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Scrap Uranium Recycling via Electron Beam Melting

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SCRAP URANIUM RECYCLING VIA ELECTRON BEAM MELTING

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Abstract

A program is underway at the Lawrence Livermore National Laboratory (LLNL) to recycle scrap uranium metal. Currently, much of the material from forging and machining processes is considered radioactive waste and is disposed of by oxidation and encapsulation at significant cost. In the recycling process, uranium and uranium alloys in various forms will be processed by electron beam melting and continuously cast into ingots meeting applicable specifications for virgin material.

Existing vacuum processing facilities at LLNL are in compliance with all current federal and state environmental, safety and health regulations for the electron beam melting and vaporization of uranium metal. One of these facilities has been retrofitted with an auxiliary electron beam gun system, water-cooled hearth, crucible and ingot puller to create an electron beam melt furnace. In this furnace, basic process R&D on uranium recycling will be performed with the goal of eventual transfer of this technology to a production facility.

Introduction

In 1972, Airco Temescal and Airco Viking, sister divisions at the time, developed a process to recycle low-value scrap titanium metal and alloys(1). At that time, titanium machine chips and turnings were available on the scrap market in tonnage quantities for essentially zero value. The Viking division developed and patented(2) methods for cleaning, drying, and blending chips at their plant in Verdi, Nevada. The Temescal division designed and retrofitted a bulk-feeding system onto their existing 1200 kW Electron Beam Cold Hearth Refining (EBCHR) furnace in Berkeley, California. From what had been scrap machine chips and turnings, this pioneering effort produced 18 in.

diameter, 6 ft long, in-specification, titanium ingots. Figure 1 shows the melting process in the 1200 kW EBCHR furnace now located at Viking's plant in Verdi. This enterprise has blossomed in the ensuing years, and today remains a viable business. Between Viking and now A. Johnson Metals, there is currently approximately 6 megawatts of installed electron beam capacity in the U.S. devoted to the scrap recycling of titanium.

Uranium metal is now a prime candidate for a similar recycling program. Typically, uranium is vacuum induction melted (VIM) in graphite crucibles(3). However, uranium, like most refractory metals, is extremely reactive, and the higher melting point uranium alloys will pick up carbon from the graphite crucibles limiting the possibility for remelt via the VIM process. Even machine turnings and chips of pure uranium are difficult to recycle via VIM as their high surface area results in large amounts of oxide slag and low recovery rates at typical VIM pressures.

Lawrence Livermore National Laboratory has been using electron beam technology to vaporize uranium metal since 1975 in a process known as Atomic Vapor Laser Isotope Separation (AVLIS). The process and its purpose were covered in some detail in a paper presented at this conference last year(3). Through LLNL's uranium AVLIS involvement, working with others in the uranium metal field, and with the LLNL Hazardous Waste Management group, we have seen the cost of uranium scrap disposal rise in recent years to a current cost of approximately $10 per kg. The procedure for disposal of a radioactive and hazardous material such as uranium is to first oxidize (burn) the metal, then encapsulate the oxide in concrete and finally ship the concrete blocks to a disposal site for burial.

The cost for recycling uranium via EBCHR is projected to be around $4 per kg and the value of ingots produced range from $25 to $200 per kg, so there are economic as well as environmental savings to be realized in recycling rather than disposing of the material as waste. This is not a large market, probably only 20 to 30 metric tonnes of recyclable uranium scrap is generated in the U.S. per year. In the present environmental, health, safety, and economic climate, however, recycling of uranium is definitely an idea whose time has come.

The Project

One year ago, Lawrence Livermore National Laboratory found itself in a unique position. Because the AVLIS program and its facilities were fairly new, it turned out that LLNL had the only electron beam vacuum furnaces in the US in full compliance with current environmental, safety and health regulations for handling uranium. One of these, the Mars facility, housing a 6 ft box vacuum chamber, was available, and appeared to be about the right size for an EBCHR furnace. A few quick design layouts revealed that the Mars vacuum chamber could successfully be retrofitted to a melting and casting configuration at reasonable cost. Internal LLNL funding was obtained for construction of a proof-of-principal demonstration unit to convert Mars into an EBCHR furnace capable of melting and casting uranium. The understanding was that if credibility could be demonstrated by converting the facility on time and within budget, additional follow-on money would be made available to build and install a scrap feeder. In actuality, by the time a budget was in place, only 10 months were left to complete the project.

The Design

Due to time and budget constraints, as much as possible of the existing Mars system was incorporated into the new design. The existing AVLIS design utilized a metal frame on rollers onto which was mounted all components necessary for EB evaporation and subsequent collection of uranium metal. This frame was then rolled into the Mars vacuum chamber and the system pumped to high vacuum. This design philosophy was retained by mounting a hearth, crucible and cooled shielding on an existing frame which could then be rolled into the vacuum chamber with minimal changes to the overall system. An artist's concept of the redesigned Mars chamber is shown in Figure 2.

Although existing LLNL built electron beam guns were available, commercial systems appeared to offer more flexibility for our proposed melting configuration, and design layouts showed that there was room to mount a gun on top of the vacuum chamber in place of an existing 20 in. cryopump. Existing ports in the bottom of the chamber through which an ingot could be cast, were 6 in. I.D., so we designed the process around producing ingots with a maximum diameter of 5.5 in. Hearth size (8in.x17in.) was dictated by the size of existing feeder and feedstock, and the distance from feed point to pour point.

Design calculations coupled with a literature search on electron beam melting indicated that approximately 150 kW would be required to effect the EBCHR process in the intended geometry. It was decided, however, to procure a 250 kW system to provide developmental flexibility for the installation. Also, 250 kW systems were available from all three manufacturers of this equipment. The only unknown seemed to be the ability of a single gun system to effectively cover the melt, hearth and cast areas. Conversations with the manufacturers indicated that with modern electron beam systems capable of 1000 hz sweep frequencies, single gun coverage of the required areas would not be a problem.

Requests for bids were then sent out for a 250 kW electron beam gun, power supply and beam deflection system and for a hearth, crucible and ingot puller. Low bidder for the electron beam system was Leybold Technologies with their KSR-250 gun, shown in Figure 3. The contract for a hearth, crucible and dovetail went to Alamo Vacuum Technology. The remainder of the system, shields, support structures and peripherals were designed at LLNL and fabricated through local shops.

Installation

Both Leybold and Alamo Vacuum Technology met or exceeded specifications in all respects, including deliveries. Figure 4 shows the hearth and crucible as received. The hearth, crucible, and ingot puller were installed on the LLNL pod and the system was completely plumbed and instrumented as shown in Figure 5. The pod was ready for installation in the vacuum chamber in mid July. The electron beam system was checked out in Hanau in early July and received at LLNL on July 28. Installation and check-out at LLNL were completed in August, and the first ingot, using titanium as a surrogate material during check-out, was cast on September 3. Figure 6 shows removal of the first uranium ingot which was cast on September 22.

Follow on

The FY 93 milestones were met, and funding for the current year has been approved. The plan for this year is to demonstrate that an acceptable quality product meeting all chemistry and performance specifications for the uranium alloy being cast can be produced. This will involve some process development and extensive characterization of the uranium ingots produced. Funding has also been provided to design and install a scrap feeder and to melt and cast uranium alloy from scrap feed. Ultimately, the intent is to construct a production facility tailored to whatever the correct scrap and product mix turns out to be. This may be located at a DOE facility, or there may be technology transfer with private sector uranium scrap generators if that interest exists.

Auspices

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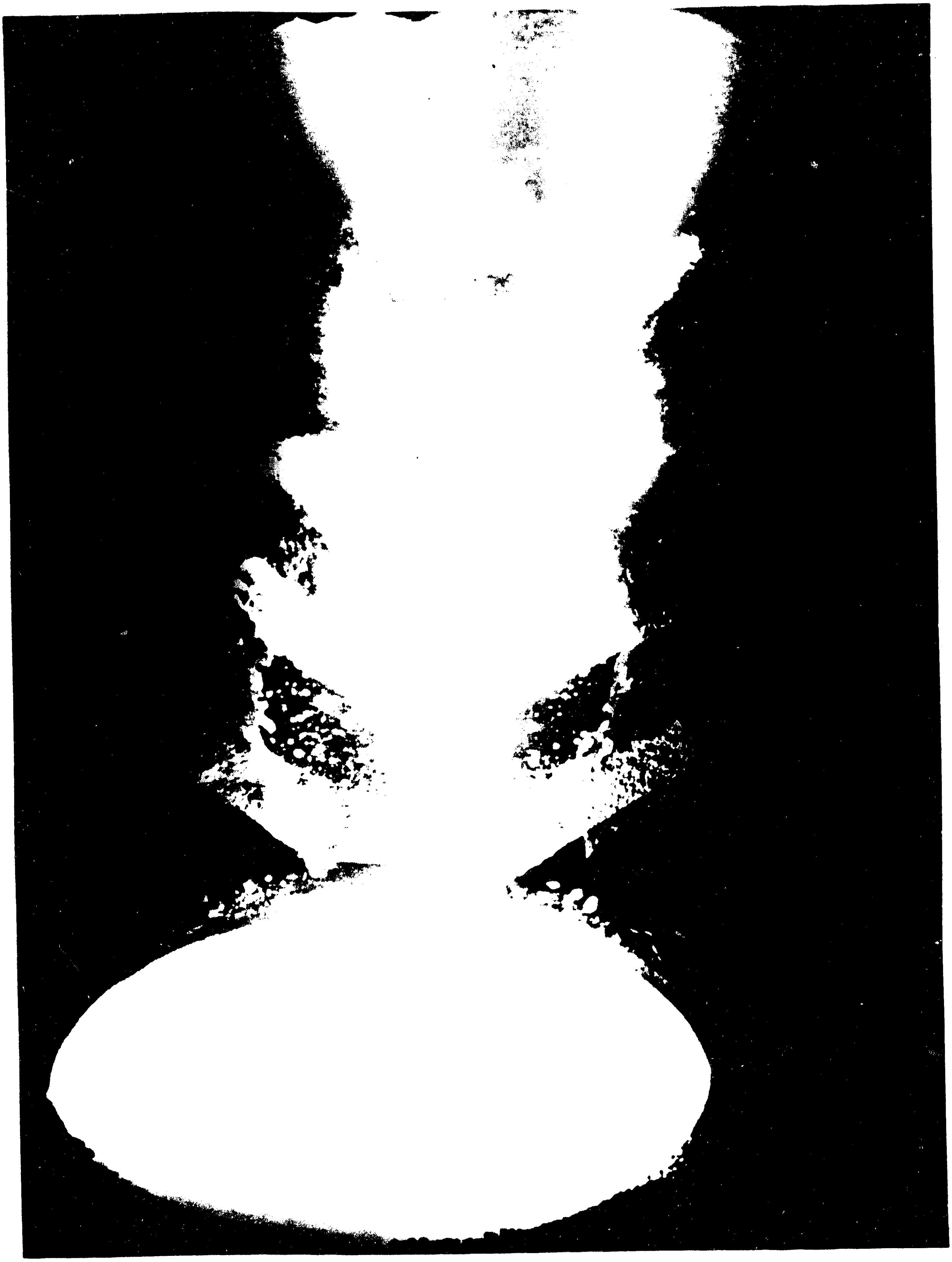
Figure 1 - Titanium chip recycling via EBCHR

E-Beam Melting and Casting Demonstration Furnace

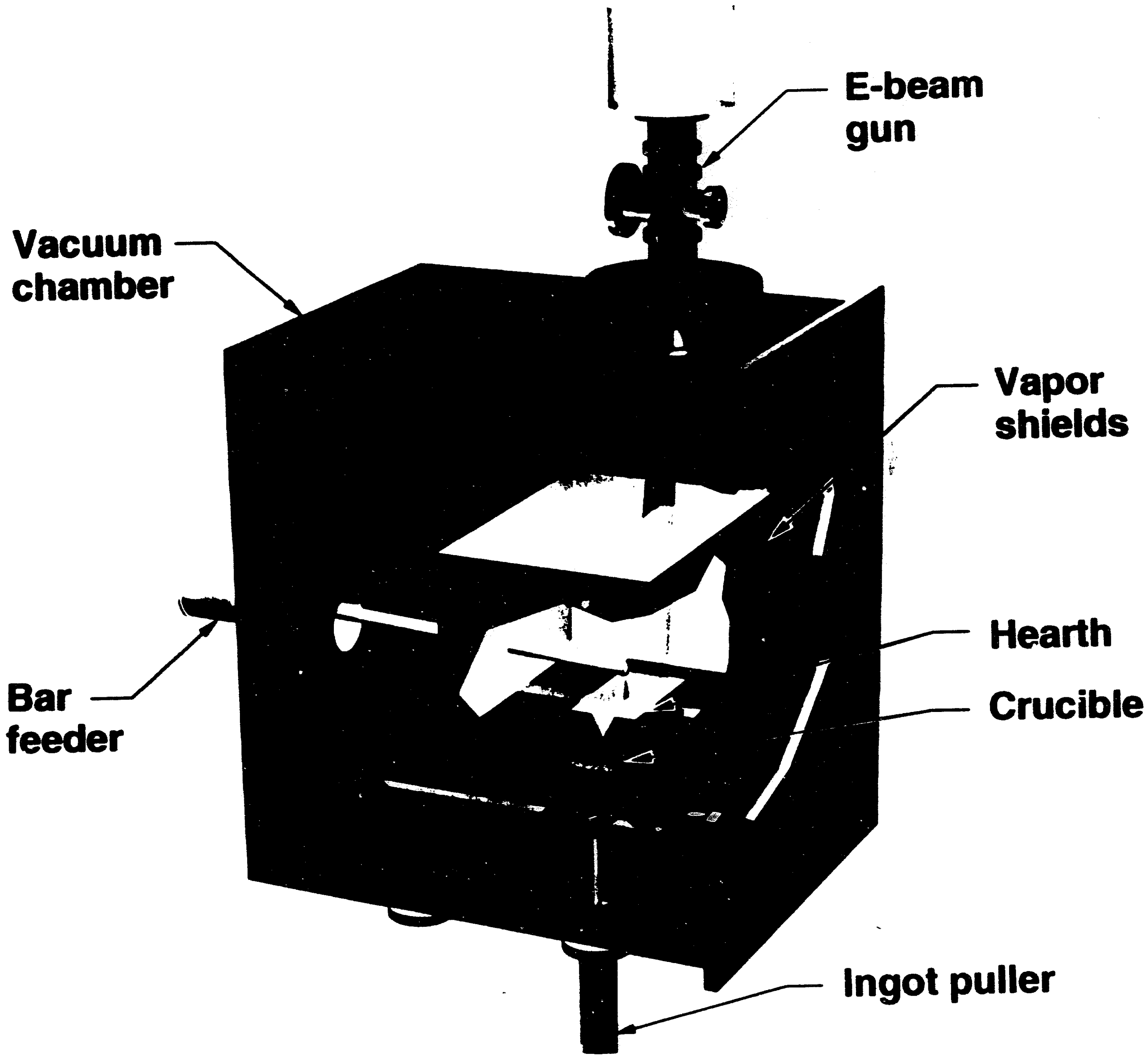

Figure 2

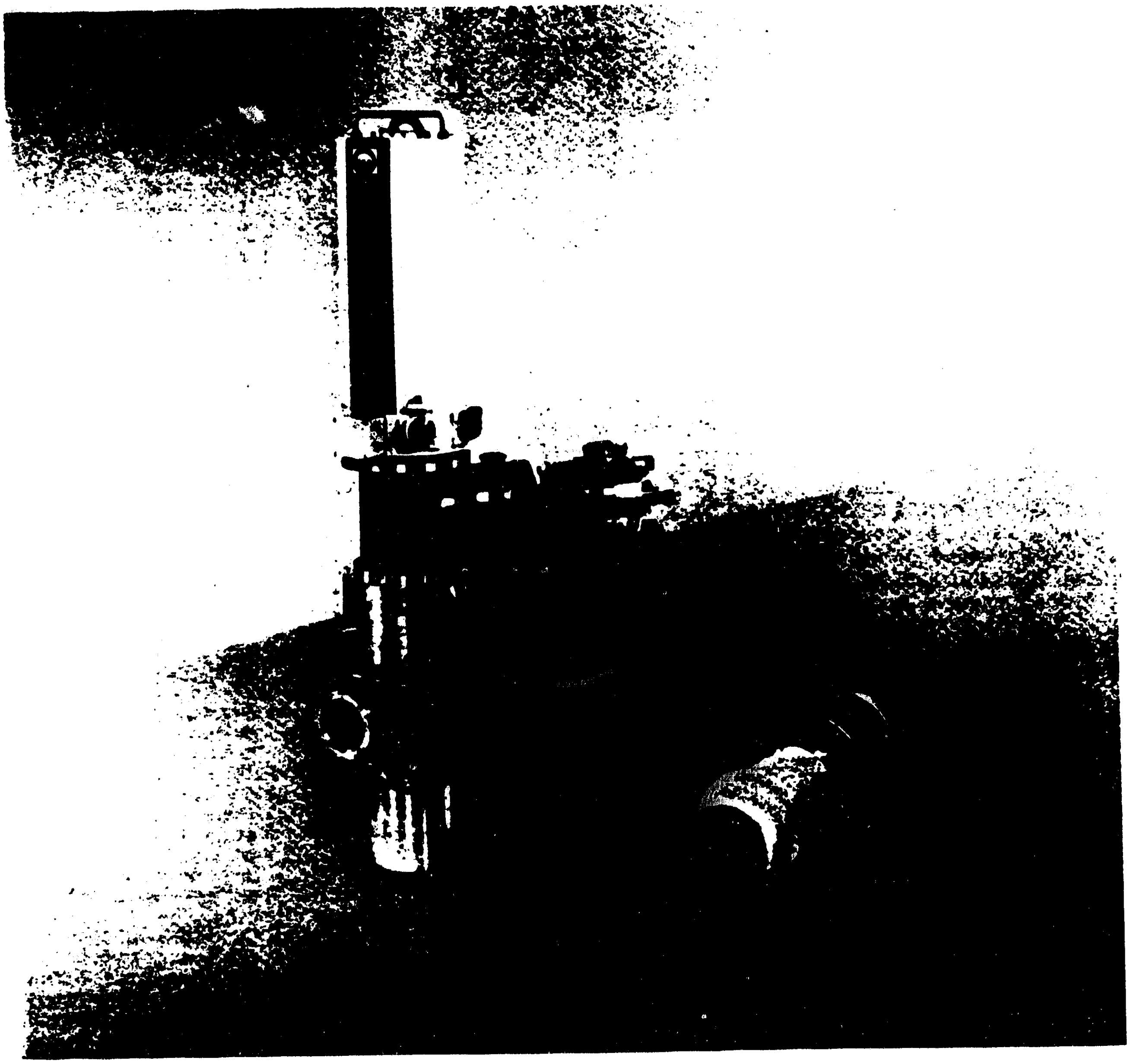

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Figure 3 - Leybold KSR-250 Electron Beam Gun

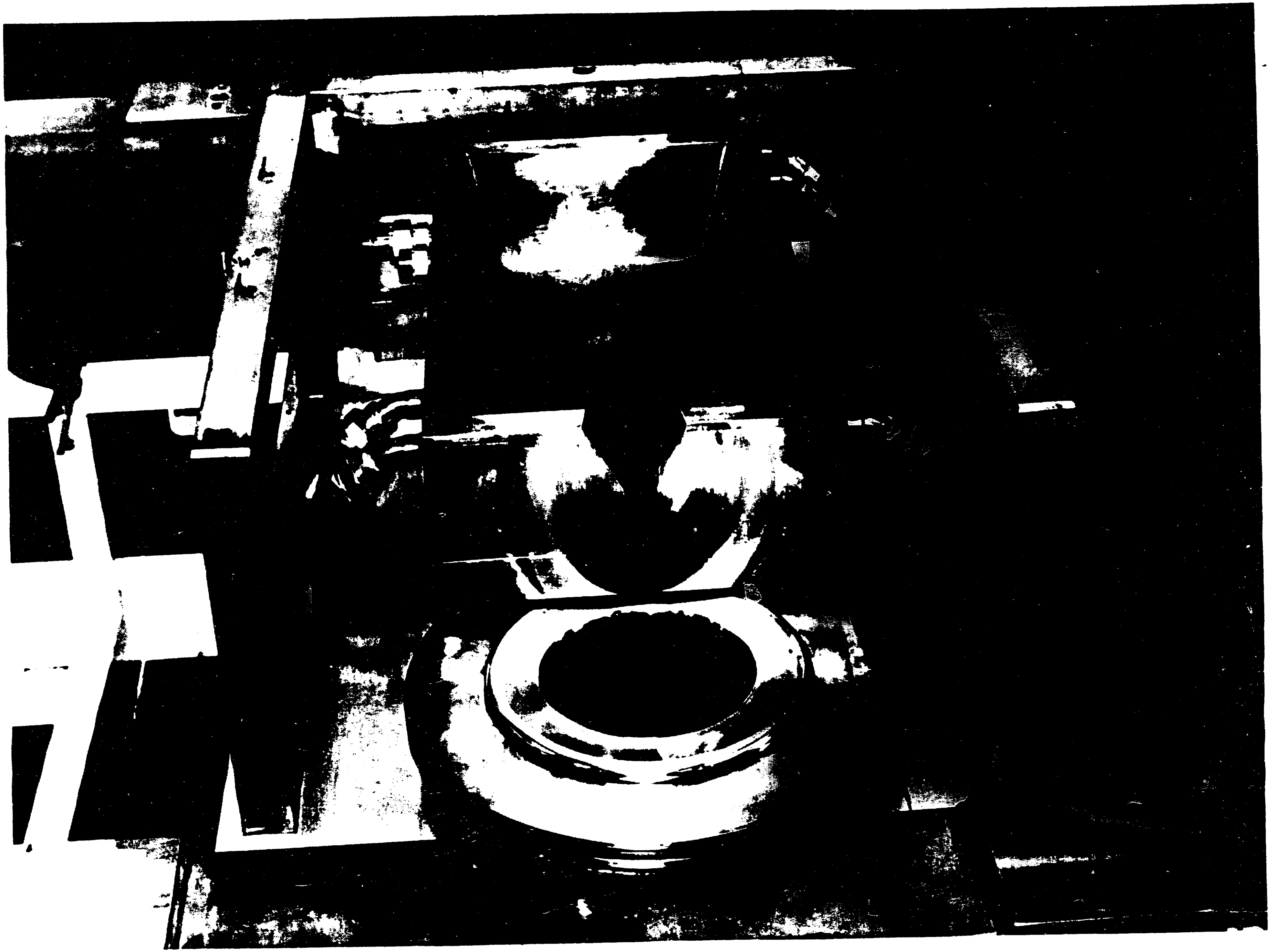

Figure 4 - Hearth and Crucible

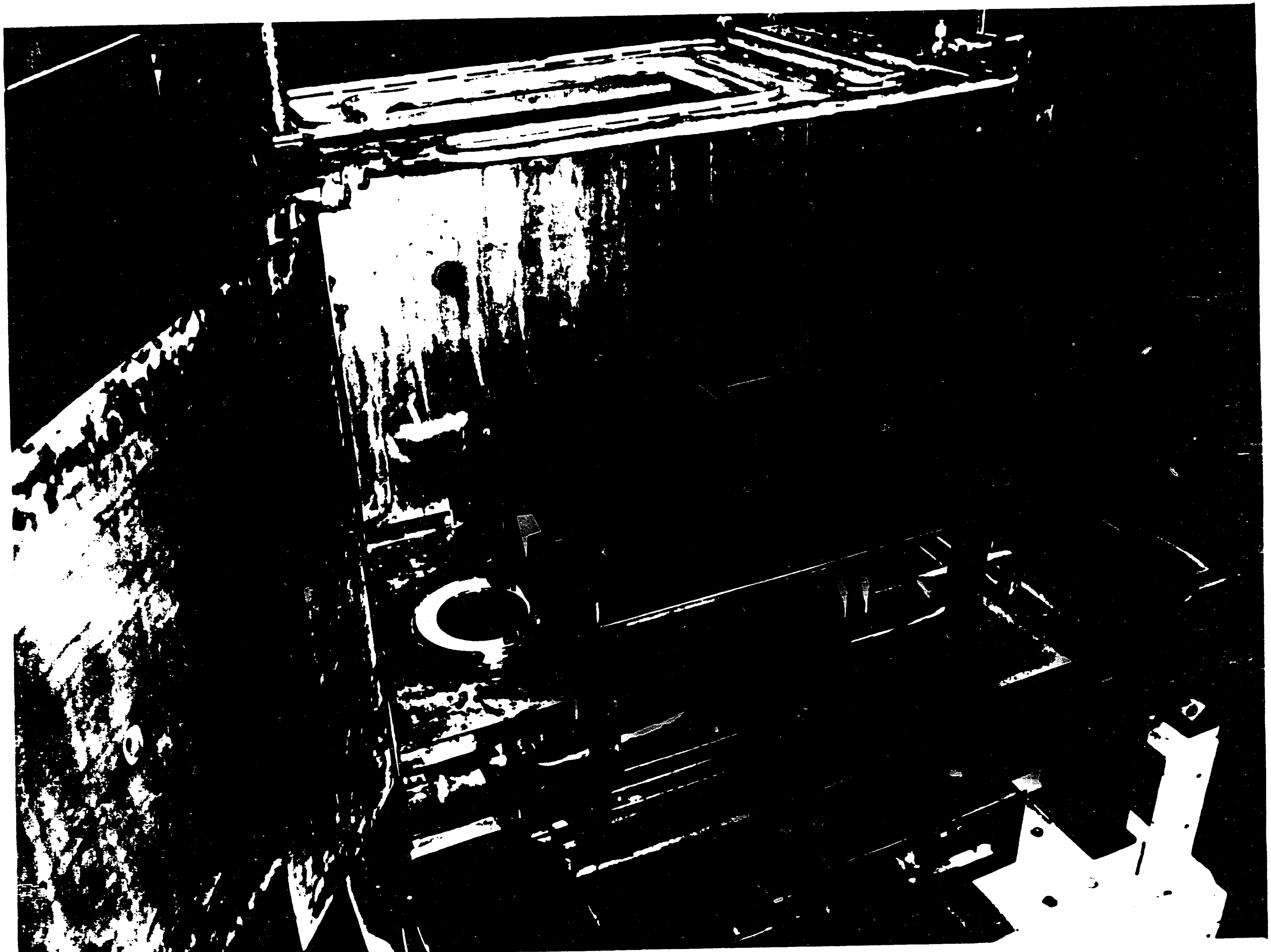

Figure 5 - Assembled Pod

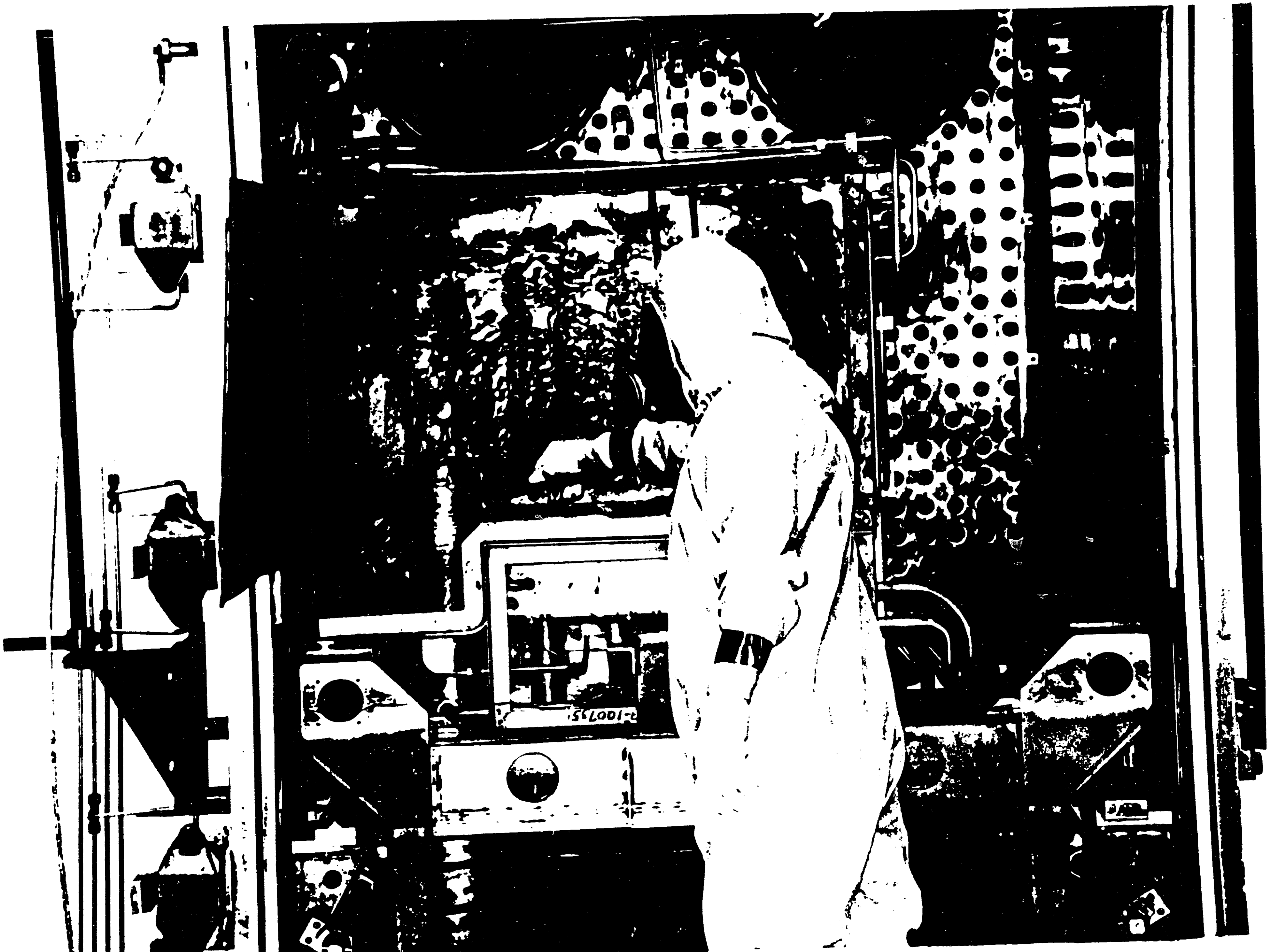

Figure 6 - Removal of First Uranium Ingot

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