

## HRP Training Aid

# Graphite

### Description

#### Commerce

- Graphites usable for rocket nozzles and re-entry nose tips **ECCN 1C107**
- Graphite not intended for use in a nuclear reactor **ECCN 1C298**
- Other graphite products (e.g., furnace electrodes) **EAR99**

#### NRC

- Nuclear-grade graphite for nuclear end-use **10 CFR 110**

#### State / DDTC

- Graphite that is part of ablative materials—fabricated or semi-fabricated from advanced composites—specifically designed or modified for defense articles in USML Category IV or XV (e.g., rockets, missiles, space launch vehicles) **22 CFR121.1**

### Key Points

- **Graphite:** a soft, silvery black mineral; occurs naturally in the earth's crust and is the most abundant form of pure carbon
- Graphite can be obtained through two primary methods: natural mining and synthetic production.

### Terminology: Natural Graphite Mining

- **Flake Graphite** (85-98% carbon) – aka crystalline graphite; most common type; used in applications such as batteries, lubricants, refractories, and lithium-ion batteries
- **Amorphous Graphite** (70%-85% carbon) – lower-purity form of graphite; soft, non-crystalline graphite; ideal for applications where extreme purity isn't required (e.g., pencils, coatings, lubricants, industrial carbon products)
- **Vein Graphite** – rarest and purest natural form; highly valued for electrical applications



Graphite core sample from the Graphite Creek deposit in western Alaska

- largest known graphite deposit in U.S.

## Terminology: Synthetic Graphite Production

- **Synthetic Graphite (aka artificial graphite):**
  - a high-purity (>99% carbon) man-made material produced from petroleum coke or coal tar pitch using a controlled, high-temperature process that allows for precise engineering and tailoring of properties to meet specific needs
  - more expensive to produce than naturally mined graphite, but offers higher purity and fewer impurities
  - ideal for applications requiring high conductivity, strength, and heat resistance
  - common uses include electrodes for electric arc furnaces, semiconductor components, aerospace materials, and lithium-ion battery anodes
  - largest end use for primary synthetic graphite is production of graphite electrodes
- **Nuclear-grade graphite**
  - an ultra-high-purity (typically 99.5% to 99.999% carbon), synthetic graphite specifically manufactured for use in nuclear reactors as a neutron moderator and reflector, as well as a crucial structural material
  - key characteristic is an extremely low concentration of neutron-absorbing impurities, particularly boron
  - excellent dimensional stability under irradiation, high thermal conductivity, and easy machinability to tight tolerances



Nuclear grade graphite

# Graphite: Key Industrial and Commercial Applications

## Batteries and Electronics

- The largest—and most critical—component in any lithium-ion battery
  - Comprises 95-99% of the anode (negative electrode)
  - Average lithium-ion battery contains 15X more graphite than lithium
  - A Tesla contains over 100 kg (220 lbs.) of graphite
- Electric motor brushes and components in fuel cells and semiconductors

## Steel and Metallurgy

- Used in refractories (furnace linings, crucibles, ladles) and as consumable electrodes in electric arc furnaces (EAFs) for steel production, and to add carbon to steel

## Lubricants

- A dry lubricant for high-temperature or high-pressure applications where oil-based lubricants would fail or evaporate

## Pencils and Coatings

- The "lead" in pencils (mixed with clay) and as a water-repellent coating in paints and foundry mold washes

## Automotive

- In brake linings, gaskets, and clutch materials for friction and heat resistance

## Nuclear Industry

- As a moderator and reflector in nuclear reactors due to its ability to absorb neutrons; structural support in graphite moderated, gas cooler reactors

## Aerospace / Missile

- Used to manufacture reentry vehicle nose tips, thrust tabs, rocket nozzle throats

## Graphite: Properties and Appearance

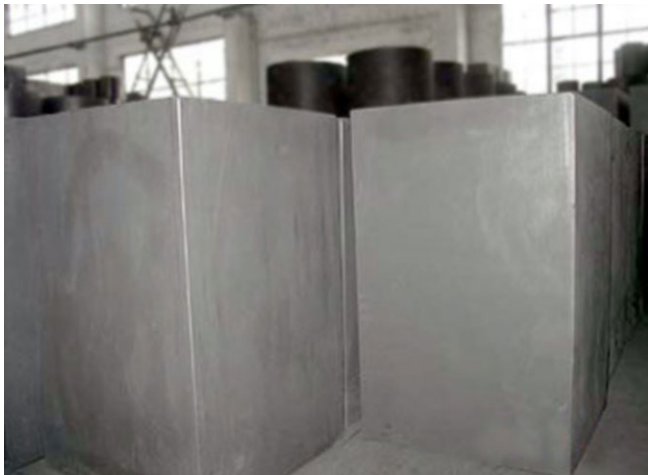
- The only known substance that doubles in strength as the temperature increases from room temperature to 2,700 °C.
- Matte black, porous appearance, some surface roughness
- Precision machining can produce a shiny grey/black surface
- Common geometrical shapes are cylinders and rectangular blocks
- Very easy to identify by its softness (can mark it with a fingernail) and the way it marks other surfaces (like a pencil)
- Note: Graphite is inert. Handling poses no special risks, other than those normally associated with the handling of large, heavy objects.



Graphite blocks on individual pallets



Graphite blocks and logs may be completely exposed or covered with a paper or plastic wrapper to protect the soft surface



Graphite blocks

- 16" x 16" x 24"
- 337 lbs. each (at 1.6 g/cm<sup>3</sup>)

## Leading Global Manufacturers

Major manufacturers across both synthetic and natural graphite markets:

- **SGL Carbon (Germany):** world's largest manufacturer of carbon and graphite products; provide specialty graphites for semiconductors, automotive, and industrial applications
- **Resonac Holdings (Japan):** formerly Showa Denko; major producer of high-quality artificial graphite powder and graphite electrodes
- **GrafTech International (USA):** leading manufacturer of graphite electrodes critical for electric arc furnace (EAF) steelmaking
- **BTR New Material Group (China):** global vendor for battery anode materials
- **Tokai Carbon (Japan):** global leader in graphite electrodes and specialty graphite for EDM and semiconductors
- **Graphite India Limited (India):** major producer of graphite electrodes and other carbon specialty products

## Leading U.S. Manufacturers

### □ Natural Graphite Production

United States currently transitioning from zero production to active mining through several key projects:

- **Titan Mining (Empire State Mines):** New York; will be first domestic producer of natural flake graphite in over 70 years with production targeted for 2026
- **Graphite One Inc.:** developing the Graphite Creek deposit in Alaska – recognized as largest known graphite resource in the United States
- **Westwater Resources:** Coosa Graphite Project in Alabama; aiming to produce battery-grade graphite

### □ Synthetic Graphite and Processing

These companies focus on high-purity synthetic graphite or processing raw materials into anode-grade products:

- **GrafTech International:** global leader in manufacturing high-quality graphite electrodes, primarily for electric arc furnace steel production
- **NOVONIX:** major player in the battery sector, rapidly expanding its synthetic graphite anode material manufacturing operations within the U.S.
- **Anovion:** developing large-scale synthetic graphite anode manufacturing facilities to support the domestic EV battery market
- **Syrah Resources:** operates active anode material plant in Vidalia, Louisiana, using feedstock imported from its mine in Mozambique
- **Superior Graphite:** U.S.-based specialist that partnered with ExxonMobil to scale its battery anode technology
- **Mersen (U.S.):** selected by the U.S. Defense Logistics Agency for a high-purity synthetic graphite contract to support aerospace and defense needs

## Nuclear-Grade Graphite: Worldwide Manufacturers and Suppliers

- Suppliers of nuclear-grade graphite are divided between those providing **structural core components** (moderators/reflectors) and those providing **sealing solutions** (gaskets/packings).

### Top Structural and High-Purity Suppliers

These companies produce the specialized isotropic graphite required for reactor cores and next-generation Small Modular Reactors (SMRs):

- **Toyo Tanso (Japan):** Manufactures **IG-110**, currently the only graphite grade used in all three of the world's operational High-Temperature Gas-Cooled Reactors (HTGR).
- **SGL Carbon (Germany):** A primary global supplier that signed a 10-year agreement with **X-energy** to provide graphite for advanced nuclear reactors.
- **Amsted Graphite Materials (USA):** The largest U.S.-owned synthetic graphite producer. They supply **PCEA™** nuclear-grade graphite for micro reactors like **Radiant's Kaleidos**.
- **Mersen (France):** A leader in high-performance materials, specializing in ultra-high-purity graphite for nuclear power and semiconductor applications.
- **Nippon Carbon (Japan):** Produces moderators and reflectors with high mechanical strength and thermal stability for global nuclear installations.

### Specialized Components and Sealing Suppliers

These companies focus on high-purity flexible graphite for gaskets and seals that maintain integrity under radiation:

- **Ibiden Co., Ltd. (Japan):** Specializes in flexible graphite sheets for reactor sealing.
- **GrafTech International (USA):** Provides high-quality graphite materials and electrodes specifically designed for nuclear reactors.
- **USG GLEDCO (USA):** Provides **GRAPHITAR®** materials used for seal faces, bearings, and structural parts in nuclear power generation.
- **SEC Carbon, Limited (Japan):** Produces graphite gaskets and components engineered for extreme radiation and pressure.

This ECCN controls graphite which can be machined to any of the following products:

- a. Fine grain graphites with a bulk density of 1.72 g/cm<sup>3</sup> or greater, measured at 15 °C, and having a grain size of 100 micrometers or less, usable for rocket nozzles and reentry vehicle (RV) nose tips as follows:
  - o a.1. **Cylinders** having a diameter of 120 mm or greater and a length of 50 mm or greater
  - o a.2. **Tubes** having an inner diameter of 65 mm or greater and a wall thickness of 25 mm or greater and a length of 50 mm or greater
  - o a.3. **Blocks** having a size of 120 mm × 120 mm × 50 mm or greater
- b. Pyrolytic or fibrous reinforced graphites, usable for rocket nozzles and reentry vehicle nose tips

### Key Points / Definitions

- Unlike nuclear-grade graphite (controlled under ECCN 1C298 or 10 CFR 110), this ECCN focuses on the high-strength, fine-grain properties needed for missile technology.
- **Fine-grained recrystallized bulk graphite**
  - o a high-density, synthetic carbon material characterized by extremely small grain sizes and a uniform, isotropic structure (properties are identical in all directions thus preventing weak points)
  - o produced through advanced manufacturing processes like isostatic pressing and high-temperature graphitization (turning carbon-based materials into graphite)
  - o the resulting block can be easily machined into the required part
  - o used to create very strong, heat resistant parts (e.g., RV nose tips, thrust tabs, nozzle throats)
- **Appearance**
  - o bulk graphite is a very fine, dark gray to black powder
  - o machined parts are black with a gloss dependent on the machining operation
  - o fine-grain graphite can be distinguished by its lack of surface pitting
  - o packaged to protect delicate surfaces and to prevent surface contamination
  - o typical billet for a nose tip could be as small as several centimeters in each dimension



#### Fine grain graphite on pallet

- Note extremely smooth surfaces and lack of surface pitting

- **Pyrolytic graphite**

- a unique form of graphite produced via chemical vapor deposition (CVD), where carbon is deposited from a hydrocarbon gas (like methane) onto a substrate at high temperatures
- highly anisotropic, meaning its properties (like thermal conductivity) vary significantly depending on the direction; often used in a "highly oriented" form (look for any references to "HOPG")
- used in rocket nozzles because of its excellent structural integrity and thermal properties
  - forms an ablative (capable of being burned away in a controlled manner) and insulating layer
  - does not erode by hot gasses expelled from the nozzle; can withstand temperatures exceeding 3,000°C

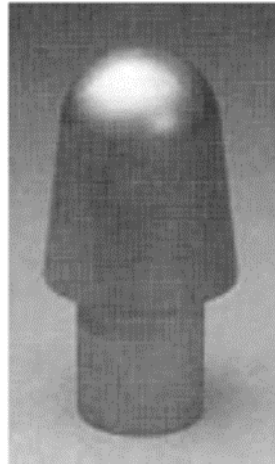
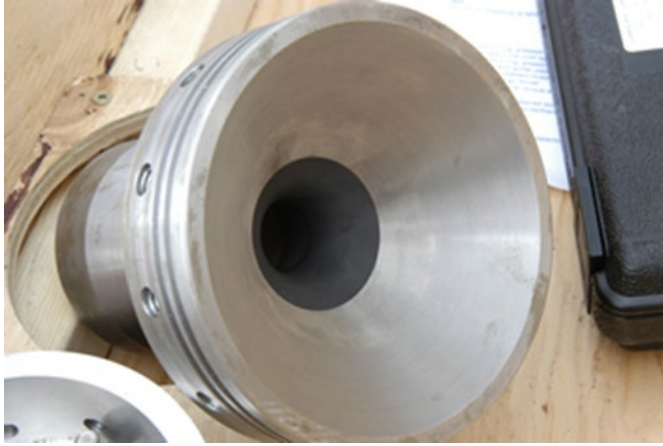
- **Appearance**

- dark grey to black in powder form
- non-uniform texture; look for pitted or bumpy surfaces resulting from the manufacturing process
- susceptible to cracking requiring that it be well-packaged



**Pyrolytic graphite**

- Note pitted surfaces



Graphite nozzle insert (left); Molded graphite nose cone (right)



Various rocket nozzles



38 mm nozzle sitting on a 10.5" x 14" graphite blank

## Graphite not intended for use in a nuclear reactor

ECCN 1C298

This ECCN controls graphite with a boron content of <5 parts per million (ppm) and a density >1.50 g/cm<sup>3</sup> that is intended for use other than in a nuclear reactor.

Note: While this control is based on the material's properties rather than specific finished products, high-purity graphite with these characteristics is typically found in:

- **Industrial Components:** Refractories (heat-resistant materials) such as high-temperature crucibles and furnace linings, molds, or heating elements used in non-nuclear industries such as medicine and commercial manufacturing.
- **Semiconductor Manufacturing:** Graphite components used in the production of silicon wafers often require extreme purity that matches the parameters of ECCN 1C298
- **Aerospace Materials:** High-density graphite used for thermal protection or structural components in non-missile applications (missile-related graphite is typically under ECCN 1C107)



High-density graphite crucibles for induction furnaces



High-purity graphite blocks for ladle refractory linings

- ECCN 1C298



High-purity graphite parts used in semiconductor manufacturing



Carbon graphite aircraft rotors can withstand the high temperatures and extreme conditions within jet engines



Carbon graphite mechanical seals are common in the aerospace industry

## Other industrial or commercial graphite products

**EAR99**

- Other industrial or commercial graphite products (e.g., furnace electrodes, battery rods, pencil lead, common lubricants) that do not meet the high purity or density thresholds of ECCN 1C298

### □ Graphite Electrodes for Steel Industry

Largest end use for primary synthetic graphite is in the production of graphite electrodes. Electrodes can handle very high currents and are used mainly in electric arc furnaces (EAFs) for the production of steel, iron, and non-ferrous metals.

In the steel industry, these electrodes are typically categorized by their power-handling capacity. The following types are standard industrial products **generally classified as EAR99**:

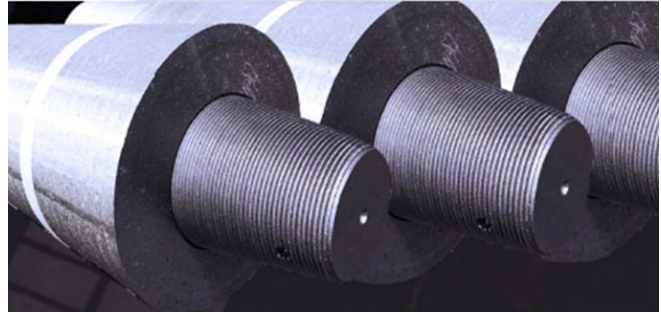
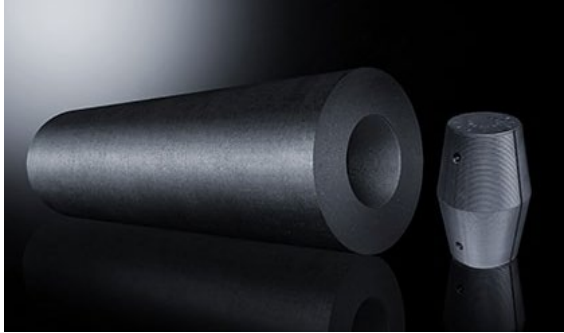
- **Ultra-High Power (UHP) Graphite Electrodes** – the top-tier standard electrodes used in modern steelmaking; designed to handle high electric currents; essential for modern, high-efficiency electric arc furnaces (EAF) and ladle furnaces
- **High Power (HP) Graphite Electrodes** – used in ladle furnaces or smaller electric arc furnaces for melting scrap
- **Regular Power (RP) Graphite Electrodes** – most cost-effective and common electrodes used in standard EAF for melting scrap steel
- **Ladle Furnace (LF) Electrodes** – smaller in diameter (14–18 inches); used specifically for the refining stage of steelmaking rather than the primary melting
- **Specialized Graphite Rods and Blanks** – smaller graphite electrodes used in Electric Discharge Machining (EDM) to shape steel
  - Examples: POCO, Ibiden, Mersen USA, SGL Carbon Group, and Toyo Tanso graphite products (tubes, rods, sheets, plates, blocks)
  - Material: SIGRAFINE® fine-grain graphite

### Key Characteristics

- **Material:** Primarily synthetic graphite
- **Typical Boron Content (EBC):** 0.6 – 10+ ppm
- Steel industry electrodes focus on electrical conductivity and thermal shock resistance rather than low neutron absorption (i.e., extreme purity as measured by equivalent boron content, EBC). For steelmaking, neutron absorption is irrelevant, so the expensive purification processes required to remove trace boron are not performed for industrial electrodes.
- **Density:** 1.6–1.72 g/cm<sup>3</sup>
- **Diameters:** 200 mm to 800 mm (8 to 32 inches)
- **Lengths:** 1,500 mm to 3,600 mm (60–142 inches)
- **Weight:** 300 kg to over 3,200 kg per electrode
- **Key Feature:** Often include graphite nipples (joining pins) which allow the electrodes to be threaded together into long columns; pins weigh between 11kg – 62.8kg

## Manufacturers: Graphite Electrodes

- GrafTech International, Resonac (formerly Showa Denko), Graphite India Limited, Tokai Carbon, Fangda Carbon



### UHP Graphite Electrodes for DC Furnace

- Size: 22-32 inches in diameter
- Note threaded joining pins (typically 3-4 threads per inch)



Graphite electrodes for steel production

## □ Graphite Rods for Zinc-Carbon Batteries

Serve as conductive electrodes in the center of zinc-carbon (not alkaline) heavy-duty batteries

- Provide high electrical conductivity, thermal shock resistance, and chemical stability
- Used in electrochemistry experiments, metal melting, spectroscopy, and as heating elements



Graphite Rod Electrodes for Zinc-Carbon Dry Cell Battery Material

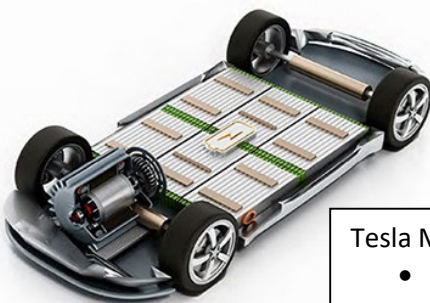
- EAR99

## □ Graphite for Lithium-Ion Batteries for EVs

### Types of Graphite for EV Batteries

- Lithium-ion batteries in electric vehicles (EVs) primarily use a combination of synthetic graphite and natural graphite in their anodes:
  - synthetic graphite is the dominant material in the EV market, making up ~90% of the graphite used in modern battery anodes
  - synthetic graphite is generally used in high-performance EVs, whereas natural (flake) graphite is common in mid-range models
  - both types often processed into blended/coated spherical graphite (CSG) to balance cost, performance, and charging speed

**EAR99** is the most common classification for standard battery-grade natural and synthetic graphite used in typical EV applications.



Tesla Model S Battery Pack

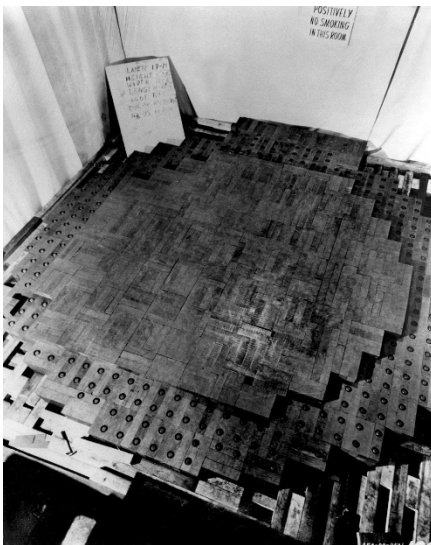
- 7000 individual lithium-ion cells



Nuclear-grade graphite for nuclear end-use is subject to the export licensing authority of the Nuclear Regulatory Commission (see 10 CFR part 110).

### Key Points and Appearance

- **Nuclear grade graphite for nuclear end use** means graphite having a purity level better than (*i.e.*, less than) 5 parts per million boron equivalent, as measured according to ASTM standard C1233-98 and intended for use in a nuclear reactor. Note: as revised in recent years, a density parameter is no longer specified for jurisdiction.
- Nuclear grade graphite shapes are formed by both extrusion and pressing into molds
- The shape, called a log, is normally a right circular cylinder but rectangular cross section logs may be encountered.
- First graphite moderated reactor (CP-1) used graphite bricks 4.25" on a side
- Subsequent reactors used much larger graphite pieces to construct the core



#### First graphite moderated reactor (CP-1)

- 45,000 graphite bricks stacked in 587 layers
- Graphite obtained from the National Carbon Company
- Each brick: 4.25" x 4.25" in cross section; 16.5" long; 19 lbs.

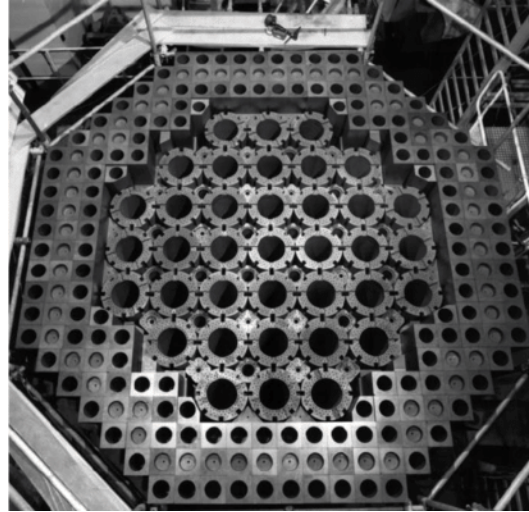


Nuclear grade graphite for N-reactor at Hanford





Graphite core from the ORNL Molten-Salt Reactor Experiment



Graphite components of gas-cooled reactors before uranium fuel insertion



**TRISO (TRI-structural ISOtropic) fuel particles embedded within graphite "pebbles" for HERMES reactors (Kairos Power)**

- Each graphite pebble roughly the size of a golf ball (~4 cm diameter)
- Graphite acts as neutron moderator, structural material, and heat conductor
- Graphite is nuclear-grade; specifically known as "IBIDEN ET-10"



Graphite blocks forming the outer reflector in Pebble-Type HTGR (PBMR)

## Graphite in ablative materials for defense articles 22 CFR Part 121.1

Graphite that is part of ablative materials specially designed for defense articles is subject to the export licensing authority of the Directorate of Defense Trade Controls (DDTC) within the U.S. Department of State – which administers the International Traffic in Arms Regulations (ITAR) and the U.S. Munitions List (USML) under 22 CFR Part 121.

### USML Category XIII – Materials and Miscellaneous Articles:

- Graphite that is part of ablative materials—fabricated or semi-fabricated from advanced composites—specifically designed or modified for defense articles in USML Category IV or XV:
  - Category IV—Launch Vehicles, Guided Missiles, Ballistic Missiles, Rockets, Torpedoes, Bombs, and Mines
  - Category XV— Spacecraft and Related Articles

### Key Points:

- Graphite is considered a critical material for military applications, including aerospace engineering, advanced weaponry, and electronic warfare systems due to its high resistance to heat and corrosion.
- Graphite (and aluminum) are the two most used materials in the defense industry:
  - aircrafts
  - helicopters
  - amphibious assault ships, offshore patrol vessels, frigates, submarines
  - tanks, infantry fighter vehicle
  - artillery
  - missiles
- In defense applications, graphite is used in:
  - Radar-absorbent coatings for stealth technology
  - Thermal management systems in high-performance electronics
  - Advanced composites for lightweight armor and aerospace components
  - Drones and satellites, where weight, conductivity, and durability are critical
  - Military-grade lithium-ion batteries, which require high-purity, spherical coated graphite
- Graphite subject to the ITAR depends on its form and specific military application, e.g.:
  - Graphite as a base for ablative materials (used in heat shields) when those materials are specifically developed or modified for defense articles like missiles, rockets, or launch vehicles
  - Finished Defense Component: If graphite is machined into a specific part (e.g., a nozzle for a rocket or a component for electronic warfare) that is "clearly identifiable" as a defense article, the finished part falls under ITAR.
- Companies that work with or produce specialized graphite components for defense purposes are required to be ITAR-registered.