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THE PRODUCTION OF URANIUM METAL BY METAL HYDRIDES INCORPORATED

BY

P. P. Alexander

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Metal Hydrides, Inc.

Technical Information Service, Oak Ridge, Tennessee

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THE PRODUCTION OF URANIUM METAL BY METAL HYDRIDES INCORPORATED

BY

P. P. Alexander

NO.45003

Synopsis

Metal Hydrides Incorporated was a pioneer in the production of uranium metal on a commercial scale and supplied it to all the laboratories interested in the original research, before other methods for its production were developed.

Metal Hydrides Inc. supplied the major part of the metal for the construction of the first experimental pile which, on December 2, 1942, demonstrated the feasibility of the self-sustaining chain reaction and the release of atomic energy.

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PRODUCTION OF URANIUM BY METAL HYDRIDES INCORPORATED

by

P. P. Alexander

I. Original Work

Metal Hydrides Incorporated, a subsidiary of Ventures Limited, was a pioneer in the work on the production of uranium on a commercial scale. This pure metal and its alloys were produced for use in various scientific laboratories and by a few commercial companies.

Uranium metal was produced by the reduction of black oxide with calcium hydride (1) Various sources of black oxide were investigated including oxide from Canada, the Belgian Congo, and domestic oxides produced from Colorado ore purchased from the Union Carbide & Carbon Research Laboratories Inc.

The pure metal was at first produced in the form of powder (Plate I) which was fused into small ingots (Plate II) in laboratory vacuum furnaces. The powder was fused at a temperature as low as 1100°C and even somewhat lower.* At this stage of development the uranium metal was produced in one pound lots.

The production of commercially pure metal began on a larger scale when Columbia University started research work in the use of this metal, and placed their first order for sintered uranium in the form of discs. These were produced without difficulty and supplied to the University for Dr. Fermi's and Dr. Szilard's work. Later the conditions of the experiments were changed and larger amounts were needed. Columbia University therefore placed orders for uranium metal in the form of powder which was used to fill hollow discs and spheres. At that time it was not known what impurities in the

*METALS AND ALLOYS, October 1938

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metal will be detrimental and the metal was ordered without any specifications of analysis, except that the amount of occluded hydrogen should be as low as possible. This condition was easily met by degassing the powdered metal at high temperature in vacuum.

The scale of production was increased. At that stage uranium was produced in lots of twenty pounds in the form of fine powder.

In 1941 it became evident that still larger quantities of this metal would be needed, and a contract was placed by the Bureau of Standards for very much larger quantities of commercially pure metal in powder form.

II. Production of Metal from Canadian Black Oxide

The work was started on the production of this initial order for the Bureau of Standards and some five hundred pounds of metal was produced by using the Canadian black oxide purchased by the Bureau of Standards from the Eldorado Gold Mines Limited of Canada.

In the meantime the scientists found that in addition to hydrogen, another impurity, boron, was extremely detrimental and that its presence in the metal would prevent them from obtaining the desired results. It was also found that the domestic calcium produced by the Union Carbide & Carbon Corporation contained appreciable amounts of boron. It was further found that boron was also present in minute quantities in the Canadian black oxide. It was decided that before going any further with the production of pure uranium metal, it would

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be necessary first, to obtain calcium free from boron, and then to make arrangements for the purification of the Canadian black oxide.

The test made by Mr. Rodden of the Bureau of Standards demonstrated that by distilling commercial calcium in vacuum it was possible to eliminate practically all the boron and so obtain calcium which would be entirely satisfactory for use as a reducing reagent in the production of pure uranium. With the help of the Bureau of Standards the distillation plant was set up at the plant of Metal Hydrides Inc. for the production of distilled calcium metal on a commercial scale. At first this operation presented considerable difficulties since the removal of pure distilled calcium crystals from the retort often resulted in fires.

Metal Hydrides Inc. however found that distilled calcium could be converted into calcium hydride in the same operation. This eliminated additional expense and considerable danger in handling freshly distilled calcium. The production of distilled calcium hydride was started at first on a reduced scale which was gradually increased to several hundred pounds per day. The first small lot of purified black oxide from Canada was reduced with pure distilled calcium hydride and the produced metal sent to the Bureau of Standards for analysis. It was reported by Mr. Rodden that the boron content was less than one half part per million and the rare earths were entirely absent, which indicated that by these means it would be possible to produce uranium metal of satisfactory purity from Canadian black oxide and distilled calcium.

III. Beginning of the Work for O.S.R.D.

In the meantime the scientists found that still larger quantities of material would be needed for their experiments. A contract was negotiated, therefore, with the Office of Scientific Research and Development. It was agreed that in view of the unusual nature of this material, no analysis would be specified. In fact, at that stage of the work the scientists themselves did not know what purity of metal will be necessary in order to achieve the desired results.

The first contract with the O.S.R.D. expiring on June 30, 1942, was renewed to November 1, 1942. From that date on the production of uranium by Metal Hydrides Inc. was on direct contract with the Manhattan District of the U. S. Engineers. At that stage the production of uranium metal by Metal Hydrides Inc. was increased to two hundred and fifty pounds per day.

IV. Casting and Sintering of Metal

The original work of Metal Hydrides Inc. demonstrated as early as 1935 that uranium powder could be melted very successfully in vacuum at the comparatively low temperature of 1100°C. (2) The melting was carried on in small laboratory furnaces and was necessarily limited to the production of only very small ingots. However, an investigation was started to find a more rapid method of melting, and uranium in powder form was sent to several laboratories equipped with high frequency vacuum furnaces.

The first results at the Bureau of Standards and in the

General Electric Research Laboratory in Schenectady were negative, and opinions on the practicability of using the high frequency method were divided. Metal Hydrides Inc. wanted to continue the investigation and find some laboratory where the melting of uranium powder in a high frequency furnace could be tried out again; whereas other interested parties held the opinion that the fusion should be made in the resistance heater type furnaces.

In the meantime samples of powdered uranium metal were submitted by Metal Hydrides Inc. to the Massachusetts Institute of Technology and arrangements were made at the Department of Metallurgy for Dr. J. Chipman to fuse this metal in a high frequency vacuum furnace. Dr. Chipman succeeded in fusing the sample of metal into a well-formed disc of 1" diameter, by using a special technic, namely by placing the powdered metal in an alundum crucible which was surrounded by a graphite shield. (Plate III) High frequency currents were generated in the graphite shield which was quickly brought up to a very high temperature. The material in the crucible was therefore heated and melted, not by the high frequency currents generated within its mass, but by radiation from the incandescent graphite shield. The previous failures by the Bureau of Standards were due to the fact that attempts were made to fuse powdered metal in crucibles without the graphite shield. In this case, the heat was generated only in isolated particles of the metal. It took too long to bring the powdered mass to a temperature sufficiently high for fusion, and in spite of vacuum the mass was partly oxidized by the remaining traces of air before the desired temperature was reached.

Arrangements were made immediately between Metal Hydrides Inc. and the Massachusetts Institute of Technology. Metal Hydrides Inc. furnished a more efficient and larger capacity vacuum pump and made a subcontract with the Massachusetts Institute of Technology providing the necessary funds to proceed with this work without delay.

In the meantime metal for the initial experiments in Chicago was needed so urgently that it was decided temporarily to use another expedient of consolidating powdered metal into small solid billets. The sintering of the powder which was successfully carried on by Metal Hydrides Inc. in the production of the first solid discs for Columbia University was resumed. Arrangements were made with the Massachusetts Institute of Technology to get a larger hydraulic press for pressing the powdered metal at 70 tons per square inch pressure into 1" cubes. (Plate IV) Facilities were provided by the Massachusetts Institute of Technology and the work was started.

The uranium powder produced by Metal Hydrides Inc. in Beverly was transported by special truck to the Massachusetts Institute of Technology and pressed into cubes which were transported back to Metal Hydrides Inc. in Beverly where they were sintered into solid blocks. The density specified by the Chicago group was not less than 15, and the first series of pressed cubes after sintering were of even higher density, in some cases reaching 17. These cubes were well-formed and after sintering were resisting successfully any further oxidation. A group of scientists were sent from Chicago and the work of pressing at the Massachusetts Institute of Technology was organized on a very much larger scale. Facilities were provided to press up to several hundred pounds of cubes per day which on the following day were transported back to Beverly and sintered into solid blocks.

At that time, however, Metal Hydrides Inc. was requested to change the raw materials used in the production of powdered uranium, and instead of black oxide, to use exclusively brown dioxide.

The change of raw materials created immediately new problems. The brown dioxide produced by Mallinckrodt Company by purification and partial reduction of the black oxide, is a pyrophoric material which will burn in air if overheated, and for this reason it cannot be ground in a ball mill to a powder of uniform fineness. However, since the purity of the brown dioxide is greater than that of the commercial black oxide, it was decided to use it in all further work.

The physical structure of the oxides is quite different. The black oxide consists of very fine solid particles. It can be ground in a ball mill if necessary to further reduce it to any fineness, if so desired. The brown dioxide, on the contrary, is a mixture of extremely fine particles mixed together with very much larger particles which are not solid throughout but are in the shape of very small hollow spheres and fine pieces of lace-like filigree structures. This admixture of large particles to fine particles has a very definite effect on further operations and on the results obtained. During the reduction of this brown dioxide with calcium hydride the physical structure and the shape of the particles is not changed. The reduced powdered metal consists of particles of the same shape as in the oxide, that is, it consists of particles and an appreciable percentage of the above mentioned microscopic spheres and filigree-like flakes (Plates V,VI,VII,VIII)

The resulting metal therefore is far more dangerous to handle than that produced from oxide consisting of particles of uniform size.

The apparent density of the metallic powder produced from the brown dioxide is less than that produced from the black oxide. Furthermore, the pressing of the powder containing microscopic spheres was not satisfactory. The pressed compacts had a very much lower density, often as low as 13. The production of sintered blocks was a temporary expedient and allowed our scientists to proceed with their work without waiting until the casting method was perfected (3). The pressing of the compacts was discontinued as soon as Professor Chipman succeeded in bringing his method of fusion and pouring and casting in vacuum to the desired degree of perfection.

The total amount of pressed and sintered cubes produced during this transition period was 3,868 pounds. This metal was shipped to Chicago Metallurgical Laboratory.

V. Reduction of Brown Dioxide

The reduction to metal of the brown dioxide by the calcium hydride process has certain advantages. It contains less oxygen and, therefore, involves a somewhat smaller amount of calcium hydride. The difference is not very great and does not affect materially the cost of reduction. The important advantage, however, is the fact that the reaction was proceeding much more quietly without a sudden evolution of heat as in the case of the black oxide.

The disadvantage of using the brown dioxide is that the resulting powder is not uniform. It consists of a mixture of minute particles of less than one micron in diameter, a series of solid particles of larger dimensions and very large particles in the form of hollow spheres.

The leaching of such material was complex problem since the conditions had to be regulated to leach quickly and without excessive oxidation the particles of micron size which required only a short time. The larger particles, surrounded by larger amounts of calcium oxide, required a longer leaching time. Finally the hollow spheres could not be leached effectively at all in a short time with dilute acids since the calcium oxide held inside of the hollow sphere was more or less protected from the action of the acid and was not removed from it but merely transformed into calcium hydroxide which completely filled the hollow spheres.

These large particles containing entrapped calcium hydroxide could not be dried thoroughly and retained the moisture for several days. During this period the entrapped calcium hydroxide was reacting with the metal with the generation of heat. This would invariably produce overheating of the powder and the ignition of same.

The leaching operation was regulated to be suitable for the bulk of the material, that is, the medium size solid particles. The very fine particles of course were partly oxidized since the time was too long, and they had to be separated by decantation, since the partly oxidised particles are extremely pyrophoric and on several occasions ignited the whole charge. The very large particles consisting of either hollow spheres or filigree-like structures had to be separated by screening the wet powder. The percentage of this material was on an average about 4% of the total weight of the metal. It could not be melted and was too dangerous to be left standing in air and therefore had to be burned to black oxide and sent for retreatment. The necessity of the separation of the very find particles as well as very large ones was reducing considerably the efficiency of the process.

In conslusion it may be stated that the purified brown dioxide from a certain point of view was more suitable for reduction by calcium hydride than the black oxide, yet its use involved far greater danger in handling and due to the necessity of discarding very fine metal and coarse particles, was reducing the efficiency very considerably.

VI. Distillation of Calcium

Calcium hydride produced from distilled calcium was used exclusively for the reduction of the brown dioxide since the crude calcium or recast calcium still contained boron in amounts far above acceptable limits. The distillation of calcium and the production of pure hydride was carried out as follows.

Crude calcium metal to the amount of an average 60 lbs. was placed in the bottom of an iron cylinder as shown on Plate IX. The cylinder was then placed in the nichrome retort. The lower part of this retort was placed in an oil-fired furnace and heated to a temperature above the melting point of calcium. The retort was provided with a tight cover firmly held with bolts and connected with the vacuum system. The calcium was distilled in vacuum and was condensing in the form of a ring in the upper part of the iron cylinder. After the completion of the distillation which required about five minutes per pound of calcium, and while the material was still at a temperature of about 400-500°C, a mixture of hydrogen and helium was admitted to the retort. The percentage of helium at first was in the order of 25-30%. However, as the skill of the operators increased the percentage of helium was reduced to 15% and even 10%.

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This separation of very fine particles was done as follows. The leaching drum in which the treatment of powdered metal was carried out by agitation of powdered materials in dilute acid by rotating the cylinder, was interrupted from time to time, the treatment was stopped, the heavy large and medium particles were settling to the bottom of the drum in a few seconds, but the very fine particles remained in suspension for a very much longer time. Then the drum was partly decanted, which resulted in the elimination of fine particles. This alternate agitation and decantation was repeated three or four times during the leaching which resulted in the elimination of very fine particles which were one of the causes of trouble. The very heavy course particles were eliminated from the charge by discharging it from the drum and passing it through the screen. The coarse particles were caught by the screen. Since no permission was given to build an adequite catch basin in which most of the fine particles could be trapped and subsequently recovered, this operation was quite wasteful. However, due to the extreme urgency of this work, it had to be carried on.

Accidents were reduced to an absolute minimum by adopting the technic of separation of very fine and very large particles from the bulk of the metal. However, this separation of fine and coarse particles entailed a loss of about 20% of metal. Most of the 20% loss was recovered as oxide and sent to the supplier of the oxide for reprocessing. The exact amount of loss could not be estimated since the fine material, decanted and collected in the catch basin in the yard, periodically was spontaneously igniting.

Helium was admixed to hydrogen to slow down the reaction, because if pure hydrogen was added, the reaction, being exothermic, was proceeding too rapidly with the result that the produced calcium hydride was melting and running down and mixing with the residue of distillation. However, by using helium as a "chemical brake", the speed of reacting could be controlled and the conversion of the metallic calcium to calcium hydride was accomplished withoug melting same. It should be mentioned that inside of the iron cylinder it was necessary to use baffle plates which were placed just above the crude calcium. This separation of crude calcium and distilled calcium by baffle plates prevented the splashing of the impure molten calcium and therefore the contamination of the distilled product. By this method it was possible to produce distilled calcium in one operation and convert it into calcium hydride.

The purity of the calcium hydride produced by this method was very high. The percentage of boron in most of the runs was less than half of one part per million.

VII. Reduction of Oxide to Metal

The pure distilled calcium hydride was removed from the upper part of the iron cylinders by means of a cold chisel, an operation which did not involve any difficulty since calcium hydride is a brittle chalk-like material. Then the obtained pure calcium hydride was crushed in a jaw-crusher to a mixture consisting of fine powder and particles of about ¼" x ¼" x ½". The mixture of brown dioxide and calcium hydride was placed in an iron cylinder which was placed in a nichrome retort of identical design as those used for distillation. (See Plate X)

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VIII. Pyrophoric Properties of the Powdered Metal

Uranium in the form of very fine powder is subject to oxidation by air or moisture at a comparatively low temperature. For instance, it slowly reacts with water at temperatures above 20°C. Therefore, uranium in the form of fine powder must be kept always in a perfectly dry atmosphere of such neutral gas as helium or argon.

The dry powder also reacts with air at a comparatively low temperature and if large masses of powdered metal are exposed to air for a few days they gradually oxidise at least on the surface to black oxide with the consequent generation of heat which under favorable conditions leads to the ignition of the powder. Furthermore, it was found that various samples of powdered uranium react differently with air or moisture in accordance with the temperature at which they were produced from the oxide. To minimize the pyrophoric properties of the powdered metal, the temperature of reduction must be above 960°C, preferably above 1000°C. If the material is produced at a lower temperature it quite often displays pyrophoric properties and often ignites spontaneously during the drying or packing operations.

Our investigation of the pyrophoric properties of the produced powder also indicated that the previous treatment of the oxide has a very considerable bearing on these properties. Some of the shipments of oxide were displaying a very much greater tendency to give pyrophoric metal than others. The oxide containing an appreciable amount of larger particles usually was giving pyrophoric material. In the past it was observed that occasionally pyrophoric material was produced from the black oxide received directly from

Canda. Yet since that oxide was of very much finer grain size, the tendency to give pyrophoric metal was very much less than in the case of the brown dioxide.

IX. Leaching

After reduction of uranium oxide to metal, the charge was left cooling in the furnace to a temperature of about 30-40°C. During all that time a vacuum was maintained to eliminate all the hydrogen remaining in the charge after the reduction with calcium hydride. The reduced metal therefore was thoroughly degassed. The charge after being removed from the furnace was in the form of a sintered clinker and had to be removed from the iron cylinder by breaking it with the air chisel. Then this material was passed through the jaw crusher and crushed to a rough powder consisting of fine material and pieces up to ½" in diameter. Before leaching this material an analysis was made on this product. If it was reported that boron was within the acceptable limits, which usually was in the order of one half part per million, the charge, now consisting of fine particles of uranium metal embedded in pure calcium oxide, was placed in the hopper and gradually shaken into the leaching cylinder containing a very dilute solution of acetic acid. (See Plate XII)

The leaching of uranium powder in batches of several hundred pounds is a distinctly dangerous operation and can be undertaken only by a well-trained crew thoroughly familiar with all the dangers of such an operation.

The concentration of acetic acid in the leaching operation never exceeded some 2% by weight. A greater acid concentration is likely to oxidize the material. The temperature of the water is also an important point and has to be kept at the lowest possible

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limit and should never be allowed to rise above 35°C. A constant vigilance of the temperatures in the leaching tanks is a primary consideration for the safety of the operation.

X. Drying

The wet uranium powder, after thorough washing on the screen with filtered cold water, was removed to a drying room where after spreading in a very thin layer on metallic trays it was placed in the drying ovens provided with a continuous circulation of dry nitrogen. The dry nitrogen was passing over the surface of the uranium powder, then through moisture-absorbing drums filled with silica where the moisture was removed and back again into the drying oven. The drying operation required twelve hours on an average and was conducted at nighttime. Every charge, therefore, was dried by the following morning and was ready to be sent to the foundry for melting.

The storage of powdered uranium was found possible at low temperature. Therefore, cans filled with powdered metal were stored in special refrigerators and cooled to a temperature of -15°C until such time as they were removed to the furnace room for remelting.

XI. Melting

The uranium powder, as stated before, had been melted in vacuum by Metal Hydrides Inc. when producing this metal for various laboratories since 1936. However, the melting and casting of this material in large quantities requires a different technic. The problem was solved by a group of scientists working with Professor John Chipman at the Massachusetts Institute of Technology. They devised a method of fusing uranium powder in high frequency furnaces in graphite crucibles. After the development of this method of fusion and casting at the Massachusetts Institute of Technology a special foundry was equipped at Metal Hydrides Inc. in Beverly, where powdered material was melted at the rate of about one ton per day.

Due to an extremely slow delivery of the ordered machinery, changes in specifications, and raw materials, the regular production was delayed until the end of the summer of 1942. However, by the end of November, 1942, Metal Hydrides Inc. had supplied the largest part of the metal which went into the construction at the Chicago Metallurgical Laboratory of the first experimental pile, which on December 2, 1942, as reported in the Smyth report, was put in operation and definitely demonstrated the existence of a chain reaction.

XII. Conclusions

Metal Hydrides Inc. was the pioneer in the production of uranium metal and supplied it to all the laboratories interested in this research before other methods for its production were developed. The conditions with regard to the analysis, physical form or quantities have been changing, as in every research project, continuously. Therefore, Metal Hydrides Inc. went through various stages of production of this metal as requested by the interested parties.

At first the metal was produced in small sintered discs about 1" in diameter. Then it was produced in small fused ingots of 2" x $\frac{1}{4}$" x $\frac{1}{4}$". Later larger amounts were supplied in powder form. Later the sintered cubes were produced and finally all the metal was cast into ingots of various sizes which varied from time to

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time from 1" to 6" in diameter, and height was varied from 1" to 11".

The chemical analysis was changed in accordance with the progress of the research by the physicists experimenting with this material. At first standard black oxide shipped directly from Canada was used in experiments with the only precaution of eliminating hydrogen from the produced metal. Gradually it became known that other elements should be eliminated from the metal. The latest specifications list about fifty various elements which must be kept below specified limits. The most difficult problem was the elimination of boron which at first was as high as 5 parts per million. Gradually it was reduced to below one part per million and most of the metal which Metal Hydrides Inc. produced had a boron content of only .1 to .5 of one part per million.

TABLE I

The Densities of Pressed and Sintered Blocks

Data taken from the Laboratory Record Book Number 3, pages 11, 14, 17, and 45, from June 26 to August 30, 1942

Block sintered from Black Canadian Oxide	Block sintered from Brown Dioxide
17.75	14.35
17.64	14.99
17.80	15.40
17.22	15.17
14.64	14.82
14.95	14.43
15.18	14.39
15.34	14.07
17.62	13.78
17.91	14.02
18.09	14.08
15.01	14.50 average density
16.60 average density	

The average density specified by Dr. Compton was 15 or over.

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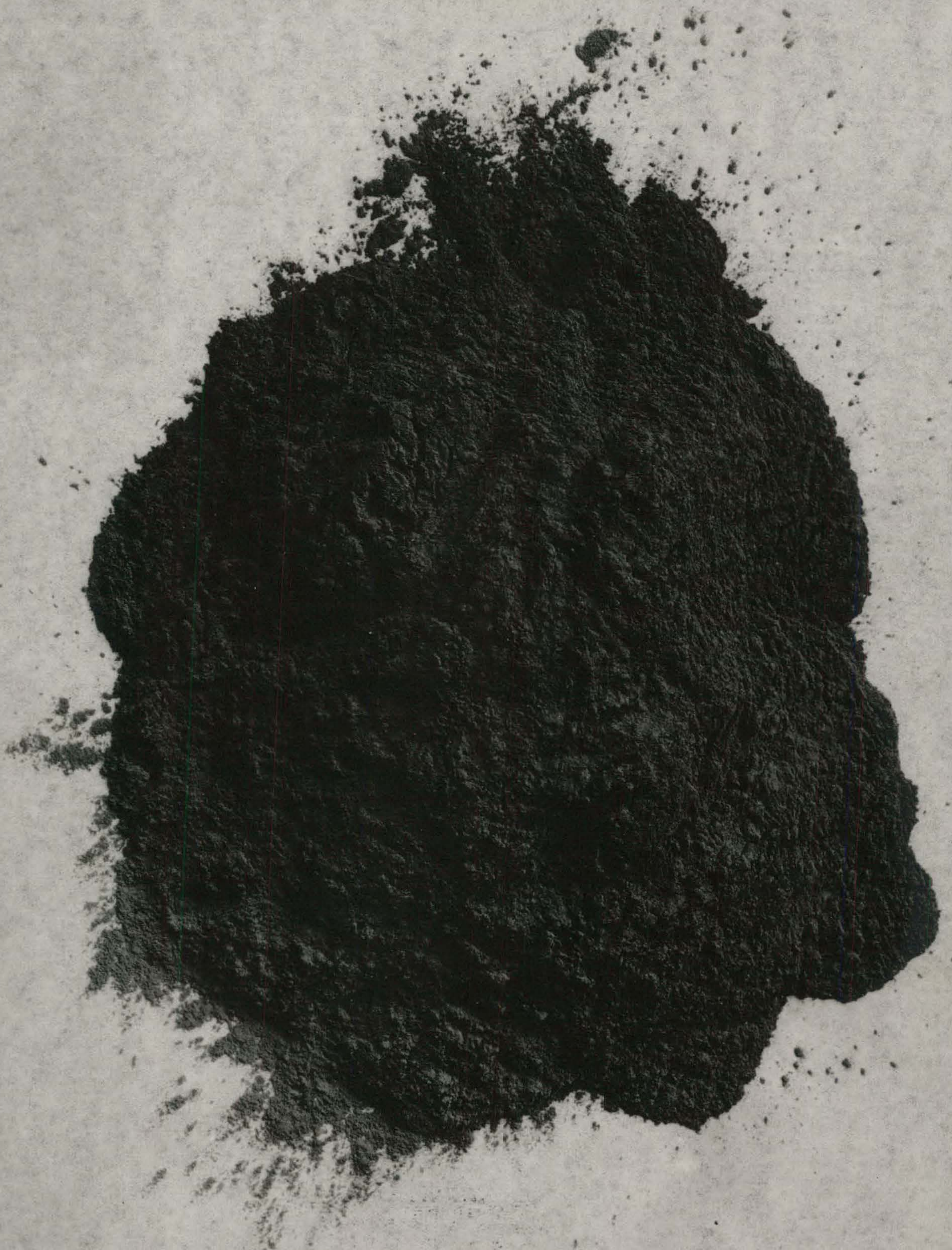
PLATE I [redacted]



Uranium Metal in Powder Form

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PLATE II

[redacted]

Uranium Metal Fused and Cast in Vacuum at a Temperature of 1150°C.
Original Ingot Produced in 1938.

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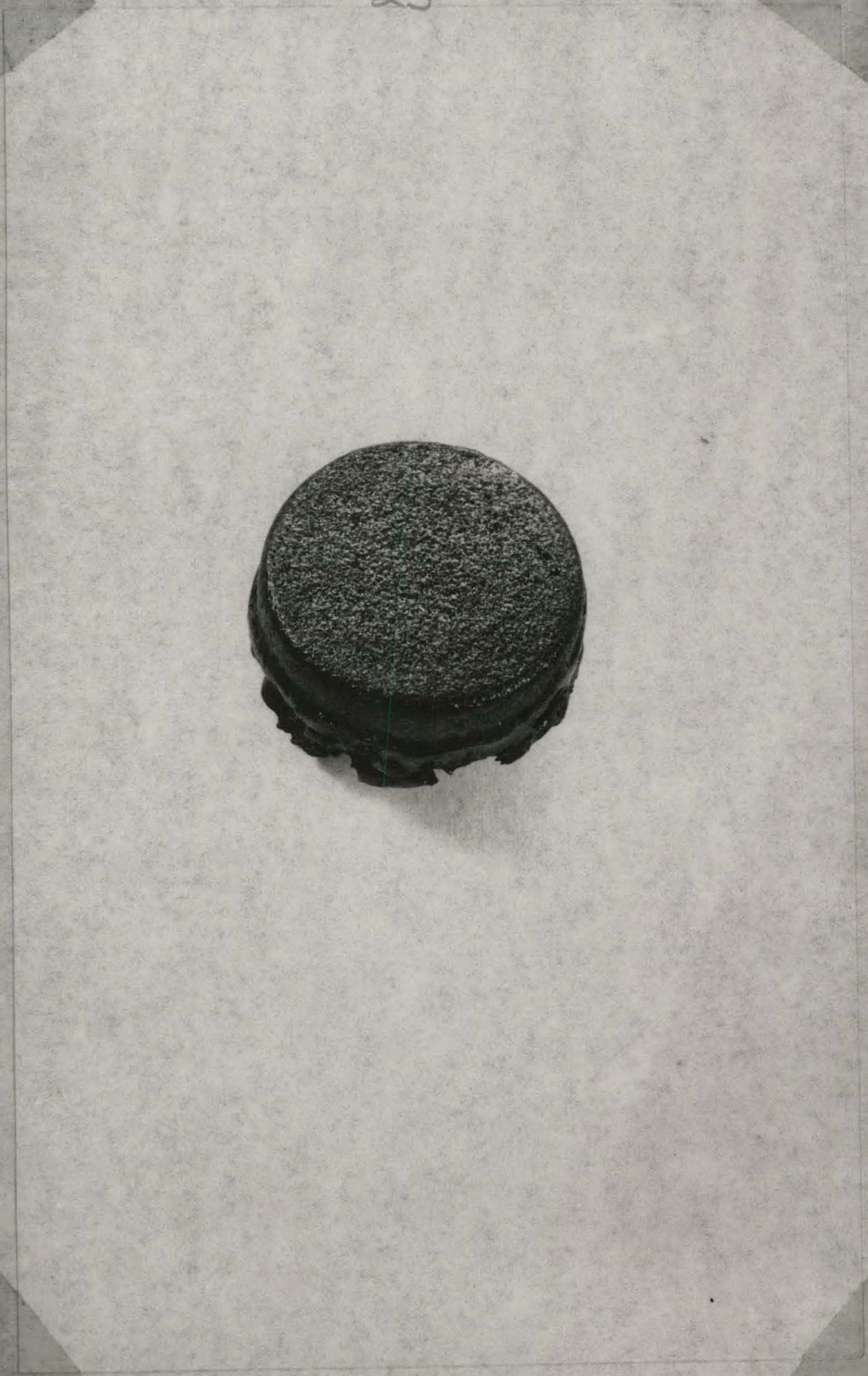
PLATE III

[redacted]



The First Uranium Ingot Produced by Fusing Powdered Uranium by High Frequency Current using Graphite Shield.

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PLATE IV

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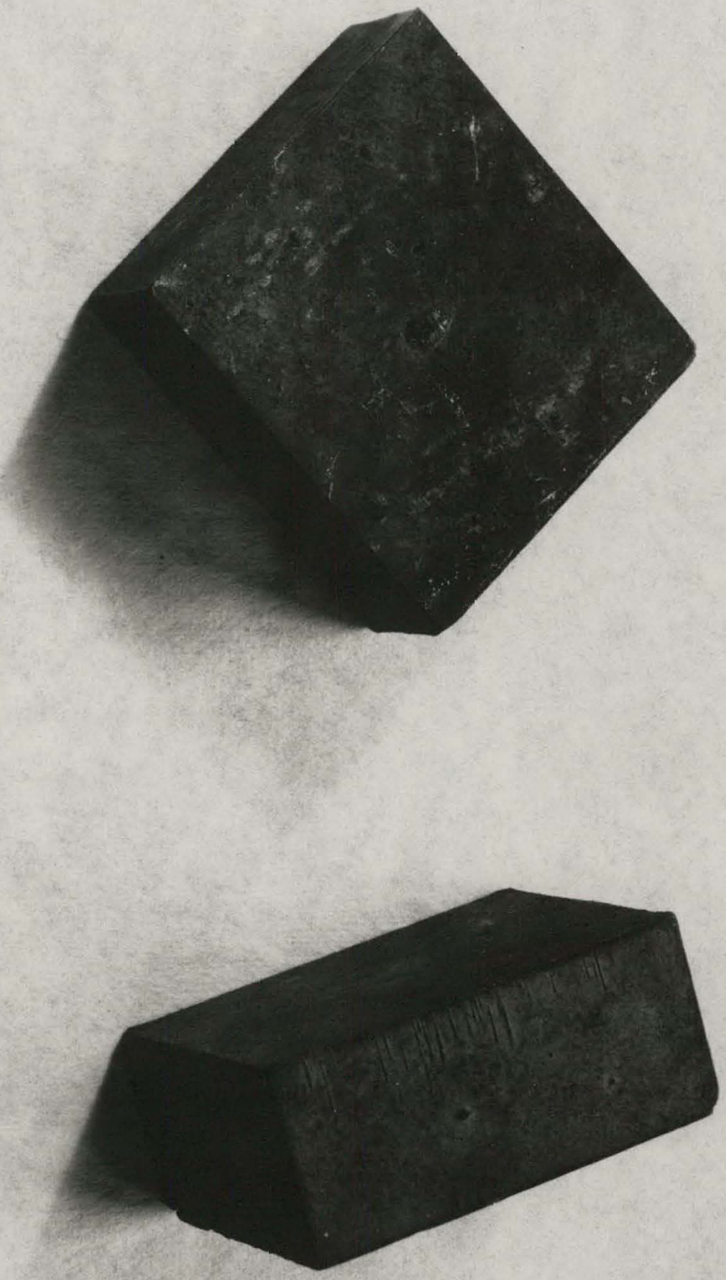

Powdered Uranium Metal Pressed and Sintered in Vacuum into 1" x 1" x $\frac{1}{2}$" Ingots.

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SECRET

PLATE V

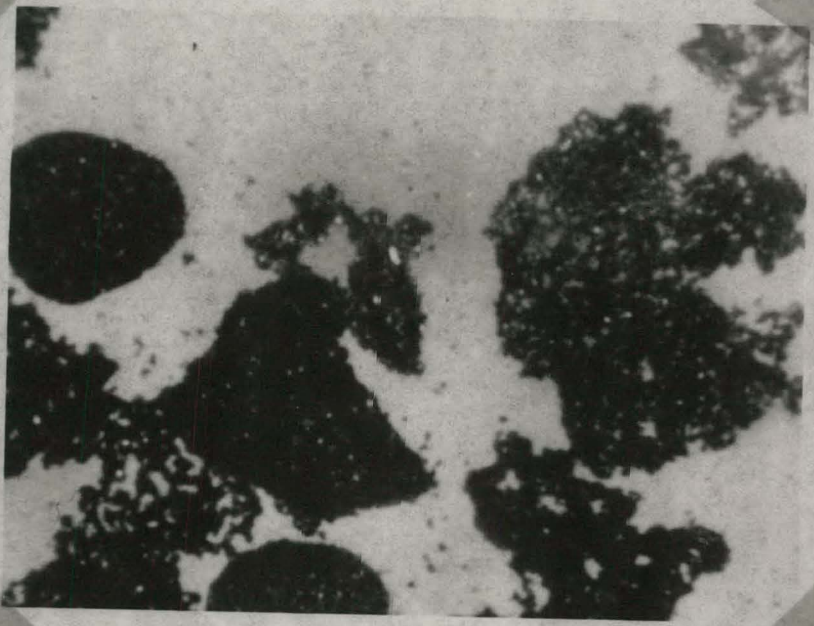
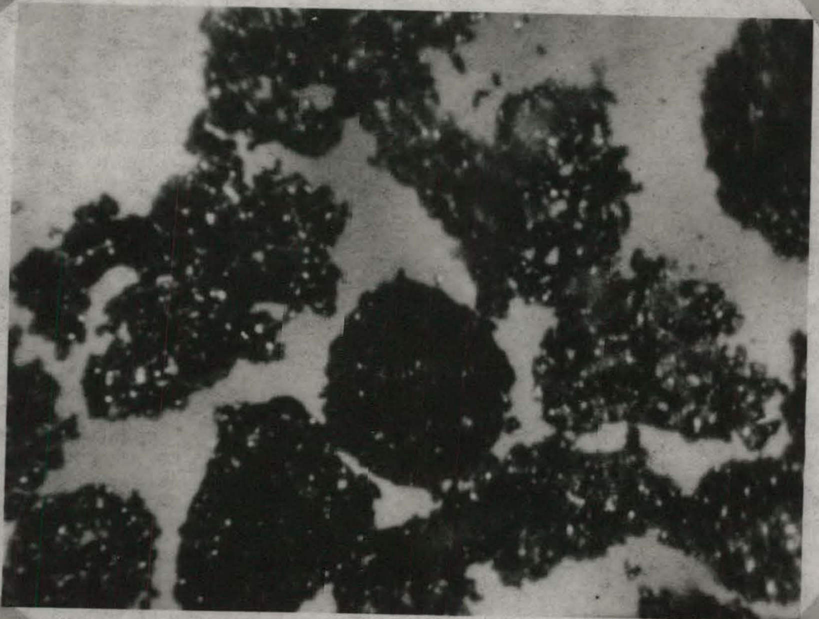


PLATE VI



Coarse Uranium Metal Powder Produced
from Brown Uranium Dioxide x 100

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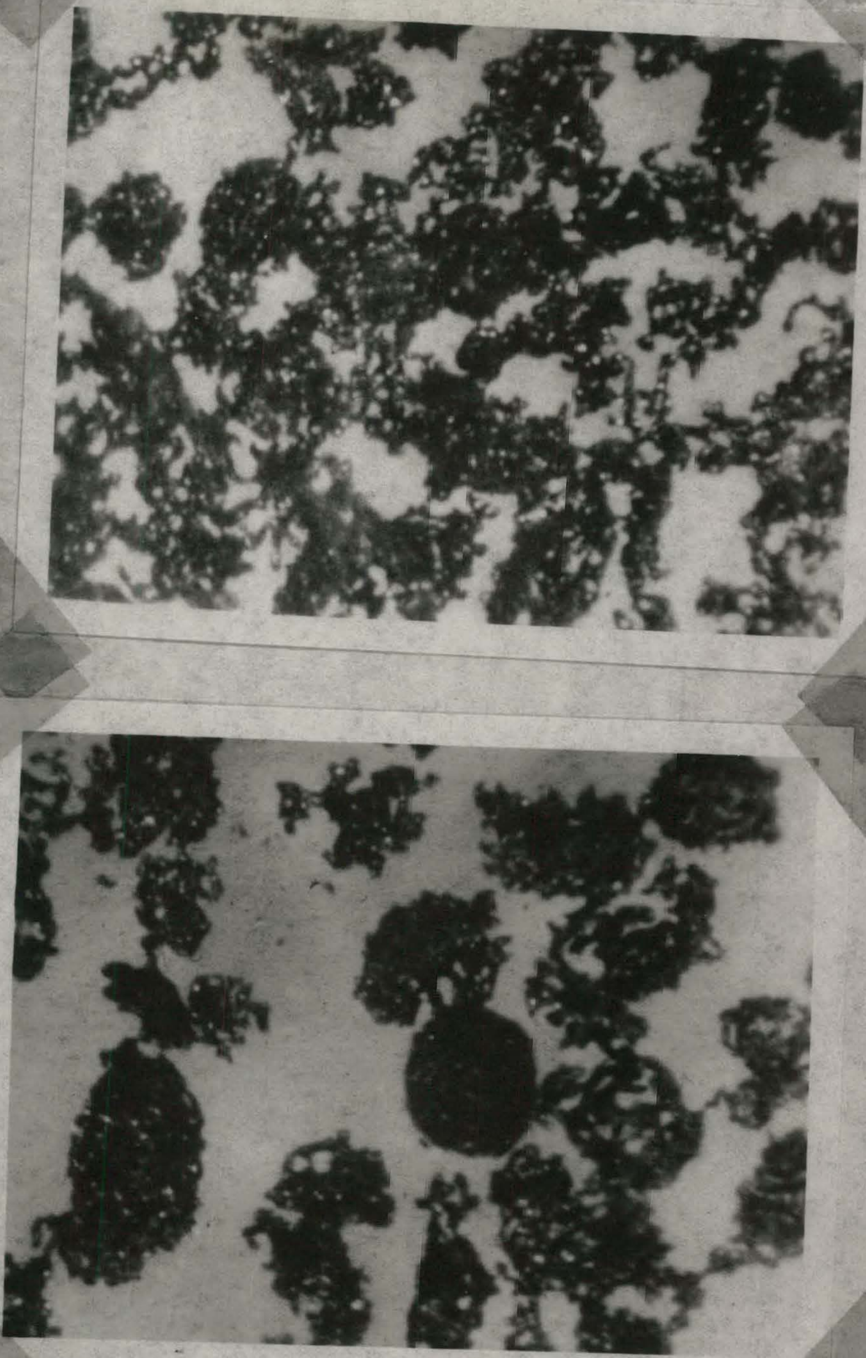
[redacted]

PLATE VII



Medium Uranium Metal Powder Produced from Brown Uranium Dioxide x 100

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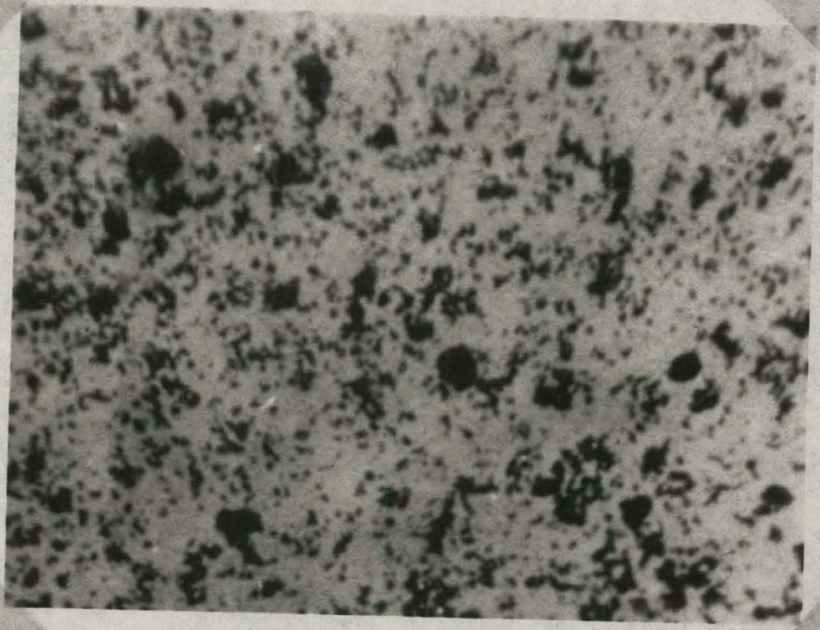
PLATE VIII



Fine Uranium Metal Powder Produced from Brown Uranium Dioxide x 100

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PLATE IX

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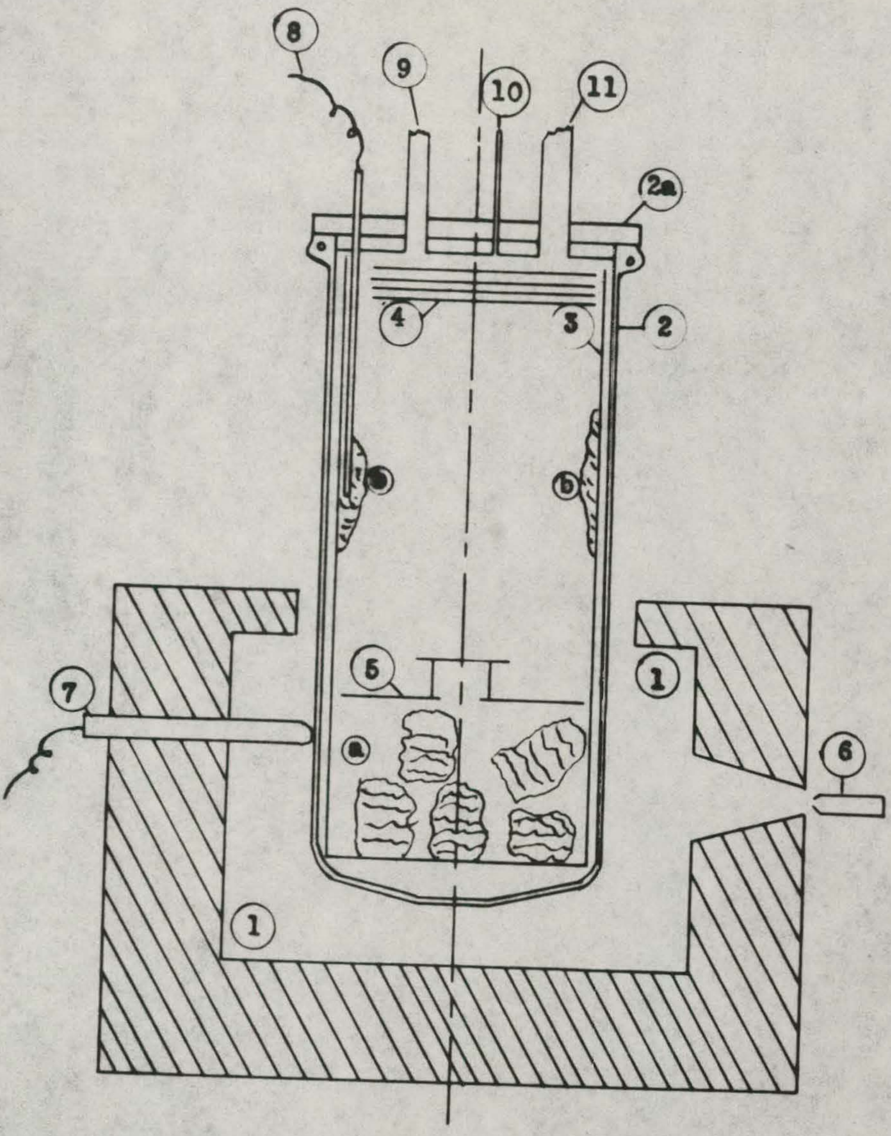

CALCIUM DISTILLATION and HYDRIDING FURNACE

a. Calcium Carrots
b. Distilled Calcium·
1. Furnace, brick lined, steel shell
2. Retort (Special Alloy) 40"X18½" OD
2a. Retort Cover (Special Alloy)
3. Inside Cylinder (Steel) 33" X 16½" OD
4. Heat Baffle and Sodium Trap
5. Anti-splash Baffle
6. Burner (tangential) oil
7. Thermocouple
8. Pyod
9. Safety Valve
10. Gauge
11. Hydrogen and Vacuum Line

METAL HYDRIDES INCORPORATED
Beverly, Massachusetts
Scale:- Approximate

Calcium Distillation and Hydriding Process

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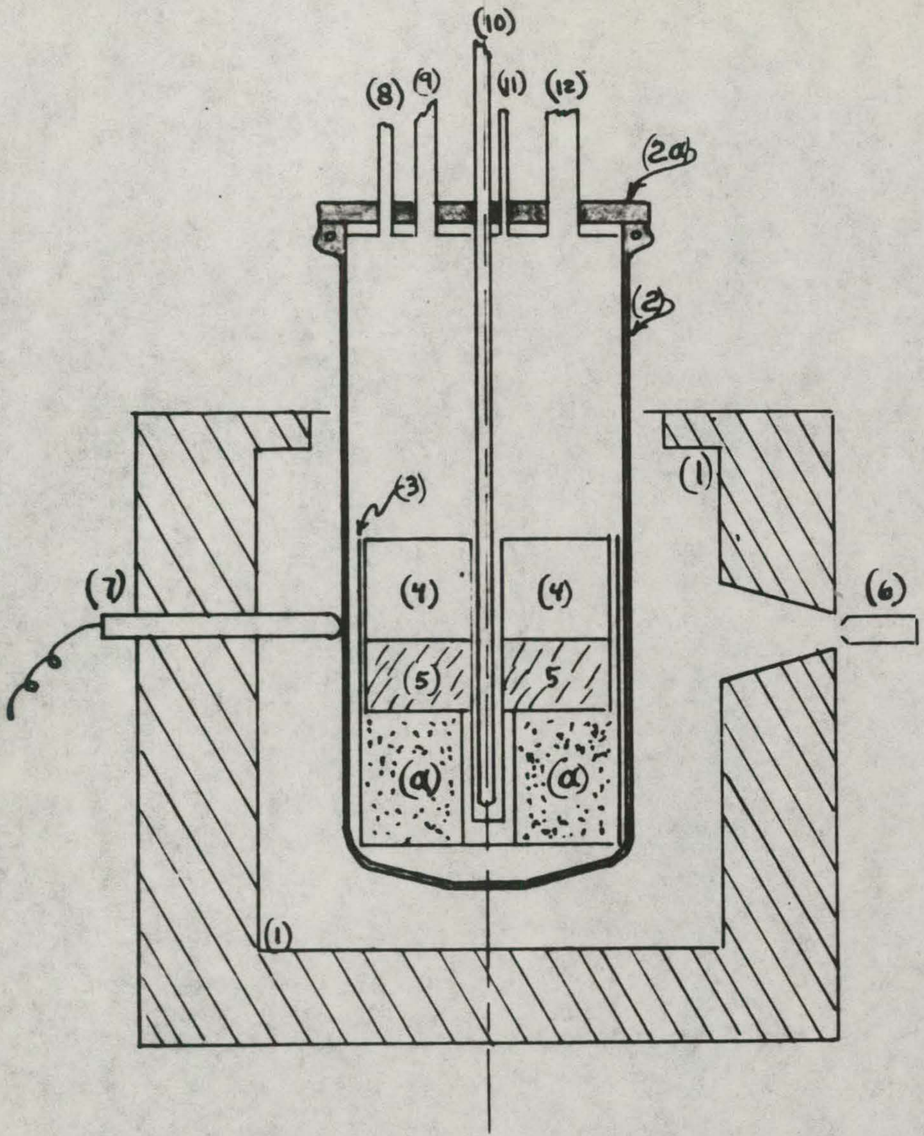

REDUCTION FURNACE

a) Charge: Tri-Alloy Oxide and Calcium Hydride
1) Furnace: brick lined, steel shell
2) Retort: (Special Alloy) 40"X18½"OD
2a) Retort Cover (" ")
3) Inside Cylinder (steel) 18"X 16½"O.D.
4) Heat Baffle: fire brick in steel shell
5) Sodium Trap
6) Burner (tangential) oil and gas (2)
7) Thermocouple
8) Hydrogen Relief
9) Safety Valve Line
10) Pyod
11) Gauge
12) Hydrogen + Vacuum Line

METAL HYDRIDES INCORPORATED

Beverly, Massachusetts

Drawn approximately to scale

A.C.H.Jr July 20, 1943

Reduction Furnace

PLATE XI

SECRET

Very coarse Particles and Globules
Occasionally Found in Dioxide x2

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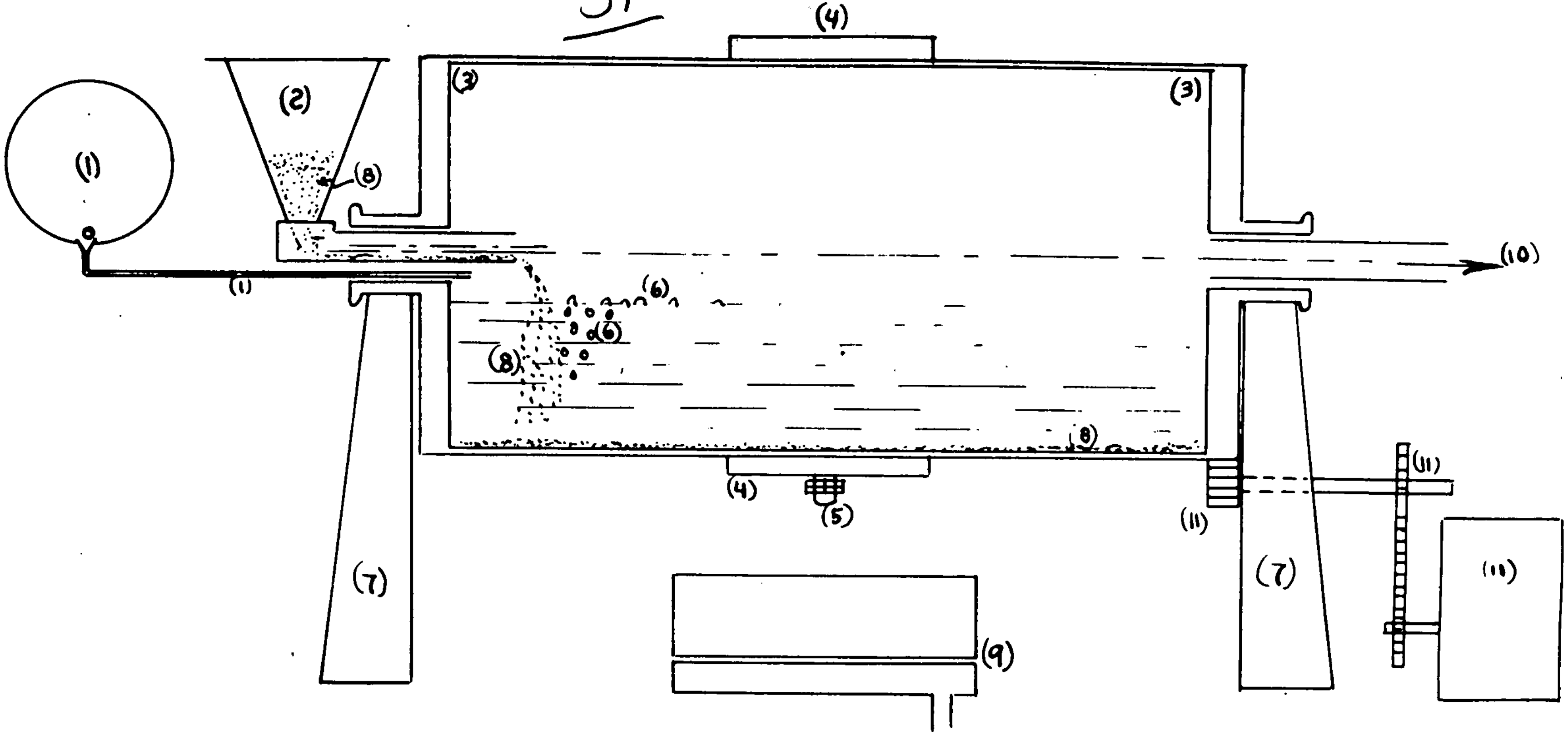
Leaching Equipment

PLATE XII



1) Acetic Acid Supply
2) Syntron Feeder with Charge
3) Drum: steel shell, rubber lined
4) Manhole
5) Plug for hose attachment to empty
6) Hydrogen bubbles rising through acid and water
7) Supports
8) Charge
9) Vacuum Filter
10) Hydrogen Exhaust
11) Drive, chain and reduction gear

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LEACHING EQUIPMENT

METAL HYDRIDES INCORPORATED

Beverly, Massachusetts

A.C.H.Jr. July 21, 1943