development of ingenious methods and equipment for vacuum testing. The degree of tightness required, the vast amount of equipment involved, and the limited time available, combined to make the vacuum engineering job of a different order of complexity than ever before tackled. It also involved the study and testing of methods for joining various parts to insure that the plant would remain tight after construction. CONFIDENTIAL

Leakage of atmospheric air into the equipment or piping handling the process stream had to be kept within exceedingly small limits, as the moisture carried by the air would react with the process gas, causing loss of product and plugging of the barrier. For these reasons, the process equipment and piping have been surrounded by an atmosphere of dried air ranging in dew point between -70° F and -40° F. All process equipment and piping of the main cascade are enclosed by air tight sheet metal casings, the total volumes of which exceeds 6,000,000 cubic feet. This entire volume is filled with dry air supplied from a large central drying plant through miles of distribution piping.

The internal surfaces of each piece of equipment, each piece of pipe, and each auxiliary device coming into contact with process gas had to be cleaned to a degree approaching surgical standards. This tremendous task was necessary to prevent contamination of the process stream, to prevent loss of process gas due to reaction with impurities, to prevent undue corrosion and to eliminate a source of plugging of the porous barrier. This cleaning has proved to be an invaluable precaution.

In addition to the stringent cleaning methods, consumption of process gas has been minimized by constructing the cascade of materials most resistant to UF_6 corrosion and by chemically conditioning all process equipment before exposure to the process stream.

An extensive series of tests were carried out on an accelerated scale to determine what materials should be used and specifications were set up which were particularly exacting as to impurities. A balance had to be struck in some cases between the optimum material from the corrosion standpoint and the practicability of obtaining the large quantities of the special materials involved.

The conditioning involved treating the internal surfaces of all process equipment and pipe before exposure to the process stream. This was done by exposing these surfaces to fluorine under controlled temperature and pressure conditions, thus forming a coating which is nearly impervious to UF_6 penetration. Special techniques and extensive systems were developed for this procedure.

The development of the shaft seals for the process pump shafts was another major task. It was necessary to prevent out-leakage of process gas, to hold the in-leakage of sealing medium to a minimum and to positively eliminate in-leakage of atmospheric air. This involved the development and manufacture of over 12,000 triplex sealing devices and the design of a complicated and delicately controlled sealing system for the controlling of pressures and feeding of dry nitrogen used as the sealing medium.

For the overall control of the plant there is a central control room connected to all parts of the process area by a network of wires and cables. On panel boards in the master control room are mounted instruments scattered throughout the plant, and indicators which show the positions of important valves. This is the nerve center of the plant where the vast operations are scanned and coordinated and from which instructions are sent out through the plant telephone system to local operators. Some of the important motor operated valves can be operated by means of push buttons located in the master control room.

The K-27 plant has been designed to prepare enriched feed for the K-25 plant, thereby increasing the productive capacity of the latter. Except for the flow of K-27 product to K-25, and the flow of K-25 waste to K-27, the K-27 plant functions as a separate unit with the complete feed, product, purging, surge and waste facilities. Operation of K-27 could be completely divorced from K-25, if desired.

Section 400, the main cascade of the K-27 plant, consists of nine 10-cell buildings, K-402-1 through K-402-9, each similar in its principal features to Building K-302-3 of the K-25 plant, except that it is run at a controlled tails pressure and the normal interstage flow rate is per day.

During combined operation of the K-25 and K-27 plants, product from Section 400 is piped directly to the K-25 plant from the top of the K-27 plant to any one of four feed points in the K-25 plant.

CELL

The cell is the smallest individually operating unit. It consists of six diffusion stages and piping housed in a metal enclosure. In the K-25 cascade, there are two pumps at each stage, namely, the "booster" and the "blower". The booster pump takes the diffused gas from a given stage, compresses it and advances it to the next higher stage. The blower receives the diffused gas from the stage below and the undiffused gas from the stage above, compresses the mixture and feeds it to the stage it serves.

While it would have been possible to design a cascade with only one pump per stage, this would have necessitated throttling the undiffused gas to the same pressure as that of the diffused gas and then re-compressing. Such a scheme would have consumed considerable additional power. Further, to have used only one pump for the entire pressure range would have required a compression ratio of 6 in some cases as against 3 in the present system. Whereas a compression ratio of 6 is feasible with reciprocating pumps, it could not be obtained in a centrifugal machine except at extremely high tip speeds.

The motors and half of the pump casing are outside of the cell enclosure but all piping to and from the pump is inside. The flow of material through the cell is as follows:

The A stream after entering the No. 1 converter, together with the B stream from No. 2 converter of the same cell, flows through the converter with further separation taking place. Emerging from the A discharge of the converter, it flows to the intake side of the No. 2 blower, where, upon mixing with the B stream from the No. 3 converter, it is forced by the blower into No. 2 converter. Leaving No. 2 converter, it mixes with B from No. 4 converter and subsequently enters No. 3 converter. This process continues until the A stream emerges from the No. 6 converter, where it then flows through the cell A stream block valve, the building header, and into the next cell.

The B stream entering the No. 6 converter from the cell above, works its way towards the No. 1 converter in the same manner that the A stream works towards the No. 6 converter. That is, the B stream from No. 6 converter mixes with A from No. 4 converter and enters No. 5 converter. Leaving No. 5 converter, it mixes with A from No. 4 converter and enters No. 5 converter. Leaving No. 5 converter, it mixes with A from No. 3 converter and enters No. 4 and so on until it leaves the cell in a No. 1 converter and the cell block valve.

In the intake side of each converter the C-616 passes through a cooler where it is cooled down by circulating C-816 or coolant. After the 6A pump, the A stream passes through an aftercooler located on the cell side of the A outlet block valve.

Direct Recycle.

If, during normal operation, the porosity of the tube section of a converter in any given cell should be reduced, for example, by plugging, the pressure would be increased and the flow reduced back all along the line to the previous cell (A stream direction) and hence A stream flow from the previous cell would be proportionately reduced. This change in rate of flow would be detected by a flow sensitive element located in the A discharge of the No. 6 converter of this previous cell. Suitable transmitters will than operate an air motor valve, located in a line, called the Cell Direct Recycle line, between No. 6 booster output and input, causing it to open and permitting some of the A stream to return to the input side of the converter instead of the next cell. This decreases the A output of No. 6 and prevents additional pressure rise in the direction of the block. To compensate for the increased flow of material through the B section of No. 6 converter, the air operated motor valve in the B discharge line opens, allowing the flow to No. 5 to increase. The B discharge valve of No. 5 may now open to increase the flow to No. 4 and so on until sufficient volume has been involved to absorb the surge. Under certain conditions, this may mean a surge clear back to the 600 section depending on the nature and completeness of the block. It should be remembered that, due to the mechanical construction of a converter, it is improbable that any obstruction other than reduction of porosity of the tubes is likely to occur.

Inverse Recycle.

In putting a cell on the line, it is first necessary that the cell temperatures and pressures be brought to those of standard operating conditions. This is accomplished by running the cell as a separate unit and adjusting the temperatures and pressures to their normal operating conditions. This process is known as inverse recycle, and consists of nothing more than setting by-pass, block, and inverse recycle valves in such a manner that material normally leaving a cell for the next cell, instead returns to its starting point within the same cell. In other words, A leaving No. 6 converter flows through the A inverse recycle line back to No. 1 converter of the same cell.

while B leaving No. 1 converter flows through the B inverse recycle line back to No. 6 converter of the same cell. In taking a cell off the line, the operation consists only of opening two cell by-pass valves, two inverse recycle valves, and finally closing four cell block valves. In putting a cell on the line, the reverse applies.

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CASCADE IN SECTIONS

In an ideal cascade the two streams entering any stage, i.e., the undiffused portion from the stage above and the diffused portion from the stage below, have identical compositions. Then there is no mixing of materials of different composition, which would obviously represent a loss in separation. To attain such an ideal system, it is necessary to reduce successively the mass of material circulating in each stage from the feed point to the top of the cascade and from the feed point to the bottom of the cascade. This could conceivably be done by using different size equipment for each stage. However, the required change from stage to stage would be very small, and the ideal cascade can be approached sufficiently closely for all practical purposes by limiting the equipment to four or five sizes and changing operating conditions every hundred or so stages. This latter plan was used in the design of the K-25 plant. Above the feed point the plant is divided into six sections, and below, into three sections. There are four different sizes of equipment used. Pressure conditions are varied from section to section, and, to a lesser degree, within sections.

The distribution of stages into sections and the salient operating conditions are shown in the following table:

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TABLE II

NUMBER OF STAGES IN EACH SECTION WITH OPERATING CONDITIONS

Section	No. of Stages	Size of Stages (Sq.ft. of Tube Area)	Pump Capacity cfm.	Typical Converter Pressure (psia)	Temperature Inside Converter
4	582		1200		
3b	708		3800		
3a	288		3800		
2b	552		9200		
2a	276		9200		
1	222		11200		
-1	90		11200		
-2	126		9200		
-3	54		3800		

Note: The equipment sizes are keyed to the section number, i.e., Section 4 uses size four equipment; Sections -3, 3a and 3b use size three equipment, etc. The sub-letters after the section number designate a change in operating conditions as shown in the table.

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TABLE III

TABULATION OF OUTSTANDING QUANTITIES OF MATERIALS AND EQUIPMENT INSTALLED IN THE K-25 & K-27 PROCESS AREAS

MECHANICAL

8,740 Pumps - 1/6 to 700 H.P. including:
- 6,888 Centrifugal Stage Pumps (Blowers)
- 132 Reciprocating Stage Pumps
- 665 Coolant Pumps

3,562 Diffusers - 1' 5½" x 2' 1-3/8" to 6' 10-3/8" x 11' 3"
1,060 Ventilating Fans - 5 to 25 H.P.
14,105 Motors - 1/20 to 700 H.P.
594 Coolant Coolers
634 Process Gas Coolers
2,502 Drums - 4" x 15-3/8" to 8' to 22'
18,703 Tons Sheet Metal

INSTRUMENTATION

132,157 Instruments
1,025 Instrument Panel Boards
126 Line Recorder Units consisting of total of 4,157 component parts.
44,600 Instrument Transfer Cocks
4,000,000 ft. Copper Tubing

ELECTRICAL

1,070 Transformers - 25 KVA to 1000 KVA
501 Switchgear - 1,000 A to 150,000 A
4,450 Circuit Breakers - 15A to 225A
2,310 Relays
1,982 Safety Switches - 5 A to 200 A
206 Push Button Stations
134 Control Panels
14,255 Calrod Heaters
10,312 Electric Air Heaters
1,223 Lighting Panels
40,220 Lighting Fixtures
3,375 Motor Starters and Contractors
2,500,000 ft. Cable (All sizes)
11,282,000 ft. Single Conductor Wire

CONFIDENTIAL

SECRET

TABLE III (Continued)

PIPING

251,000 Valves - 1/8" to 42" including:
114,544 Special Crane Valves of which 1,348 are electric motor operated
3,707,700 ft. Piping - 1/4" to 54"
414,525 ft. Pipe Insulator
2,200,200 Sq. ft. Housing Insulation

STRUCTURAL

851,137 Cu. yds. Concrete
41,473 Tons structural, miscellaneous and pipe bridge steel
11,184 Tons reinforcing steel
3,523,800 Cu. yds. excavation earth and rock.