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DEVELOPMENT OF NUCLEAR FUEL MICROSPHERE HANDLING TECHNIQUES AND EQUIPMENT*

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MICROSPHERE HANDLING EQUIPMENT

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ABSTRACT

Considerable progress has been made in the development of microsphere handling techniques and equipment for nuclear applications. Work at Oak Ridge National Laboratory with microspherical fuel forms dates back to the early sixties with the development of the sol-gel process. Since that time a number of equipment items and systems specifically related to microsphere handling and characterization have been identified and developed for eventual application in a remote recycle facility. These include positive and negative pressure transfer systems, samplers, weighers, a blender-dispenser, and automated devices for particle size distribution and crushing strength analysis. The current status of these and other components and systems is discussed.

INTRODUCTION

The use of microspheres in the nuclear industry is not new. They are an integral part of the High-Temperature Gas-Cooled Reactor (HTGR) fuel concept, and packed beads have been investigated as substitutes for powder-pellet fuels in other power reactors.[1-4] A number of recent developments have also focused on gel-sphere formation and sphere-pac loading[5,6] of fuel rods. An assessment[7] of fuel concepts for improved fuel performance has recognized the sphere-pac process because it mitigates localized cladding attack, reduces fuel-cladding mechanical interaction, and improves thermal conductance.[8-11]. Also, the trend toward use of shielded canyons for fuel refabrication has generated interest in the gel-sphere-pac process because it is ideally suited to remote operation. In addition, gel-sphere formation has been proposed[12] as a method for fixation of high-level nuclear wastes in a form amenable to coating, pressing, or embedding in a ceramic matrix. Again, the applicability of gel-sphere-pac technology to remote operation makes it attractive for fabrication of waste forms.

We will discuss many of the equipment designs and techniques that have been developed for handling microspheres. Note that the basic techniques are not process-specific. Their adaptation to other manufacturing processes where small spherical particles must be formed, characterized, transported, and dispensed is not discussed.

GEL-SPHERE FORMATION

Microspheres are typically produced by a chemical gelation process, such as illustrated in Fig. 1. In the formation of high-density UO_2 microspheres,[13] an acid-deficient uranyl nitrate solution is combined with gelation additives, such as urea and hexamethylenetetramine (HMTA). The mixture is pumped through a dispersion device into a hot organic liquid, which gels the droplets. The spheres are then washed, dried, calcined, and sintered in a reducing atmosphere to obtain spheres of 99% theoretical density.

Gel-sphere fabrication has several advantages over powder agglomeration for remote application. The former process uses liquids and spheres that are easily transferred and handled in a relatively dust-free manner because of their fluency. The entire process takes place within a closed system, virtually eliminating the spread of contamination. No crushing or grinding of the microspheres is required. Hence, dusting and scrap recycling is minimized. Microsphere fabrication requires fewer mechanically intensive steps than the powder-pellet process. The relative cleanliness and simplicity of the gel-sphere process should significantly reduce radiation exposure to operating and maintenance personnel in both contact and remote fabrication.

MICROSPHERE HANDLING TECHNIQUES

While significant advancements have been made during the past 40 years in commercial material handling equipment, many of the basic ground rules are changed when fissile or radioactive materials are being considered. Because of criticality and maximum permissible dosage criteria, the basic equipment must be scaled down by an order of magnitude. Material loss or holdup in process equipment must be virtually eliminated to minimize operator exposure and facilitate material accountability. Ease of decontamination and of remote or semi-remote maintenance are considerations peculiar to hazardous materials. Consequently, off-the-shelf items or systems are not often available or require significant modification.

Material transfer, a crucial facet of the fabrication process, is readily accomplished for microspheres by pneumatic conveyance. The practicality of this process was demonstrated in the experimental test loop[14] shown in Fig. 2. Data from pressure taps and photoelectric sensors were used to determine minimum flow requirements and to establish operating parameters that minimize material degradation and loss. Two prototypic transfer systems have been designed and operated in support of process development. Each employs a programmable logic controller, which simplifies operator requirements and provides built-in safety interlocks.

Development of associated material handling equipment is also well under way. An unloading system for a batch-type furnace for coating HTGR fuel particles,[15] shown in Fig. 3, is presently in operation. After being pneumatically conveyed the batch of spheres is gravity fed into the furnace through a remotely actuated ball valve. Use of an oversized, full-port valve eliminates seal degradation and particle holdup. After the furnace operation the crucible containing the coated particle batch is lowered by an elevator. It is grasped and lifted off the elevator by a manipulator, which then retracts and dumps the batch onto a scalping screen. The manipulator then either replaces the crucible or rotates 90° and exchanges it for a new one through an air lock. The manipulator is shown in Fig. 4.

Following the screening operation the batch is pneumatically conveyed out of the enclosure, which provides inert atmosphere protection, to a collection hopper. The particles are then fed by gravity to a weigher shown in Fig. 5. After weighing, the batch falls through a passive sampler. A representative portion of the batch is dispensed to the sample inspection system, and the remainder is pneumatically conveyed to rod loading.

Although the special connectors, lifting bales, and guide fixtures needed for a truly remote operation are not provided by this engineering-scale system, the particle handling equipment does meet all functional requirements. Through testing and operation of the equipment a proven design with high reliability and low maintenance requirements will be available for future prototype development. This first generation system permits evaluation of the effects of high temperature and inert atmosphere on the various components.

In the sphere-pac loading operation for metal clad fuel rods, microspheres of two or more sizes are blended together and compacted in the fuel rod by low energy vibration. Fuel smear densities of up to 88% theoretical density have been achieved. A continuous ring blender, shown in Fig. 6, was developed as both a blender and dispenser. Particles of several sizes are volumetrically dispensed by gravity to the blender. They flow down the sides of an internal cone and collect at its base in a trough formed by the cone and a vertical flexible band. As the band is unwound the cone rotates, and a uniformly mixed blend of particles is fed to the rod at the point where the band leaves the cone. The blender has been scaled up to a 2.5 kg capacity device, shown in Fig. 7. It is used routinely in support of sphere-pac rod loading development.

MICROSPHERE CHARACTERIZATION

A number of equipment items and systems have also been developed in support of microsphere characterization and analysis. Since analytical facilities are typically separated from the process line, a means for automatically sampling and transferring samples is required. A loose particle sample transfer system was developed that eliminates the need for encapsulation by eliminating particle holdup and by minimizing particle abrasion and degradation. The feasibility of this approach was again established by operation of a test loop.

A prototypic system is shown in Fig. 8. The sample is dispensed from a passive splitter in-cell to an "isolation" valve, which is essentially a receiving valve providing a three-way seal between the transfer line, sampler enclosure, and cell atmosphere. A cyclone receiver was designed to disentrain the particles from the airstream without damage at the receiving end. A negative pressure system was selected to minimize the potential for outleakage of contamination since the lines could be run outside the hot cell and between analytical stations.

Development of the particle size analyzer[16] and remote weigher have also been completed. Size analysis is based on a light blockage technique. The device is capable of automatically sizing and counting each particle in the sample at rates up to 100/s. The analysis can be performed on particles as small as 150 μm diam with a precision of 2.5% and as large as

1500 μm with a precision of 0.05%. Since the analysis is nondestructive and noncontaminating (no liquid suspension medium required) the sample is available for further characterization.

The remote weigher is a modified torsion balance with external electronic controls and a specially designed hopper. A tube is extended into the hopper and particles are dispensed to the weigher by gravity. A "floating seal" contacts with the hopper top as the tube is extended to prevent material loss. After loading the hopper the tube is retracted, and the sample is weighed in the free standing hopper. An electric motor is then used to invert the hopper, which dumps the particles into the transfer line. Both the particle size analyzer and weigher have been installed in a glove box, as shown in Figs. 9 and 10, respectively.

The heart of the particle size analyzer is the rotating singularizer drum, shown in Fig. 11. It extracts one particle at a time from a sample hopper and dispenses it for analysis. This basic concept has been used in the development of two other devices. A sample subdivider was designed to provide small, representative subsamples. A singularizer moves particles from a hopper to pockets in a rotating turntable. Subsamples accumulate in each pocket until the entire sample is dispensed. Subdividing permits several destructive analyses to be performed on a single sample pulled from the process line. It also provides the smallest amount of material required for the analysis by its recombinate and resubdividing capabilities. This minimizes both scrap material and radiation levels at the analytical stations. The subdivider, shown in Fig. 12, was found to be superior to conventional riffling techniques in maintaining true representability of the parent sample in the small subsamples.

An automated particle crushing strength analyzer is currently under development. It also uses the singularizer to supply individual particles to a crushing stage. The particle is crushed between two flat plates, and the force required to initiate fracture is recorded. A multiprogrammer controls valve sequencing and switching, while a desk top calculator acquires data from the load cell.

Conceptual design of a sample handling system for receiving, encapsulating, identifying, and transferring archive samples to storage has been completed. The system is shown in Fig. 13. Irradiation of the bar-code reader indicated it would withstand doses as high as 300 gray (30,000 rad) and still make valid readings.

CONCLUSIONS

Development of techniques and equipment for handling, characterizing, and dispensing spherical particles has demonstrated the feasibility of this approach for nuclear applications. When these techniques are combined with existing processes for producing small spheres, they open the door to alternate processes for fuel element fabrication[17] or waste fixation. The techniques and equipment are designed for or are easily adaptable to remote operation, thus providing a means for reducing both operating personnel exposure and the opportunities for material diversion or loss.

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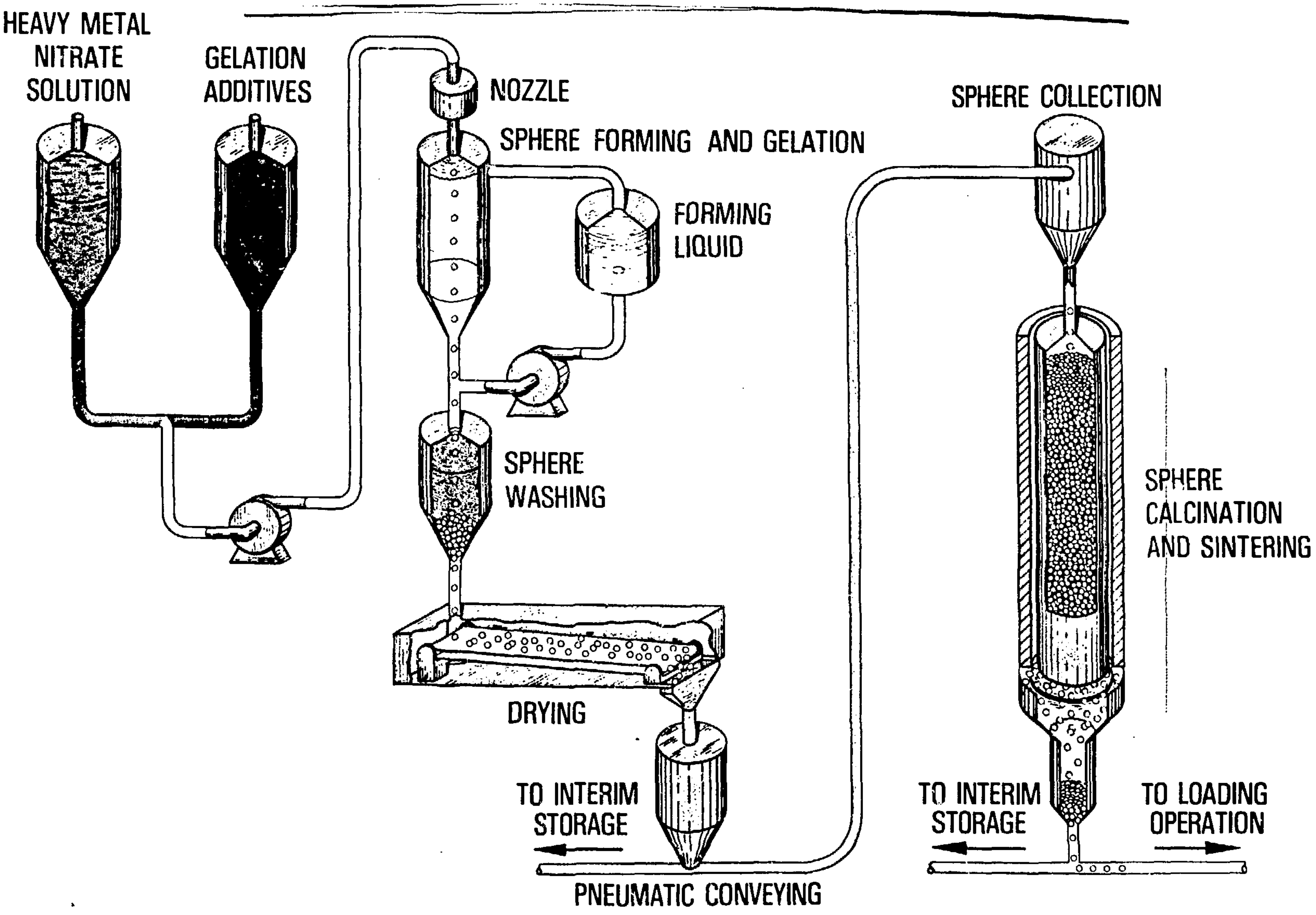

Fig. 1. Spheres are Formed by a Chemical Gelation Process.

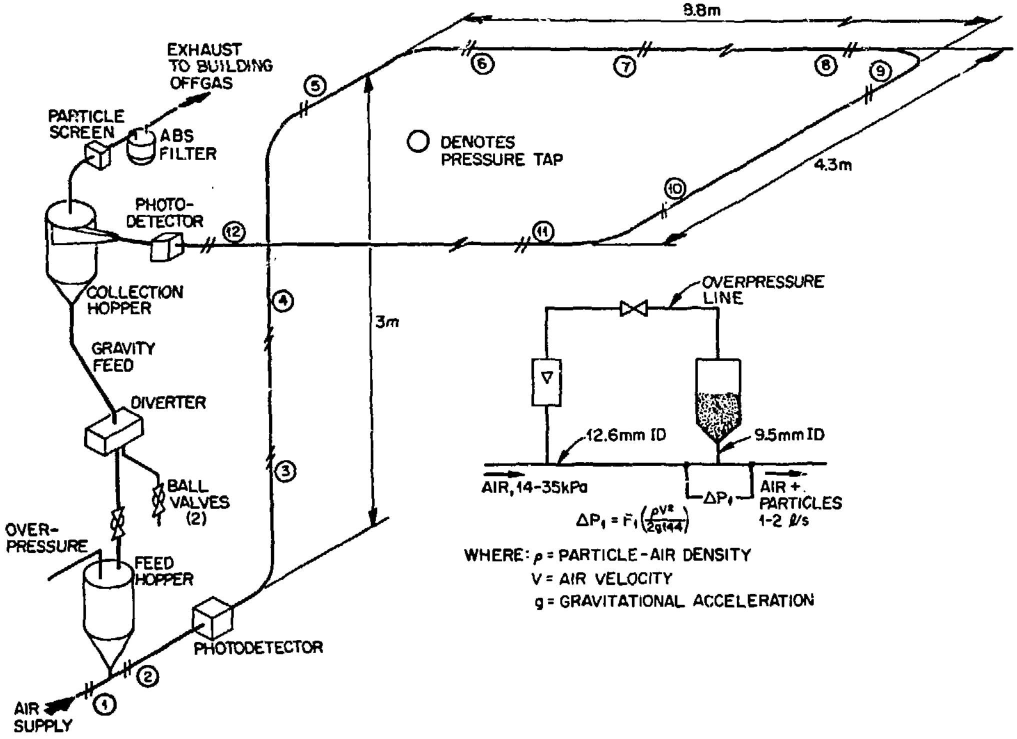

Fig. 2. Operating Parameters were Determined from Test Loop Operation.

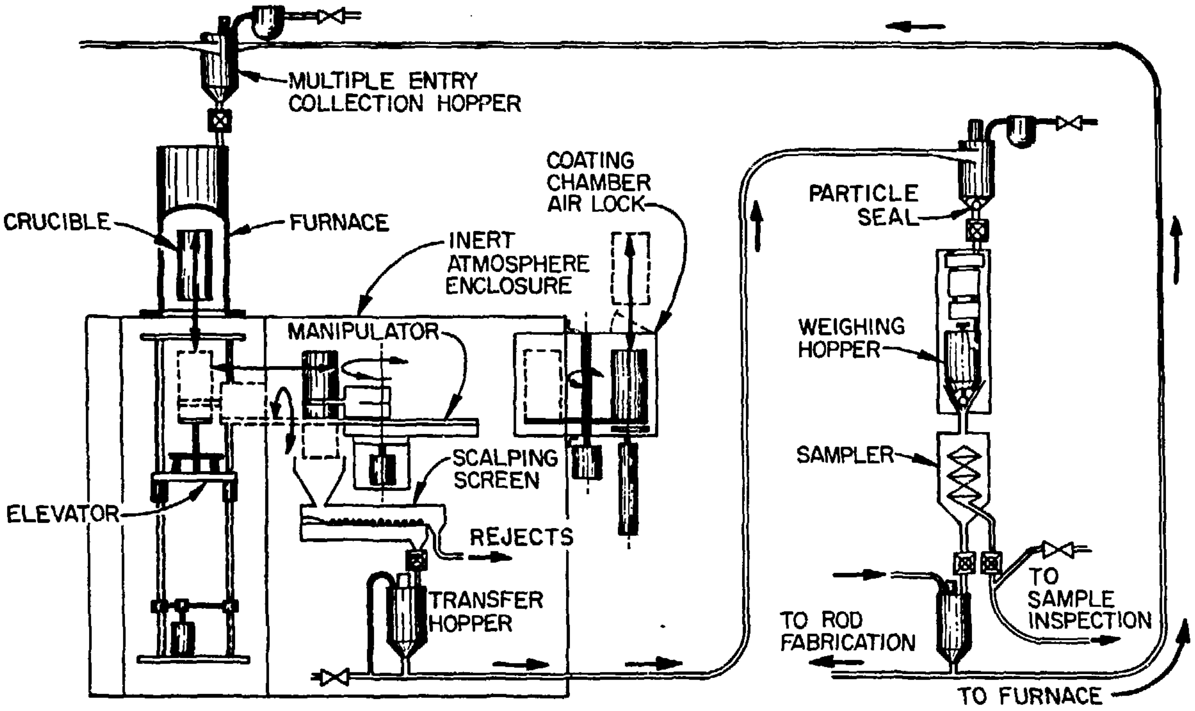

Fig. 3. Automated Furnace Unloading and Batch Handling System.

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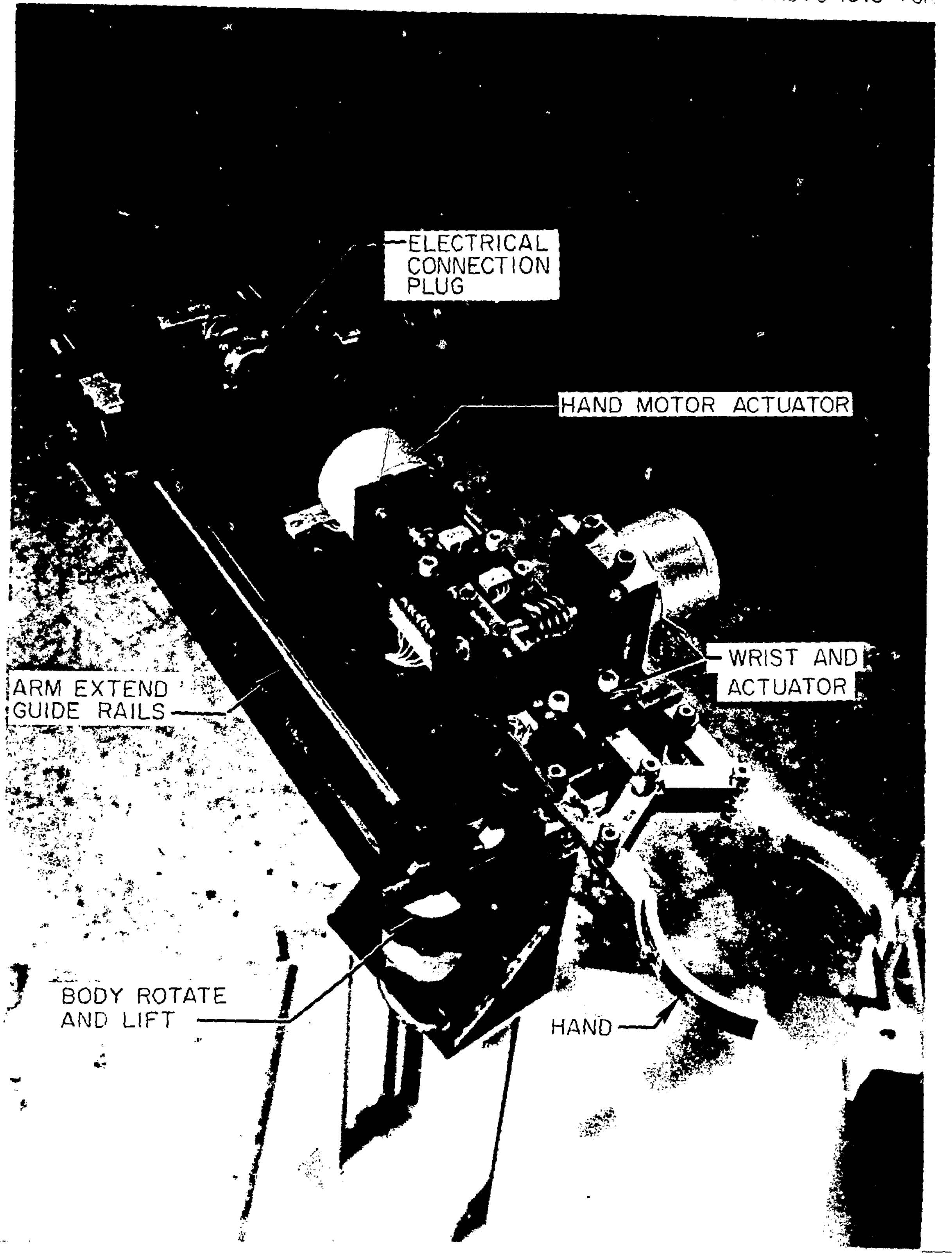

Fig. 4. Manipulator for Handling Furnace Crucible.

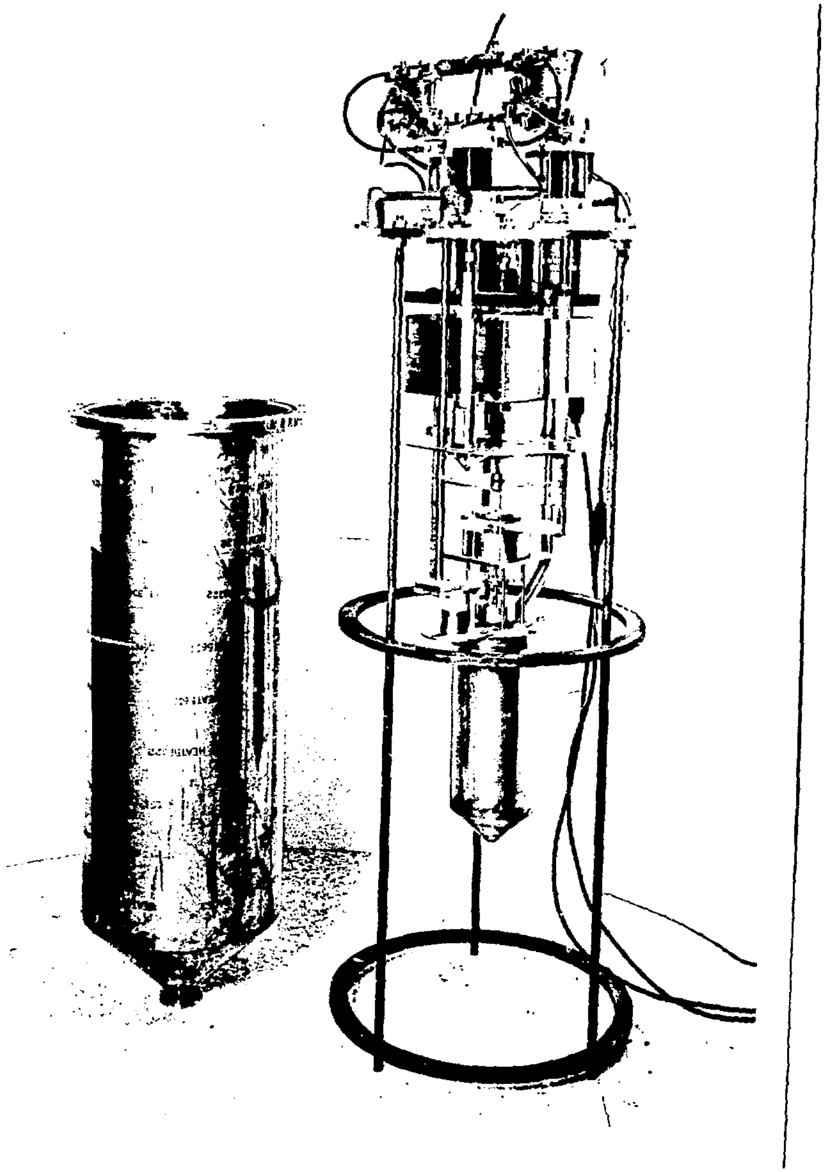

Fig. 5. Batch Weigher with Protective Housing Removed.

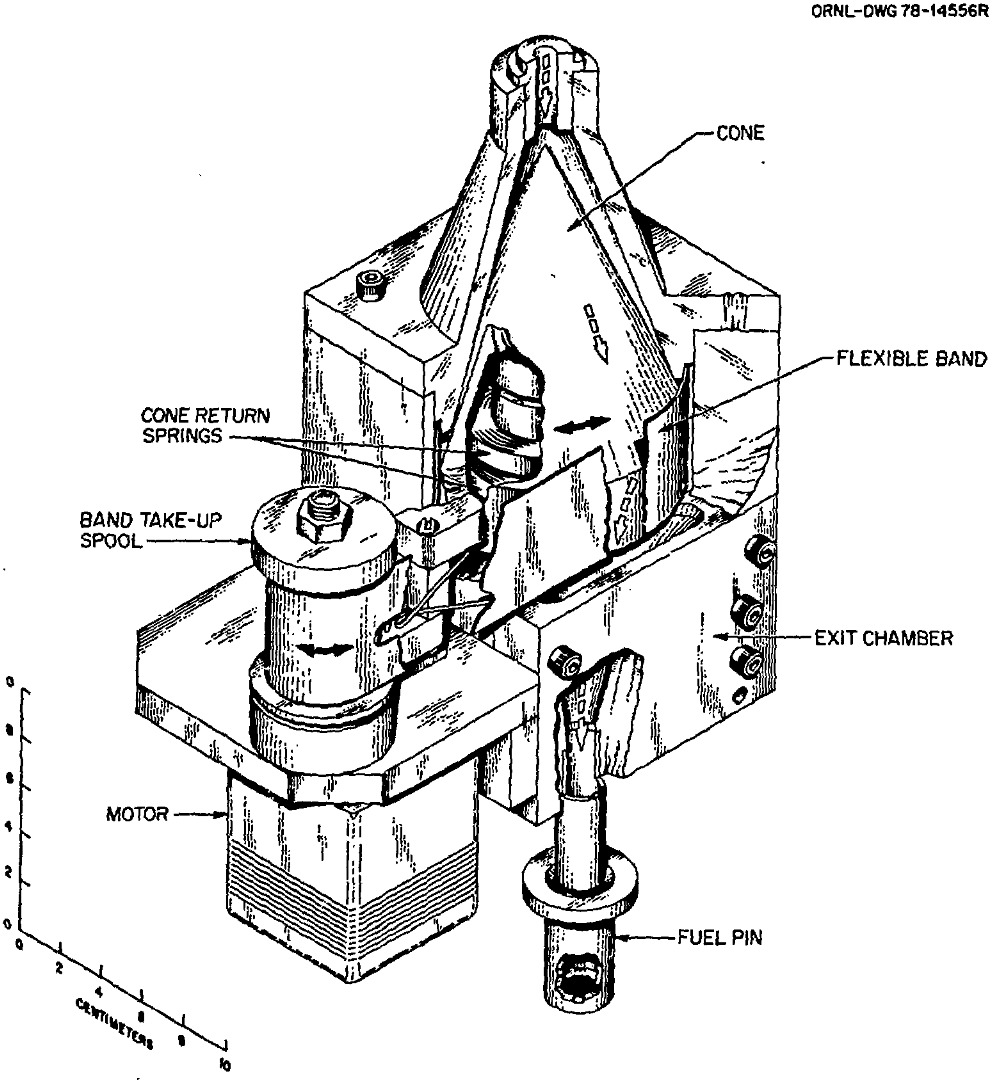

Fig. 6. Laboratory-Sacle Continuous Ring Blender-Dispenser.

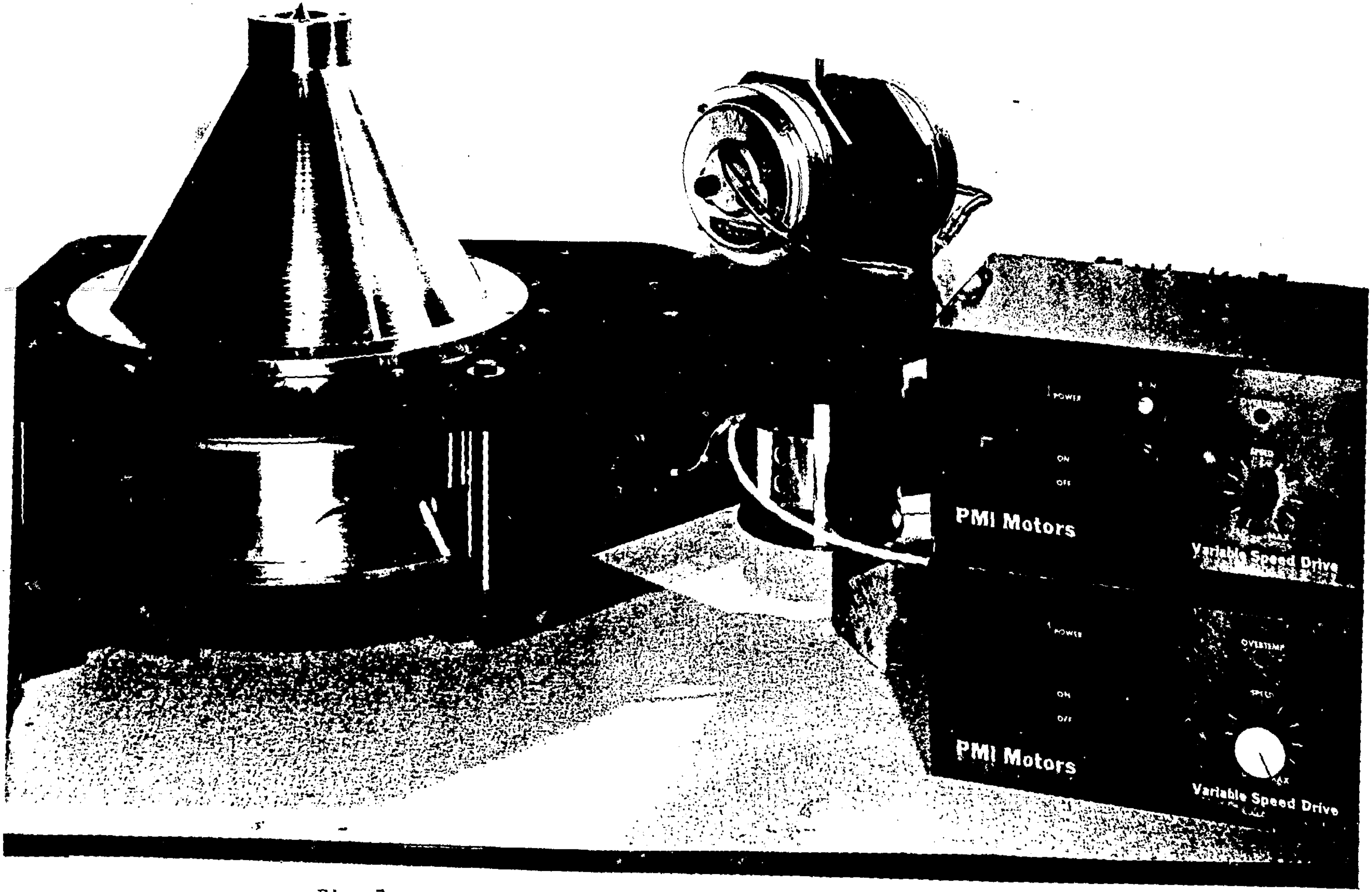

Fig. 7. A 2.5 kg Capacity Continuous Ring Blender-Dispenser.

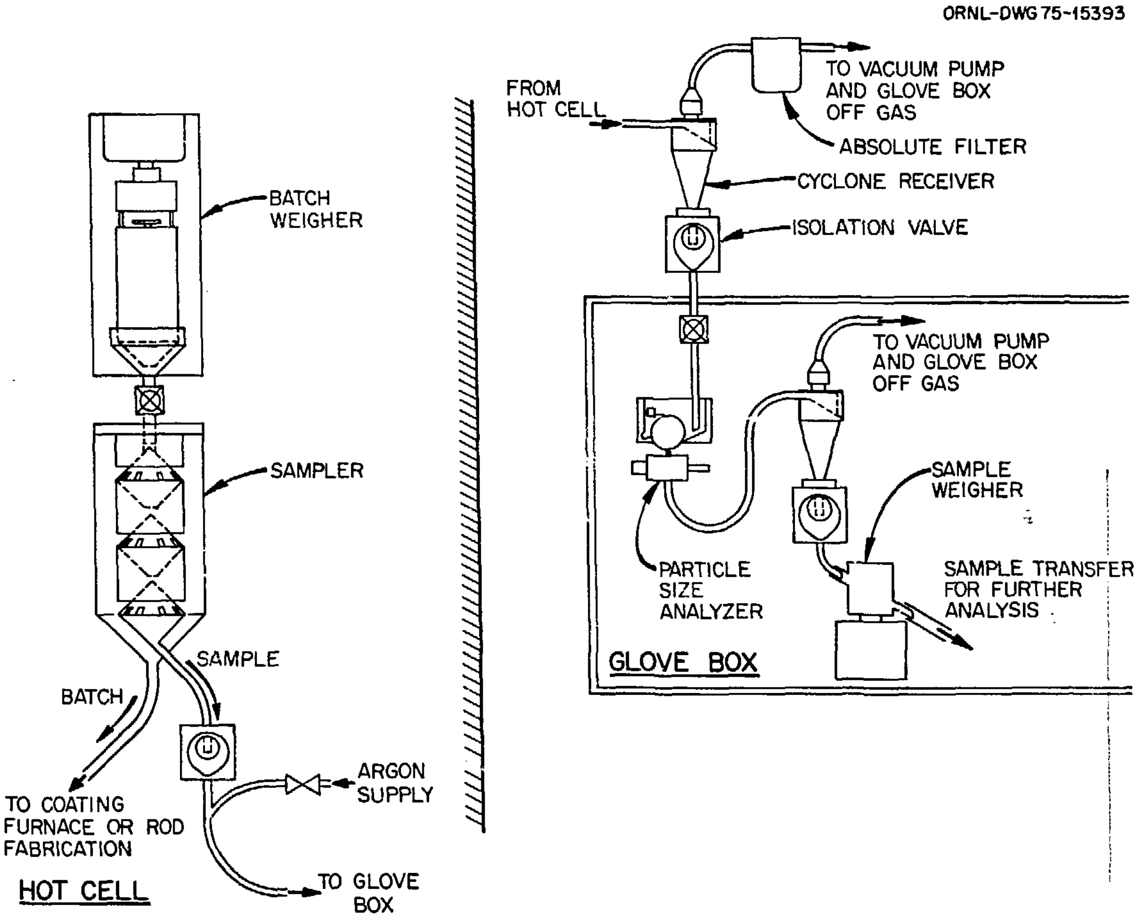

Fig. 8. Automated Sample Handling and Analysis.

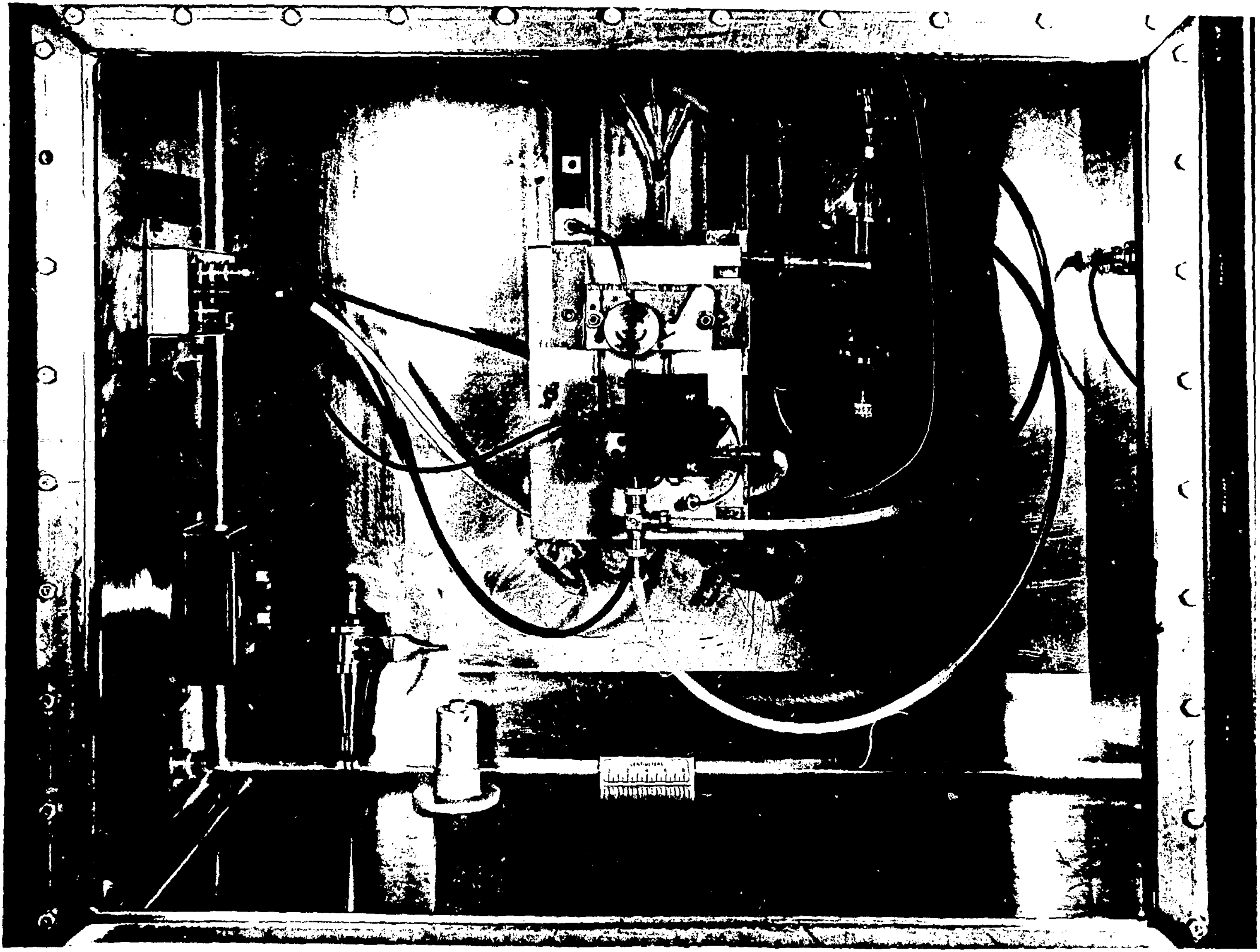

Fig. 9. Glove Box Installation of Automatic Particle Size Analyzer.

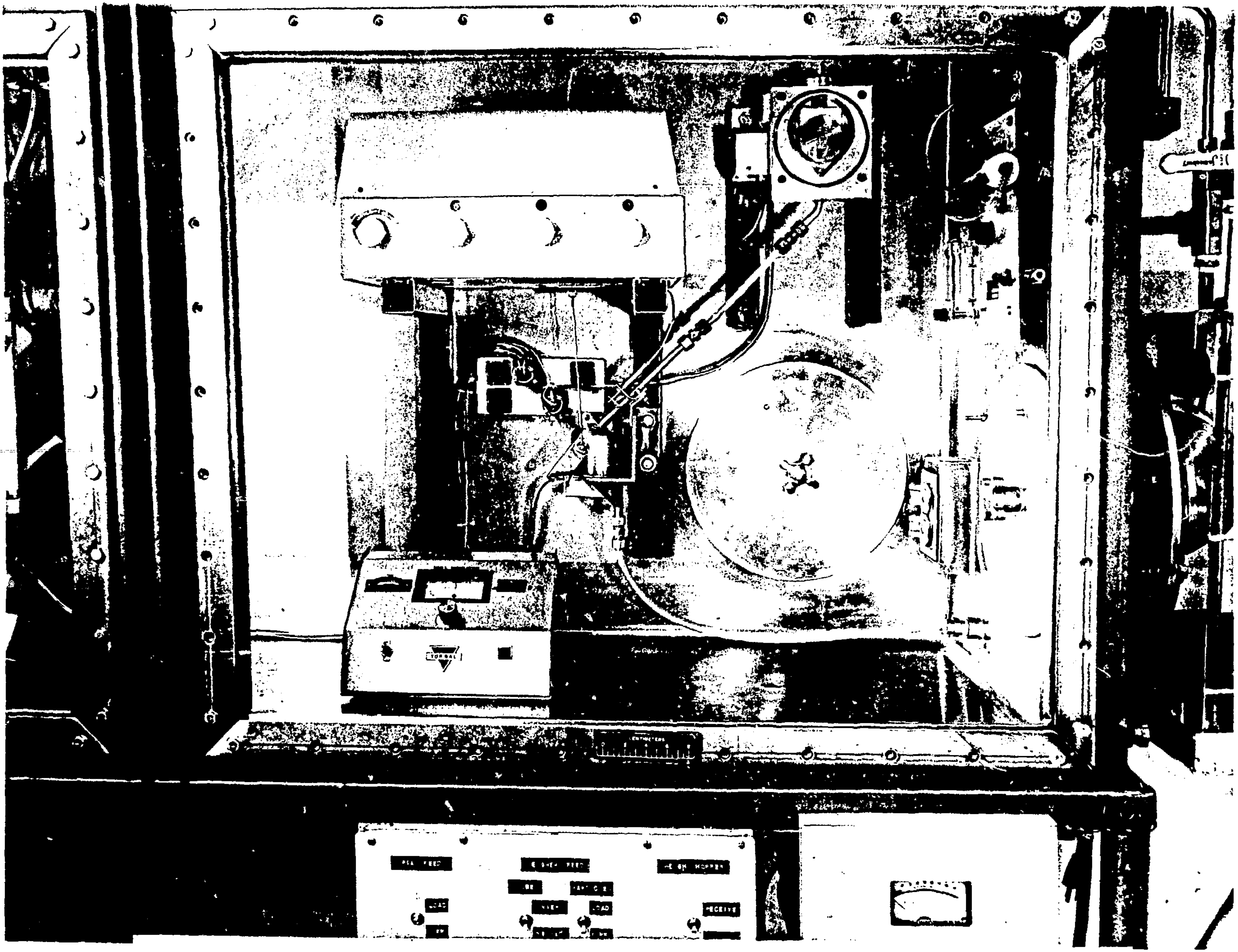

Fig. 10. Glove Box Installation of Remote Sample Balance.

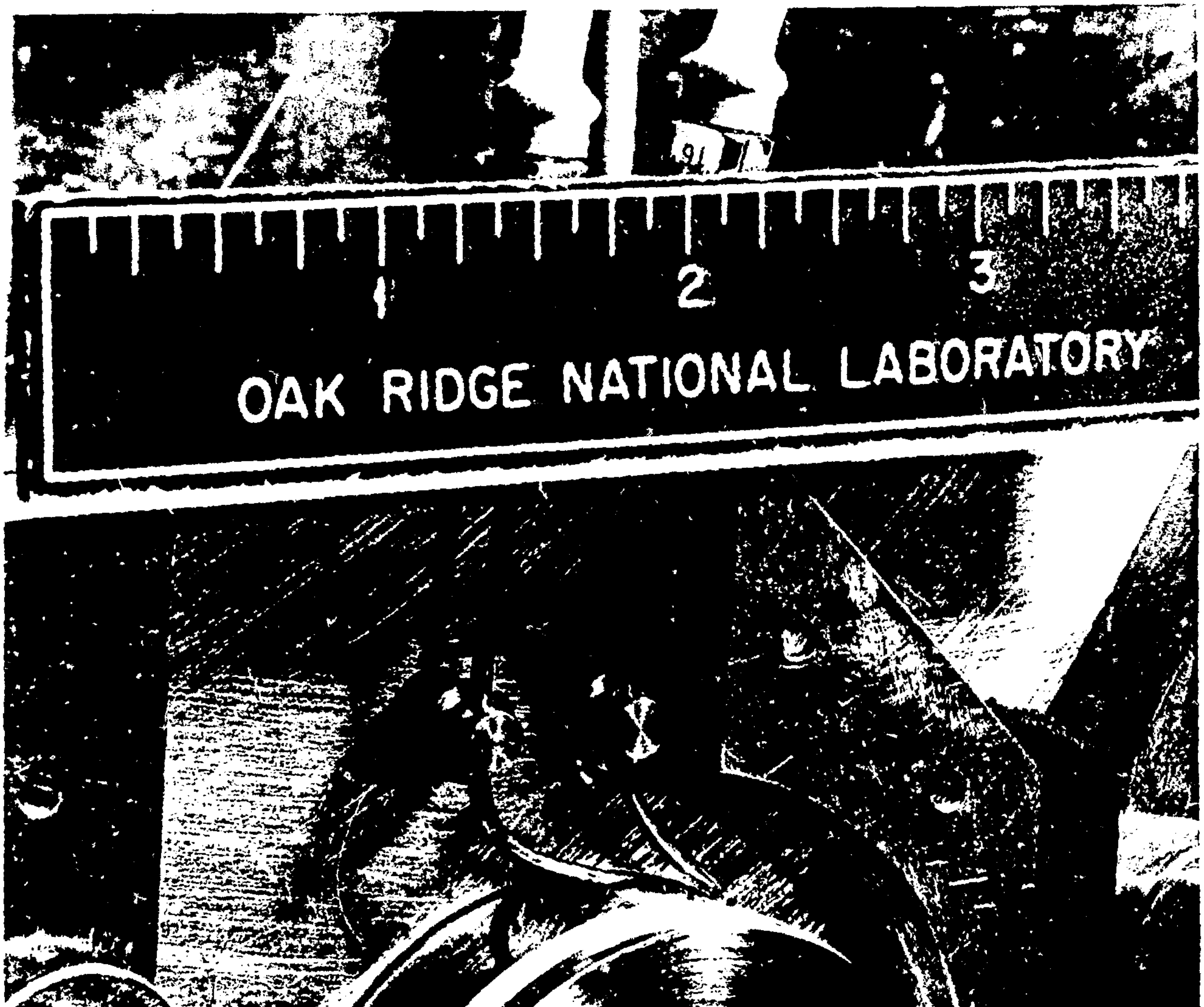

Fig. 11. Particles are Singularized by a Rotating Drum.

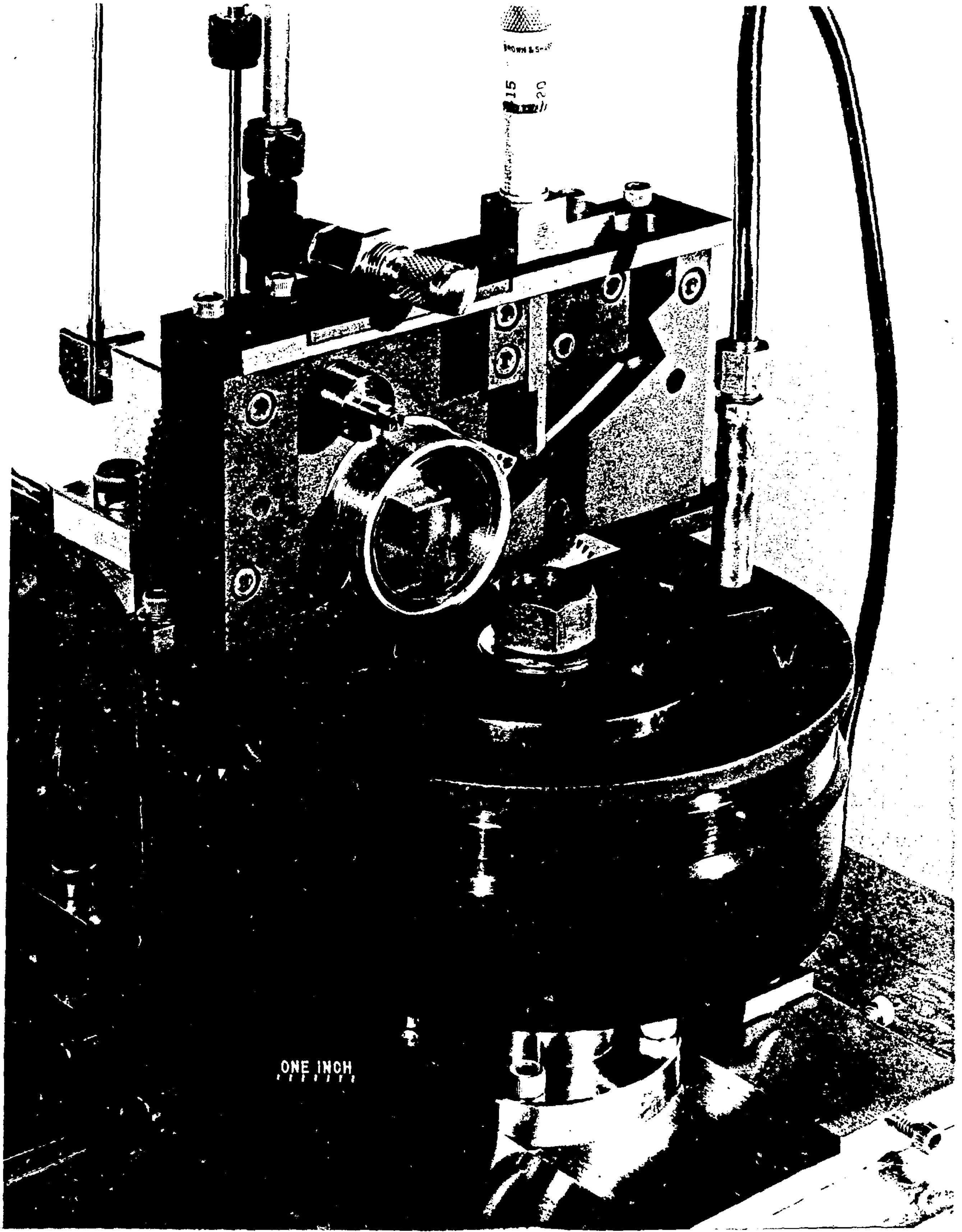

Fig. 12. Singularizer and Turntable Divide Sample into Representative Subsamples.

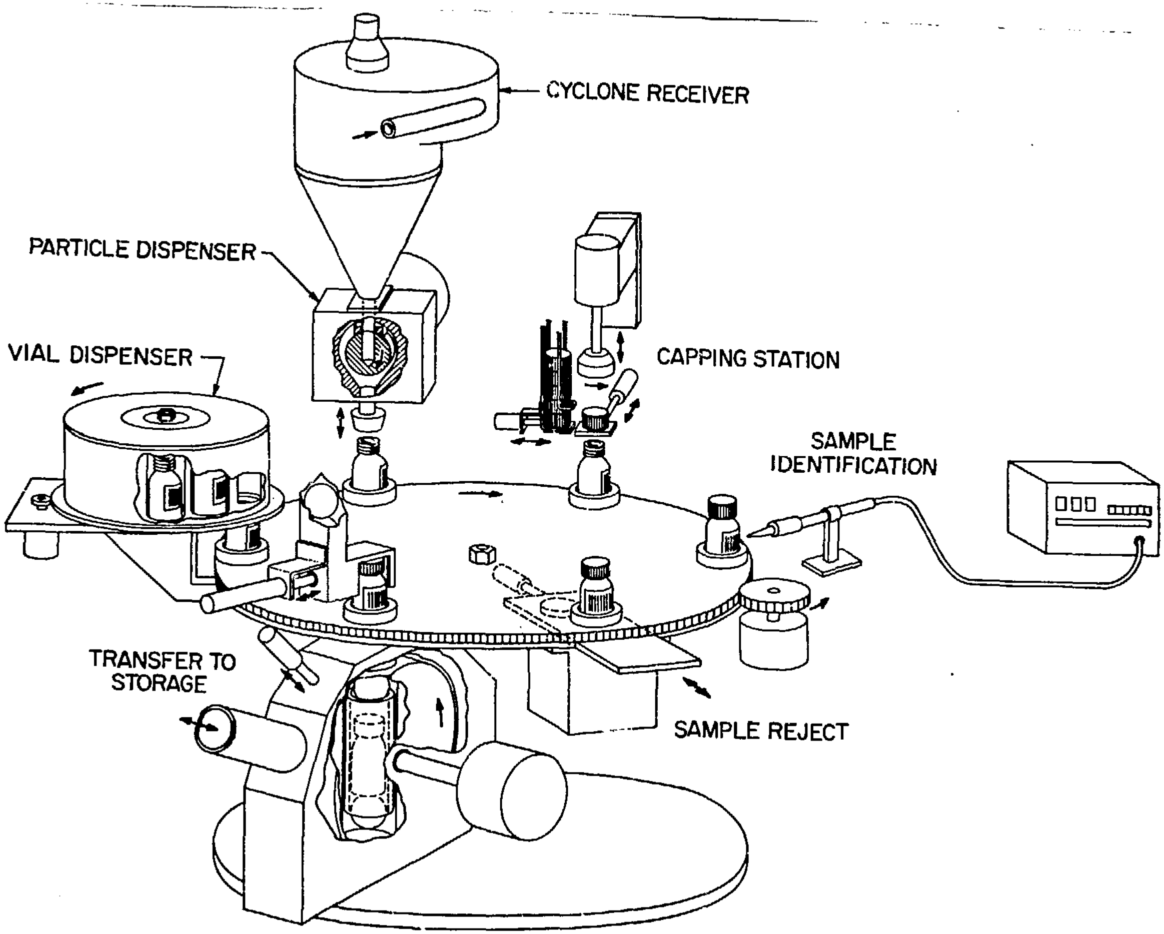

Fig. 13. Sample Handling Subsystem Remotely Receives, Encapsulates, and Identifies Particle Samples.