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UNION CARBIDE CORPORATION
Nuclear Division

OAK RIDGE GASEOUS DIFFUSION PLANT

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THE OAK RIDGE GASEOUS DIFFUSION PLANT

A talk presented by R. G. Jordan, Superintendent, Oak Ridge Gaseous Diffusion Plant, at the United States Army Nuclear Science Seminar held in Oak Ridge, Tennessee, on July 17, 1967.

Oak Ridge, Tennessee

THE OAK RIDGE GASEOUS DIFFUSION PLANT

BACKGROUND

The Oak Ridge Gaseous Diffusion Plant (K-25) has played a unique and historic role over the past quarter century in the production of uranium enriched in the U-235 isotope. This enriched uranium has met vital requirements for weapons for the national defense, as well as fueling reactors for propulsion, research, and the production of radioisotopes. Now we are looking forward to the role the plant certainly will play in providing an economical source of energy to supply the electrical power demands of our fast-expanding, national economy.

Since the City of Oak Ridge is celebrating its twenty-fifth anniversary this year, it seems appropriate to include some historical perspective as part of my remarks. I also want to give you a brief description of the gaseous diffusion process so you may get a better feel for some of the problems involved and the truly remarkable technological and engineering achievements it represents. Finally, I want to tell you something of what we think the future holds with regard to demands for enriched uranium, a future which we at K-25 are vitally concerned about and are so deeply involved in planning for at the present time.

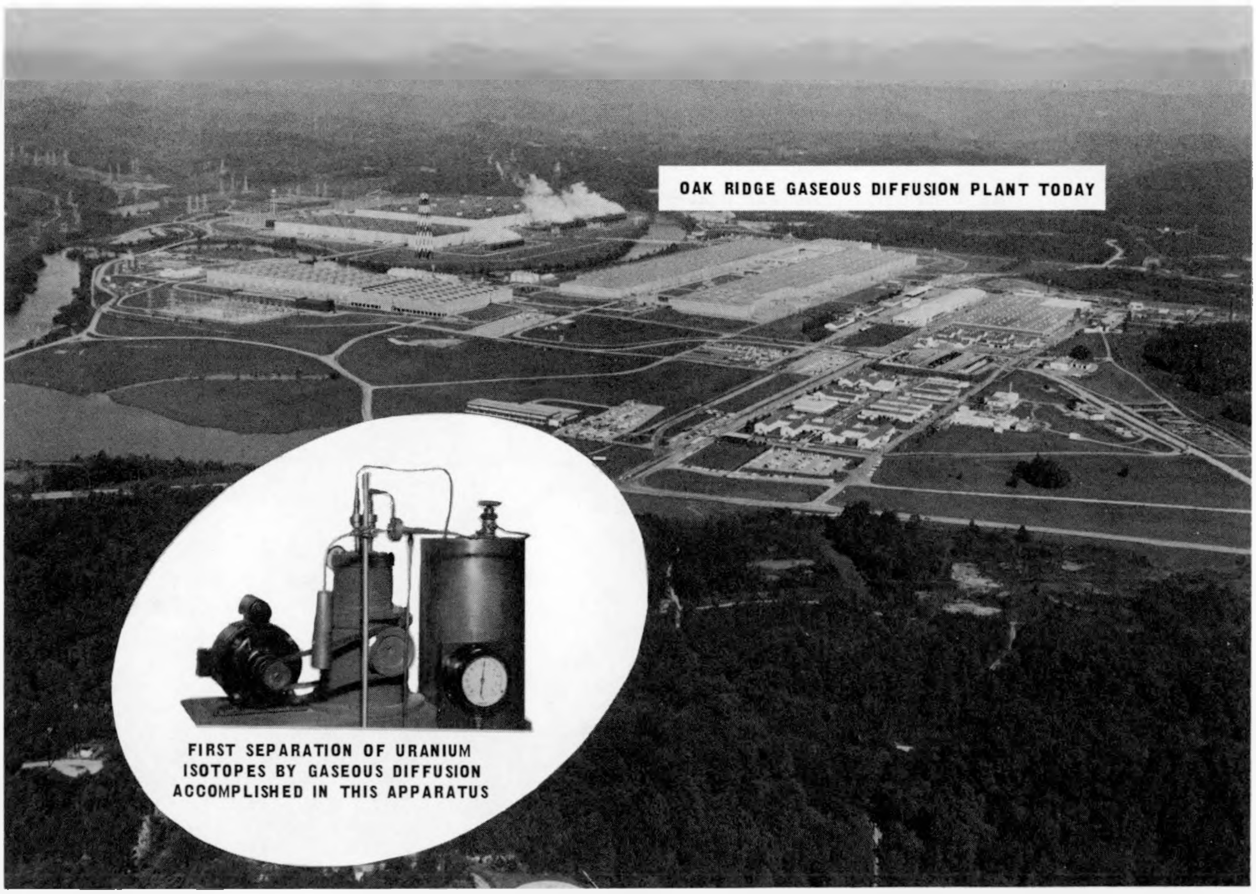

Figure 1
25 YEARS OF GASEOUS DIFFUSION TECHNOLOGY

Our story starts at Columbia University back in 1940 when scientists became interested in the possibility of large-scale separation of the uranium-235 isotope, following the discovery that it was the uranium-235 isotope which was fissionable by slow neutrons. The possibility of constructing nuclear weapons, of course, sparked an intensive search for a process which would provide some separation or enrichment of the uranium isotopes. Gaseous diffusion as a process had been used earlier by Aston in 1920 and later by Hertz in 1936 to separate the isotopes of neon. Research on the gaseous diffusion process for uranium started during 1941 at Columbia University. After two years of intensive study, but without any really satisfactory pilot plant demonstration with uranium, it was decided that plant construction and operation should be attempted.

Almost twenty-five years ago, Union Carbide accepted the contract to operate the gaseous diffusion plant. The contract also provided that Carbide should perform research and development on the process. This contract was signed in January 1943. Ground was broken at the K-25 site in Oak Ridge in September that year, and just a year and a half later, in March 1945, the first enriched material was shipped out. In August 1945, the K-25 cascade was in full operation. Figure 2 shows the first process building. The tremendous accomplishment that this represents is hard for us to visualize today. The process proved successful beyond the most optimistic expectations, primarily because the equipment proved more reliable and performed more efficiently than anyone had hoped. By the next year, 1946, the economic superiority of the gaseous diffusion process had been established and the electromagnetic process, another process for producing enriched uranium isotopes, was shut down. Then began a period of intensive efforts to improve the efficiency of the process in order to meet the military requirements, which for many of the following years exceeded the capacity of the diffusion cascade, and resulted in the construction of entirely new diffusion cascades in the 1950's. But let us now interrupt our account of the history and spend a few minutes describing the process and the problems encountered in building and operating a gaseous diffusion plant.

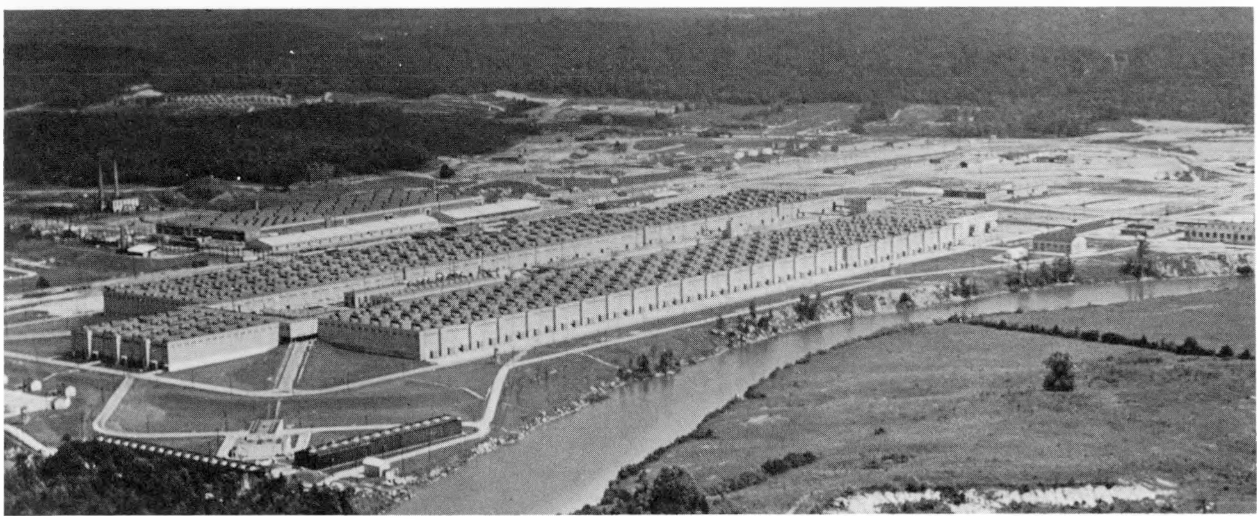

Figure 2
ORIGINAL K-25 PRODUCTION FACILITY

THE GASEOUS DIFFUSION PROCESS

The fundamental principle on which the process is based was discovered by Graham in 1829. This principle is that the average velocities of gas molecules at a given temperature depend on their masses. Therefore, in a gas made up of molecules containing different isotopic species, those molecules containing the light isotope will, on the average, have velocities a little faster than those which contain the heavy isotope. Now this velocity difference is very small. The theoretical maximum separation that can be achieved is determined by the difference in mass of the molecules and is equal to the square root of the ratio of the weights of the gas molecules. In our case, this is 1.00429, a very small ratio. This brings out a very important point, namely, that the process of diffusion must be repeated thousands of times. For example, to produce 90% U-235 material from the 0.7% U-235 one finds in natural ore, requires about 3,000 diffusion stages in series.

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$$\text{Kinetic Energy} = \frac{1}{2} MV^2$$

$$\frac{1}{2} M_1 V_1^2 = \frac{1}{2} M_2 V_2^2$$

$$\frac{V_1}{V_2} = \sqrt{\frac{M_2}{M_1}} = \alpha^*$$

$$\alpha^* = \sqrt{\frac{M_{U^{238}F_6}}{M_{U^{235}F_6}}} = \sqrt{\frac{352}{349}} = \underline{1.00429}$$

Figure 3
MAXIMUM THEORETICAL SEPARATION FACTOR α^*

Diffusive Flow

Another basic consideration is this. To take advantage of the separation factor we have just discussed, we must provide that diffusion takes place, not just simple gas flow. Because, if our gas molecules collide with each other, the velocity difference that we are trying to exploit will soon be lost. To get diffusion instead of simple gas flow we must provide for its diffusion through very small holes, "small" in terms of about one-tenth the mean-free path of the gas molecules. For example, this means holes about 100 A. in size, a fraction of a millionth of an inch. You will recognize also that the size of the pores is crucial in determining to what extent the flow is diffusive and, therefore, we see that the uniformity of size of these pores is of utmost importance.

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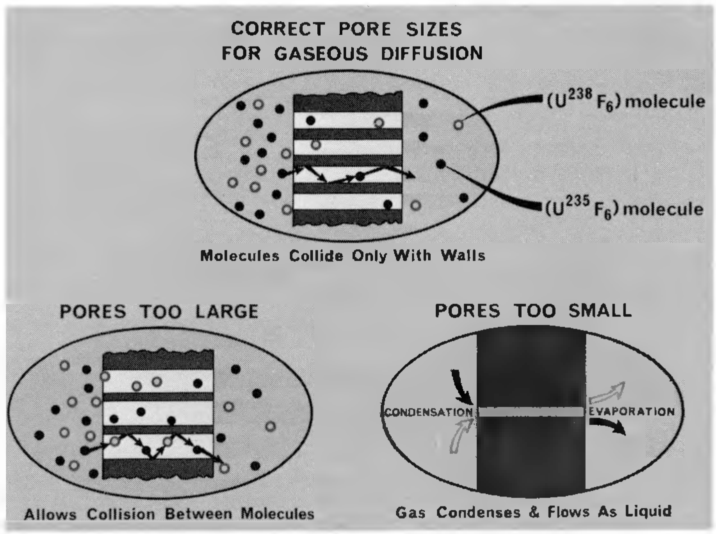

Figure 4
MOLECULAR FLOW THRU POROUS MEMBRANE

Several factors that determine our plant design arise from these basic conditions: firstly, our porous material, or as we call it the barrier, is a key to the process efficiency; secondly, that because the holes are so small there must be literally acres of barrier areas if we wish to produce any substantial quantity of product; and thirdly, that to force the gas to diffuse through these pores, we are faced with the necessity of providing a significant pressure drop across the barrier, which means many large gas pumps or compressors are needed and large motors are required to drive them.

Process Gas

Still more restraints on design are imposed by the diffusing gas itself. We must use a volatile compound of uranium, and the hexafluoride is the only suitable compound we can use. At room temperature, it is a solid so that the entire cascade must be run at elevated temperatures. Although it is a stable compound, it is extremely reactive with water, very corrosive to most common metals, and not compatible with organics such as lubricating oils.

This chemical activity dictates the use of metals, such as nickel and aluminum, and means that the entire cascade must be leak-tight and clean. Inleakage of atmospheric air will cause plugging of the barrier because of the reaction of the UF_6 with the water in the air. The corrosiveness of the process gas also imposes added difficulties in the fabrication of the fine pore barrier material which must maintain its uniform pore size over long periods of time.

Single Stage

Now let us see how we might put a workable process together giving these basic requirements and restrictions. Figure 5 illustrates the basic concept of the gaseous diffusion process. It shows schematically what takes place in a single stage and applies to any stage in the plant. Gas is introduced as UF_6 and made to flow along the barrier tube. The pressures are controlled so that one-half the gas diffuses through the barrier and one-half does not diffuse. The diffused stream is slightly enriched with respect to U-235, and the stream which has not been diffused is depleted to the same degree. The enriched stream is the product; the depleted is the tails or waste.

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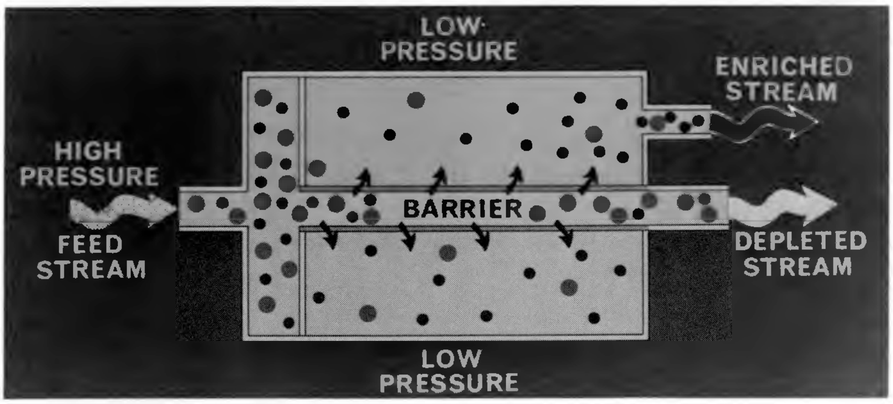

Figure 5
GASEOUS DIFFUSION STAGE

Multiple Stage

In Figure 6, we see how the single stages are connected so as to accomplish significant separations. This figure also indicates the basic equipment components we must have for our process. Looking at the central one of these three stages, we notice an axial flow compressor (similar to a jet engine) which is used to compress the UF_6 gas so it will flow through the barrier, and an electric motor required to drive the compressor. Notice that a gas cooler is provided since gas compression unavoidably generates heat of compression which must be removed at each stage. The diffuser is the large cylindrical vessel which contains the barrier material. It is arranged in such a fashion that the diffused stream and the stream that has not diffused are kept separate. You may notice that the sizes of the pipes coming out of the diffuser are quite different. The streams are at different pressures, but the mass flow is about equal. The control valve in the undiffused stream is used to assist in obtaining the proper balance of flows.

If we now follow the flow streams, you can see how individual stages are linked together in a cascade. The product stream from the bottom stage enters the central compressor and, after being partly compressed, is mixed with the depleted stream from the top stage. This mixture is then compressed still further and is fed to the diffuser in the center. The product stream from this central stage moves to the next compressor upstream, and the depleted or tails stream is sent to the stage below. Groups of stages are coupled in this way to make up operating units and such groups, in turn, make up the cascade.

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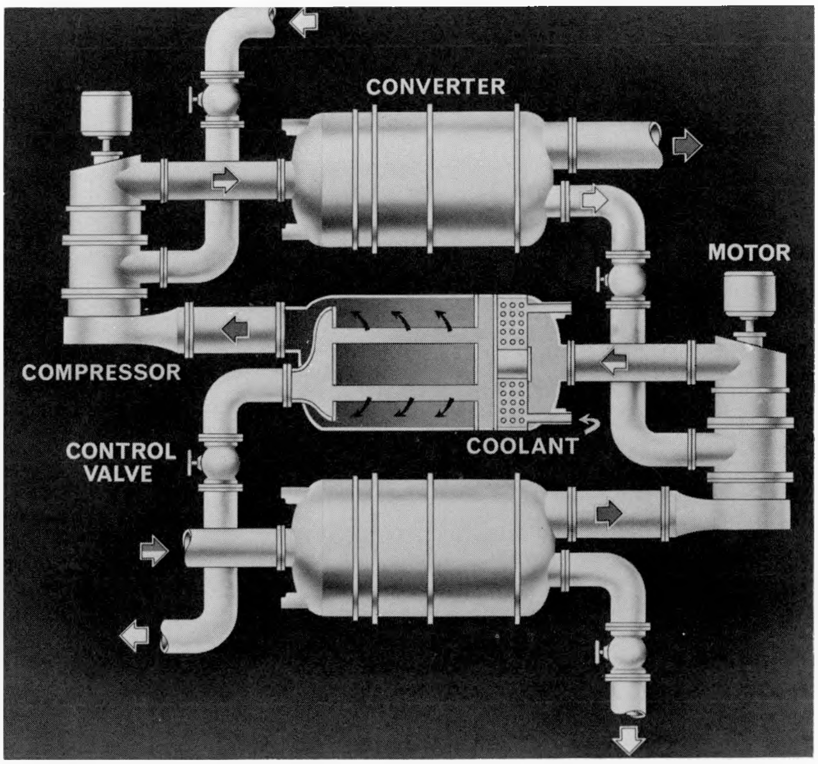

Figure 6
STAGE ARRANGEMENT

Cascade

Figure 7 is an aerial view of the Oak Ridge Gaseous Diffusion Plant's production area and the major units making up the cascade. The original wartime cascade referred to here as "K-25" leads to the confusion of many people, since we also use this term to refer to the entire gaseous diffusion plant at Oak Ridge. The other buildings, designated K-29, K-31, and K-33, are the more recent additions to the gaseous diffusion cascade, and we will have more to say about these units later. Although these large buildings are separated physically, they are connected by the necessary piping so that they may be joined in any arrangement needed to produce the most efficient operation. These cascade buildings have a ground coverage of over 100 acres, and represent a capital investment of some 840 million dollars. Both the distances and the economics involved dictate a high degree of equipment automation, reliable instrumentation, and remote control. From a central control facility an operator can monitor the entire plant operation by observing the information presented. He is able to take immediate action to cope with any emergency that might develop in a remote portion of the cascade which, in some cases, may be over a mile away.

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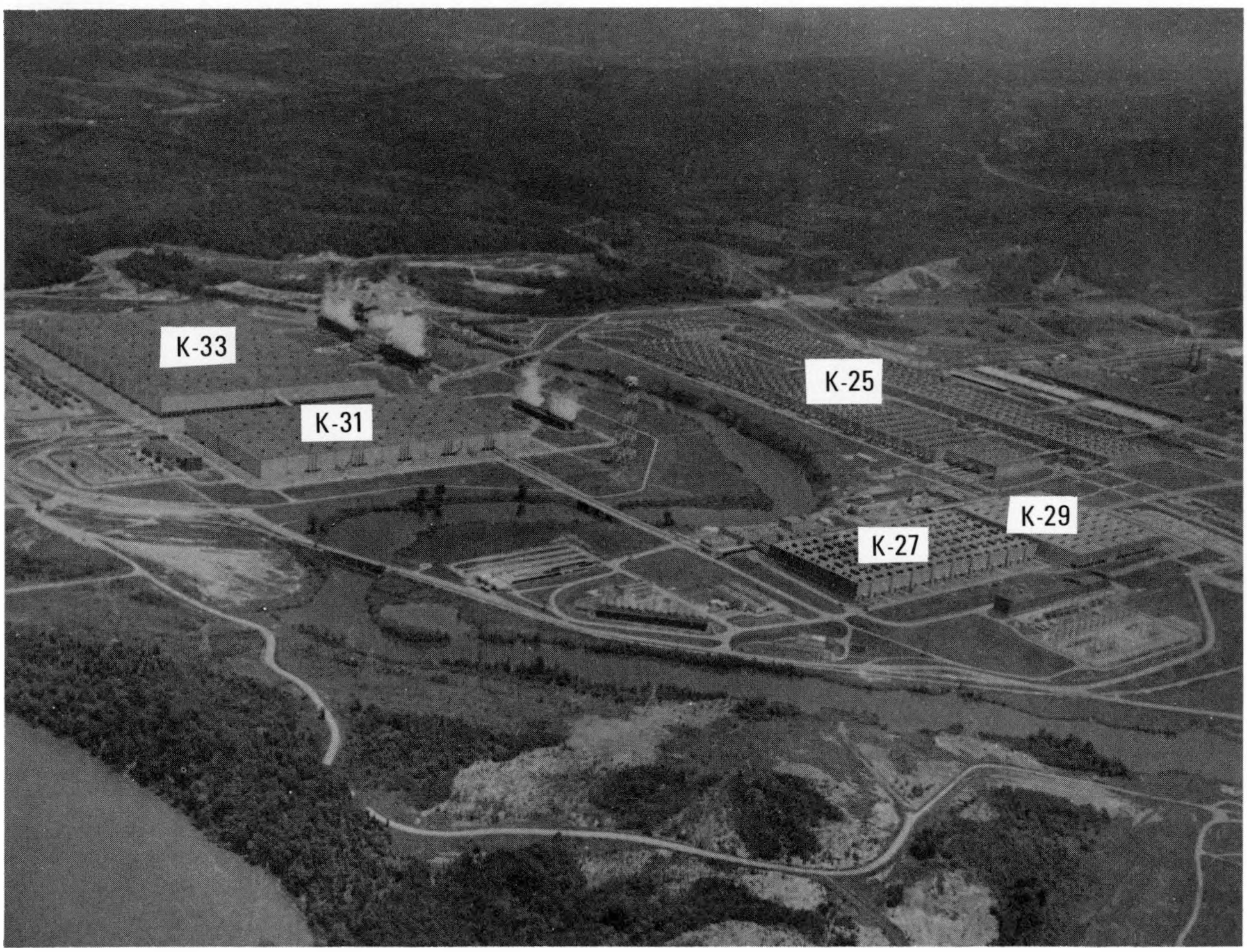

Figure 7
AERIAL VIEW OF PRODUCTION AREA

Support Facilities

The cascade consists of thousands of stages, each consisting of compressors, heat exchangers, diffusers, piping, valves, etc. Even though the equipment is exceptionally reliable, the large number of units means a considerable amount of maintenance is necessary.

The large building shown in Figure 8 is devoted to this maintenance of equipment. The view (Figure 9) inside this maintenance building shows the area in which maintenance of the large diffusers is carried out. In addition to this shop, there are other areas such as welding shops, electrical shops, instrument and electronic shops, sheet metal shops, assembly areas, cleaning and degreasing areas, plating shops, and a precision machine shop shown in Figure 10.

PROCESS IMPROVEMENT

Suppose we now turn back from this brief description of what the gaseous diffusion process involves to our historical account which we left at the point of finishing construction of the wartime plant in 1946. The power requirements of the gaseous diffusion process are tremendous, and there is a great deal to be gained economically in reducing the amount of power needed. It is apparent, from what I have said, that the barrier material itself is a key to the efficiency of the whole process, and that improving its quality even a very slight amount, considering the role that it plays, will have a most beneficial effect on the overall economics of the process. And so it is that since the very early days of our

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Figure 8

MAINTENANCE AND FABRICATION BUILDING

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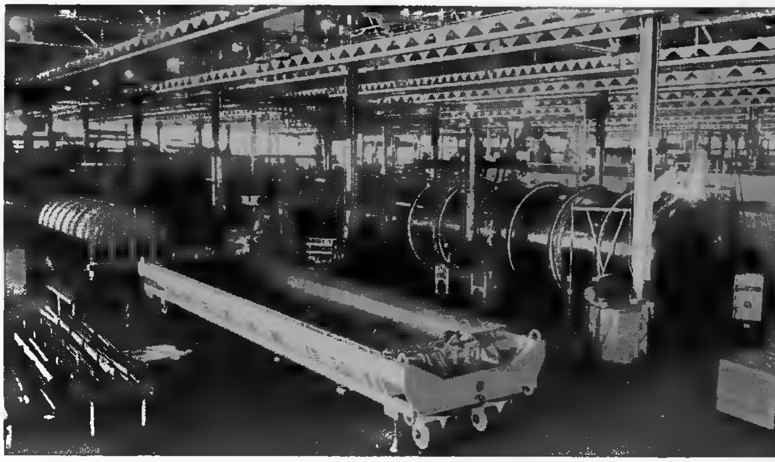

Figure 9

WELD AND ASSEMBLY AREA

PHOTO NO. PH-64-422

Figure 10

PRECISION MACHINE SHOP

work on the gaseous diffusion process, Union Carbide has been vitally concerned with the improvement of the process and has operated the plant with the same philosophy that is applied to its own private operations.

1946-1949 - K-25 The Sole Supplier

A vigorous research and development program was undertaken from the earliest days and has made possible truly tremendous gains in enriched uranium economics. Of course, during the early days of the plant operation in 1945 and 1946, a large portion of the technical effort was devoted to getting the plant in operation and making the necessary field engineering changes that had to be made for the process to work satisfactorily. It was not at all unusual to find a chemist or an engineer of any of the engineering disciplines in the field operating units, making changes, planning maintenance work, and developing maintenance and operating procedures.

I have already alluded to the fact that the plant in its initial operating period exceeded the expectations of the most optimistic people in terms of its performance. I point this out again because this is the base line that we refer to as our wartime operation, and it is our point of reference in discussing plant improvements since that time. As is so often the case when we look back to where we started in a given field from a later vantage point, it is easy to minimize or even to forget how great an accomplishment the achievement of the original position or the first working model really represented.

Early efforts to reduce the cost of operation were very gratifying. For example, the total number of employees in the plant was reduced from the 1945 level of 12,000 to 6,800 just one year later. At the same time, maintenance costs were decreased greatly and on-stream efficiency approached 100%. With the settling down of plant operations, the technical people were able to undertake studies of equipment design changes which would provide improvements in process economics.

In the laboratory, the barrier development specialists, as a result of their research programs, laid the foundation for major advances in improvement of barrier stability and barrier quality. The conviction on the part of Union Carbide management of the value of continuing the research and development programs, and the willingness of the Manhattan Engineering District and later the Atomic Energy Commission to provide the necessary dollar support for these scientific and engineering programs, proved to be of great value in the 1950's.

1950-1955 - New Plant Construction

When the decision was made that new gaseous diffusion facilities should be built to provide a major increase in production capacity, we were ready with new designs and materials which represented a quantum jump over the efficiency of the wartime plants. The first new gaseous diffusion facility was called the K-29 Plant and it was constructed during 1949 and 1950. Full operation was achieved early in 1951.

By that time, decisions had been made to build more facilities since production requirements for the military had grown still larger. Two other facilities were authorized, designed, and constructed at Oak Ridge during the early 1950's, the plant designers in each case utilizing the latest technology that was available. These new plants were designated the K-31 Plant and the K-33 Plant.

The K-33 Plant covers a ground area of 32 acres and, at the time of its construction, the structural steel involved in that building was the third largest tonnage in one structure in the United States. These new facilities were completed and in operation by the middle 1950's.

More production capacity was desired than could be furnished by these much expanded facilities, and two new cascades were constructed at Paducah, Kentucky, and Portsmouth, Ohio.

The Union Carbide organization at the Oak Ridge Gaseous Diffusion Plant was asked to and did provide the process engineering, conceptual design engineering, and other technical assistance needed to supervise the construction of these new plants.

What did we do to improve these plants? I think that one of the best ways to give you a feeling for the impact of the research, development, and engineering work is to review the cost of these new facilities. These new plants (K-29-31-33, Paducah and Portsmouth) were built at a total cost of 1.9 billion dollars. This capital cost, of course, was considerably lower than what it would have been if the wartime design used for the original K-25 plant had been employed. These costs were lower because of major improvements in compressors, improvements in the barrier material, etc. It is our conservative estimate that had these plants been built using the wartime

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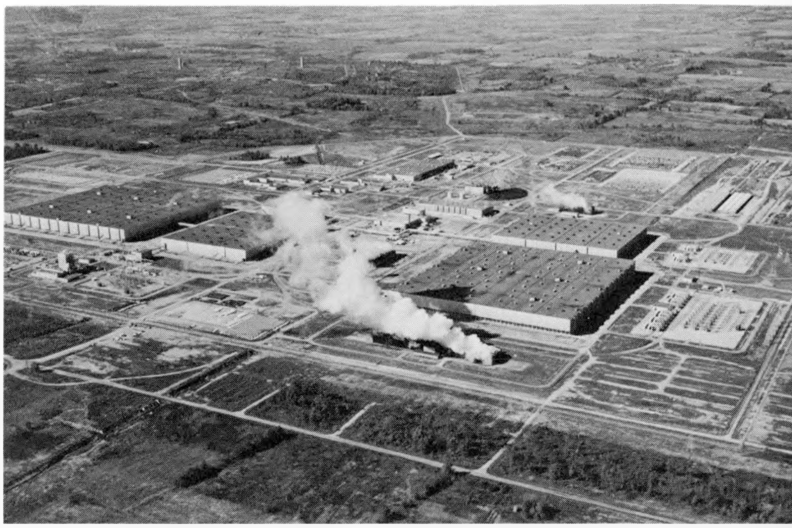

Figure 11
PADUCAH GASEOUS DIFFUSION PLANT

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Figure 12
PORTSMOUTH GASEOUS DIFFUSION PLANT

design, their costs would have been near 6 billion dollars. A savings was made in capital costs of 4 billion dollars without adjusting the costs for price escalation. Just as impressive is the saving in terms of operating costs each year of about 400 million dollars over those to be expected had the wartime design been used.

1955-1960 - Plant Improvement

The period of time represented by the second half of the 1950 decade saw a continued era of process technology development which was used to advantage in an active program of equipment replacement and improvement. The changes made possible by the aggressive program of barrier development, and component and plant improvement programs to exploit these developments, resulted in highly significant additional increases in the separative capacity of the plants.

1960-1964 - Minimizing Costs

By the early 1960's the pressure to increase capacity eased, and target objectives for the plant emphasized the goal of decreasing unit costs. Unit costs had been decreased sharply through the years by the improvements I have already described. As you have probably recognized, many of the improvements made have been of the type which could be taken advantage of in either of two ways- increased capacity, i.e., more production for the same power input, or lower costs, i.e., the same production for less power input. The main thrust of the program during the first half of this decade has

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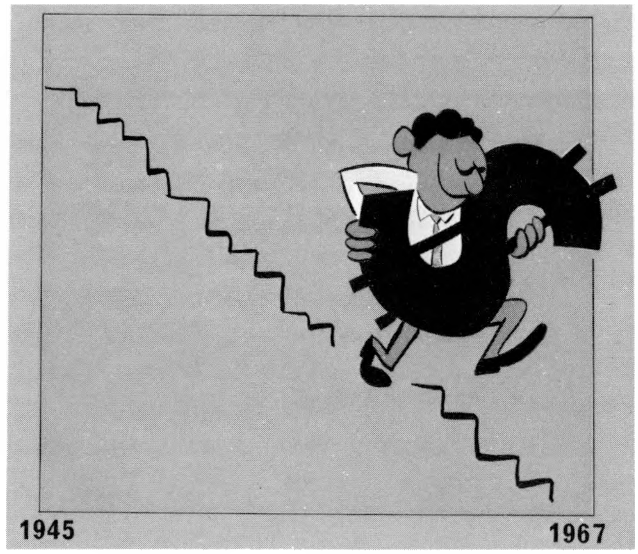

Figure 13
COST OF SEPARATIVE WORK

been toward achieving lower unit costs, and the gains have been substantial.

1965-Present - Preparing For The Future

During the second half of the 1960 decade, we have become more and more concerned with the future demands for U-235 for civilian uses. You are all aware of the flourishing business in nuclear reactors to supply electric power. It is this market which we now foresee will require all the capacity we have to produce enriched uranium toward the end of the next decade. Currently there are 13 operating power reactors, 10 under construction, and over 100 in various stages of planning.

With each new estimate of the electric power demands for the future, the conviction is growing that these requirements will have to be met by enriched-uranium - fueled, nuclear reactors--reactors which are economical and have given this country a lead in the reactor business only because of the tremendous strides we have made in reducing the cost of separative work. Separative work as applied to our operations is a measure of the job of separating a feed stream into a product stream enriched in U-235, and a waste stream depleted in U-235. Separative work costs are reflected in power costs at about 0.5 of a mil per Kw/hr. You can readily see that it is an important cost factor. If it were 2 or 3 times as much, enriched reactors would not be economical as compared to fossil fuel plants. A recent forecast of nuclear power capacity is shown in Figure 15, and you can see how fast these requirements are expected to rise.

This business of forecasting is not just risky, it is very difficult. There are many complicating factors which make the forecast of requirements for diffusion plant capacity a hazardous game, not only questions involving the domestic needs and foreign requirements, but questions of various alternative ways of meeting them. Perhaps you noticed in the press this last month the signing of the first toll enriching contract with a Swedish nuclear power company. This is an arrangement made possible by new legislation under which private owners may have their uranium enriched in the government plants.

Much of our current effort is being devoted to studies of what these future demands are likely to be and the most economical way to meet them. Our

ORO PHOTO NO. 67-0065

Figure 14

THIS TRUCK LOAD OF OUR PRODUCT CONTAINS APPROXIMATELY 12 TONS OF URANIUM HEXAFLUORIDE. THIS AMOUNT OF MATERIAL IS ENOUGH TO GENERATE 1 1/2 BILLION KILOWATT-HOURS OF ELECTRICITY, ENOUGH POWER TO SUPPLY THE ELECTRICAL NEEDS OF A CITY OF MORE THAN 200,000 PEOPLE FOR A YEAR.

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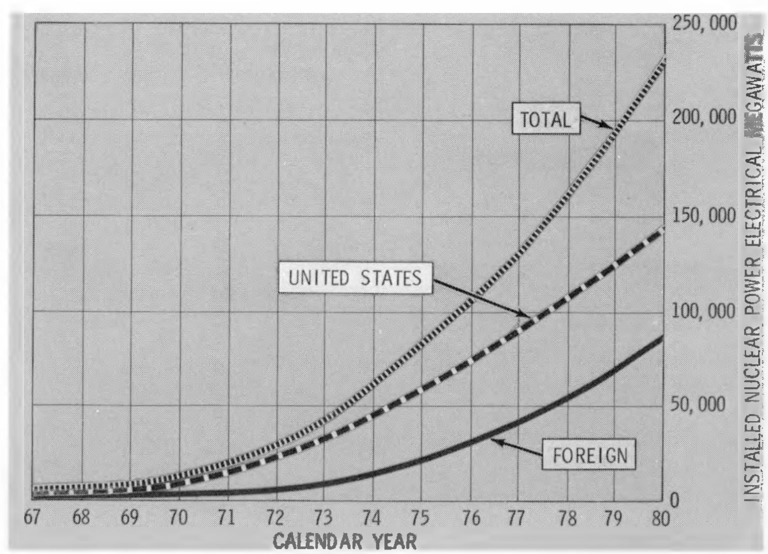

Figure 15

ESTIMATE OF INSTALLED NUCLEAR POWER CAPACITY research, development, and engineering groups are actively engaged in studies for increasing plant capacity and developing the technology needed to provide that capacity increase at the lowest possible cost.

Members of our staff at the Oak Ridge Gaseous Diffusion Plant are enthusiastically responding to the challenges which they indeed have helped to create by making this basic energy source available in quantities and at costs which we are confident will soon permit its much more widespread use in the services of mankind.

Thank you.