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Title:	Fuel Technology for Radioisotope Heater Units and General Purpose Heat Sources, Inclusive of a Historical Review
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Fuel Technology for Radioisotope Heater Units and General Purpose Heat Sources

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Characteristics of ^{238}Pu

- Half-life = 88 years
- Principal Decay Mode: a (~5.5 MeV)
- Specific Power = 0.568 Watt/gram
- Neutron emissions
  - Spontaneous fission: ~3000 n/s/g
  - (a,n) reactions with natural O, F, etc →>20,000
- g from decay products of ^{236}Pu
- Typical Enrichment: 80-86% ^{238}Pu

Fuel Forms

- Pu metal Early 1960's
  - Transit (navigational)
  - Lower operating temperatures
- PuO_2-Mo cermet: Late 1960's-early 1970's
  - Nimbus (meteorological)
  - Pioneer (planetary)
  - Viking (Mars)

Fuel Forms (continued)

- Oxide microspheres: Late 1960's-early 1970's
  - Apollo (lunar)
- Pressed oxide
  - Multihundred Watt (MHW): Mid 1970's
    - LES (communications)
    - Voyager (planetary)

Fuel Forms (continued)

- Pressed oxide (cont.)
  - General Purpose Heat Source (GPHS) 1980's to present
    - Galileo (Jupiter)
    - Ulysses (solar)
    - Cassini (Saturn)
  - Light Weight Radioisotope Heater Unit (LWRHU)

Requirements for Pressed PuO_2 Fuel Form

- Power Density
- Crack Resistance
- He Release
- Impact Properties

Process Flow

- ^{16}O Exchange to reduce neutron emission rate
- Milling to achieve desired particle size distribution and morphology
- Slugging and screening to produce granules of size desired (<125 μm) for hot pressing
- Granule seasoning to form reactive and nonreactive components

Process Flow (cont)

- Die preparation and loading
- Hot pressing
- Post-press sintering and pellet storage
- Encapsulation
- Nondestructive evaluation

Direct Fabrication Efforts

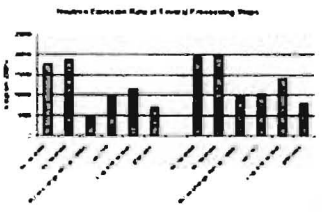
- Potential for reducing processing steps
- Approach:
  - Use coarser as-precipitated material (Pu^{4+}) to preclude need for milling and granule formation
  - Adjust tap density by presintering to reduce pellet internal stresses from compaction

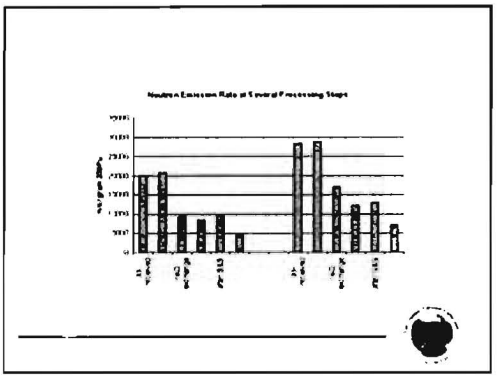
Sol-Gel Preparation of Feed Material

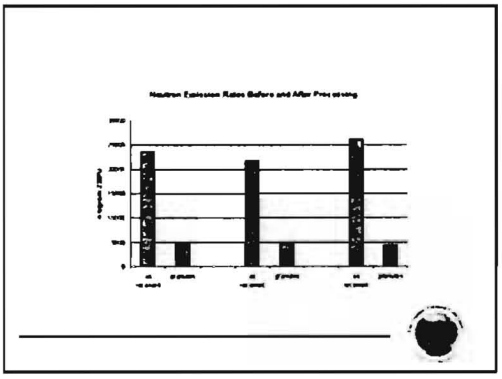
- Potential to improve microstructural homogeneity, stoichiometry
- Would minimize worker exposure and oxide dust
- Small-scale experiments in design phase
  - Radiolytic degradation of organics
  - Production of mixed waste

^{16}O Exchange

- Neutron emissions from 2 mechanisms
  - Spontaneous fission — 3000 n/s/g ^{239}Pu
  - (alpha, neutron) reactions from low-Z elements
    - Be, F
    - ^{17}O, ^{18}O (0.038% & 0.205% natural abundance)
- Rate of exchange depends on
  - Temperature, rapid near 700°C
  - Particle size distribution
  - Surface reactivity
  - Concentration of ^{16}O in carrier gas
  - Area available for reaction







The Future

- Streamlined Processes
- Dust Minimization
- Automation
- Improved Properties

GENERAL PURPOSE HEAT SOURCE FUEL PROCESS

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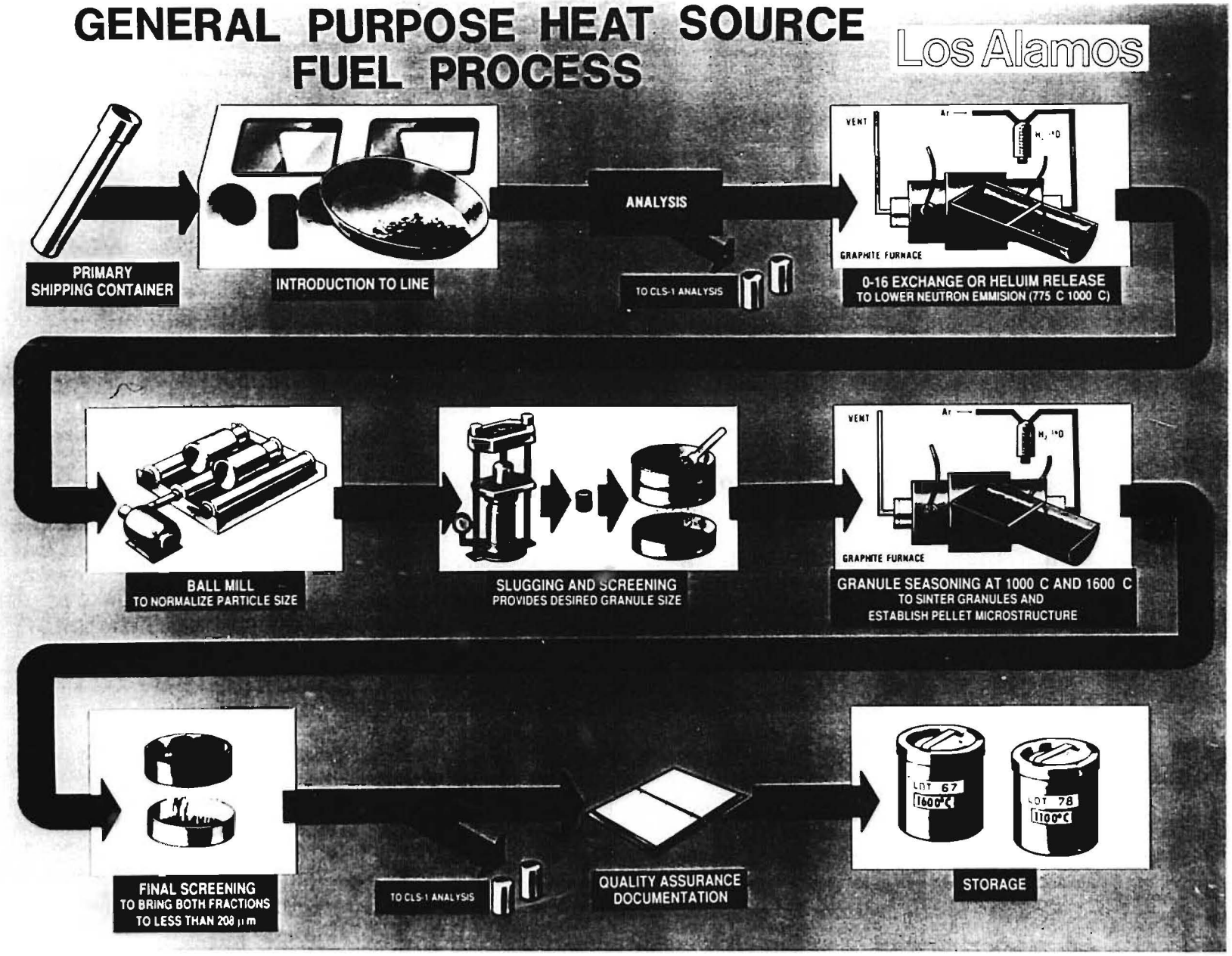

GENERAL PURPOSE HEAT SOURCE FUEL PROCESS (cont.)

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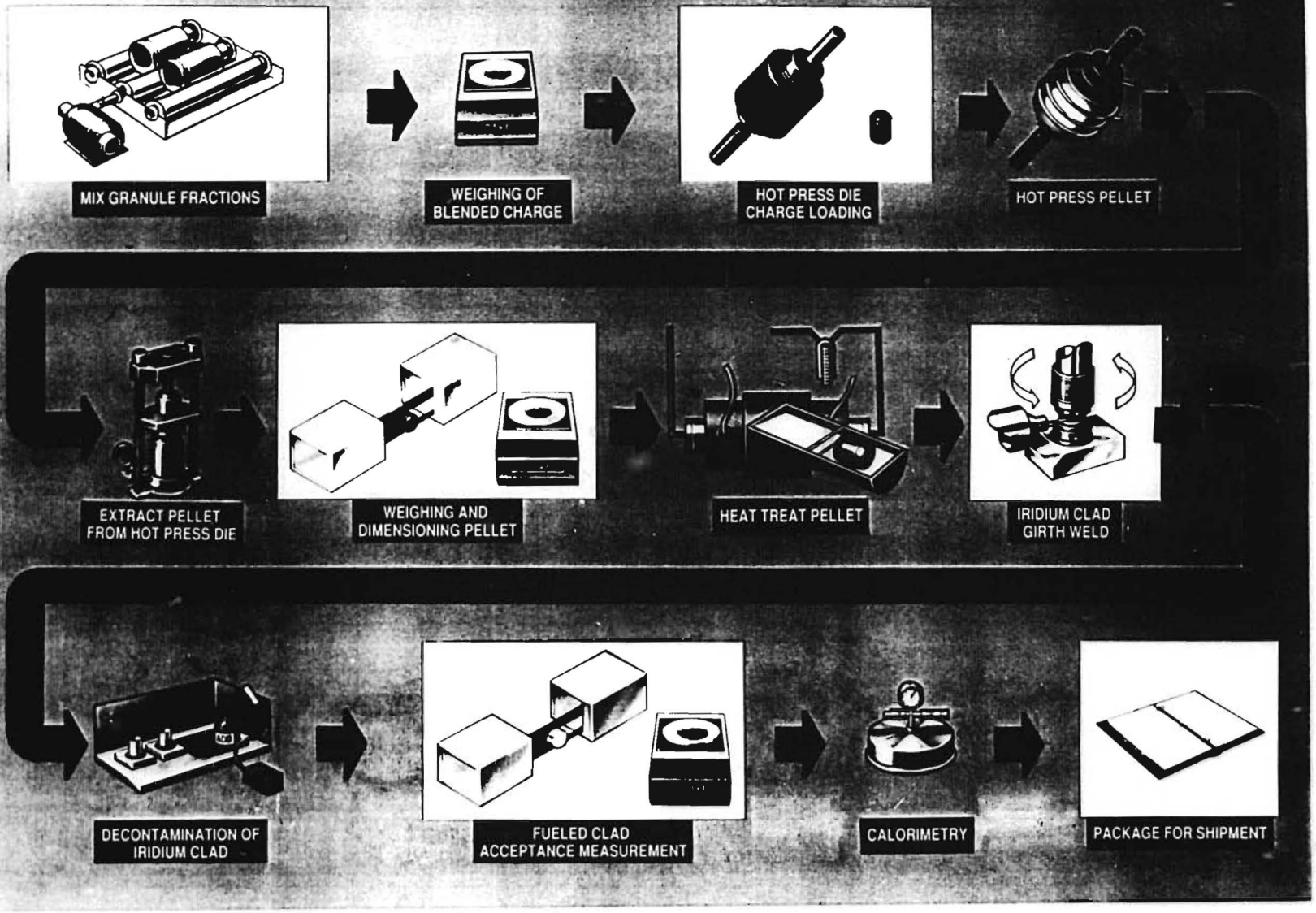
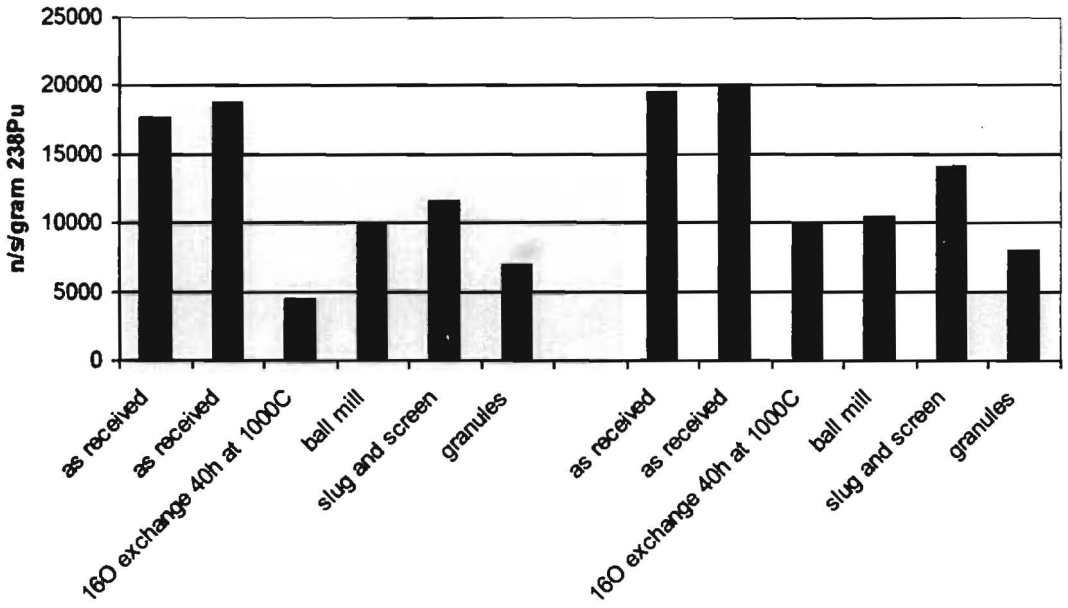


Neutron Emission Rate at Several Processing Steps



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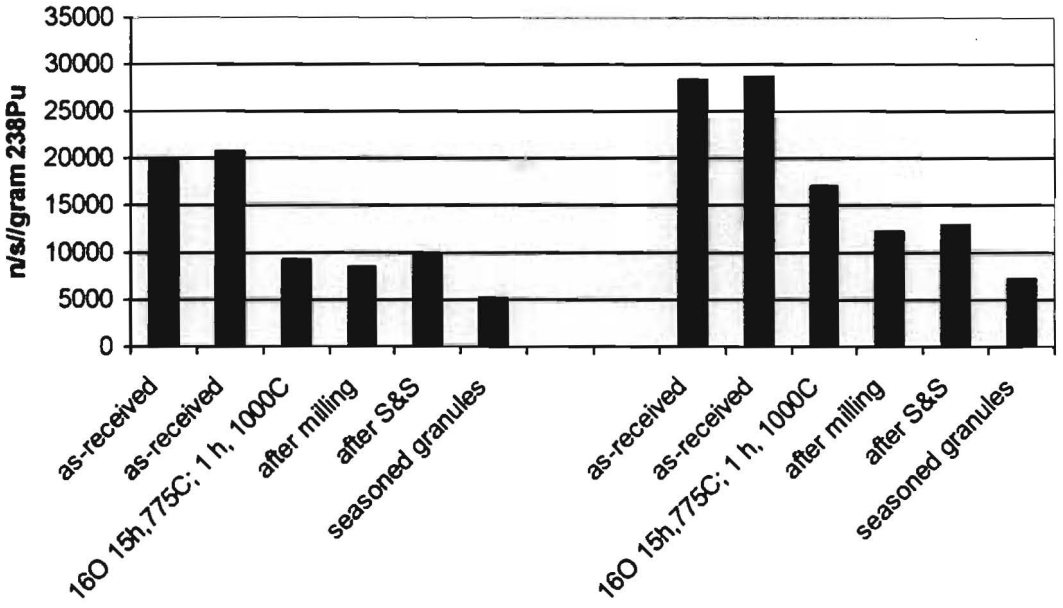
Neutron Emission Rate at Several Processing Steps



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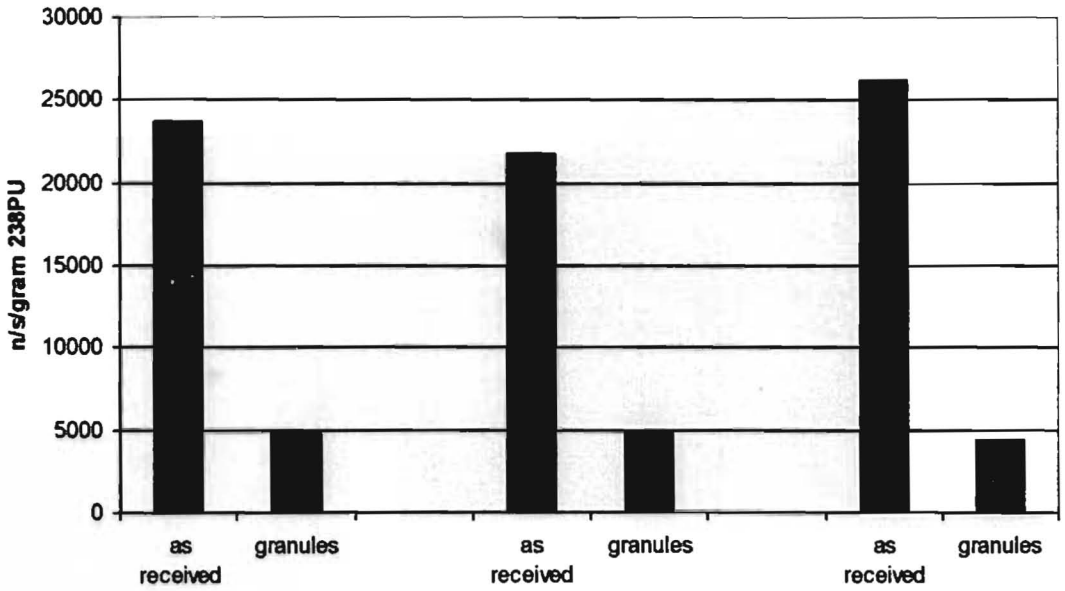
Neutron Emission Rates Before and After Processing



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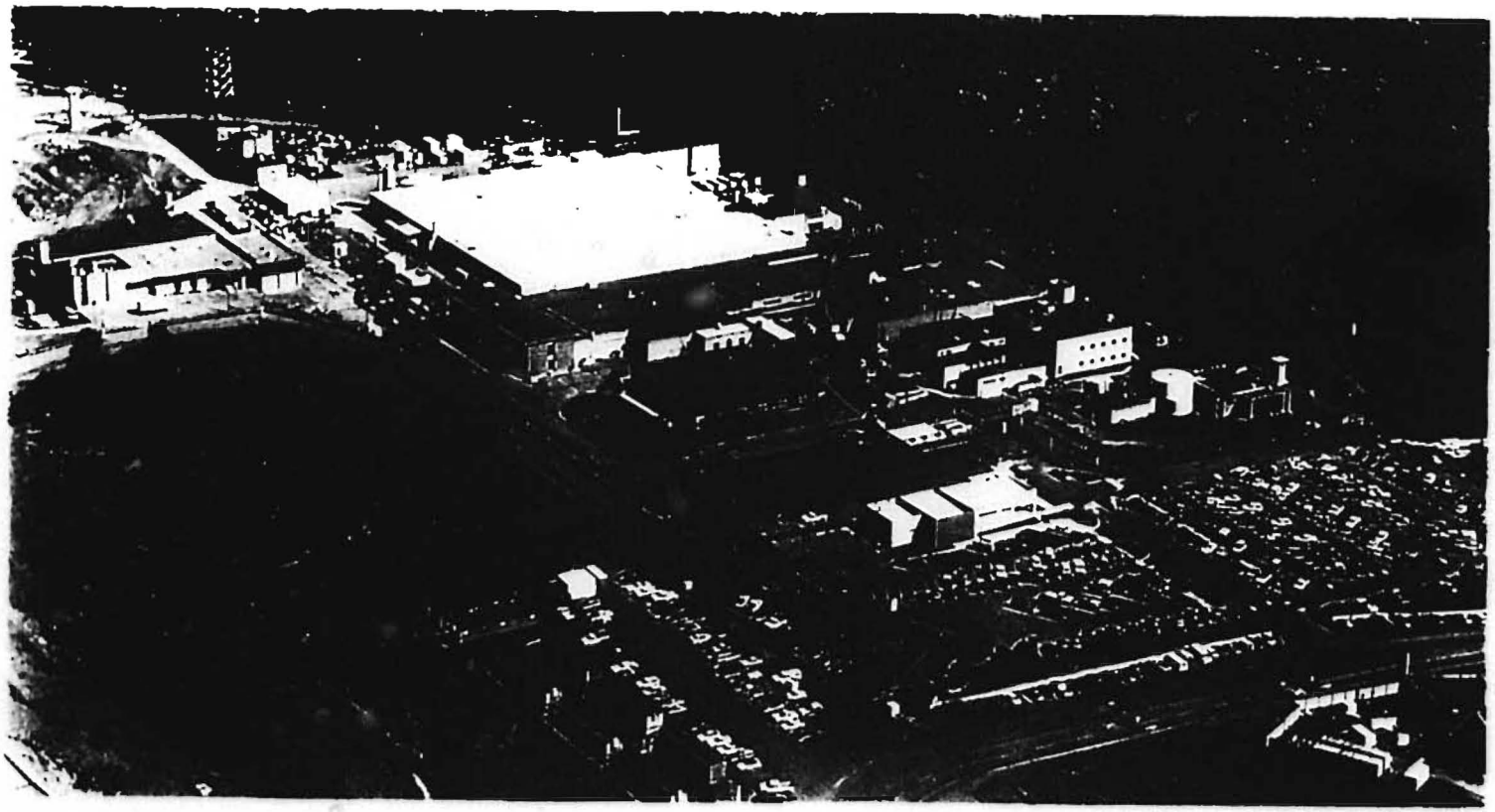

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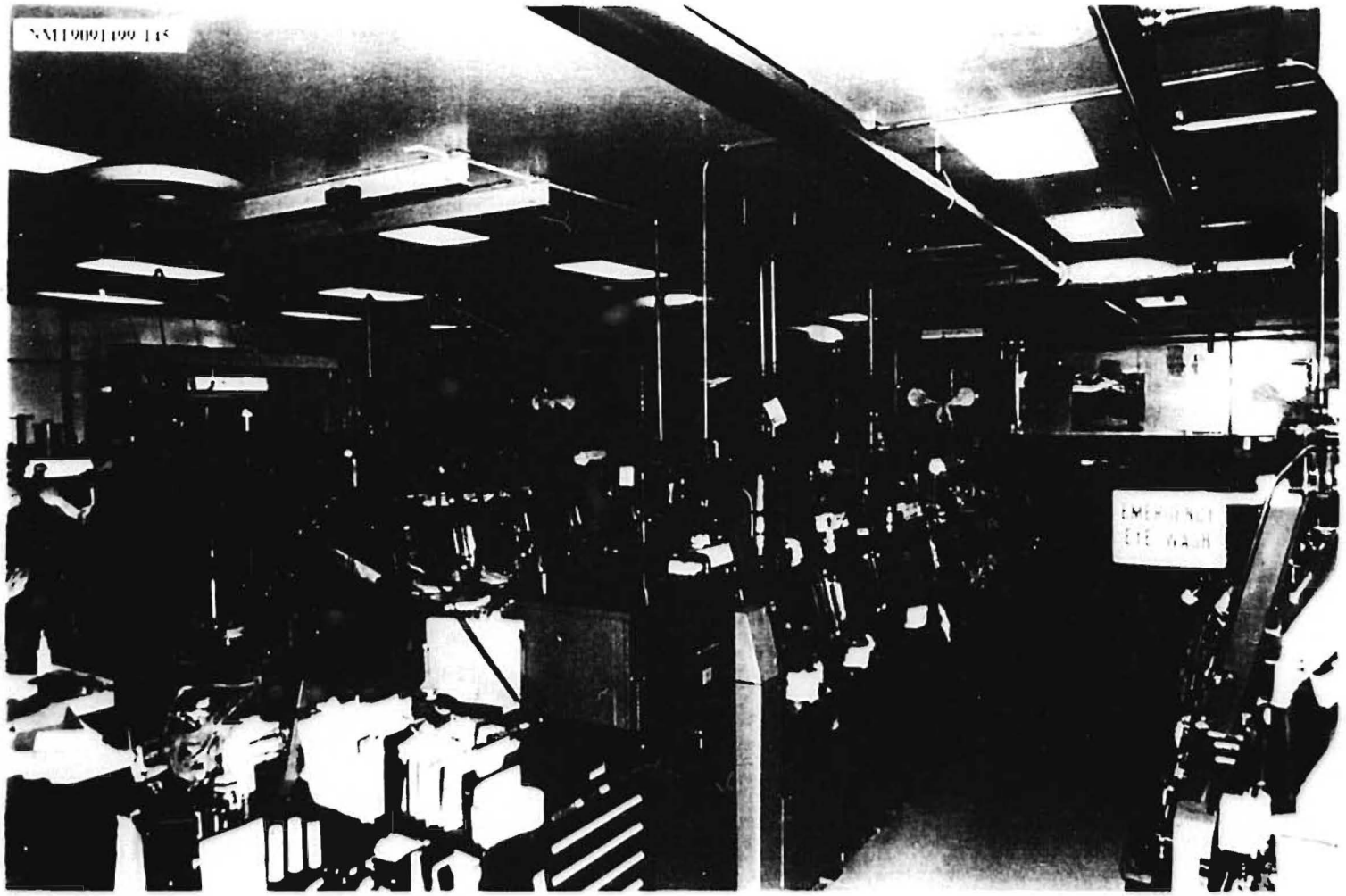

(FUEL PROCESSING LAB)

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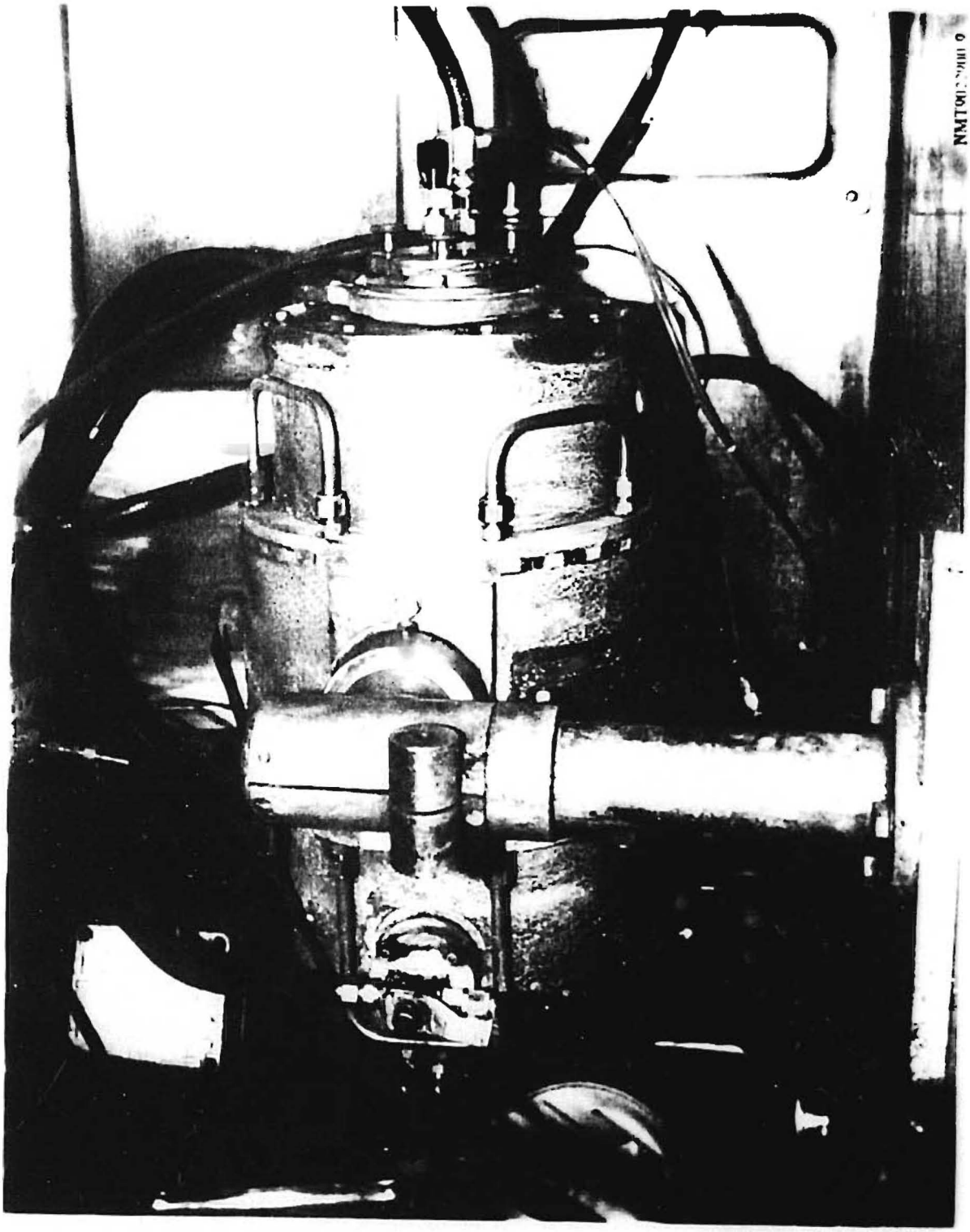
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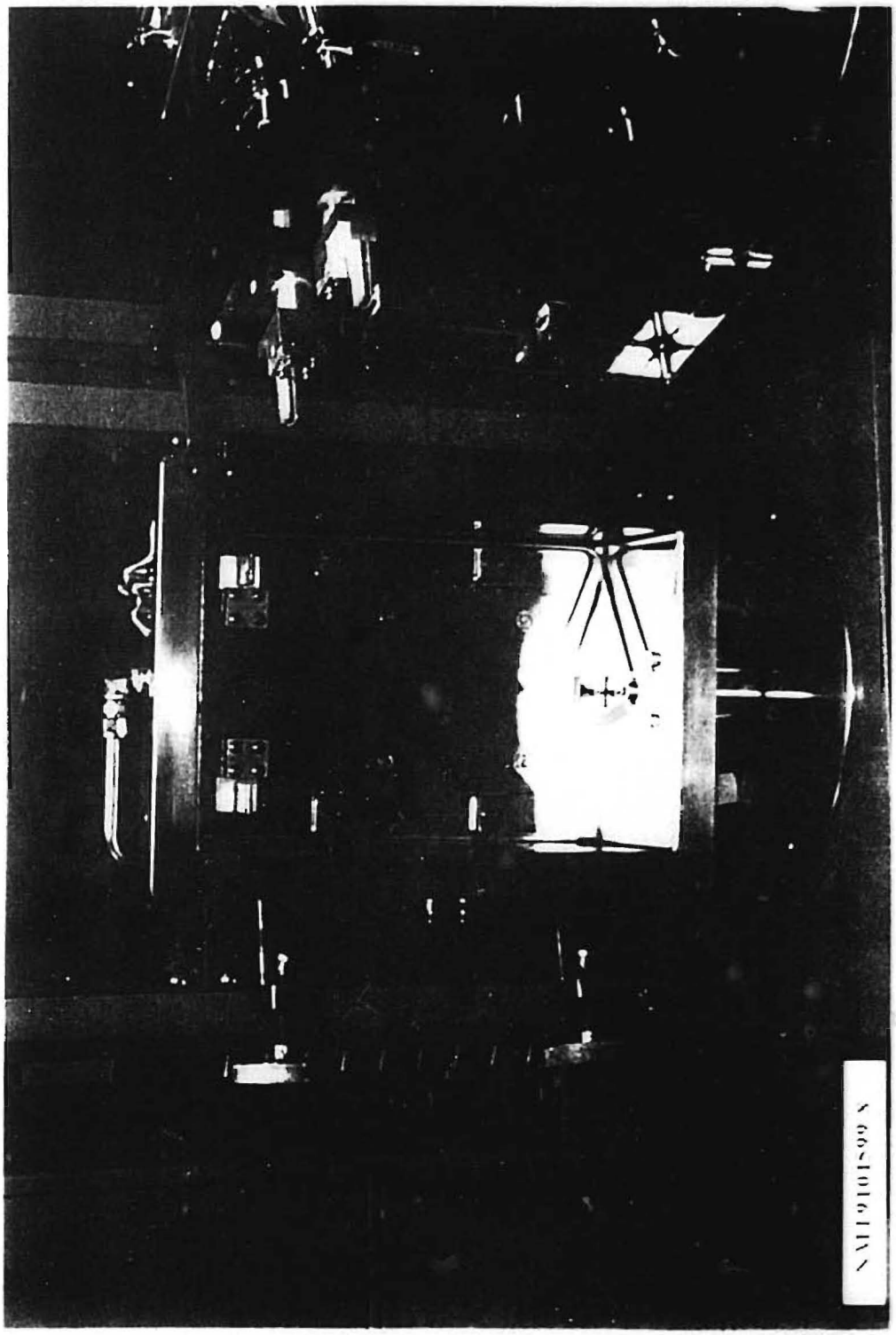

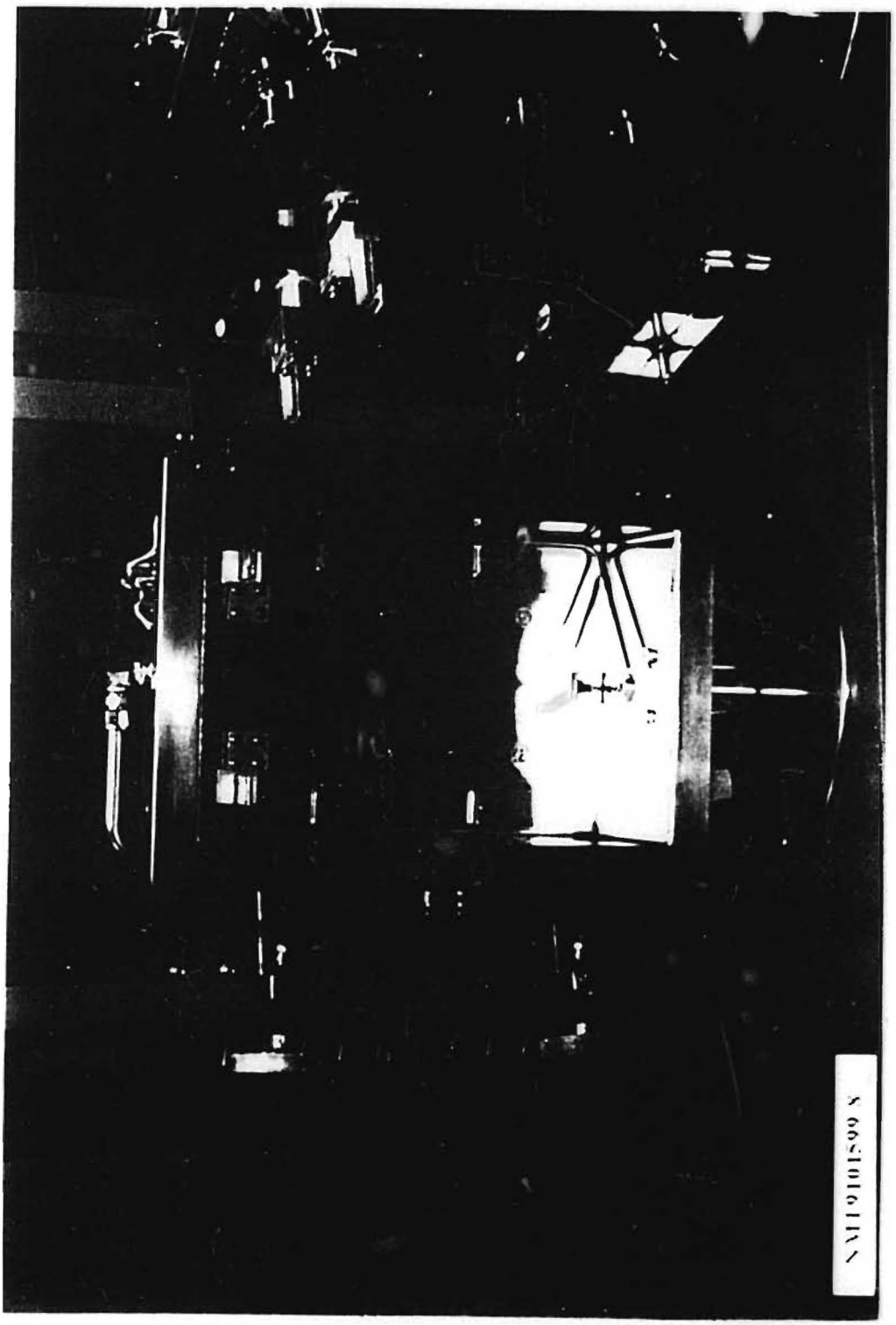
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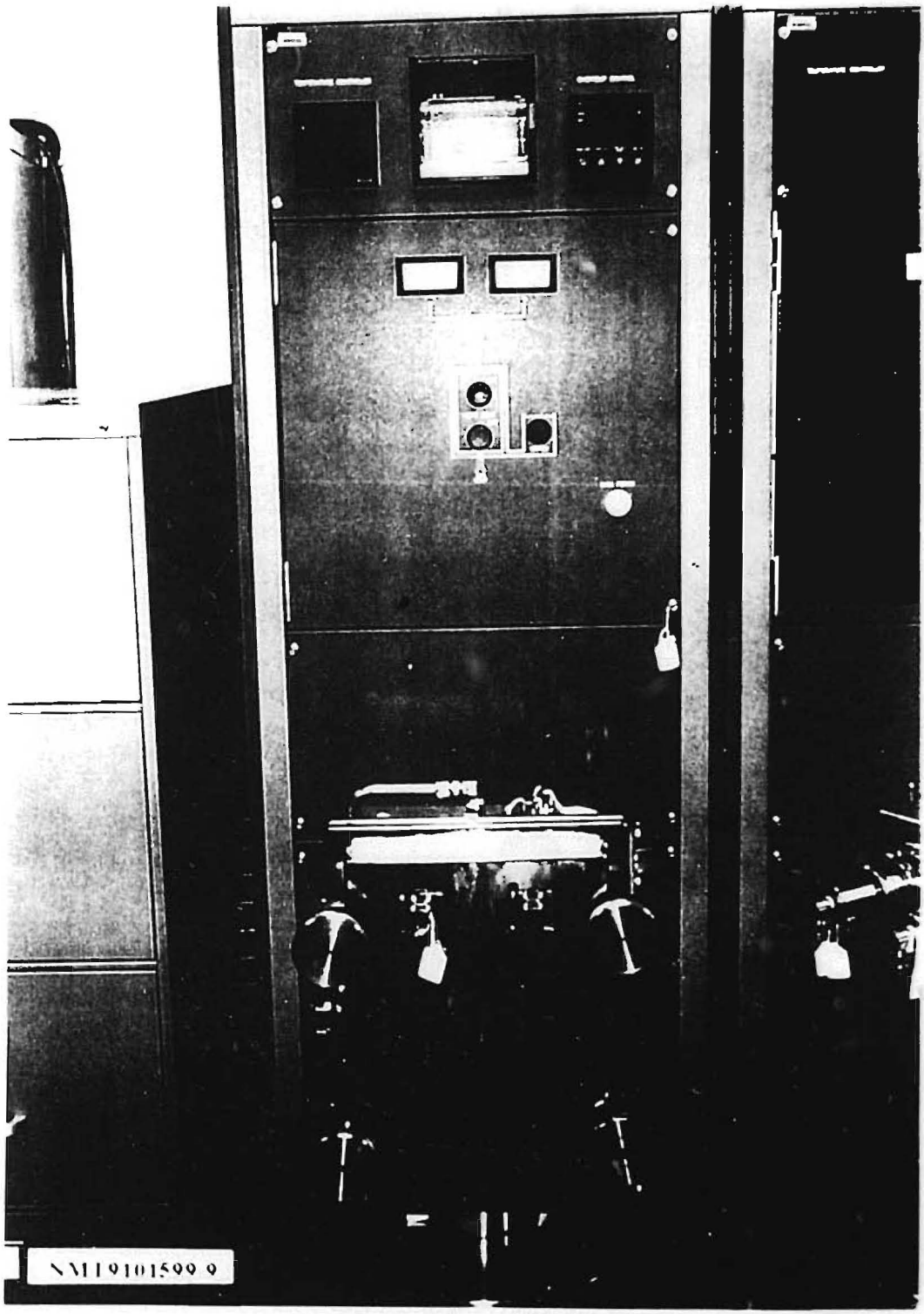
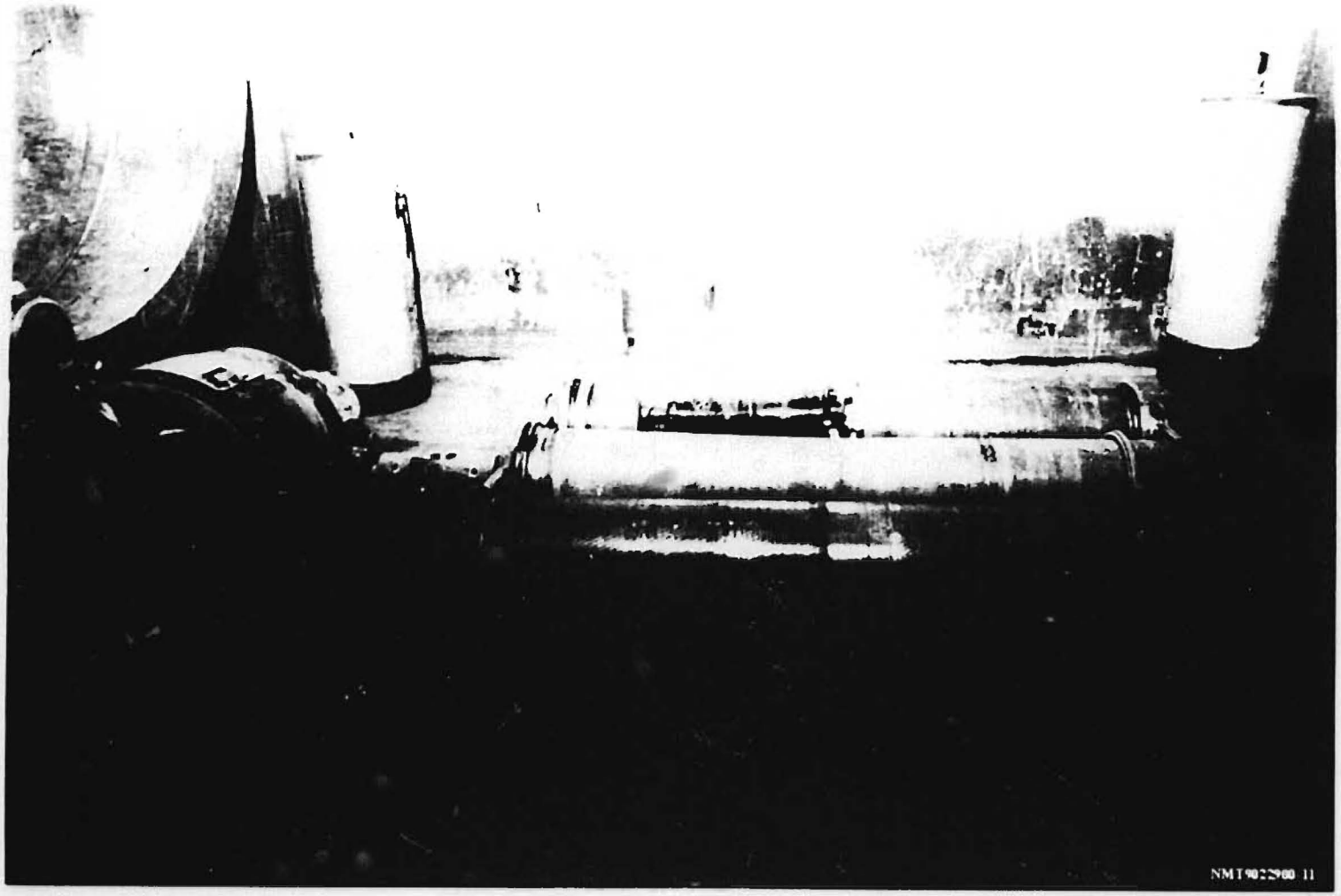
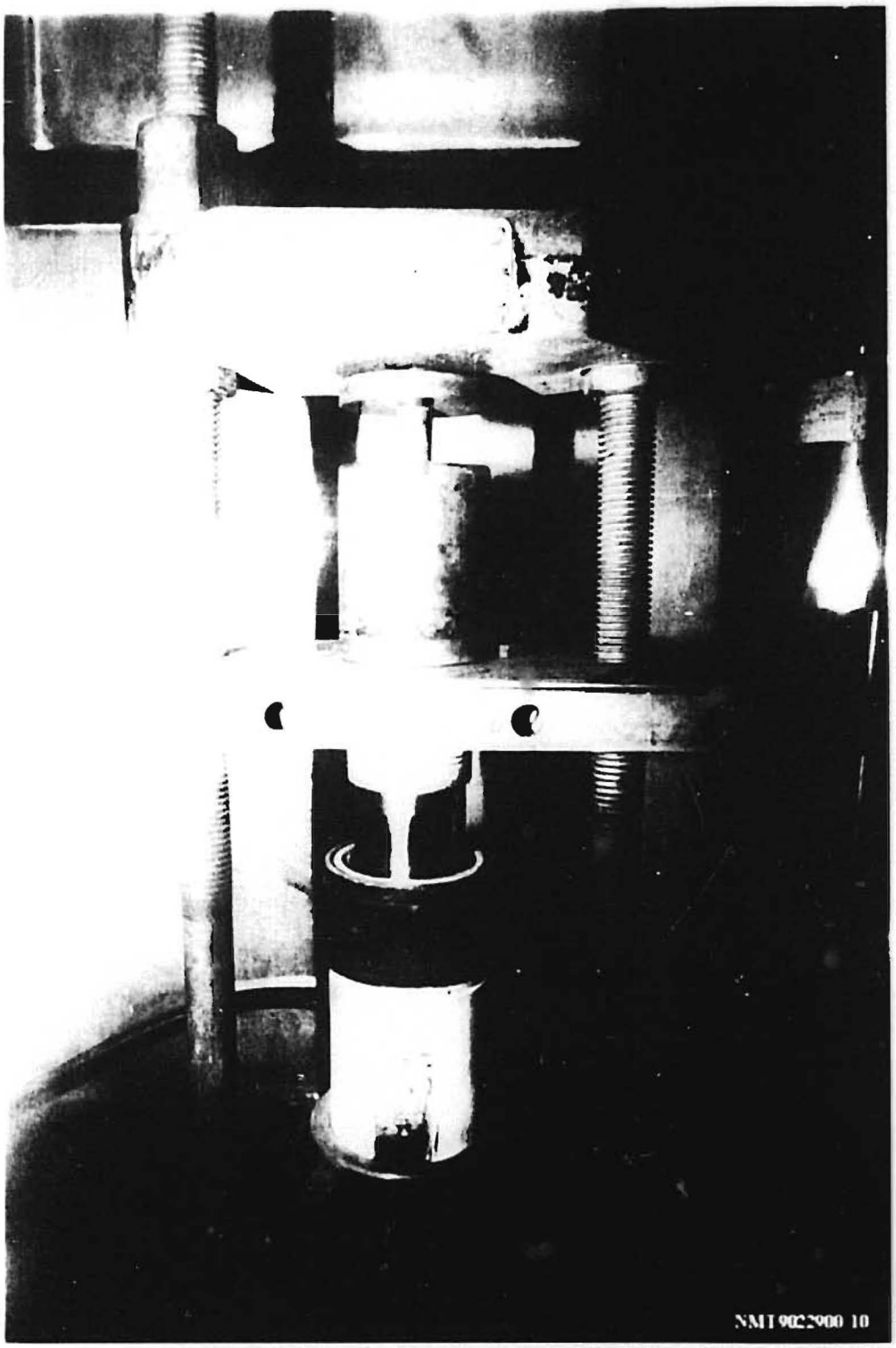


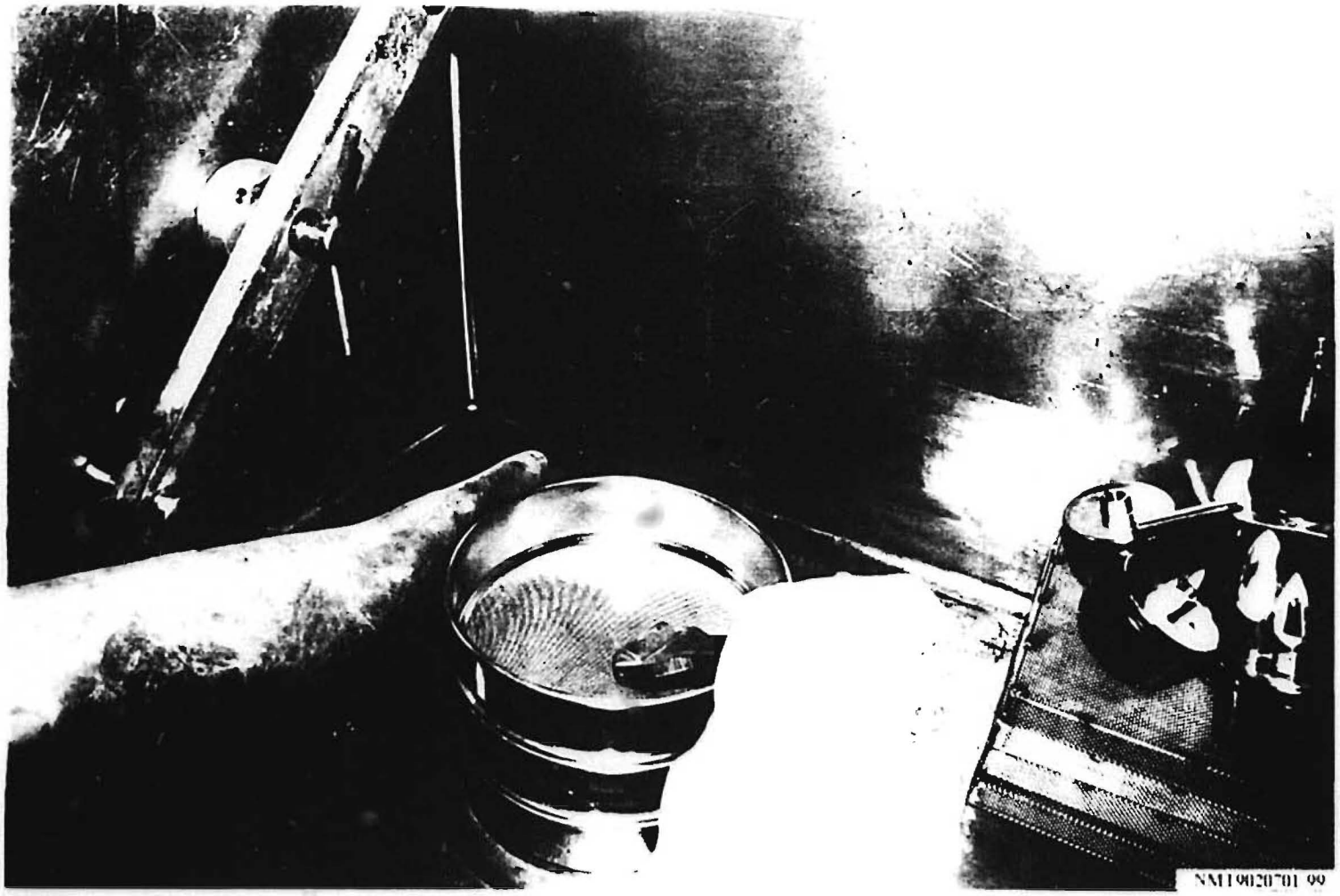
(NEW FUEL PROCESSING FURNACE)



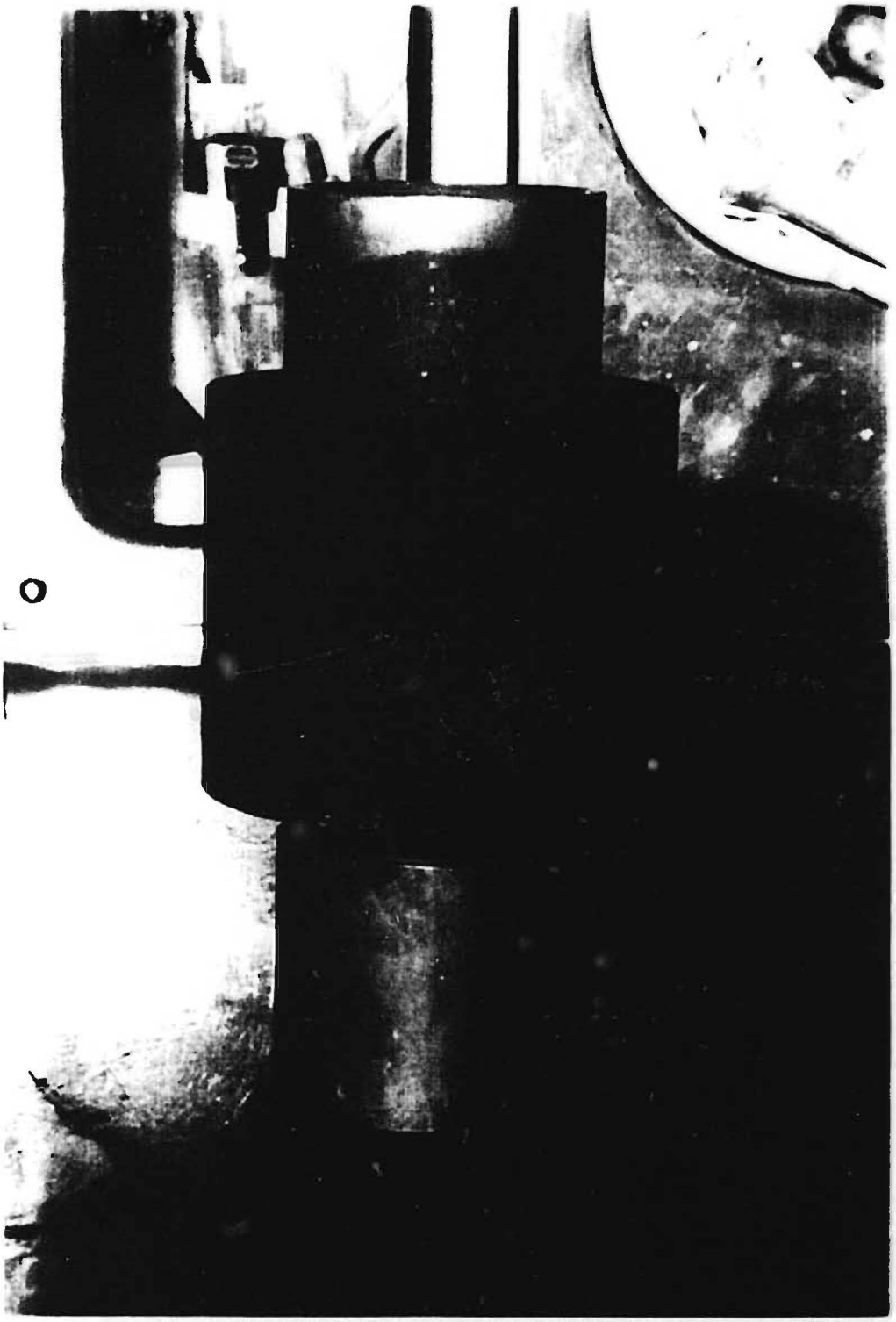
(BALL MILLING FUEL IN GLOVEBOX)



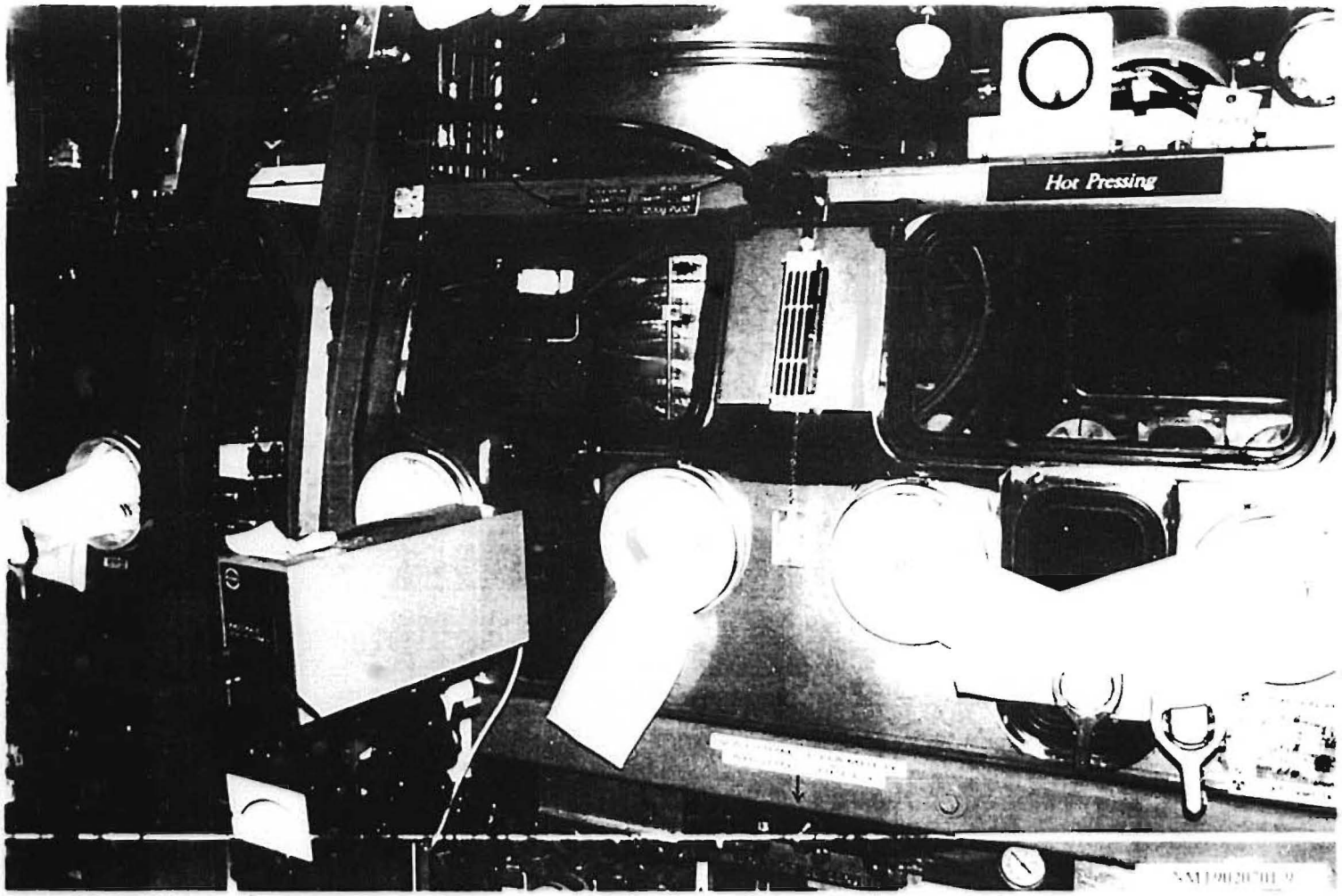
(COLD PRESSING FUEL PELLET IN GLOVEBOX)

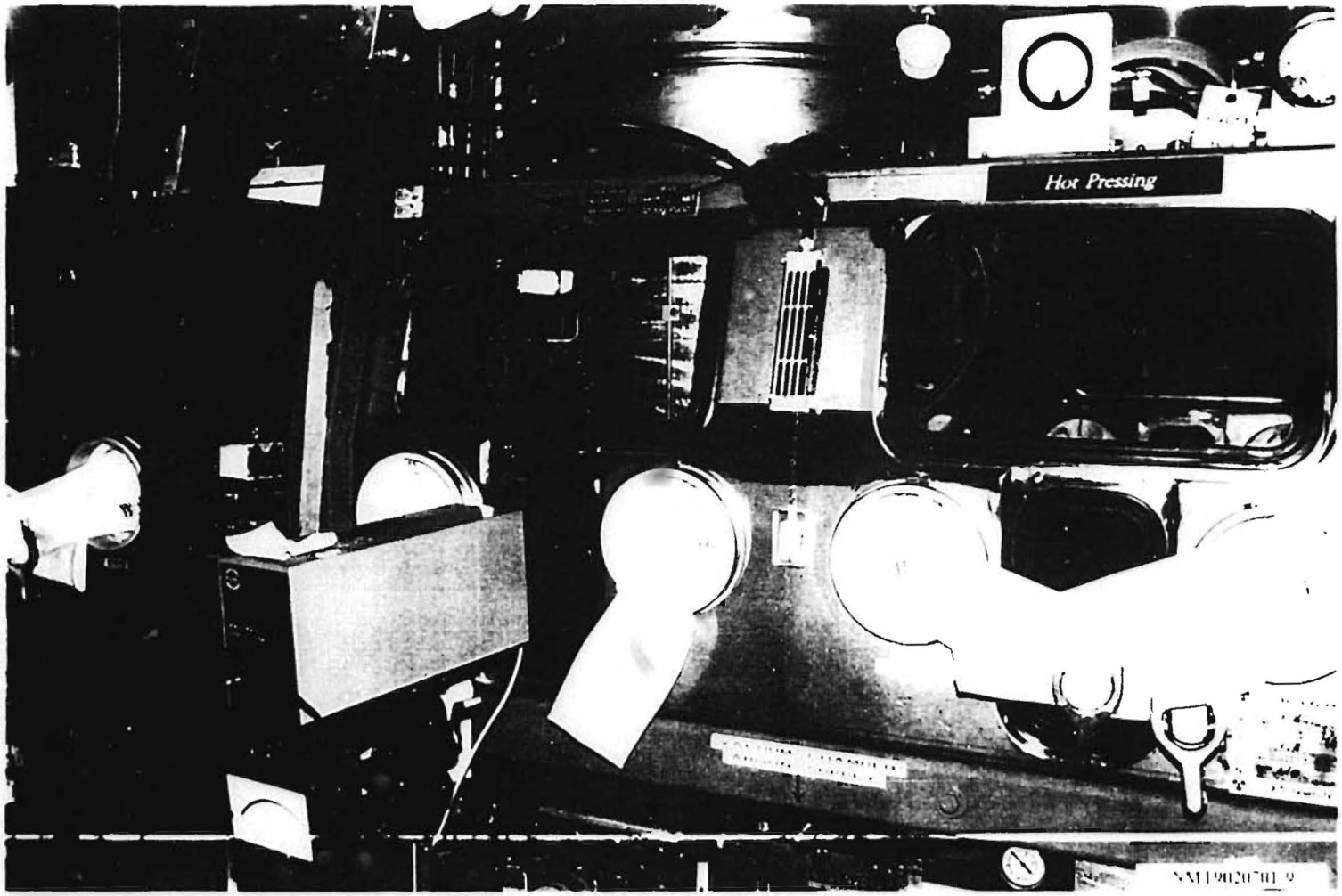


(SCREENING FUEL TO FORM GRANULES)

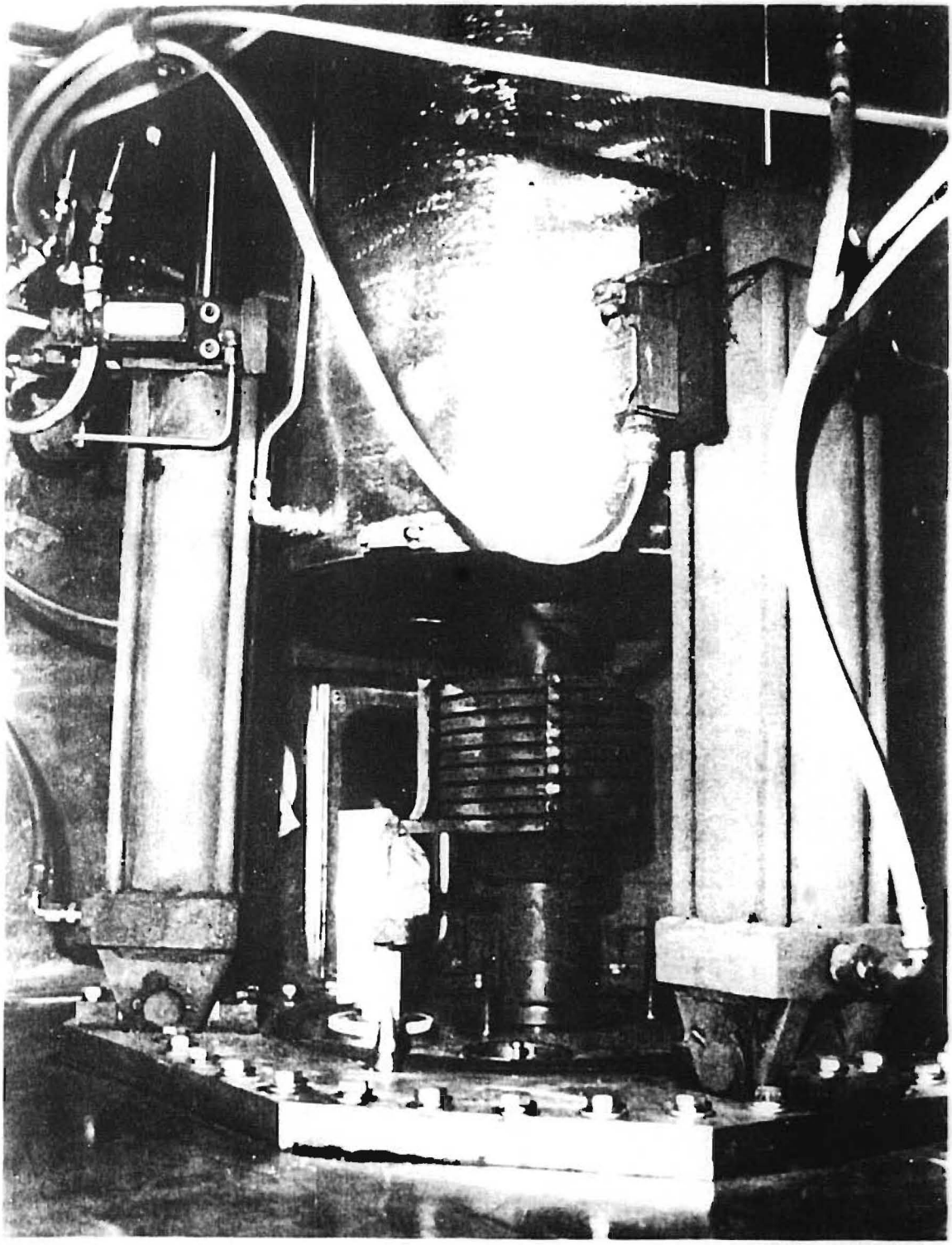


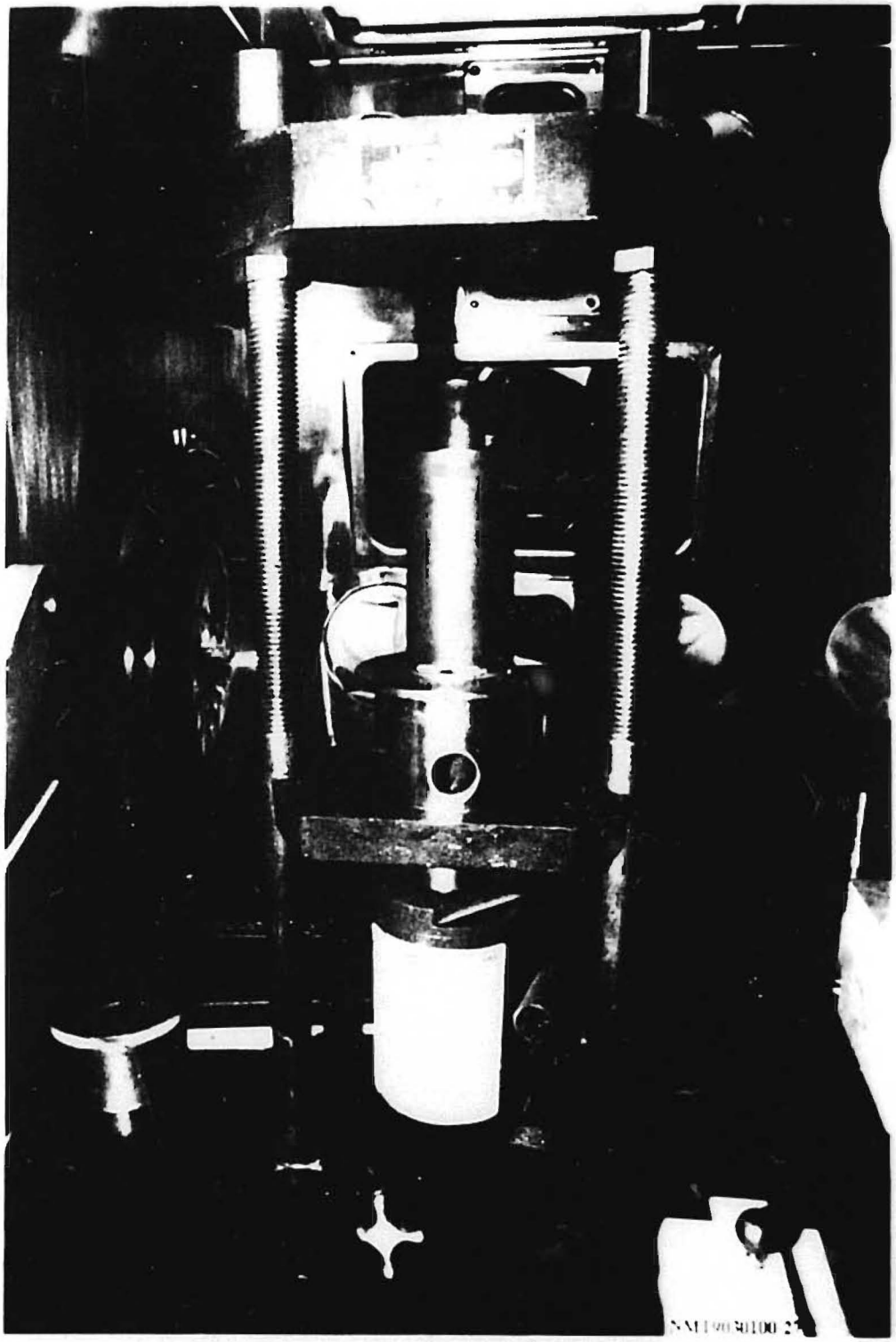
(GRAPHITE HPT PRESS DIE)


Hot Pressing



HOT PRESS - POWDER X - RAY DIFFRACTOMETER





EXTRUDING THE HOT PRESSED PELLET

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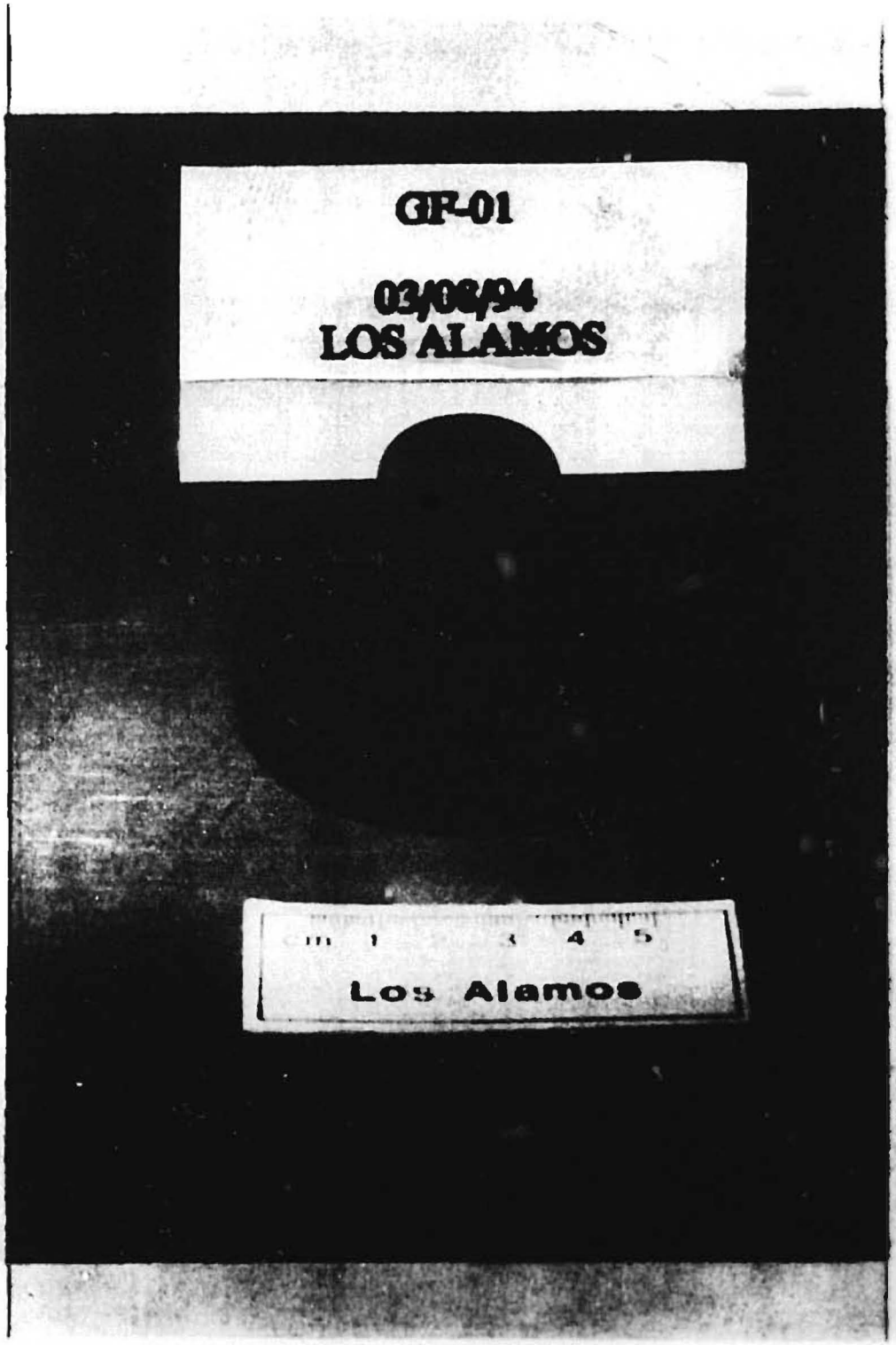
(... HEAT SOURCE PELLET)



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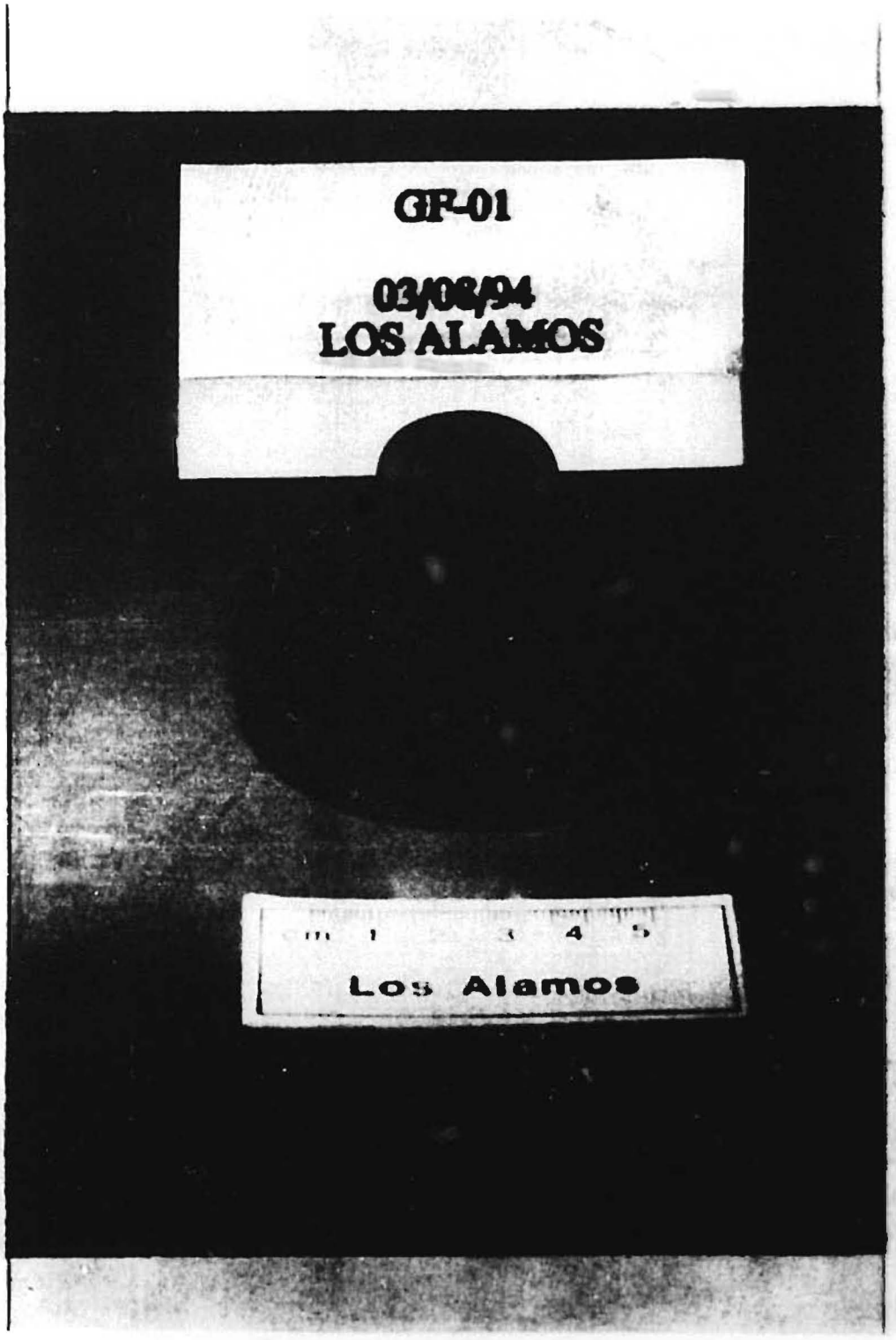

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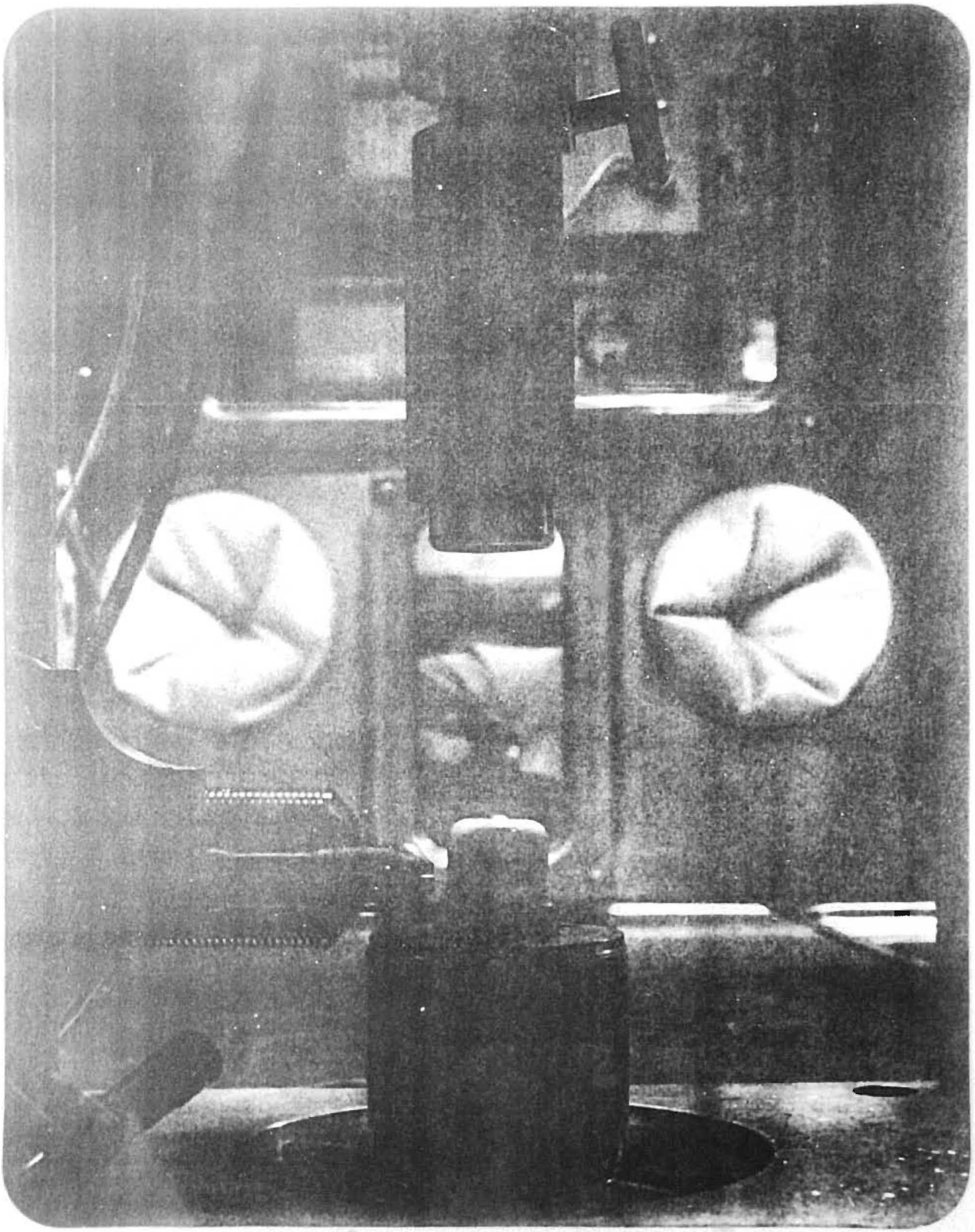
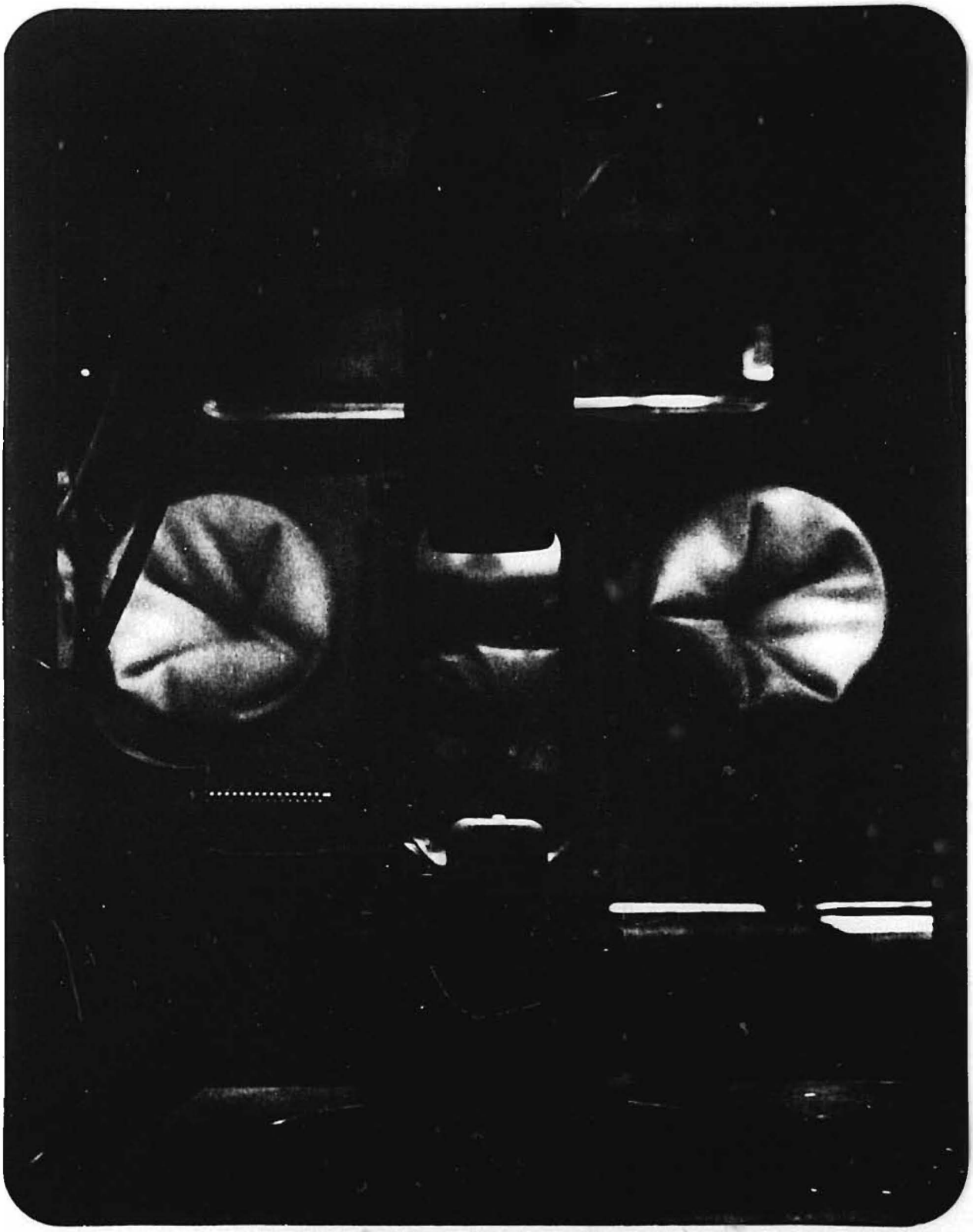
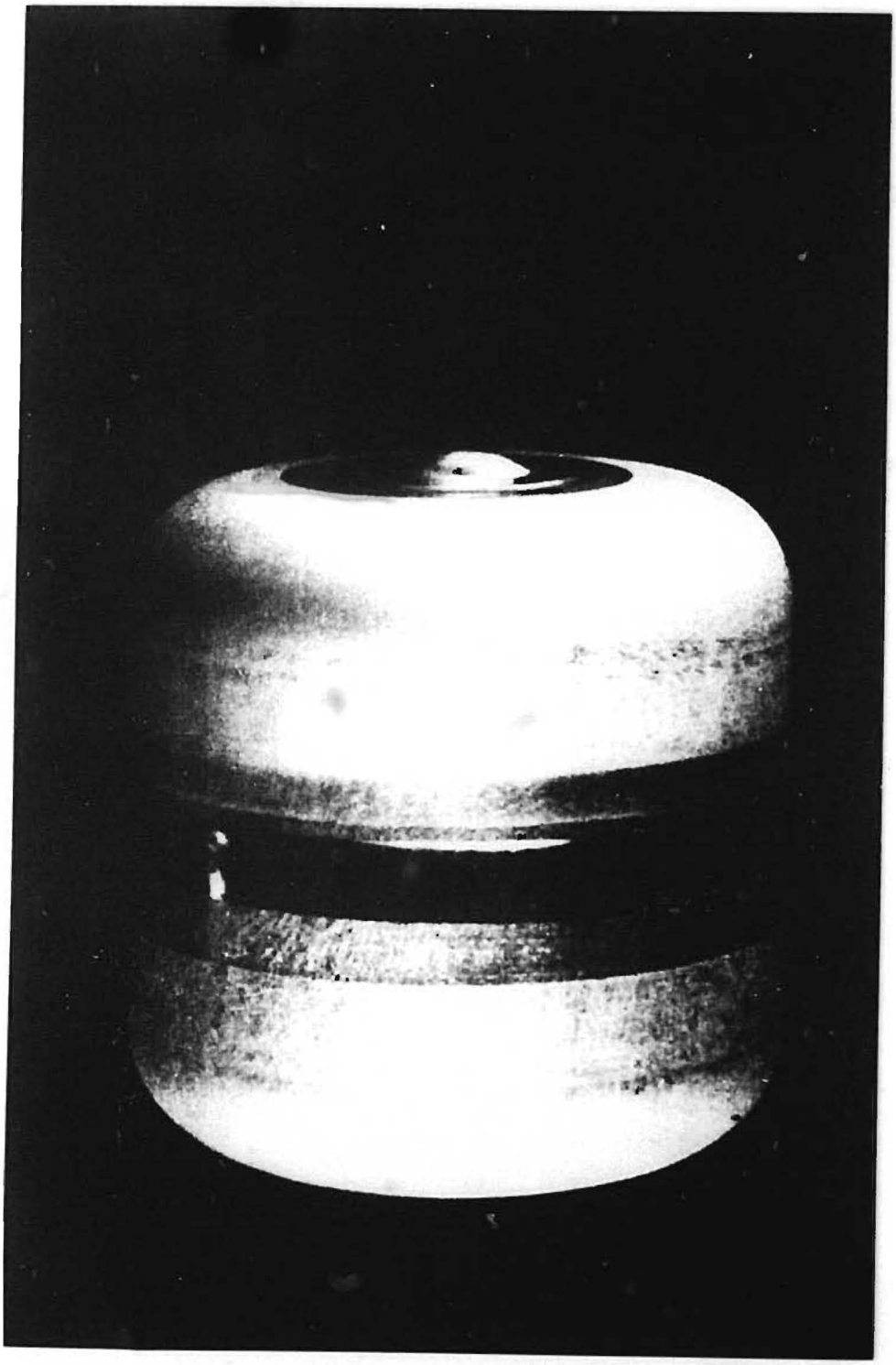
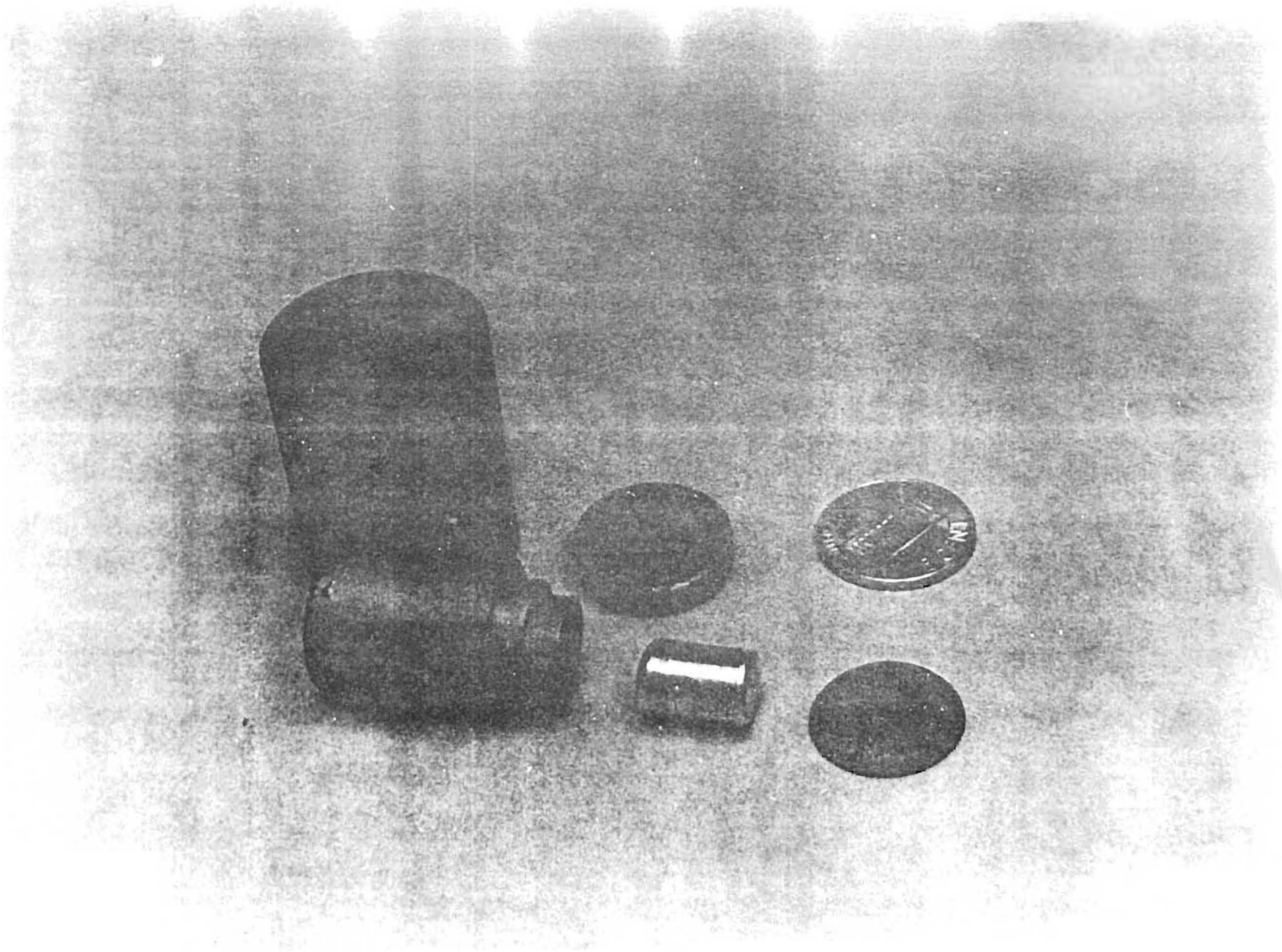




(WELDING CLADDING ON PELLET)





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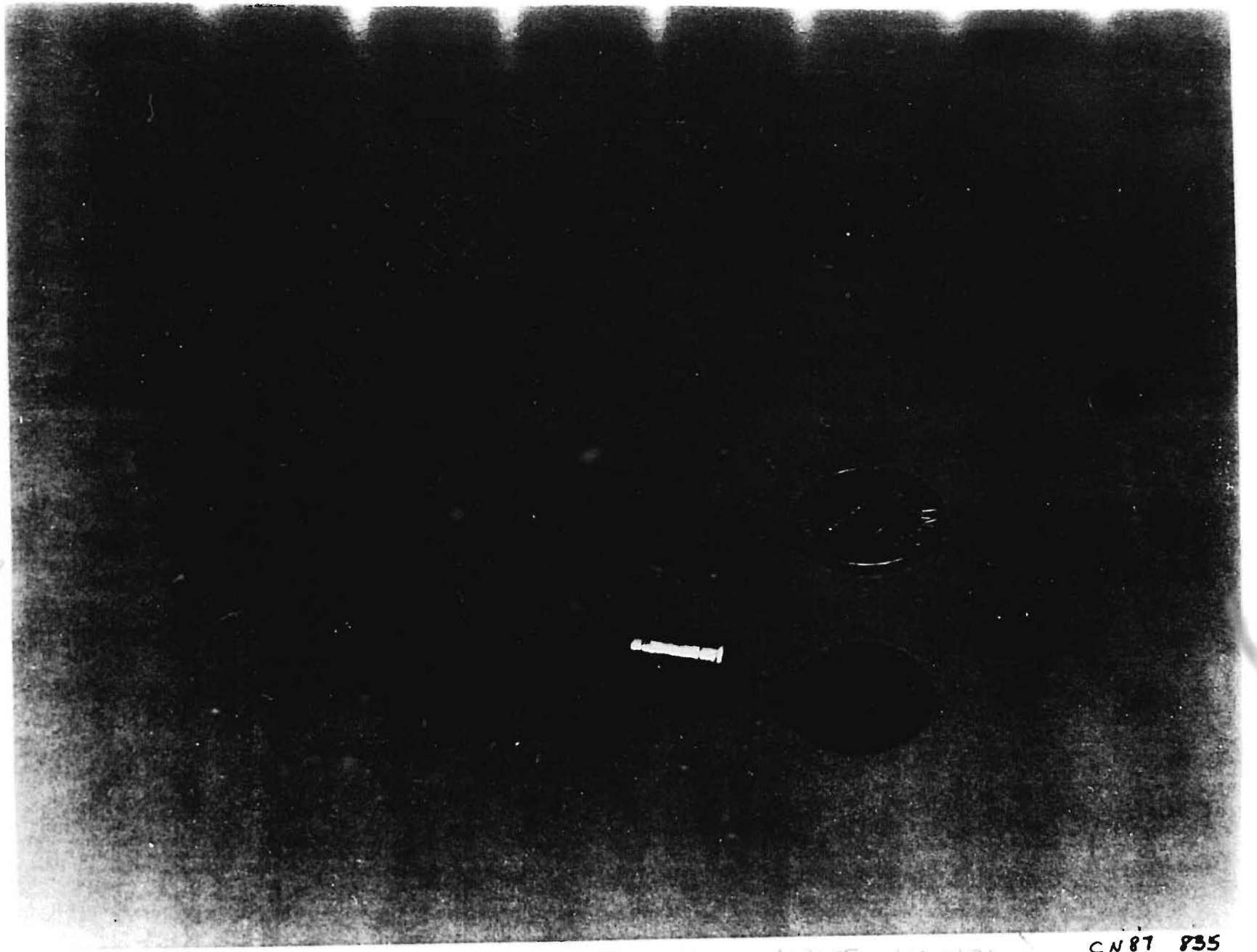

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LIGHTWEIGHT RADIOISOTOPE HEATER UNIT + GRAPHITE AEROSHELL