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Dear Alex:

I want to thank you again for the assistance you provided during my research into the role of Metal Hydrides, Inc. In the development of atomic energy. Your willingness to help uncover documents and information made the paper more than it might have been without your help. I am enclosing a copy as submitted for publication. I will definitely follow up with a reprint of the published document when that occurs.

Your comments and observations would be very much appreciated. I would be happy to discuss further any aspects of the paper with you.

Sincerely,

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METAL HYDRIDES, INC.
AND THE DAWN OF THE ATOMIC AGE

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October 7, 1994

Introduction

When Peter Alexander founded Metal Hydrides, Inc. in 1937, he probably had no idea that this small Beverly, Massachusetts metals processing company was destined to play a key role in the early dawn of the atomic age[1]. That dawn came at 3:25 p.m. on December 2, 1942 when the first controlled, self-sustaining nuclear chain reaction was achieved. This first nuclear reactor was constructed under the guidance of physicist Enrico Fermi in a squash court located under the west stands of Stagg Field on the University of Chicago campus.[2] The reactor, built under strict security as part of the World War II Manhattan Project, was dubbed "Chicago Pile-1" or CP-1. The word "pile" described the reactor's actual physical appearance - a stack or pile of graphite and uranium blocks.

CP-1's success demonstrated that nuclear fission could be both self-sustaining and controlled, and that uranium could be transformed into plutonium. This latter demonstration was important because plutonium, like uranium, undergoes nuclear fission. The success of the CP-1 reactor paved the way for the controlled production of energy by nuclear power plants and the construction of atomic bombs.

Chronologically, atomic bomb development was exploited first, ultimately leading to the Trinity Test in July, 1945 and the bombing of Hiroshima and

Nagasaki in August, 1945. Large scale peacetime uses of atomic energy did not appear until the mid-1950's, when the Atoms for Peace Program was launched. During this time the first of over 100 nuclear power plants was built in the United States. The metals producing processes first used at Metal Hydrides, Inc. were of historic importance in the early hours of this new atomic age. This paper examines those processes and their significance.

Metal Hydrides, Inc.

During the 1930's Dr. Peter Alexander, while working at General Electric in Cleveland, Ohio and Lynn, Massachusetts, developed a technique to produce metals from their oxides using active metal hydrides (1). Alexander was given the rights to this process and started Metal Hydrides, Inc. in Marblehead, MA. The company was financed and owned by venture capitalist Thayer Lindsley of Canada (2; 3, p 28). Initially, Metal Hydrides produced heavy metals and their alloys for specific commercial markets. For example, the company produced Zr for camera flash bulbs, TiH for mercury furnaces, and CaH_2 for weather balloons (4). Metal Hydrides also experimented with the production of small amounts of pure uranium metal and explored some of its properties when alloyed with metals such as Ni (1, p 273).

Then, in 1938-1939 it was discovered that uranium fission releases vast amounts of energy (5). This revelation changed everything for Metal Hydrides.

Nuclear Fission and Chicago Pile-1 (CP-1)

At the outset of WWII, allied scientists were very concerned about possible Nazi progress toward developing the atomic bomb. In late 1938, Otto Hahn and Fritz Strassman discovered nuclear fission while working at the Kaiser Wilhelm Institute in Berlin. In addition, the Germans had access to and were stockpiling uranium ore from mines in Czechoslovakia and Werner Heisenberg, a strong supporter of German nationalism, if not the Nazi regime, remained in Germany to work on fission experiments[3] (6). In order to balance this perceived German progress, scientists in America and Great Britain initiated studies toward a better understanding of nuclear fission, its control, and potential uses.[4]

Enrico Fermi, first at Columbia University and later at the University of Chicago, supervised projects, CP-1 among them, designed to demonstrate the self-sustaining nature of the fission process and the production of Pu-239 from U-238. Many of these experiments involved building structures of layers of graphite blocks with uranium embedded in them and control rods inserted at various positions in the "pile". At first the experiments used uranium in the form of uranium oxide but this was insufficient to provide a self-sustaining reaction. Pure uranium metal was needed. As early as December of 1941, Ed Cruetz of Princeton University, later to become head of the uranium fabrication division of the Metallurgical Laboratory at the University of Chicago, adamantly stated: "All I need is a lump of uranium as big as this. But I need it now". He cupped his hands making a sphere about the size of an orange as he spoke (7, p 90-1). Eventually CP-1 used graphite as the moderator and both uranium oxide and uranium metal as the fuel. The use of a fuel mixture was dictated by the need for uranium metal as a concentrated fuel but its lack of ready availability at the time.

Production of Pure Uranium Metal

Before 1941, there was less than a pound of pure uranium metal in the United States, and even that was of lower purity than needed (8, p 65; 9, p 116). When the Planning Board of the Office of Scientific Research and Development (OSRD) sought suppliers of pure uranium in early 1942 only two possibilities surfaced -- Westinghouse Electric and Manufacturing Company in New Jersey and Metal Hydrides in Beverly, MA (8, p 65-66; 10, p 62; 11, p 1). Both companies were placed under government contract and asked to accelerate production of the pure, precious metal.

Westinghouse produced uranium by electrolytic reduction of KUF_5, which in turn was made by photochemical reaction of uranium oxide with KF (8, p 65). Westinghouse later learned that UF_4, the "green salt", could be used in place of KUF_5 (12, p 93). UF_4 was made via hydrofluorination of UO_2, the "brown" oxide.

$$UO_2 + 4\,HF \xrightarrow{550^{o}C} UF_4 + 2\,H_2O$$

Metal Hydrides' hydride or "hydramet" process (2) used calcium hydride, CaH_2, as the reducing agent for the ore to metal conversion. In 1941 Metal Hydrides, under contracts with the National Bureau of Standards (NBS) and the OSRD (13), produced a few pounds of pyrophoric uranium powder or "trialloy" as it was code-named at the time (4). This powder was used in fission research at Columbia University. (11, p 1) In spite of the pyrophoric nature of the uranium powder and the difficulty in casting it, the "hydramet" process demonstrated sufficient promise for large-scale production to cause Columbia University to order the delivery of six new furnaces for the Beverly plant in January of 1942 (8, p 65). By May of 1942 a total of nineteen new furnaces were in place and ready for uranium production. By November of the same year Metal Hydrides was producing up to 300 pounds of uranium metal per day (8, p 88). In fact, of the little more than

6 tons of pure uranium metal used in Fermi's CP-1, approximately three came from Westinghouse, two from Metal Hydrides and one from the University of Iowa[5] (12, p 93-94 & 239). Remarkably, Metal Hydrides production of pure uranium metal had soared from just 2 pounds in late 1941 to over 8500 pounds by November of 1942 (8, p 88) - how was this possible?

The Metal Hydrides "Hydramet" Process

The raw material for the process was uranium ore. In 1940-1941 the uranium ore uranitite was supplied by the Canadian Radium and Uranium Corporation of New York. Their source was a mine owned by Eldorado Gold Mines, Ltd. located on the shores of Great Bear Lake in the Northwest Territories of Canada[6] (10, p 62). In 1940 hundreds of tons of partially processed ore, eventually used to supply the early fission experiments, were stored at Port Hope, Ontario[7] (7, p 90). This black ore was initially used by Metal Hydrides in producing the first batches of uranium metal. However, since the raw ore was a mixture of UO_2 and UO_3 along with other metal and metallic oxide impurities (14, p 20), the resulting uranium was of insufficient purity to sustain a successful fission chain reaction. The neutron absorbing impurities had to be removed before pure uranium production could proceed.

At the Mallinckrodt Chemical Company in St. Louis the uranium ore was purified and chemically converted to the "brown oxide" UO_2. The purification process, developed at the NBS, included digestion of the raw ore in nitric acid (9, p 117). During this process the uranium was converted to the uranyl ion, UO_2^{2+} in the form of uranyl nitrate (15, p 222).

$$2\,UO_2 + 4\,HNO_3 + O_2 \rightarrow 2\,UO_2(NO_3)_2 + 2\,H_2O$$

$$UO_3 + 2\,HNO_3 \rightarrow UO_2(NO_3)_2 + H_2O$$

Ether extraction dissolved and separated the $UO_2(NO_3)_2$ from impurities (16, p 588) and subsequent evaporation left uranyl nitrate hexahydrate. The uranyl nitrate hexahydrate was then converted into UO_3,, the "orange oxide", by high temperature heating. Finally, UO_3 was reduced by hydrogen to UO_2 (15, p 223).

$$2\,UO_2(NO_3)_2.6H_2O \xrightarrow{500^oC} 2\,UO_3 + 4\,NO_2 + O_2 + 6\,H_2O$$

$$UO_3 + H_2 \xrightarrow{700^oC} UO_2 + H_2O$$

During 1942 the brown oxide was delivered by truck to the Beverly plant and subjected to the hydramet process. The oxide was mixed with calcium hydride and heated in an evacuated steel alloy retort at 960^{o}C in an oil-fired furnace for 6-7 hours (4;17, p 1). The calcium hydride was produced at Metal Hydrides using distilled calcium metal and hydrogen gas. The calcium was distilled to remove all traces of boron, a neutron absorbing material. The powder resulting from the hydride reduction contained uranium metal and calcium oxide, hydrogen gas having been released and burned off during the heating.

$$UO_2 + 2\,CaH_2 \xrightarrow{960^{o}C} U + 2\,CaO + 2\,H_2$$

During the heating, at 180°C, the CaH_2 decomposed into Ca and H_2 and at 375°C the Ca melted.

The product mixture was then chipped into pieces using an air hammer and dumped into a leaching tank containing distilled water and acetic acid to neutralize the CaO, thus bringing it into the aqueous solution (4). After filtering the pure uranium powder on a rack filter, it was manually scraped onto stainless steel trays to dry. Initially the trays were placed in the open air to dry. Due to recurring uranium fires, however, the drying process was modified to occur under an inert argon atmosphere.[8] The purified uranium powder was then placed in one quart metal containers, each holding six pounds of metal, under argon. The containers were subsequently sealed, clipped shut and stored in a large wooden chest cooled with dry ice (4). Cooling was necessary because in its absence the uranium powder, even when packed in metal cans, became red hot (8, p 89).

Uranium Lumps and CP-1

The next day the metal, still cooled in dry ice, was transported in a company owned beach wagon to MIT in Cambridge. At MIT the powder was compressed into lumps of dimensions 1 inch square and 1/2 to 3/4 inches thick (4). These pressed lumps were returned to Metal Hydrides the next day by the same means, sintered at approximately 1500°C in the furnaces, and packed into special argon filled fiberboard boxes for the trip by truck to the University of Chicago and CP-1 (4). The pressing and sintering reduced the pyrophoric properties of the metal and at least partially relieved the overheating problem. The ideal solution would have been to melt and recast the metal into solid ingots. But since this techniques had not been sufficiently perfected for large-scale use, the pressing and sintering operations offered a temporary solution that allowed the metal to be used in Fermi's pile experiments.

On the afternoon of December 2, 1942, as scientist George Weil carefully withdrew the final control rod from the Fermi experimental reactor, stopping at a predetermined point, the lumps of uranium metal supplied by Metal Hydrides underwent fission in a self-sustaining manner. For the first time in history, nuclear fission had been controlled.

CP-1 was dismantled in early 1943 and reconstructed, with modifications, at the Palos Forest Preserve located 25 miles to the west of Chicago.[9] This reactor was renamed Chicago Pile - 2 (CP-2), and was operated as a research reactor from 1943 through 1954. In 1956 CP-2, along with CP-3', the first heavy water moderated reactor and also built at the Palos site, were disassembled.[10] The uranium, graphite and heavy water were removed and the CP-2 and CP-3' reactor shells were buried at the location of their operation. Today an engraved stone marks this spot (18, p 40; 19, p 11). The uranium metal from CP-2 was transferred in 1955-1956 to the Argonne National Laboratory-East (19, p 8).

The Iowa Process and Recasting at Beverly

At the University of Iowa, in August of 1942, Dr. Frank Spedding used calcium, produced at Metal Hydrides, to reduce UF_4 to pure uranium metal[11] (8, p 88). The reaction heat was sufficient to melt both products, with the more dense uranium settling to the bottom of the reaction vessel and solidifying upon cooling. The reaction may be written as:

$$UF_4 + 2\,Ca \xrightarrow{1300^{\circ}C} U + 2\,CaF_2$$

Because the Iowa process was rapid and yielded uranium metal in solid ingot form, it was used to supply the pure metal for the remainder of the Manhattan Project. By the summer of 1943 Metal Hydrides shifted operations from production of uranium powder to recasting up to 500-1000 pounds of the pure metal per day into billets- solid cylindrical ingots (20). Metal Hydrides now received shipments of the "heels" (unusable end portions) remaining from the fabrication of uranium slugs (one inch by four inch cylinders of uranium in aluminum cans used for reactor fuel) from both the Hanford, WA and Oak Ridge, TN Laboratories. Metal Hydrides also received shavings from the Iowa process which were melted and recast. These uranium heels and scraps were collected at Beverly, melted and recast into billets of dimension 4 inches in diameter and 10-12 inches long. The billets weighed an average of 185 pounds and were produced 24 hours a day, 7 days a weeks (4). The billets were shipped to the DuPont Chemical Company in Hanford and Oak Ridge for fabrication into rods and then uranium slugs (8, p 209). As of late August, 1944 Metal Hydrides had delivered 610 tons of uranium metal, both new and recast (10, p 317). This work continued throughout the Manhattan Project and stopped in approximately 1947.

Metal Hydrides Inc. Site

The site of the Metal Hydrides, Inc. operations during its Manhattan Project activities consisted of approximately three acres in Beverly, Massachusetts. It was located at the confluence of the Bass, Danvers, and North Rivers near Massachusetts Route 1A and the Beverly-Salem bridge. In the early 1940's, there were five separate buildings in which the Manhattan Project uranium production work was conducted (4, 13). These included the main building which housed the furnaces and recasting operations, a worker cafeteria, a locker room, a firebrick cutting building, and a carpenter shop for making wooden boxes (4). The latter three buildings were located at the rear of the main building and were torn down by the end of 1945. Today the three acre site remains and the main building on Congress Street in Beverly still stands.[12] In addition, there are several buildings on the site today that were not present during the 1940's.

In approximately 1947 all useful uranium producing materials and equipment were trucked to Hanford, WA. In 1947 and 1948, the Atomic Energy Commission (AEC), successor to the Manhattan Engineer District, examined the Metal Hydrides plant for radiological contamination (13). As a result of these investigations virtually all contaminated materials at the site, including the internal building materials, furniture and equipment, clothing and anything else that was exposed, was packed into canisters, loaded onto vessels provided by the U.S. Navy, towed 12 miles into Massachusetts Bay and sunk by Captain George Perry, a local boat owner (2,21,22). The canisters were not fully loaded to ensure water would seep in and sink them. If they did not sink, Perry shot them with bullet holes to accomplish this purpose. This disposal operation occurred sometime during 1947-48 and was conducted in accordance with U. S. Army Corps of Engineers directives. Approximately 120,000 pounds of dirt at the rear of the main building were excavated in 1944 and shipped to the DuPont Chemical Co. Recovery Plant for uranium recovery[13] (23;24).

Uranium metal production at Metal Hydrides ended in 1947 and the company received its last atomic energy related government contract in 1954. After that time it produced metals such as zirconium, thorium and titanium and metal hydrides such as sodium borohydride and lithium aluminum hydrides for the commercial and laboratory markets along with other specialty chemicals.[14] The company name was changed to Ventron Corporation in 1965 and, in 1976, Thiokol Corporation assumed control of the company. In 1982 Ventron became a division of Morton Thiokol, Inc. which was renamed Morton International in 1990 (25). In

1994, Morton International moved the manufacturing and research and development operations to other of its plants around the country and was scheduled to abandon the Beverly site late in the year. The final disposition of the site, still privately owned by Morton International, awaits the outcome of on-going state and federal remediation projects.[15]

Conclusion

Although the bulk of the war related work conducted at Metal Hydrides took place under the auspices of the Manhattan Engineer District of the U. S. Army, there is also evidence that the company produced materials for the Navy Department during 1943 or 1944 (26). In addition, records suggest that in 1948 the company produced ton quantities of uranium powder again, but no specifics on this possibility can be located (17).

At the conclusion of the war, employees of Metal Hydrides were presented with certificates from the OSRD and small silver or bronze medallions embossed with a large "A" for Atomic. The presentations were made in Beverly by Maj. General Leslie Groves, the military leader of the Manhattan Project.

The scientific experiments that successfully demonstrated the self-sustaining nature of nuclear fission and the ability to control it were essential to the beginning of the atomic age. Metal Hydrides, Inc. and its workers played a crucial role in this demonstration. Notwithstanding its small size and lack of national name recognition, it supplied the very first shipments of uranium to Columbia University in 1941 and contributed crucial supplies of uranium metal to CP-1 and The University of Chicago in 1942. It also operated a highly successful uranium recasting process from 1943 to 1948. The role of Metal Hydrides, Inc. at the dawn of the atomic age is indeed both chemically and historically significant.

FOOTNOTES

1. Metal Hydrides, Incorporated began operations in Clifton (a village in Marblehead), Massachusetts in 1937 and later relocated to Beverly in 1940 (3).
2. The reactor shortly afterward was moved to the Palos Forest Preserve, and the Stagg Field stands - previously used for football, a sport abandoned by the University - were torn down in 1957. The spot of the first reactor today is marked by an historic marker and the sculpture "Nuclear Energy" by Henry Moore placed there in 1957.
3. Much speculation exists regarding Heisenberg's role in the German atomic bomb effort. Recent evidence suggests that he purposely led his superiors astray to delay bomb development (5).
4. Based on data available on uranium shipments the allies speculated that the Germans had an 18 month head start on bomb development.
5. CP-1 also contained 50 tons of uranium oxide and 400 tons of graphite (8, p 112).
6. Eldorado Gold Mines Ltd. processed the ore at its refineries at Port Hope, Ontario, Canada and marketed it in the US through the Canadian Radium and Uranium Corporation. Eldorado Gold Mines, Ltd. changed its name to Eldorado Mining and Refining in the early 1940's and was subsequently taken over by the Canadian government. The same Thayer Lindsley who financed Metal Hydrides is said to have had a stake in the Eldorado Gold Mine (2). Further, since Mr. Lindsley was a classmate a Franklin Roosevelt (both Harvard '04), it is said that FDR called upon his old friend to help out with the ore supply and uranium production in the early days of the atomic effort (3, p 28).
7. The radium was extracted from the ore for commercial uses and the uranium, which was not in demand at the time, was simply stockpiled.
8. The use if depleted uranium in the tips of armor piercing artillery shells takes advantage of this pyrophoric property of the metal.
9. The Palos Forest Preserve was the site originally chosen for CP-1 but, due to a labor strike, Fermi used Stagg Field in its place. The Preserve is about 2 miles from the present day Argonne National Laboratory - East.
10. The original CP-3 reactor was renamed CP-3' in 1950 when it was structurally modified.
11. Magnesium later replaced calcium as the reducing agent in this process.
12. Prior to 1937 the main building housed the Stuart Last Company, a manufacturer of wooden shoe lasts.
13. In 1944 certain soil samples, taken from the rear of the site by Manhattan Project personnel, contained 79% uranium metal (24). This was at the site of a dry well used at the time for rubbish disposal. The average soil sample from the site, however, contained approximately 5% metal (24).
14. Metal Hydrides, Inc. produced $NaBH_4$ under an exclusive license.
15. The Beverly site was designated a FUSRAP project by the U.S. Department of Energy in 1986. As of late 1994, radiological remediation is scheduled to be completed by the end of 1998. The State of Massachusetts is also assessing the site under the auspices of Chapter 21E of the Massachusetts General Laws for oil and other hazardous materials contamination.

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