HRP Training Aid: Furnaces

DESCRIPTION	ECCN
Arc remelt and casting furnaces	**2B227.a**
Control units for metallurgical melting and casting furnaces	**2B227**
Controlled atmosphere melting and casting furnaces	**2B227**
Controlled environment (vacuum or inert gas) induction furnaces	**2B226**
Crystal pullers and furnaces	**3B991.b.1.c**
Electron beam melting furnaces	**2B227.b**
Furnaces, Chemical Vapor Deposition (CVD) designed or modified for the densification of carbon-carbon composites	**2B105**
Inert gas environment induction furnaces	**2B226**
Metallurgical melting & casting furnaces	**2B227**
Plasma atomization and melting furnaces	**2B227.b**
Pyrolysis equipment, for rocket nozzles and reentry vehicle nose tips (chemical vapor deposition furnaces)	**2B105**
Vacuum furnaces	**2B226; 2B227**
Vacuum induction furnaces, power supplies	**2B226**
Vacuum melting, remelt and casting furnaces	**2B227**
Furnaces – Especially Designed or Prepared (EDP)	**10 CFR Part 110**

Description

- Equipment used to heat, melt, or otherwise process materials.
- Vacuum or controlled environment induction furnaces are used to heat or melt metal using the heat of induction current.
- Arc furnaces, electron beam (e-beam) furnaces, and plasma furnaces are typically used to remelt metals to achieve high purity or to combine materials with different melting points to produce an alloy.

Aliases

- Chemical Vapor Deposition (CVD) furnace
- Plasma Beam Furnace
- Electron Beam (e-beam) furnace
- Vacuum Arc Remelt (VAR) furnace
- Vacuum Induction Melting (VIM) furnace

Weapon Uses

- Nuclear:
  - Melting
  - Casting
  - Heat treating
  - Sintering nuclear explosive-related materials
- Missile:
  - Making lightweight carbon-carbon rocket nozzles and nose tips

Commercial Uses

- Metallurgical research
- Production of specialty steels or superalloys for the aerospace industry
- Manufacturing refractory metal ingots of niobium, tantalum, and hafnium; and high-purity molybdenum and tungsten for the electronics industry
- Melting and casting reactive metals such as titanium, zirconium, and vanadium
- Small induction furnaces: jewelry-making
- Semiconductor fabrication and coating applications

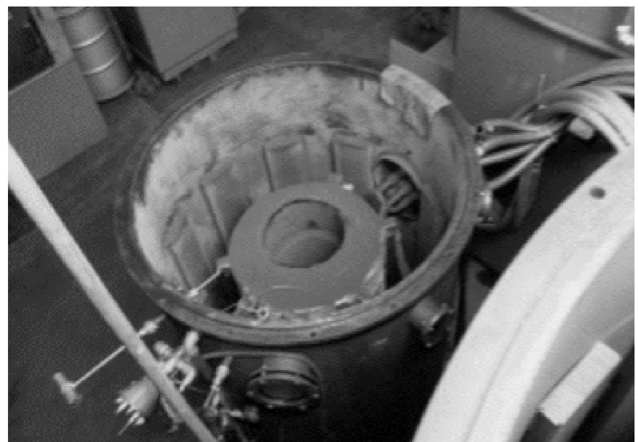
Chemical Vapor Deposition (CVD) Furnaces — ECCN 2B105

This ECCN controls chemical vapor deposition furnaces designed or modified for the densification of carbon-carbon composites.

Key features: Chemical vapor deposition furnaces

- Double-walled for water cooling during operation
- Multiple ports and lines to accommodate power feeds and instrumentation
- Viewports for optical or infrared pyrometers to measure temperature
- Large size for processing multiple items
- CVD can also be done in resistive heating furnaces

Chemical Vapor Deposition Furnace. A complete system would generally have a chamber, power supply, and programmable control system.



Inside of a CVD furnace showing the retort (cylindrical chamber), heaters, insulation, and ports.

Missile applications

- Heat-treat/strengthen the nose cone of reentry vehicles
- Deposit materials on missile exterior to fill voids in carbon-carbon composite structures

Commercial applications

- Making refractory ceramics
- Coating optics
- Making medical instruments and components such as heart valves
- Coating and polishing precision surfaces
- Making semiconductors

Induction Furnaces, Powers Supplies ECCN 2B226

This ECCN includes controlled atmosphere (vacuum or inert gas) induction furnaces and power supplies as follows:

a. **Furnaces** having **all** of the following characteristics:

- a.1. Capable of operation above 1,123 K (850 C);
- a.2. Induction coils 600 mm (24 in) or less in diameter; and
- a.3. Designed for power inputs of 5 kW or more.

b. **Power supplies**, with a specified power output of 5 kW or more, "specially designed" for furnaces controlled by ECCN 2B226.a.

Note: ECCN 2B226.a does not control furnaces designed for the processing of semiconductor wafers.

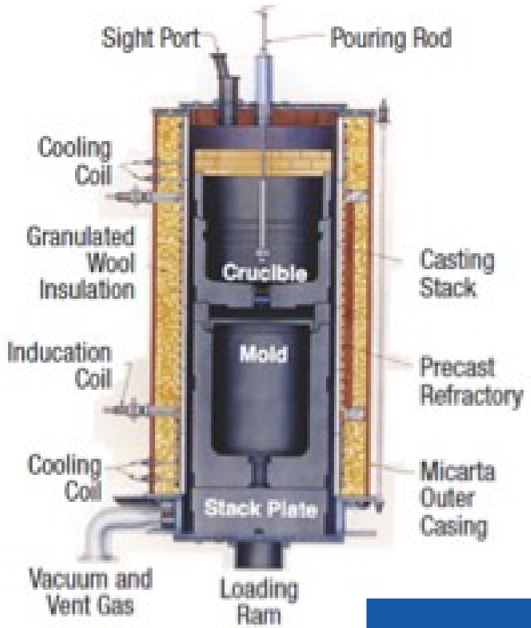
Appearance: Vacuum induction furnaces

- Typically closed cylindrical vessels with many ports and feedthroughs, as well as an opening for loading and unloading the furnace
- Usually accompanied by a solid-state power supply, including a cabinet with a control panel and display units for voltage, power, and frequency
- The outer casing of a furnace is often made of steel
- Coils usually made of copper and may be hollow (e.g., copper tube) for coolant to flow through it

Induction furnace vessel (right) and power supply (left).

Graphite crucible for an induction melting furnace.

- Crucibles for melting actinide metals (such as uranium or plutonium) are often made of graphite.
- Note hole in bottom through which molten metal flows into a mold.



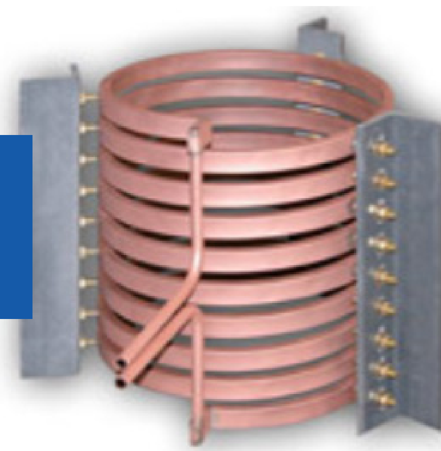
Schematic of a typical controlled atmosphere induction furnace showing various features.

Notes regarding nuclear applications

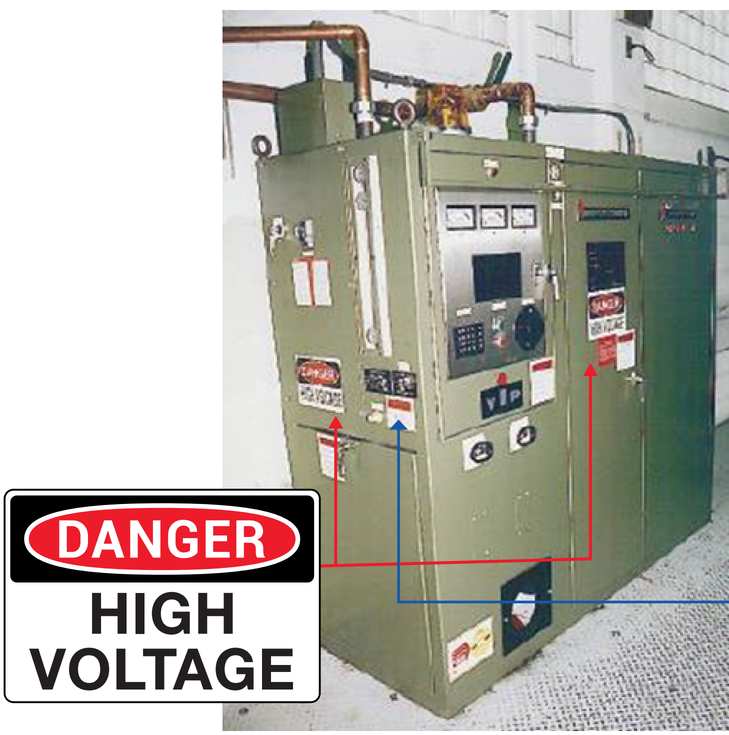
- Plutonium melts at 641°C (1,186°F), and uranium melts at 1,132°C (2,070°F).
- Large furnaces are not used for plutonium or highly enriched uranium because nuclear criticality limits the amount of material that can be processed in each batch.
- Furnaces capable of **bottom pouring** by means of stopper rods or break plugs are especially desirable for casting uranium.
  - **Stopper rod**: a pouring rod inserted into the hole in the bottom of the crucible during melting and lifted out of the hole to allow liquid metal to flow into the mold.
  - **Break plug**: a frangible plug in the bottom of the crucible that is broken by the pouring rod to pour molten metal into the mold. Bottom-break plugs are not widely used in nonnuclear applications and are somewhat indicative of furnaces intended for melting uranium.
- A strong indicator of a furnace for melting enriched uranium or plutonium is the **use of air-cooled or refrigerant-cooled induction coils** to help control nuclear criticality rather than the use of water-cooled coils.


Typical induction furnaces and coils.

Two small vacuum induction furnaces.
Export controlled: ECCN 2B226



Induction Furnace Coils.Tip: Coil diameter is easy to measure. Control is on small furnaces with coil diameter 24 inches or less.



Nameplates containing useful information (including the name of the manufacturer, model number, power rating, etc.) may be affixed to both the furnace vessel and the power supply.

Melting and Casting Furnaces, Control Units ECCN 2B227

This ECCN controls vacuum- or other controlled-atmosphere metallurgical melting and casting furnaces and related equipment, as follows:

a. **Arc remelt and casting furnaces** having both of the following characteristics:

a.1. Consumable electrode capabilities between 1,000 cm^3 and 20,000 cm^3 and

a.2. Capable of operating with melting temperatures above 1,973 K (1,700°C).

b. **Electron beam melting furnaces and plasma atomization and melting furnaces** having both of the following characteristics:

b.1. A power of 50 kW or greater; and

b.2. Capable of operating with melting temperatures above 1,473 K (1,200°C).

c. Computer control and monitoring systems specially configured for any of the furnaces controlled by ECCN 2B227.a or .b

Key features: Arc remelt furnaces

- Tall main mast supporting a hydraulic ram used to lower and raise an electrode
- Continuous melting between the electrode and the collected melted material is achieved via an electrical arc
- The melt and subsequent solidification occurs in a cooled copper crucible
- Capable of very accurate melt parameters, so computer control and monitoring is likely
- Complete furnace system includes vacuum pump systems, electrical power supplies, and computer control equipment

Arc remelt furnaces. In each photo, note (top) hydraulic ram driving the electrode housing, (bottom) melting chambers, and (platforms on left) vacuum pump systems. Arc remelt furnaces are controlled by their electrode size.

Arc remelt furnace. Heavy, flexible electrical leads and copper busbar visible near center of picture.

Melting chambers for an arc remelt furnace.

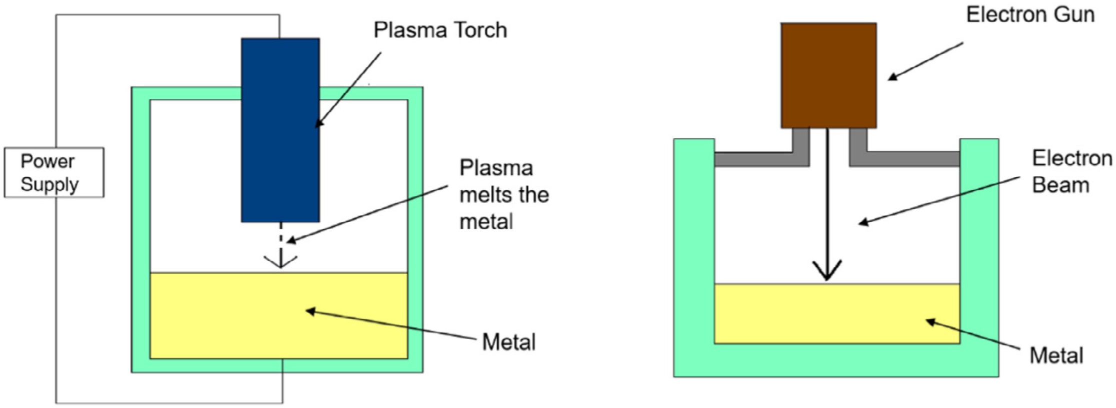
Arc furnace transformer bus.

Computer control and monitoring system for an arc remelt furnace.

Key features: Plasma and electron beam furnaces

- Similar to induction furnace: steel cylindrical heating chamber with many pass-throughs
- No induction heating coils
- Plasma furnaces melt the metal in the chamber by the heat of the plasma generated by a plasma torch
- Electron beam furnaces melt the metal in the chamber by the heat of the electron beam from the electron gun

Plasma torch.

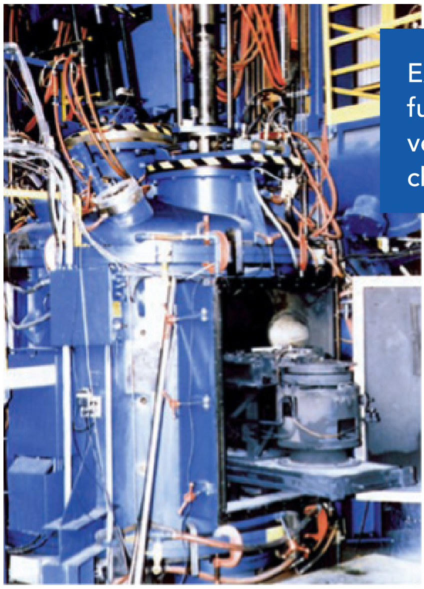


Plasma Furnace

Electron Beam Furnace

Schematics of (left) plasma furnace and (right) electron beam furnace.

Van Adenne electron beam gun.



Exterior of a plasma furnace with a vertical melting chamber.

Interior of the melting chamber of a horizontal plasma furnace.

Crystal Pullers and Furnaces

ECCN 3B991.b.1.c

ECCN 3B991 controls certain equipment "specially designed" for the manufacture of semiconductor devices, integrated circuits, and electronic assemblies, including item b.1.c:

b.1.c. Crystal pullers and furnaces, as follows:

> **b.1.c.1.** Annealing or recrystallizing equipment other than constant temperature furnaces employing high rates of energy transfer capable of processing wafers at a rate exceeding 0.005 m^2 per minute
>
> **b.1.c.2.** "Stored program controlled" crystal pullers having any of the following characteristics:
>
> > **b.1.c.2.a.** Rechargeable without replacing the crucible container,
> >
> > **b.1.c.2.b.** Capable of operation at pressures above 2.5×10^5 Pa, or
> >
> > **b.1.c.2.c.** Capable of pulling crystals of a diameter exceeding 100 mm.

Note: 3B991.b.1.c does not control diffusion and oxidation furnaces.

- **Stored program controlled** (Cat 2, 3, and 5): A control using instructions stored in an electronic storage that a processor can execute in order to direct the performance of predetermined functions. Equipment may be "stored program controlled" whether the electronic storage is internal or external to the equipment.

Crystal puller and furnace (circa 1968):

- Used to create silicon ingots for use in the semiconductor industry
- Two main parts: the furnace and the puller
- Furnace features: cylindrical and located at the bottom of the instrument, sits on a square base that houses the electrical components, and has a thick outer wall and clamps located at the bottom of the wall
- Puller features: extends above the furnace, has a hydraulic lift that gently pulls the furnace wall and the contents vertically
- Not controlled

Crystal growing methods and associated furnaces

Acronyms: Look for the following on available paperwork.

- **Czochralski (CZ)**
  - Also known as "crystal pulling" or "pulling from the melt"
  - Technique to produce high-quality crystals of semiconductor materials (e.g., silicon and germanium) for use in integrated circuits, microsystems technology, and radiation detectors
- **Kyropoulos**
  - Also known as "KY method" or "Kyropoulos technique"
  - Main application is to synthetically grow large boules (single-crystal ingots) of sapphire for the electronics and optics industries
- Edge Defined Film-Fed Crystal Growth **(EFG)**
- Micro Pulling Down **(MPD)** Crystal Growth Furnace
- Laser Heated Pedestal Growth **(LHPG)**
- **Bridgman** high temperature furnace
- **Tetra Arc** high temperature melting and crystal growth furnace
- Liquid Phase Epitaxy **(LPE)** furnace for crystal growth
- Vertical Liquid Phase Epitaxy **(VLPE)** furnace

Kyropoulos crystal growing furnace system.

Single-crystal sapphire boule grown by Kyropoulos method

Czochralski Crystal Growing Furnace System CGS1218:

- Designed for the high demands of the semiconductor industry
- Unique shaft configuration enables highest precision and absolute linearity and reproducibility of the pulling speed
- Multicompartment chamber
- Operated with single or dual camera systems via interactive software

Product data:

- Max. ingot diameter: 12–18 in.
- Ingot length: 2,800 mm
- Charge capacity: 300–450 kg
- Hot zone: 32–36 in.

Export controlled: ECCN 3B991.b.1.c

Furnaces Especially Designed or Prepared (EDP) 10 CFR Part 110

Furnaces especially designed or prepared (EDP) for the processing, use, or production of special fissionable material (e.g., plutonium-239, uranium-233, uranium enriched in the isotopes 235 or 233) are subject to the export licensing authority of the US Nuclear Regulatory Commission (see 10 CFR part 110).

Examples:

Furnaces EDP for the fabrication of nuclear reactor fuel elements

- Melting, alloying, and casting furnaces used in metal fuel fabrication processes to remelt uranium ingots prior to casting the resulting alloy into billets
- Sintering furnaces used to compact UO_2, MOX, and carbon coated fuel forms

Tilt-pouring induction melting furnace. A uranium–aluminum alloy is being poured from the furnace into a graphite mold on the lower right.

Furnaces EDP for use in uranium conversion plants

Notes:

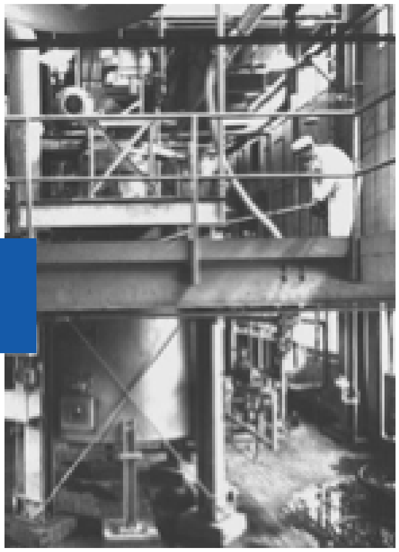
- Uranium conversion plants and systems may perform one or more transformations from one uranium chemical species to another, including:
  - Uranium ore concentrates to UO_3
  - UO_3 to UO_2
  - Uranium oxides to UF_4, UF_6, or UCl_4
  - UF_4 to UF_6
  - UF_6 to UF_4
  - UF_4 to uranium metal
  - Uranium fluorides to UO_2

- Unlike *off-the-shelf* furnaces, EDP furnaces for these plants and systems would be prepared according to requirements and specifications of the customer, including:

- Special design and construction considerations required to address the corrosive properties of chemicals and materials handled
- Nuclear criticality concerns

EDP systems for the conversion of uranium ore concentrates to UO_3

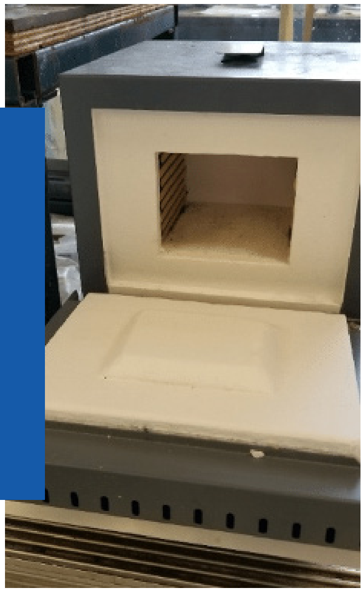
- **Calcining furnaces** are used to heat a solid material to a temperature below its melting point to effect thermal decomposition or a phase transition other than melting.



Denitration, or calcining, furnace EDP for converting uranyl nitrate hexahydrate to UO_3.

EDP systems for the conversion of UO_3 to UO_2

- **Muffle furnaces** equipped with special liners and shallow trays can be used in the conversion of UO_3 to UO_2.
- **Muffle furnace** is a furnace in which the charge (material to be heated) is contained within a refractory enclosure called the muffle
- **Muffle**, which is externally heated.



Muffle furnace used for the oxidation of uranium. Typical features include the following:

- 18 in. length with a rectangular flat face (16 × 18 in.)
- Reaction chamber 14 × 8 × 6 in.
- Sealed, corrosion-resistant liner using special alloys (e.g., Monel or Inconel)
- Fittings for gas supply and temperature control

EDP systems for the conversion of UO_2 to UF_4

Resistance furnaces EDP for horizontal stirred reactors in the conversion of UO_2 to UF_4

EDP systems for the conversion of UF_4 to U metal

- Conversion of UF_4 to U metal is performed by reduction with magnesium or calcium.
- The reaction is carried out at temperatures above the melting point of uranium in an **induction furnace.**

Induction furnace EDP for converting UF_4 to U metal:

- Closed cylindrical vessel with many ports and openings
- Outer casing usually made of steel
- Hollow copper coils for coolant flow
- Induction heating coils within the furnace