

THE ROLE OF CHEMISTRY IN THE OAK RIDGE ELECTROMAGNETIC PROJECT

Clarence E. Larsort*

The Neglect of Chemistry

In Frank Settle's article "Chemistry and the Atomic Bomb" in the American Chemical Society's publication, *Today's Chemist at Work*, he summarized the status of the literature describing the contributions of chemistry to the Manhattan Project as follows (1):

In most historical accounts, the contributions of chemistry to the development of the atomic bomb are eclipsed by those of physics.

He quotes Glenn Seaborg as expressing his disappointment that the famous Smyth Report (2) neglected to place the chemical contributions in proper perspective and suggested that the report be revised. Unfortunately the emphasis on physics and neglect of chemistry has continued in almost all subsequent publications. Settle's account of the chemical problems involved in the electromagnetic process for separating U^{235} is a good descrip-



Clarence E. Larson, courtesy Oak Ridge National Laboratory

tion of some of the complex chemical problems encountered. It is the purpose of this article to expand the depiction of the many challenges encountered during the operations.

When fission was discovered by Hahn and Strassman in late 1938, there was some controversy as to what isotope of uranium was responsible for fission by slow neutrons. Niels Bohr and John A. Wheeler showed that the readily fissionable isotope had to be the lighter one. This conclusion was confirmed by John R. Dunning of Columbia and Alfred O. C. Nier of Minnesota, who separated the

isotopes in a mass spectrograph and bombarded the samples with slow neutrons. This experiment established that it would be necessary to enrich the uranium to a high degree if it were to be of value as weapons material. Little did Nier and Dunning realize that the mate-

rials and the methods would eventually scale up to a gigantic plant employing 25,000 workers to produce the quantities of U^{235} used in the Hiroshima bomb. Other methods of separating the two isotopes included thermal diffusion, gaseous diffusion, and the centrifuge, but no serious work was done on the centrifuge method during the war. E. O. Lawrence had several cyclotrons at Berkeley that could be converted into large mass spectrographs in a short time. In spite of pessimistic views concerning space-charge limitations, there was successful separation within a short time and immediately after Pearl Harbor a large-scale project was launched.

The apparatus to accomplish this separation was called the "calutron." The main elements consisted of a vacuum chamber shaped in the form of a "D" in a strong magnetic field. A stainless steel charge box containing UCl_4 , with a slit to allow escape of vapor, was suspended at one side of the D. The uranium vapor was ionized in an arc and given a plus charge. The uranium ions were accelerated by a form of grid, entered the magnetic field where the U^{235} and U^{238} beams separated, and were collected at the 180-degree point.

The chemistry involved in the Electromagnetic Project can best be described by dividing the discussion in three phases.

1. *The Berkeley phase*, which furnished the calutron development group with the charge material, product retrieval, and recycle methods.
2. *Oak Ridge research and production operations.*
3. *Post war applications* of Y-12 chemistry developed during the war.

The Berkeley Phase

At first there was little thought given to the chemical problems; and two professors, Martin Kamen (discoverer of C^{14}) and F. A. Jenkins, handled the production and purification of the charge material with the aid of a small staff. It was soon apparent that the chemistry effort needed expansion, and I was recruited from the College of the Pacific to join the group. E. O. Lawrence had furnished me in the past with some radioactive target holders from the cyclotron, on which I did some research using the classic Lauritson electroscopes for instrumentation. In addition he expressed some interest in the fact that I was a licensed radio amateur and could be useful in instrumentation.

Several chemistry problems, however, needed solutions immediately. First, it was necessary to devise a process to produce UCl_4 from the oxide. Two processes were successful. When uranium trioxide is reduced by hydrogen to the dioxide and reacted with carbon tetrachloride vapor at about 400° C, it produces uranium tetrachloride, a green hygroscopic crystal. W. M. Latimer, a professor of chemistry at California, devised this method. About this time we recruited Charles Kraus, former president of the American Chemical Society and professor of chemistry at Brown University. At Brown Kraus established a project with graduate students and faculty to assist us in solving chemical problems. His expertise was of great value throughout the duration of the project. He immediately suggested another method using a high-pressure reactor, which subjected uranium oxide to carbon tetrachloride at elevated pressure and temperature. This reaction yielded uranium pentachloride and phosgene. The pentachloride was converted to the tetrachloride by heating in an inert atmosphere. The second process was better for large-scale production. Because UCl_4 was very hygroscopic, it was necessary to carry out all of its operations in a closed "glove box" kept dry with phosphorus pentoxide. If there was contamination the product was purified by vacuum distillation. It was then transferred to the charge bottles for use as feed material to be separated in the calutrons. One of the by-products of this process was phosgene, and all of us used gas masks in handling the material. The tragic accident in which Sam Rubin (co-discoverer of C^{14}) was killed in an experiment handling phosgene reminded us of the hazards. (His experiment did not involve work on the Manhattan Project). In spite of extreme precautions there was one fatality at Oak Ridge involving phosgene. I was slightly exposed when I was issued a gas mask that had already been used. However, outside of a temporary shortness of breath, I experienced no serious consequences.

My first task at Berkeley was to purify vapor-phase-produced UCl_4 by vacuum distillation. When UCl_5 was produced by the liquid-phase method, the extra chlorine atom could be removed by simple heating at ambient pressure to produce good quality product. When I tried an experiment with vacuum distillation at lower temperature, a brown deposit collected on the cold finger in the apparatus. Analysis of this brown deposit gave an atomic ratio of Cl to U of almost 6/1, indicating a formula of UCl_6 . It had been theorized that UF_6 could exist but that UCl_6 could not because of the size of the chlorine atoms. Martin Kamen recalculated the atomic

sizes and concluded that uranium hexachloride could exist and indeed we had discovered a new compound. Unfortunately, this was an interesting discovery but it had no immediate practical use.

Because of this preliminary work the production and purification of UCl_4 went into operation at Oak Ridge without serious difficulty. There was considerable research aimed at improving these methods, but none reached the production phase except a slight modification of the reduction part of the vapor-phase production process. While hydrogen was a good reducing agent, there was some hazard. Kraus suggested that alcohol be used as a reducing agent, which proved very satisfactory.

One of the projects at Berkeley was to develop a method for recycling the enriched uranium from the first stage of separation in the Alpha calutron plant to feed the second stage in the Beta calutron plant continually. A group under Martin Kamen developed a very sophisticated method using oxidation-reduction steps, followed by oxalate precipitation. When used in the laboratory this method worked well. In actual production there were grave deficiencies and poor yields, and the solution to these problems will be discussed in the Oak Ridge section.

There was an amusing sidelight as a result of extremism of security regulations when the German book, *Gmelin Handbook of Chemistry, Uranium Volume*, was removed from the library. It was an invaluable reference volume, and I managed to borrow a copy and photographed the entire volume. Since this was before the days of Xerox, I used a method known to graduate students at California which did not need a camera. Using high-contrast photographic paper it is possible to obtain copies using only a sheet of glass to insure contact of the original and the copy paper. In theory this should not work but it gives excellent results. This copy of *Gmelin* was consulted almost every day of our investigations.

One of the valuable references in *Gmelin* was the description of the use of hydrogen peroxide to precipitate uranium away from most of the rest of the periodic table. Unfortunately, hydrogen peroxide is catalytically destroyed by traces of iron, which was universally present. It was frustrating to attempt to carry out the precipitations only to see the contents of the beakers boil over on to the lab desk. We tried complexing reagents to sequester the iron but were unsuccessful

In my graduate work I had occasion to recover important biological compounds such as amino acids and proteins from complex solutions. Most of the purification reactions denatured or destroyed the compounds unless the reactions were carried out at low temperatures. It is common practice to construct cold rooms to carry out such reactions. When I tried refrigerating all of the solutions and the reagents, the uranium peroxide precipitation worked perfectly. Since the oxalate method was well under way, the refrigerated peroxide method was not pursued until serious difficulties developed when the oxalate method was tried on the Beta solutions at Oak Ridge operations.

When we learned that the decision was made to go into production at Oak Ridge in 1943, I proposed that pilot plants for chemical operations be constructed and operated so that bugs could be removed before the design of the operating equipment was finalized. The proposal was met with horror at that time. The fact that we were about to construct a production plant was considered "top secret." Construction of pilot plants was thought to be unnecessary and compromise security. I was reprimanded for not being security conscious. Failure to take this simple step had serious consequences, which were apparent immediately on going into operation at Oak Ridge

Because there were only a few grams of enriched uranium reaching the receivers in each run, it was assumed that the recovery of product from the receivers would be quite simple. In the experimental runs at Berkeley, enriched uranium was recovered from the receivers to determine the degree of enrichment, but little attention was paid to the importance of material balance. As mentioned above, this deficiency became serious when the Oak Ridge plant went into operation.

Early in 1943 the Army contracted with Eastman Kodak's Eastman Division to operate the electromagnetic plant in the Oak Ridge area, which for security reasons was called the Y-12 plant. I and several others transferred to Eastman and in July 1943 we went to Oak Ridge to assist in startup operations

Operations at Oak Ridge

By the end of 1943 there were over a thousand individual Alpha units ready for operation. They were installed in large electromagnets wound with silver bars. Over 400 million ounces of silver ultimately went into the installation. Fort Knox furnished all of this silver,

which was needed because of the shortage of copper. Initially there was serious shorting of the electric current powering the magnets because the construction workers had neglected to clean up construction debris. Pessimists despaired that the problem was insolvable, but the units were cleaned up and operations started. The receivers containing uranium enriched to 12-15 percent were sent to chemical operation for the recovery of this valuable product.

As head of the chemical technical staff I was to assist the operating departments in training and placing the chemical processes into operation. The production of charge material went into operation with only minor difficulties. The other problems involved with recovering and recycling the uranium used in the process immediately began to give difficulties.

The first serious difficulty came to light when the receivers, which contained the enriched product from the first stage or Alpha operations, failed to yield the predicted amount of enriched material. When the recovered yield from the receivers totaled only about 50 percent of the predicted amount, the consequences were potentially catastrophic.

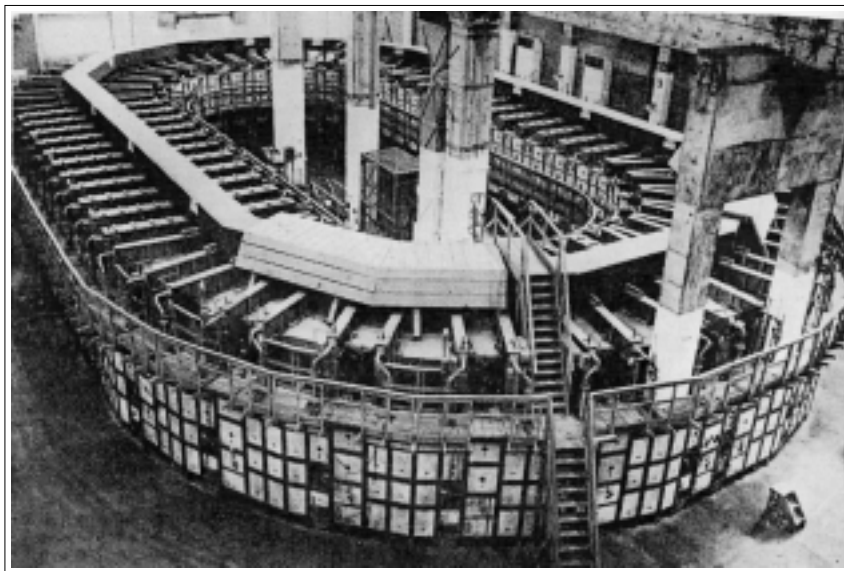
It was quickly found that the uranium ions were striking the stainless steel receivers with sufficient energy to penetrate into the stainless steel and therefore could not be dissolved by nitric acid. In theory the uranium could be recovered by dissolving part of the receiver using aqua regia, but the receivers were complicated, precision electronic devices which would be expensive and time consuming to replace. During my graduate work on the electrochemistry of biologically important compounds, I had become familiar with many applications of electrochemistry. It was apparent to me

that the solution would be to electroplate a copper film on the inside of the receiver, which could then be easily dissolved by nitric acid without damaging the stainless steel receiver. The uranium could easily be recovered by ether extraction from the copper nitrate solution and soon the yield rose to nearly the predicted levels. By a stroke of good fortune, one of the engineers who was assigned to my group had experience in operating a

metal-plating plant and was able to specify immediately the equipment needed to carry out the operation. When E. O. Lawrence asked me how long it would take to get the process into operation, I replied that we could do it in about two weeks. In typical Lawrence character, he said, "I want plated receivers in operation to-

morrow." By working day and night we had the first plated receivers ready in 36 hours.

The direct-current generators, bus bars, chemical laboratory sinks, and instruments appeared almost by magic. Within a few weeks there was enough product to feed into the second stage or Beta operation. The uranium, which was dissolved in nitric acid along with the copper, was quantitatively separated by ether extraction and converted to pure uranium oxide. In subsequent chemical operations, ether was replaced by other solvents which had superior properties. The product of this operation (12-15 percent U^{235}) was UO_3 , which was converted to UCl_4 and fed into the second stage (Beta operation) and the enrichment raised to 80-90 percent, which was suitable for the construction of a nuclear weapon. The product, after extensive purification, was converted to UF_4 and sent to Los Alamos to be converted into metal and ultimately machined into bomb parts.



Alpha I Racetrack. The reason for the name is obvious. The protruding ribs are the silver-wound magnet coils. The boxlike cover around the top contains the solid-silver bus bar.

As has already been pointed out, the Beta operation converted less than 10 percent of the UCl_4 charge which reached the receivers. The rest of the material had to be recovered from the calutron parts and recycled along with the feed from the Alpha product entering the Beta cycle. A process based on complicated oxalate precipitation had been developed at the Berkeley lab to process and purify this recycle material. In theory it should have worked well. In actual practice there were large quantities of impurities in the recycle stream which interfered with complete precipitation and the recovery was unacceptably low.

The enriched material from the Alpha receivers being fed into the Beta cycle was described by Lawrence as priceless. Based on the costs incurred, its value was more than \$100/g. No effort was too extreme to recover every gram. During the Beta recycle this valuable material was scattered over the stainless steel liners, graphite parts, filaments, and other components. In the chemical process it was necessary to minimize holdup in the process equipment. Since only 5 to 10% of the beam ever reached the receivers, it was essential that the recycle time be held to a minimum.

The oxalate process was time consuming and exacerbated the problem. As described above, the basic chemistry for the alternate refrigerated peroxide process had already been worked out while I was at Berkeley. At a conference with Eastman officials, Lawrence, Baxter of the British group, and Kraus, it was decided to scrap the oxalate process and convert the Beta chemical recovery process to the refrigerated peroxide process.

Fortunately, uranium can be selectively precipitated by hydrogen peroxide from almost all of the elements in the periodic table, which conceivably could contaminate the product. Unfortunately, peroxides decompose violently in the presence of iron impurities, which were the most common impurity in the solutions. As mentioned above, I had encountered instability problems in isolating compounds which were unstable at room temperature. Biochemists usually solved this problem by refrigerating the operations. When this principle was tried out on the impure uranium solutions, the uranium precipitated quantitatively as the peroxide. While this precipitate was difficult to filter, the separation was easily carried out by centrifugation. Fortunately, the equipment to carry out this operation was standard chemical process equipment.

The Army priority organization located the equipment and flew in the parts necessary for operation, and very soon the product stream was in operation. It is important to note that our small technical staff needed expansion and the Army organized a Special Engineer Detachment (S.E.D.) consisting of trained scientists and engineers. The Army furnished about 100 chemists and chemical engineers with outstanding training and experience, and these men put the refrigerated peroxide process into operation with speed and skill.

The fact that most of the enriched uranium was precipitated and separated in the first step was vital to speeding up the recycle process. When it was assured that the process was successfully operational, F. R. Conklin, the plant superintendent, dubbed it the Larson process and had the equipment labeled accordingly.

As the production from the Alpha and Beta calutrons reached full volume, the chemical operations began to produce kilogram quantities of enriched uranium. Los Alamos received enough material to determine the critical mass under various conditions. One piece of vital information was the critical mass of uranium in water solutions. This proved to be much smaller than expected and immediately raised the possibility of a catastrophic chain reaction in the chemical processing. R. Feynman visited Oak Ridge and confirmed that there was imminent danger that such an event could occur. Immediate steps were taken to insure that operations were carried out to avoid this possibility. It is ironic that this possibility was avoided during the war, but super-criticality did occur several years later and several workers were exposed to more than a hundred thousand millirems of radiation. Fortunately, there were no short- or long-term health effects.

About the early summer of 1944, additional improved-design calutrons were placed in operation, which greatly increased the production available for the Beta cycle. This, along with the greatly improved Beta chemical operations, insured that the objective date of July, 1945 would be met.

At the height of operations there were more than a thousand calutron units running, each requiring individual treatment. In order to minimize losses, dozens of side streams were monitored; and recovery operations were set up to return the uranium to the main stream. Over five thousand employees were involved in these chemical operations. As July, 1945 approached, every bit of uranium from all parts of the process was

sent to Los Alamos for fabrication into the Hiroshima bomb. Lawrence's goal of 40 kilograms by July, 1945 was met. On August 5, 1945, we knew that all doubts were resolved.

By late 1945 the thermal diffusion plant and the Alpha calutrons were unnecessary because the K-25 gaseous diffusion plant began to deliver 10-15 % enriched uranium to the Beta calutron units, and the operating and support groups associated with these operations were reduced in force. A year later the gaseous diffusion plants began to deliver 90 - enriched material, and Beta calutron production ceased. At this time all of the technical staff and research and development programs were consolidated, and I was appointed director of research and development.

The research and development group had been drastically reduced in force and needed new challenges. Improved chemical operations were needed to convert the uranium hexafluoride from the gaseous diffusion plant to UF_4 for delivery to Los Alamos. Shortly afterwards, the Atomic Energy Commission asked that the enriched uranium be delivered as the metal. The uranium metal production process developed by F. H. Spedding was scaled up and installed in a specially secure building. Shortly after this we were asked to develop facilities to begin machining of weapons parts.

To find new challenges for research and development, I called a meeting of the group leaders, and in a brainstorming session came up with a list of potential projects which could make a contribution to future needs of the newly formed Atomic Energy Commission. The following is a list of those projects discussed in the meeting.

1. Separation of isotopes by chemical exchange methods. Candidates for these included uranium and lithium isotopes.
2. Recovery of uranium from low-grade ores.
3. Refinement of equipment and methods for counter-current extraction.
4. Special chemical separation methods and development of analytical methods.
5. Stable isotope separation in the calutron units. Ultimately this project led to separation of most of the isotopes in the periodic table.

Isotope Separation by Chemical Exchange

Before the discovery of artificial radioisotopes in the early 1930s, the isotopes of hydrogen, nitrogen, oxygen, and carbon were separated and used in tracer experiments. One of the first uses of separated stable isotopes was M. L. E. Oliphant's use of heavy hydrogen in an accelerator to discover the fusion reaction in 1935. It was tempting to explore the possibility of separating the uranium isotopes by this method. Glen Clewett of our group organized a small team to investigate this possibility. A system based on an exchange between solutions of uranium in the plus four and plus six state showed some promise, but further work demonstrated that it was extremely unlikely that it would compete with gaseous diffusion. The effort was dropped and Clewett concentrated on developing a process for lithium isotope separation

In the case of lithium, the Li^6 isotope has a high cross section and the Li^7 isotope has a very low cross section. It is possible therefore that Li^7 might have use in nuclear reactors as a coolant. Later it was used in the experimental molten salt breeder in the form of its fluoride salt. The system first investigated was based on the chemical exchange between lithium as a metal amalgam with mercury in contact with a water solution of lithium hydroxide. The Li^6 was preferentially concentrated to a slight degree in the aqueous phase. By repeating this several hundred times in a cascade type of operation, it is possible to purify both isotopes. Since the lithium amalgam is unstable in contact with water, it was necessary to apply a reverse voltage to prevent reaction. Because of the necessity to maintain electric contact with the mercury phase, the "mixer-settler" cascade type of operation was used. This process was dubbed the Elex Process.

Shortly after initial operation, Forest Waldrop, who had worked on the refrigerated cold peroxide Beta process, suggested that the instability of the amalgam system could be controlled by refrigerating the reaction. This proved to be almost instantly successful and was used to produce almost all of the Li^7 and Li^6 isotopes needed for the AEC programs. Waldrop and John Googin designed a refrigerated cascade column to carry out the process. It was named the "Colex Process."

The requirements for mercury were enormous. Most of the world production was required for several years. Because of the poisonous nature of mercury, extreme precautions were taken to protect the health of

the workers. As a result of these precautions there were no cases of health effects during the entire operation.

According to recently declassified documents, the Soviets used calutrons to obtain separated isotopes for their initial requirements for Li^6 . Since most of the production of lithium in the United States was channeled through the Y-12 process plant, most of the lithium available in this country no longer had the original atomic weight. The requirements for Li^6 were so great that the reject stream was able to supply all domestic needs. One strange incident involved the clandestine purchase by a foreign country of our lithium with the intention of extracting the Li^6 . Imagine the surprise the purchasers felt when they found their desired isotope had been stripped away.

If the United States had found it necessary to use calutrons for this separation, it might have cost billions more than the actual experience.

Extraction of Uranium from Low Grade Ores

The second area that required research and development was the extraction of uranium from low-grade ores. Before World War II there were several mines with rich deposits. Some contained over 50 % uranium. At the end of the war all of these mines were exhausted, and within a few years most mines were operating with concentrations below 1%. If the nuclear energy enterprise were to survive, it was necessary to find an economical method to extract purified uranium from low-grade ores. A group of chemists investigated chemical methods to make the extraction more efficient. One of the largest deposits is Tennessee shale, which contains enough uranium to last 100,000 years. While the group was able to

obtain weighable quantities of uranium, it was obvious that it was not economical to do so. During the investigations there were chemical reagents discovered which were highly selective.

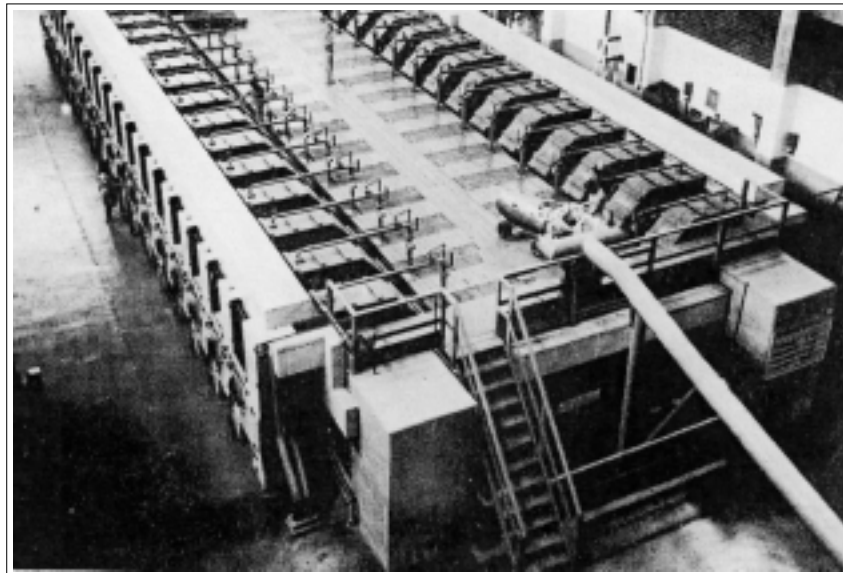
Charles Coleman investigated high-molecular-weight amines and phosphates and developed practical methods for their use at the mines. Processes based on amine extraction are used today in more than 50 % of the uranium production in the world. The group leader of

this effort, Keith Brown, was awarded the American Mining Congress medal for this work

Special Chemical Separation Methods

Nuclear reactors required materials with properties never before encountered in the industrial world. One such requirement was posed by the nuclear submarine reactor. In the operation of the original reactors at Hanford it was sufficient to protect the uranium from the corrosive effect of water with a cladding of aluminum. In the case of the pressurized water reactor, which operated at higher temperatures, the aluminum failed. It was necessary to obtain a new metal with a low cross section and low corrosion rate. The zirconium available in commerce was satisfactory but had a high cross section. When Herbert Pomerance learned of this problem, he was puzzled because zirconium should not have a high cross section. It turned out that all of the commercially available zirconium was contaminated by hafnium, which proved to have a very high cross section. When the hafnium was removed, zirconium proved to be a very satisfactory metal from all standpoints.

The materials section of the Atomic Energy Commission instituted a nationwide search for a process to accomplish the separation. Over twenty research con-



Beta Racetrack. Compare with the Alpha I racetrack, noting the rectilinear arrangement and the smaller scale of the equipment.

tracts were let to develop a method. Warren Grimes and his Y-12 group set out to investigate the applicability of solvent extraction methods to accomplish this task. The thiocyanate complex of these two atoms proved to be the key to the separation when used with methyl isobutyl ketone (MIBK) in a counter-current extraction apparatus. When I asked Grimes why he chose MIBK, he replied that it happened to be the first bottle in a row of extractants above his lab bench! At any rate, the process was successful and when put into production furnished all of the hafnium-free zirconium for the first nuclear submarines.

The final step in the process involved the precipitation by phthalate or salicylate, which easily converted zirconium to the oxide. The operation was transferred from the laboratory bench to tonnage amounts by the Y-12 production staff under John Googan. It is interesting to note that, not only did the original fractional crystallization process fail, but also none of the twenty contracts ever delivered a successful process.

Calutron-separated Stable Isotopes

In 1947 E. P. Wigner wrote the Atomic Energy Commission requesting that he and some of his staff meet with the Y-12 group concerning the possibility that the Beta experimental group might undertake to supply stable isotopes as required for physics experiments. We were very happy to explore this use of the Beta calutrons for this purpose. Following a meeting with Wigner we set up a group to develop sources and receivers to accomplish this task. Chris Ceim was the group leader, and soon several stable isotopes were available to the physics research community. Lee Haworth, director of Brookhaven National Laboratory, visited the stable isotope group early in its operation, and several stable isotopes were produced for his program. Several hundred grams of calutron-produced Li^6 were sent to Los Alamos for their early work on the thermonuclear program. This effort occurred before the chemical exchange process was developed.

The stable isotope program required that each element be synthesized in a form that could be placed in a charge bottle and vaporized under controlled conditions. Eventually nearly all of the elements of the periodic table were separated to collect the desired isotope. It was necessary not only to work out the complicated chemistry for the charge but also to develop the recovery chemistry.

Ultimately thousands of physics experiments were carried out and published. Practically none of these experiments would have been possible without the stable isotope program. As the program grew in scope, it found many applications in industrial research, medical research and treatment, and many other scientific fields.

In 1948 I was appointed superintendent of the electromagnetic plant in charge of all operations. During that time several of the above research and development projects reached the production stage, and the Y-12 plant began to become a versatile production facility for AEC operations. In addition to starting fabrication of weapons parts, the plant furnished purified zirconium for the *Nautilus* submarine and Li^6 for the thermonuclear program. An interesting operation was the retrieval of the silver from the calutrons so that it could be returned to Fort Knox. With the increase in price of silver over the years, the value of the calutron silver was now over two billion dollars. It was a great relief to learn that there was no loss in the entire operation. During the operation I viewed silver valued at \$100 million, all in one stack of bars.

In 1950 I became director of Oak Ridge National Laboratory, and all of the Y-12 research and development became a part of the Oak Ridge National Laboratory administration under Research Director A. M. Weinberg.

REFERENCES AND NOTES

* Over the past fifty years many books and articles have told the story of the Manhattan Project that produced the atomic bomb during World War II. Most of these works focused on the physics involved and the extraordinary efforts needed to design, build, and operate the mammoth production plants and laboratories required to create a nuclear weapon. Relatively little was written, however, about the hundreds of supporting projects in scientific research and industrial engineering that underlay the wartime effort. One of the projects neglected in these accounts was the history of the electromagnetic plant built in the Y-12 area at Oak Ridge to produce uranium 235, and buried even deeper in the record were the efforts of chemists to isolate and extract the final product.

Clarence E. Larson, who had been involved in the electromagnetic project from its inception at Berkeley

through its successful operation at Oak Ridge, decided in the last years of his life to write a paper that would describe the key accomplishments of chemists in the project, both during and after the war. He wrote his paper in 1996 and submitted a copy to the Department of Energy for classification review. Soon thereafter Larson became ill and died in 1999. In the summer of 2003 Jane Warren Larson, his widow, received word that the Department of Energy had determined that the paper was unclassified. She then asked me, as the former chief historian of the U. S. Atomic Energy Commission, to read the paper and determine whether it should be published. I had no trouble concluding that the paper was a significant historical document, and I submitted an edited version of the paper to the *Bulletin*.

The draft article as returned to Mrs. Larson by the Department of Energy required some editing. Several references to other publications had to be completed and the full names of some of the participants obtained. I also found it necessary to do some copy-editing and to add a few words and phrases to clarify meanings. In one instance I reordered two paragraphs to smooth the flow of the narrative. I have also incorporated a few small revisions suggested by the reviewer of the article for the *Bulletin*. Except for these minor changes and additions, the article appears as Dr. Larson wrote it. It has been a great pleasure for me as his friend and former

associate to assist in publication of this important work. *Richard G. Hewlett, Consulting Historian, 7909 Deepwell Drive, Bethesda, MD 20817-1927.*

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2. H. D. Smyth, *Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb Under the Auspices of the United States Government, 1940-1945*, Princeton University Press, Princeton, NJ, 1945.

ABOUT THE AUTHOR

Clarence E. Larson, 1909-1999, was professor of chemistry at the College of the Pacific before World War II. In 1942 he returned to the University of California, Berkeley, to work with his mentor, Ernest O. Lawrence, to conduct research related to the electromagnetic process for separating uranium isotopes. At Oak Ridge he directed research and development on the process for the Tennessee Eastman Corporation, and after the war was director of research and development in the electromagnetic plant for Union Carbide. After a year as director of Oak Ridge National Laboratory, he served in several management positions with Union Carbide, 1955-1961, and as a commissioner of the U. S. Atomic Energy Commission, 1969-1974.

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