Export Control of Nuclear Reactor Components and Dual Use Materials and Equipment

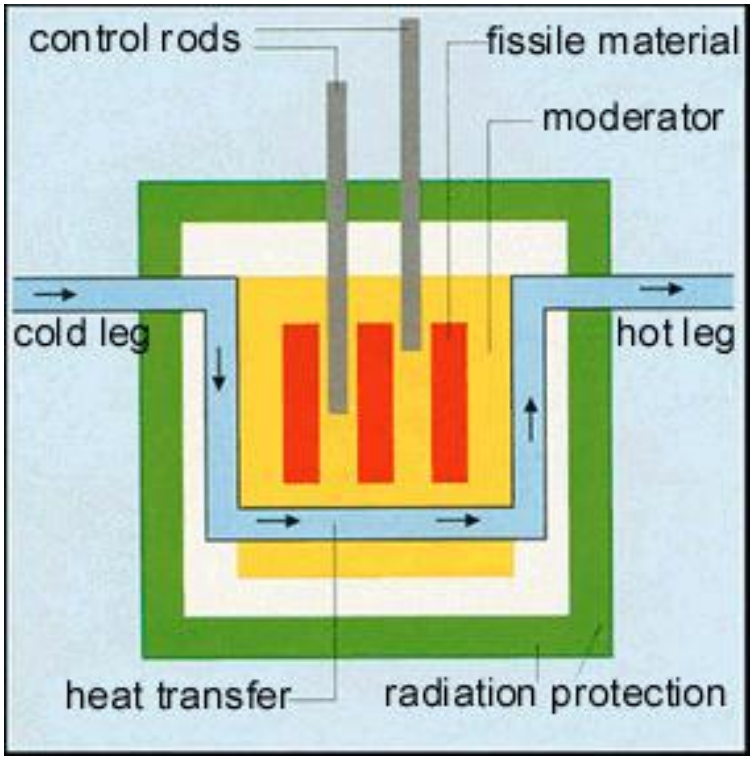
George Flanagan

Definitions Used in Export Control

- **NSG** — **Nuclear Supplier Group**
- **NSG- TL** — **Nuclear Suppliers Group Trigger List**
- **MTCR** — **Missile Technology Control Regime**
- **EU** — **European Union**
- **HTS** — **Harmonized Tariff Schedule**
- **HS** — **Harmonized Systems Code**
- **DU** — **Dual Use**

A Generic Nuclear Reactor

- Fuel
  - Uranium, Plutonium
- Moderators and Reflectors
  - Hydrogen, Deuterium, Graphite, Beryllium
  - Heavy water or graphite moderators permit the use of natural uranium, eliminating the need for enrichment.
- Coolants
  - Light water, heavy water, air, helium, liquid metal
- Control rods
  - hafnium, boron, cadmium
- Shields
  - lead, concrete, steel, water



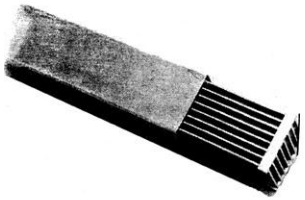
Nuclear Reactor Fuel

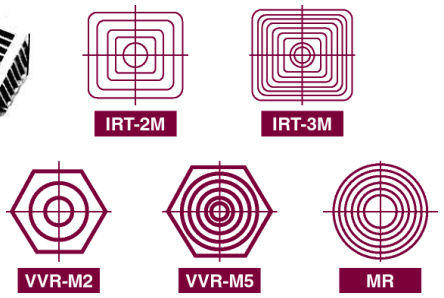
Assembly/Bundle: Most common fuel in commercial reactors (e.g., used in PWR/VVER/RBMK/Candu). For PWR/VVER, low enrichment uranium dioxide (UO_2) as fuel. (2.5-5% ^{235}U) . The pellets are inserted into fuel tubes made of zircalloy (an alloy of zirconium) and the individual fuel tubes are then arranged to make a fuel assembly.

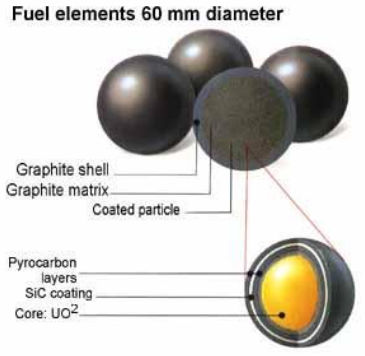
Plate: Commonly used in research reactors. Fuel assemblies are typically plates or cylinders of uranium-aluminum alloy (U-Al) clad with pure aluminum. Enrichment can vary greatly.

Plugs: Used in some graphite moderated production reactors. Old designs used natural (0.72% ^{235}U) Uranium metal, aluminum clad. Newer designs used slightly enriched (up to 1.25% ^{235}U) uranium metal, zirconium clad

Pebbles: Used in pebble bed reactors: Fuel "pebbles" contain fuel (coated pellets) and moderator (graphite). ~ 8% ^{235}U







Reactor Purposes

- **Power Reactors**
  - generate energy for electricity and sometimes also steam for district heating
- **Research Reactors**
  - used to develop weapons or energy production technology, for training purposes, for nuclear physics experimentation, and for producing radioisotopes for medicine and research
- **Production Reactors**
  - Used to produce materials that can be used in nuclear weapons

Reactor Types

- **Light Water Reactors (LWR)**
  - Pressurized Water Reactors (PWR
  - Vodo-Vodyanoy Energeticheskyi Reaktor (VVER)
  - Boiling Water Reactors (BWR)
- **Pressurized Heavy Water Reactors (PHWR)**
  - Canadian deuterium-uranium reactor (CANDU)
  - Advanced Heavy Water Reactors (AHWR)
- **Graphite-moderated/gas-cooled reactors (GCRs)**
  - Magnesium non oxidizing (Magnox)
  - Advanced Gas Cooled (AGR)
- **Light Water Cooled, Graphite Moderated Reactors (LWGR)**
  - Reaktor Bolshoi Moschnosti Kipyashchiy (RBMK)
  - Pressure Tube Graphite Reactor (PTGR)
- **Liquid-Metal Reactor (LMR)**
  - Liquid Metal Fast (Breeder) Reactors (LMFBR)
- **Modular High-Temperature Gas-Cooled Reactors (MHTGCR)**
  - Pebble Bed Modular Reactor (PBMR)
  - High-Temperature Test Reactor (HTTR)

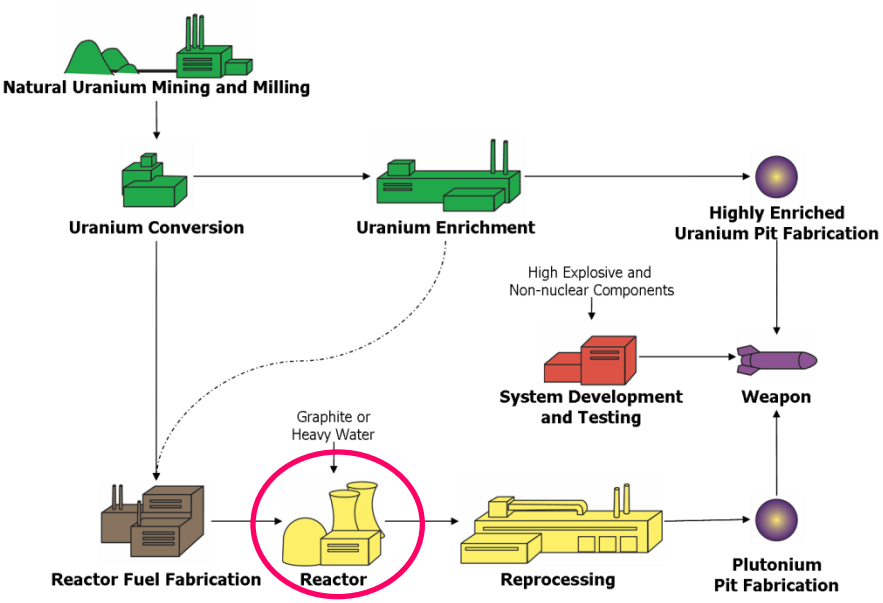
Research and Test Reactors

- **Many of the world's nuclear reactors are used for research and training, materials testing, or the production of radioisotopes for medicine and industry.**
- **These are much smaller than power reactors and many are on university campuses.**
- **There are 283 such reactors operating, in 56 countries (August 2003).**
- **The primary purpose of research reactors is to provide a neutron source for research and other purposes.**
- **Types: Pool, tank, homogeneous, critical (zero power), fast, graphite, pulse, PWR, BWR, rocket, thermionic**
- **Fuel enrichment varies: uranium (natural—90% ^{235}U), plutonium, aluminum clad, some stainless steel and magnesium.**
- **Fuel forms: uranium (metal, oxides), uranium-aluminum, uranium silicides, uranium sulfate solutions, uranium-zirconium hydride, uranium dispersed in graphite; plutonium (metal, oxides, carbides)**

Every weapons program has started from a research reactor. With sufficient power Pu production is possible from targets. Often come with complementary technologies (i.e., technology transfer). Often use highly enriched Uranium.

Nuclear reactors: Export Controlled Commodities

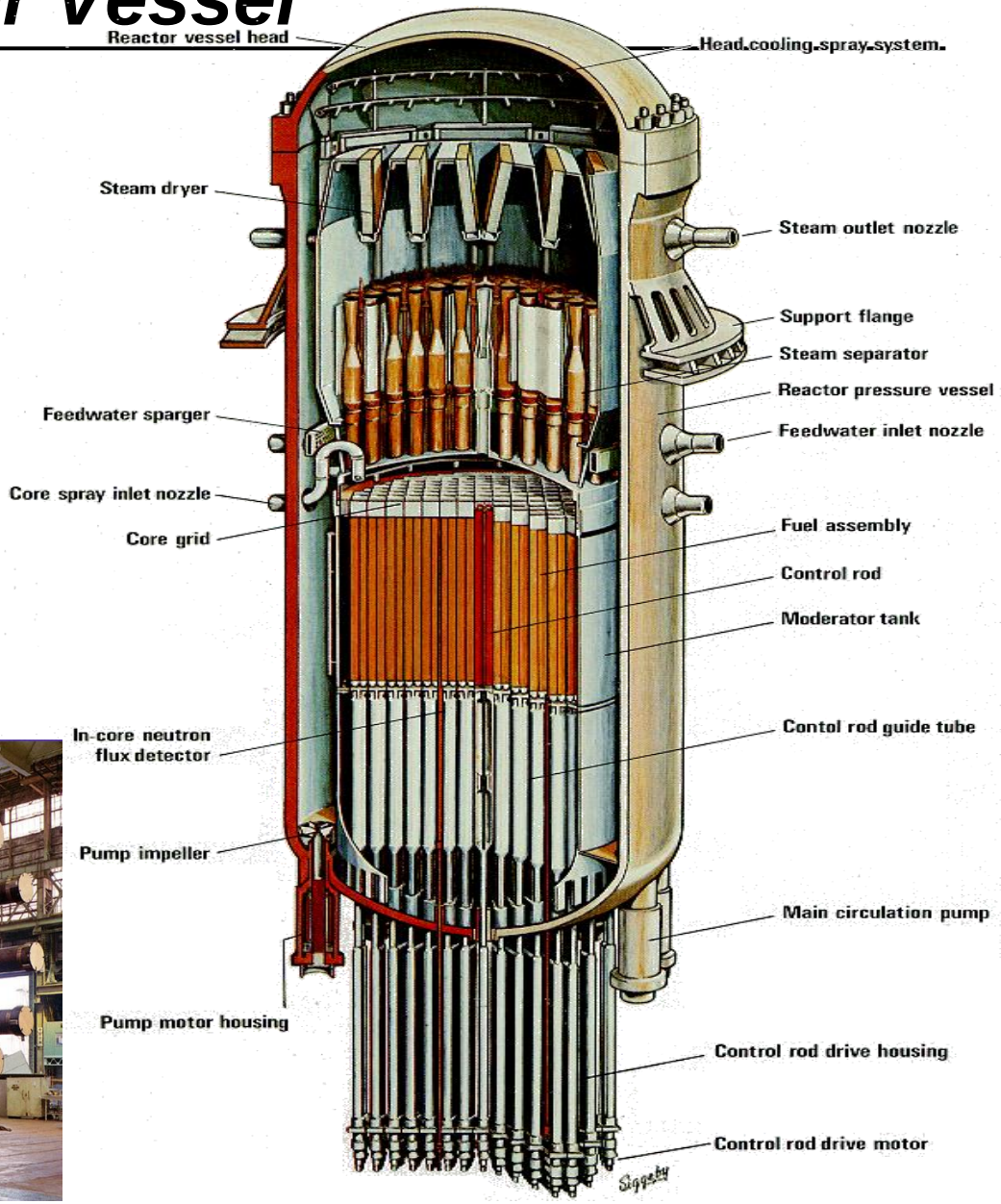
- **Especially Design or Prepared**
  - Complete nuclear reactors
  - Nuclear reactor vessels and internals
  - Nuclear reactor fuel charging and discharging machines
  - Nuclear reactor control rods
  - Nuclear reactor pressure tubes
  - Zirconium tubes
  - Primary coolant pumps
  - Heat exchangers (steam generators)
  - Neutron detectors
  - Deuterium (Heavy Water)
  - Graphite
- **Dual Use**
  - Zirconium
  - Hafnium
  - Beryllium



TL 1.2 Nuclear Reactor Vessel

- **Nuclear uses:**
  - Reactor vessels are used to contain the nuclear fuel while it undergoes fission.
- **Other uses**
  - None

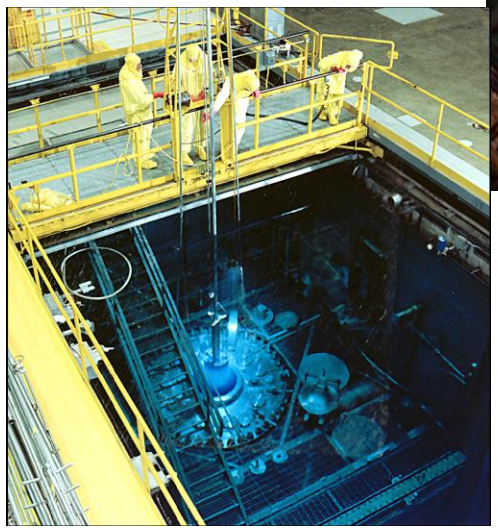
- **In most cases, the reactor core is contained in a single high-strength steel or concrete vessel that can withstand the intense radiation and contain the high pressure coolant circulating in the reactor core.**



TL 1.3 - Nuclear reactor fuel charging and discharging machines

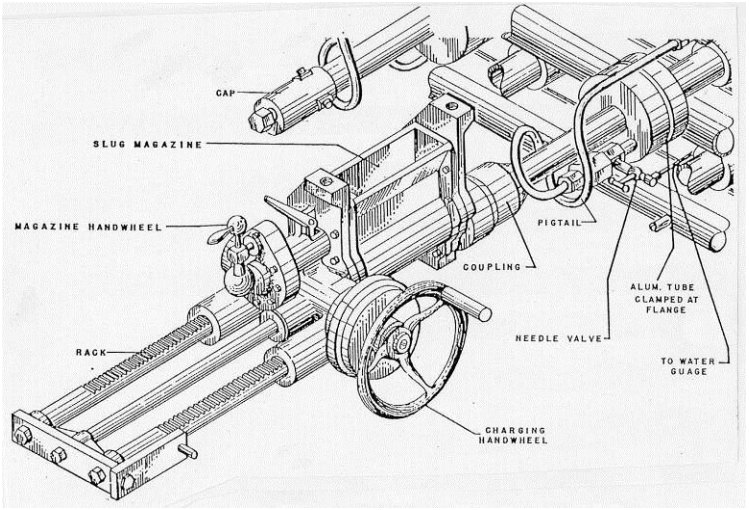
- **Nuclear uses:**
  - Used to remove irradiated fuel and add fresh fuel to a reactor
- **Other uses**
  - None
- **Fuel is placed into and removed from reactors using fuel charging and discharging machines. Depending on reactor design this may be done online or offline (i.e., operating versus shutdown)**

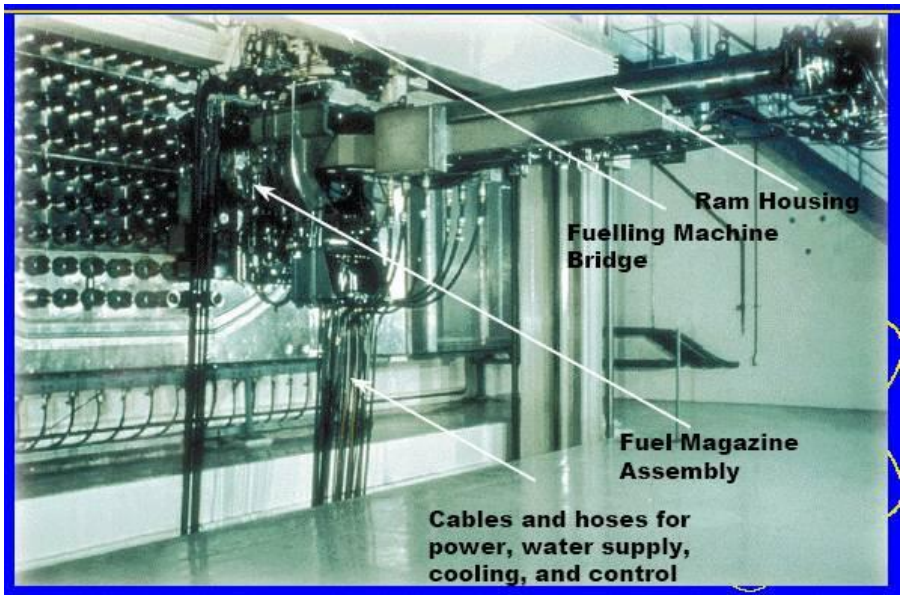
Refueling at a PWR (overhead crane)



1.3 - Nuclear reactor fuel charging / discharging machines - Appearance

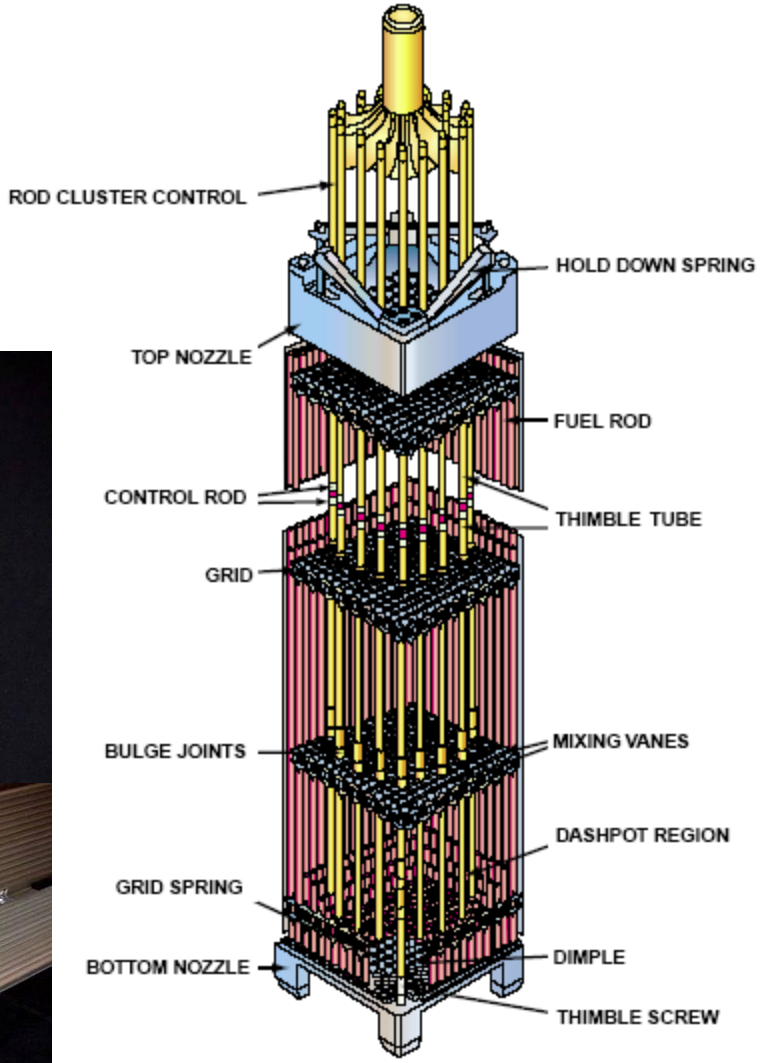
The appearance of fueling equipment varies dramatically in size and complexity with reactor design. (clockwise from right (N-reactor, CANDU, RBMK)





TL 1.4 - Nuclear reactor control rods and equipment

- **Nuclear uses:**
  - control the reactor's power level
- **Other uses**
  - None
- **Especially designed or prepared rods, support or suspension structures therefore, rod drive mechanisms or rod guide tubes to control the fission process in a nuclear reactor**



1.4 Nuclear Control Rod Drive Mechanisms

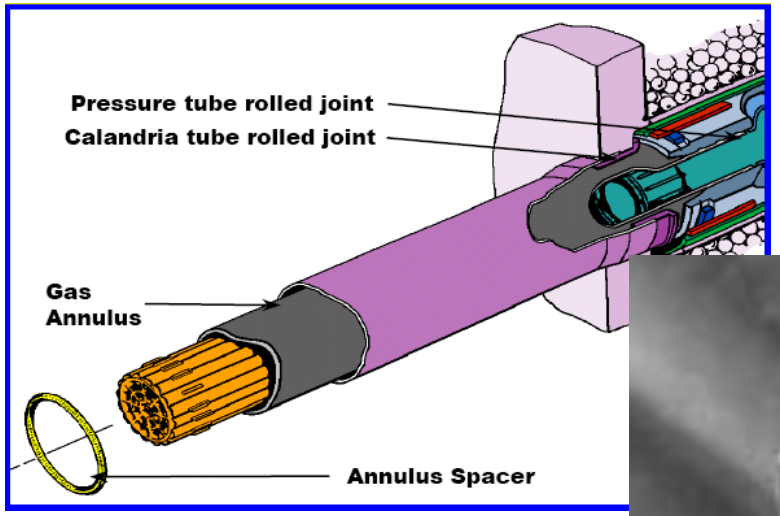
- **A device called a control rod drive mechanism (CRDM) withdraws control rods from the core to increase the power output of the reactor, holds the rods in a fixed position to maintain constant power, and inserts the rods into the core to reduce power.**

Control rod drive mechanisms of a 900-MWe PWR in China

Drive mechanisms for the control rods of a 22-MWt open-pool research reactor.

TL 1.5 – Nuclear Reactor Pressure Tubes

- **Nuclear uses:**
  - Contain nuclear fuel and the high pressure, high-temperature coolant. Their use facilitates online fuel handling by charging and discharging machines.
- **Tubes that contain fuel elements and the primary coolant. Also known as "process tubes". Used in both graphite and heavy water reactors.**

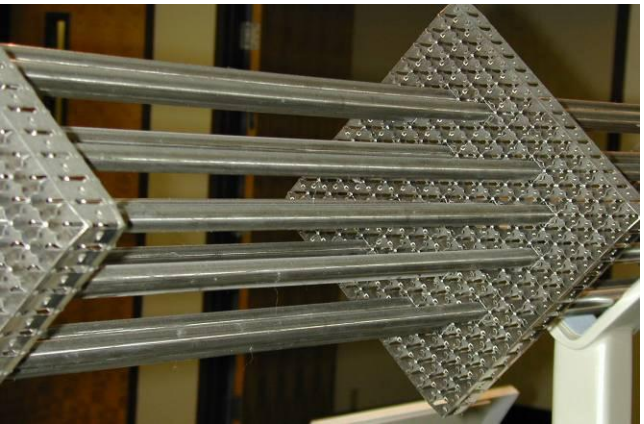


Bilibino NPP (LGR) Pressure Tubes (fresh fuel – stored vertically awaiting installation in reactor).

TL 1.6 – Zirconium Tubes

- **Nuclear uses:**
  - Encapsulate fuel in water-cooled, thermal nuclear reactors (BWR, PWR, VVER, etc).
- **Zirconium metal/alloys in the form of tubes or assemblies of tubes.**
  - Hafnium (Hf) to zirconium (Zr) ratio is < 1:500 parts by weight

PWR control rod guide tubes

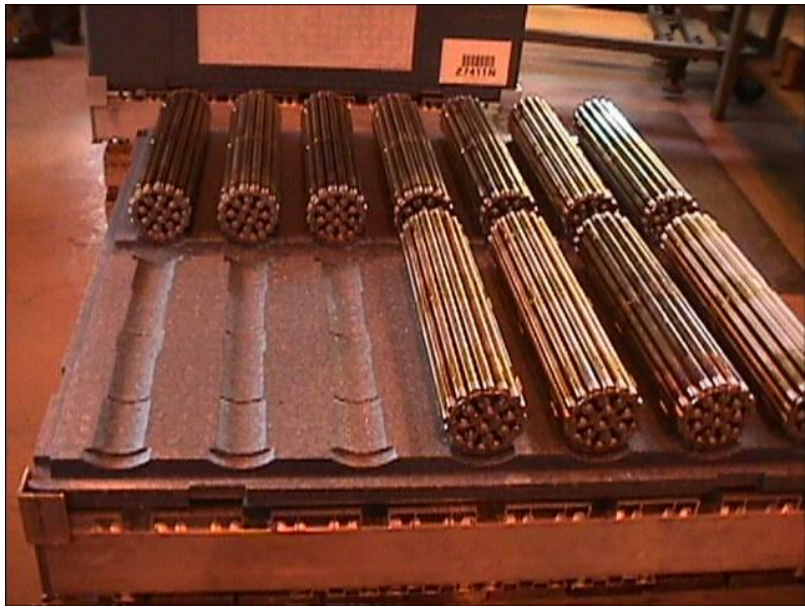


Cutaway example of VVER-1000 Fuel Assembly

1.6 – Zirconium Tubes Packaging

- **Zirconium tubes may be shipped as finished assemblies or individual tubes**
- **Zirconium intended for nuclear applications represents a substantial investment. Packaging that protects against damage is commonly used.**
- **Shipping containers may be either metal or wood.**

CANDU Fuel



TL 1.7 – Primary Coolant Pumps

- **Nuclear uses:**
  - circulate coolant through the reactor core.
- **Other uses**
  - None
- **Pumps especially designed or prepared for circulating the primary coolant for nuclear reactors**
  - Also known as “main coolant pump” or “reactor coolant pump”

This primary coolant pump for open-pool research reactor includes a 150-kW electric motor on the left, a flywheel in the center, and the pump on the right

1.7 Primary Coolant Pumps Packaging

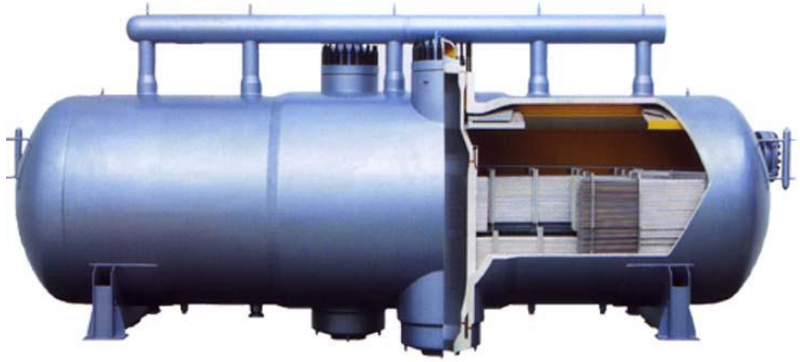
- **Primary coolant pumps will vary considerably in size and weight, depending on the design of the reactor.**
  - The smallest units may weigh less than 100 kg and can be packaged in a lightweight frame or crate easily moved by forklift.
  - The largest units may weigh more than 100 tonnes and are packaged in a sealed casing. These units require a specialized lifting frame and crane for handling.
- **Casings of such pumps may be marked with an ASME “N” stamp**

TL 1.9 Heat Exchangers Appearance

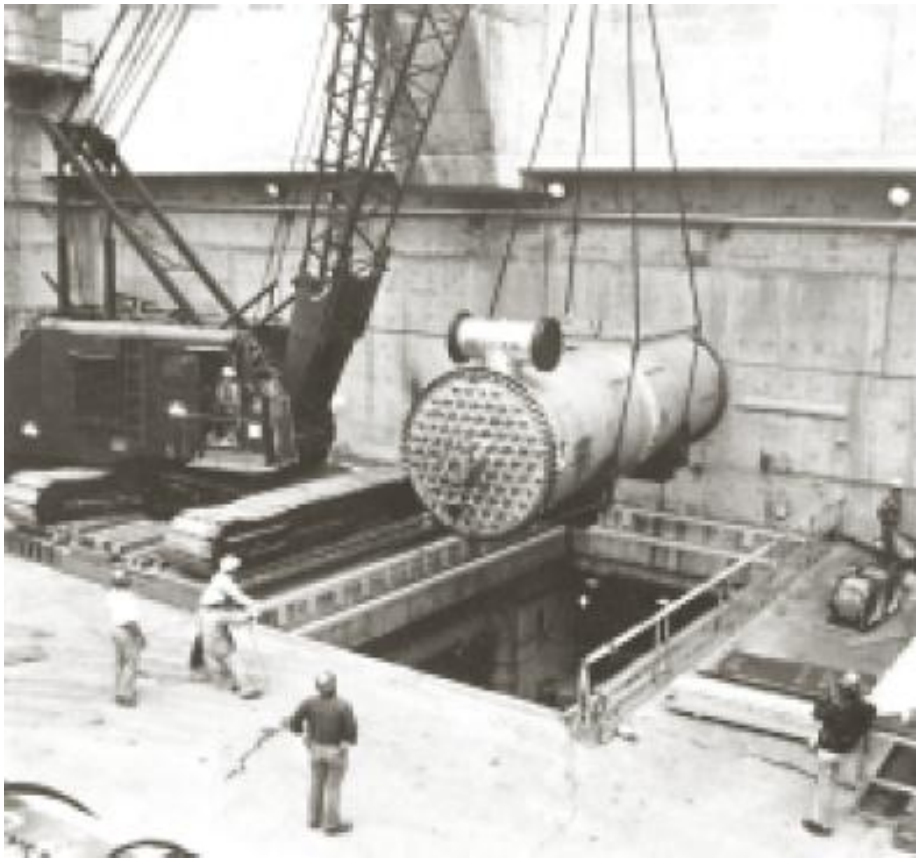
- **Nuclear uses:**
  - Steam production and cooling reactor coolant through the reactor core.
- **Other uses**
  - None
- **Pumps especially designed or prepared for circulating the primary coolant for nuclear reactors**
  - Also known as “main coolant pump” or “reactor coolant pump”
- **Typical PWR steam generator is a tall, vertical cylinder shaped somewhat like a “light bulb” with a slender lower section and a larger diameter upper section.**
  - height can exceed 20 m.
  - the lower and upper shells, which are made from steel, contain several access openings, including hand holes and manways (openings large enough for a human to enter).

TL 1.9 Heat Exchangers Appearance

- **Horizontal Heat Exchangers**
  - More closely resemble standard commercially available heat exchangers used in many non-nuclear industrial heat transfer systems



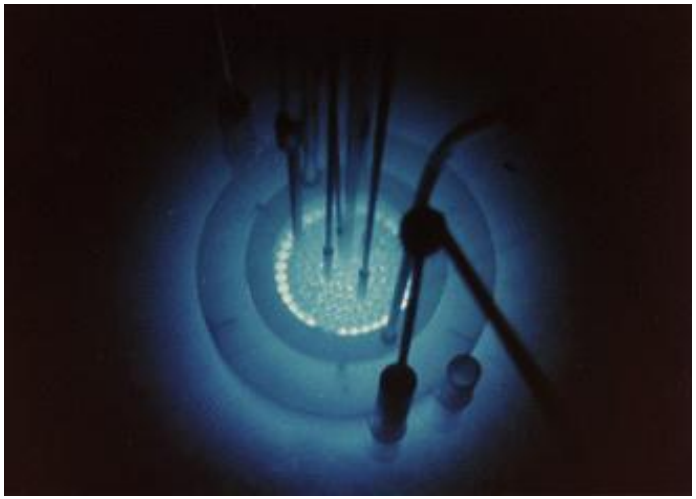
Horizontal Steam Generator for VVER reactor



Shell & tube heat exchanger for a heavy water-moderated reactor

1.10 Neutron detection

- **Neutron detection and measuring instruments for determining neutron flux levels in a nuclear reactor**
  - proportional counters, fission chambers, and compensated ion chambers
- **Controls:**
  - NSG TL 1.A.2.
  - EU ECCN 0A001.j
- **Nuclear uses:**
  - Neutron detectors monitor nuclear reactor power level



Neutron detectors in use (lower right)

1.10 Neutron detection

- **Appearance**
  - cylindrically-shaped, typically 5-13 cm diameter, 2-20 cm length
  - aluminum housing
  - several electrical leads coming from one end (may be wrapped together)
  - tube chambers usually sealed
- **Packaging and Handling**
  - container made of metal, fiberglass, plastic, or wood
  - surrounded by foam rubber or Styrofoam to absorb shock and vibration

A variety of neutron detectors

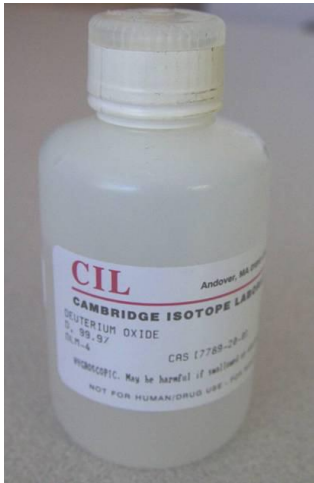
2.1 Heavy Water (Deuterium Oxide)

- **Heavy water: Water with deuterium (heavy hydrogen) atoms replacing hydrogen atoms**
  - Quantities more than 200kg per country per 12 months
  - Deuterium (D_2) and other deuterium compounds also controlled
- **Controls**
  - HTS 2845.10
  - NSG TL 2.1
  - EU 0C003
- **Nuclear uses**
  - Used as a moderator in nuclear reactors
  - Makes a sustained nuclear chain reaction possible with natural uranium
- **Other uses**
  - Research (small quantities)

2.1 Heavy Water: Appearance

- **Colorless liquid**
  - Heavy water is not visually distinguishable from regular water, although pure heavy water is about 10% more dense
- **Not radioactive**
- **Label**
  - Formula: D_2O
  - CAS #: 7789-20-0
  - EC #: 232-148-9
  - No UN number: not hazardous for transport
- **Synonyms**
  - Deuterium Oxide
  - Dideuterium Oxide
  - Heavy Water – D2
  - Water – D2

Two flasks containing regular water (left) and heavy water (right)



Small, research-sized bottle of heavy water; note CAS# on label and use of name "deuterium oxide"

Heavy Water: Packaging and Handling

- **Typically packaged in stainless steel drums with volume between 150 and 200 liters.**
  - Approximate weight of 200L drum would be ~230kg
- **Usually the tops of the drums have removable plugs**
  - One smaller than the other (~5.1 cm and 1.9cm respectively)
  - Used to transfer heavy water using pressurized inert gas
- **Drums would usually be on wooden pallets so that they can be maneuvered by fork lift.**

Drums containing heavy water

Heavy Water: Major Producers and Distributors

- **US:** **Cambridge Isotope Laboratories (research quantities)**
- **Canada:** **Ontario Power Generation**
- **Europe:** **ROMAG (Romania)**
- **Asia:** **Heavy Water Board (India; multiple plants), Arak (Iran; under construction), Multan (Pakistan)**
- **South America:** **Arroyito Heavy Water Plant/ENSI (Argentina)**
- **Former Soviet Union:** **Dneprodzerzhinsk (Ukraine)**

Production of heavy water for reactors requires large scale facilities to separate heavy water from regular water.

Equipment for heavy water production is also controlled by the NSG.

Deuterium and Heavy Water Commercial Uses

- **Moderator in CANDU reactors**
- **Nuclear magnetic resonance spectroscopy**
  - When the solvent of interest is water and the nuclide of interest is hydrogen
- **Fourier Transform Spectroscopy**
  - Often used instead of water when collecting spectra of proteins in solution
- **Neutrino Detection**
  - The Sudbury Neutrino Observatory (SNO) in Sudbury, Ontario used 1000 tonnes of heavy water
- **Deuterium used as non-radioactive isotopic tracer in molecules to study chemical and biochemical reactions**
- **Deuterated samples often used in neutron scattering techniques**

Non-industrial quantities of heavy water (i.e., in the gram to kg range) are routinely available through chemical supply dealers and from commercial companies (such as Ontario Hydro) for ~$650/kg of 99.98% purity. Smaller quantities can be purchased for ~$1 per kg

Need tonnes for a nuclear reactor application

Dual-Use Materials Useful in Reactors

- **Materials**
  - Graphite
  - Zirconium
  - Hafnium
  - Beryllium

Graphite Controls

- **NSG TL:** 2.2
- **EU** 0C004
  - Graphite having a purity level better than 5 ppm boron equivalent with a density greater than 1.50 g/cm^3 for use in a nuclear reactor …
- **MTCR** 6.C.3, 6.C.4, **EU** 1C107
  - Fine grain graphites
    - *bulk density ≥1.72 g/cm^3 and*
    - *grain size ≤100µm*
    - *which can be machined to any of the following products:*
      - Cylinders having a diameter ≥120 mm and length ≥ 50
      - Tubes having an inner diameter ≥ 65 mm and a wall thickness ≥ 25 mm and a length ≥ 50 mm
      - Blocks having a size of 120 mm x 120 mm x 50 mm or greater
  - Pyrolytic or fibrous reinforced graphites …
- **HS:** 3801.10, 3801.90, 6815.10, 8545.19, 8545.90

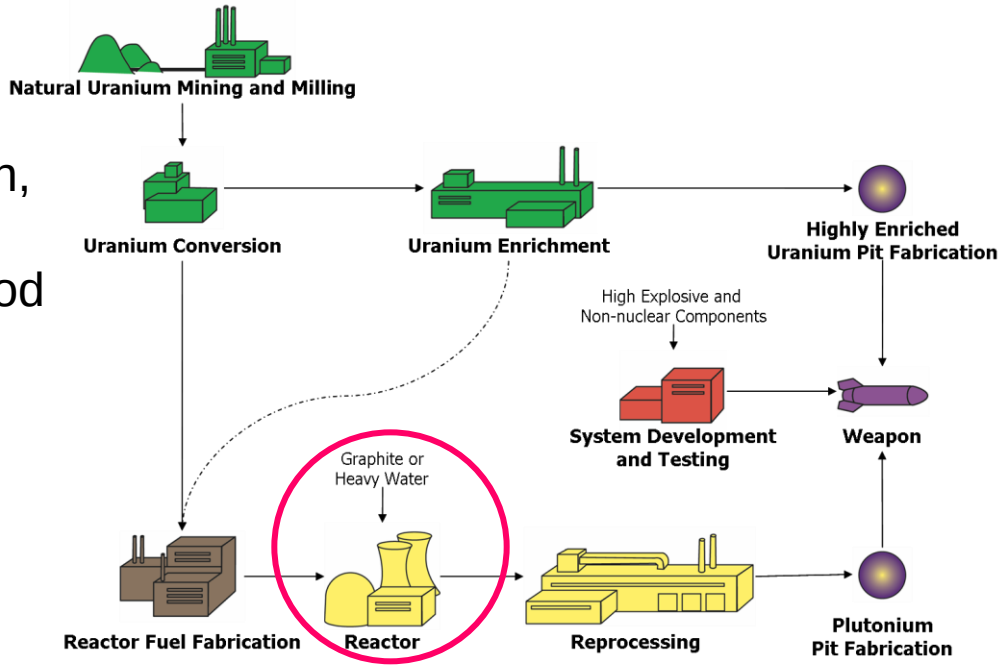
Graphite Controls

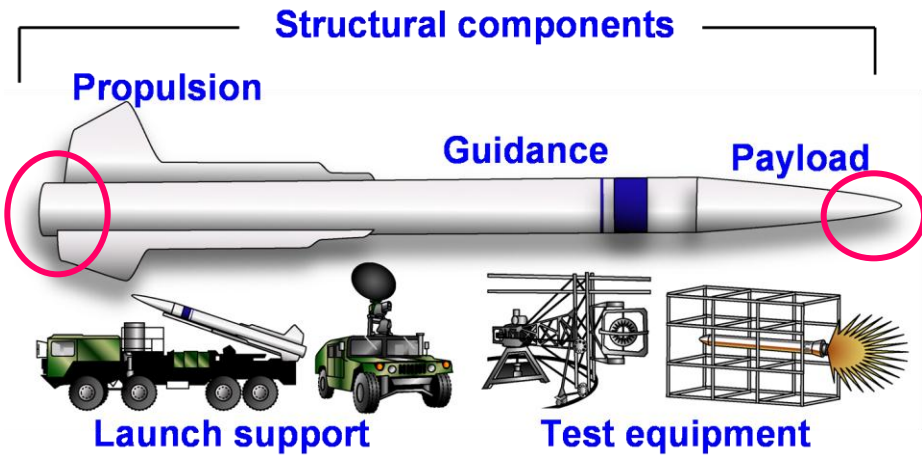
- **EU 0C004**
  - Graphite, nuclear grade, having a purity level of less than 5 parts per million ’boron equivalent’ and with a density greater than 1,5 g/cm^3.
  - does not control:
    - *Manufactures of graphite having a mass less than 1 kg, other than those specifically designed or prepared for use in a nuclear reactor*
    - *Graphite powder*

Graphite
Definition and Reasons for Control

- **Definition**
  - Graphite is a form of carbon with significant resistance to corrosion, low neutron absorption, high strength at high temperature, good resistance to ablation, and good machinability
- **Nuclear uses:**
  - Nuclear reactor moderator
- **Missile uses:**
  - Rocket nozzles
  - Reentry vehicle nose tips

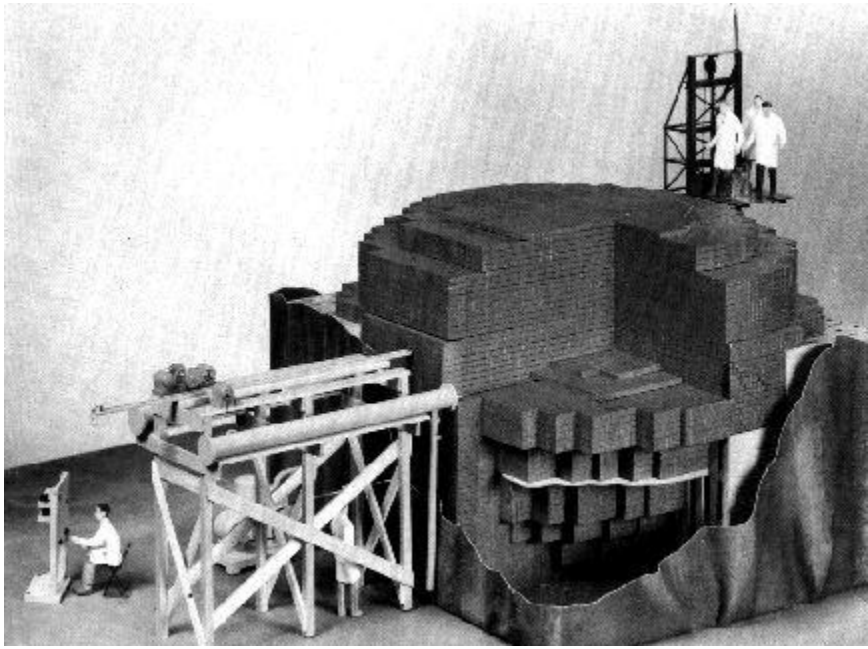
Various rocket nozzles





Graphite Commodity Information

- **Naturally occurring graphite**
  - Highly anisotropic
  - Contains other elements
- **Use of synthetic graphite made from other precursor materials is more common**
  - Can be made isotropic with appropriate molding or pyrolyzation parameters
  - Can be made more pure than natural graphite
- **Due to improvements in production processes, much graphite now produced meets the nuclear and missile specifications**

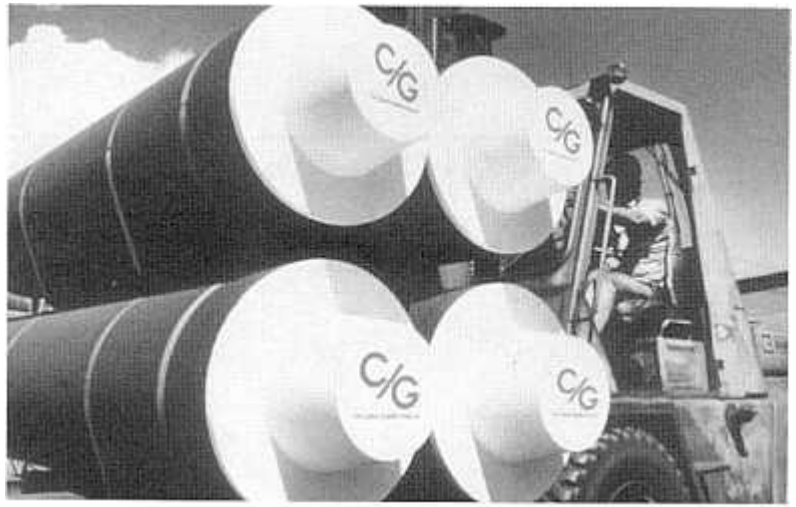


A cutaway view of the CP-1 graphite moderated reacto

Graphite block

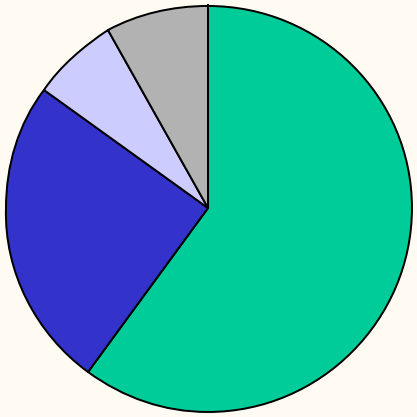
Graphite
Commercial Uses and Resources

- **Most molded graphite is used as electrodes for steel or aluminum production and not for nuclear or missile applications**



Molded graphite electrodes for steel production

Figure 1. Worldwide consumption of graphite



** semiconductor, electrical, chemical, nuclear, biomedical, mechanical, and aerospace*

Table 1. Density Specification for Certain Graphite Electrodes

Vendor	Grade	Density ($g/cm^{3)}$
Superior Graphite	HP	1.57 – 1.70
	UHP	1.66 – 1.77
	PINS	1.74 – 1.82
Graphite Sales	GS-10	1.60
	GS-30	1.76
	GS-40	1.72
	GS-50	1.68
	GS-70	1.73

Graphite
Commercial Uses and Resources

- **Toyo Tanso**
  - www.toyotanso.co.jp
- **Group Carbone Lorraine**
  - www.carbonelorraine.com
- **POCO**
  - www.poco.com
- **Minteq Pyrogenics Group, Minerals Technologies**
  - www.minteq.com
- **Graphite Machining, Inc**
  - www.graphitemachininginc.com
- **NAC Carbon Products**
  - www.naccarbon.com
- **Graphite India, Ltd**
  - www.graphiteindia.com
- **Ibiden Graphite**
  - www.ibiden.com/sc/en/index.html
- **Tokai Carbon Company, Ltd**
  - www.tokaicarbon.co.jp/
- **Metaullics**
  - www.pyrotek.info/listings.php?id=246

Graphite nose cone

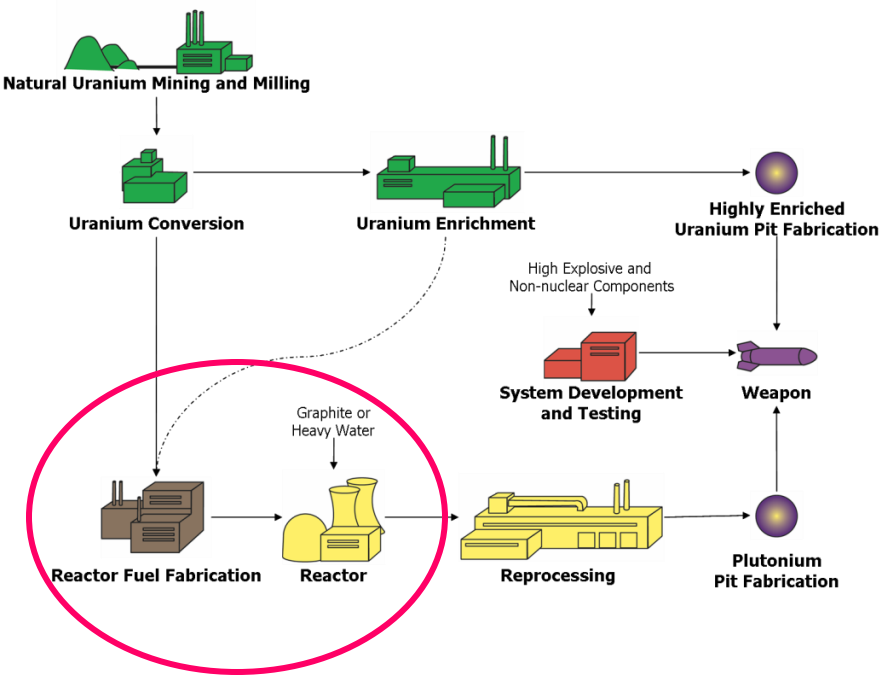
Graphite nozzle throat

Zirconium Controls

- **EU:** 1C234
- **NSG DUL:** 2.C.15
  - With a hafnium content less than 1 part hafnium to 500 parts zirconium by weight
  - Alloys containing > 50% Zr by weight
  - Compounds, manufactures, waste, or scrap of any of the foregoing
- **NSG TL 1.6 (tubes)**
- **MTCR 4.C.2 (powder)**
- **HTS:** 8109, 2825.60, 2825.90, 2826.19, 2827.39, 2827.60, 7202.99

Zirconium
Definition and Reasons for Control

- **Definition**
  - Zirconium is a corrosion-resistant metal ideal for use in nuclear reactors due to its low neutron absorption
- **Nuclear uses:**
  - Nuclear reactor fuel cladding and other reactor internal components



CANDU Fuel

Zirconium Commodity Information

- **Naturally occurring zirconium (Zr) contains about 2% hafnium (Hf)**
  - For nuclear applications, the Hf must be removed, which entails difficult and costly separation processes
- **Zirconium that is free of hafnium has low neutron absorption, high thermal conductivity, dimensional stability at high temperatures, and good corrosion resistance, making it an excellent material for use in a nuclear reactor core**
  - Zr compounds with low Hf are of concern primarily because they can be a source of low-Hf Zr
- **More than 90% of zirconium metal production is consumed by commercial nuclear power generation**
  - But non-nuclear applications are increasing rapidly
- **Zircaloy refers to a group of high-Zr alloys having < 0.01% Hf that are especially well suited for nuclear reactor applications:**
  - Zircaloy-2
  - Zircaloy-4
- **In the past few years there has been significant development of (Zr- 1% Niobium) alloys**
  - E110 (Russian)
  - Zirlo (Westinghouse)
  - M5 (Framatome-ANP).

Zirconium
Commercial Uses and Resources

- **Non-nuclear uses of Zr do NOT require low Hf content**
  - Hafnium-free zirconium can be 10 times more expensive than zirconium with naturally occurring 1-5% of hafnium.
  - But as the market value of Hf increases, its separation becomes economical, and low-Hf Zr can be economical even for non-nuclear uses

- **For non-nuclear applications, Zr has two main alloys:**
  - ASTM R60702 (Zr 702) unalloyed
  - ASTM R60705 (Zr 705), which is alloyed with 2.0-3.0 percent niobium

Table 1. Mechanical Properties of Zirconium

Zirconium Grade ASTM Designation	702 R60702	704 R60704	705 R60705	706 R60705
Tensile Strength, min ksi (MPa)	55(379)	60(413)	80(552)	74(510)
Yield Strength, min. ksi (MPa)	30(207)	35(241)	55(379)	50(345)
% Elongation, (0.2% offset)	16	14	16	20
Min. Bend Test Radius	5T	5T	3T	2.5T

Table 2. Chemical Properties of Zirconium

Zirconium Grade ASTM Designation	702* R60702	704 R60704	705* R60705	706 R60706
Zr+Hf, min.	99.2	97.5	95.5	95.9
Hafnium, max.	4.5	4.5	4.5	4.5
Fe+Cr, max.	0.2	0.2-0.4	0.2	0.2
Sn	—	1.0-2.0	—	—
Hydrogen, max.	0.005	0.005	0.005	0.005
Nitrogen, max.	0.025	0.025	0.025	0.025
Carbon, max.	0.05	0.05	0.05	0.05
Niobium	—	—	2.0-3.0	2.0-3.0
Oxygen, max.	0.16	0.18	0.18	0.16

*Approved for use in ASME Boiler and Pressure Vessel Code Construction

Zirconium
Commercial Uses and Resources

- **Chemical processing industry**
  - Zirconium can withstand highly corrosive environments, including most organic and mineral acids, strong alkalis, and some molten salts
    - *BUT: vulnerable to attack by hydrofluoric acid, acidic oxidizing chloride solutions such as ferric or cupric chloride solutions, red fuming nitric acid, concentrated sulfuric acid, aqua regia and wet chlorine environments*
  - Used for making heat exchangers, condensers, columns, pumps, piping systems, reactor vessels and valves, etc.

Zircadyne 702 column section will be used in the production of acetic anhydride

Zirconium heat exchanger http://www.titanmf.com

Zirconium
Commercial Uses and Resources

- **Non-nuclear applications**
  - zirconium chemicals and oxides have a wide variety of applications, including
    - *automotive catalysts*
    - *electro-ceramics*
    - *structural ceramics*
    - *thermal barrier coatings*
    - *optical glass/fibre optics*
    - *paints/pigments*
    - *solid oxide fuel cells*

Zirconium oxide

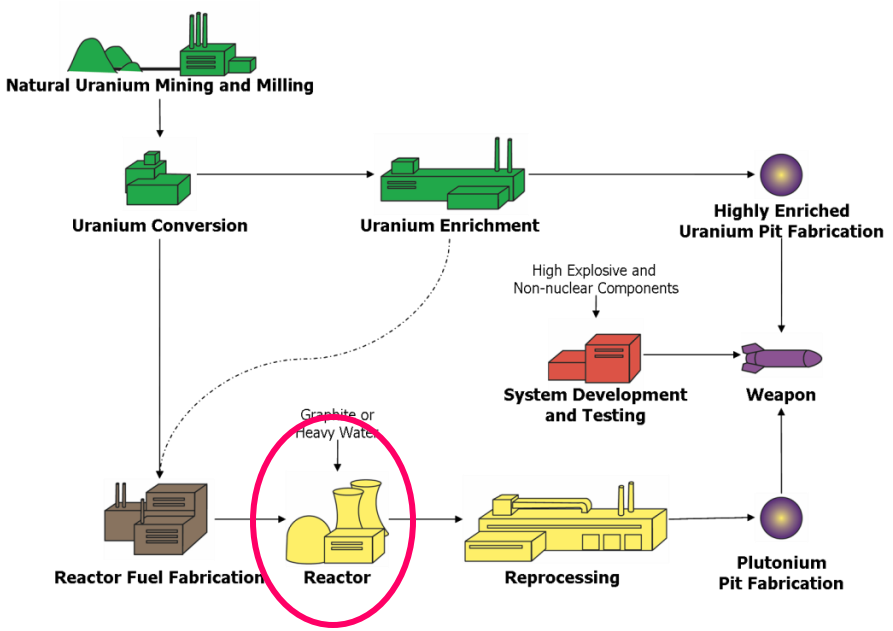
Zirconium Seizure

- In June 1995, Customs agents in New York arrested three men on charges of attempting to smuggle 7 tons of nuclear-grade zirconium to Iraq.
- The investigation, in which undercover Customs agents posed as Iraqi military officials, resulted in the seizure of five tons of zirconium in America and another two tons in Cyprus.
- The zirconium in this case had been smuggled from Ukraine, through Germany, to New York and Cyprus, where it awaited export to Iraq (circuitous route!)

Zirconium ingot seized by US Customs
http://www.cbp.gov/xp/cgov/border_security/antiterror_initiatives/safeguarding_america.xml

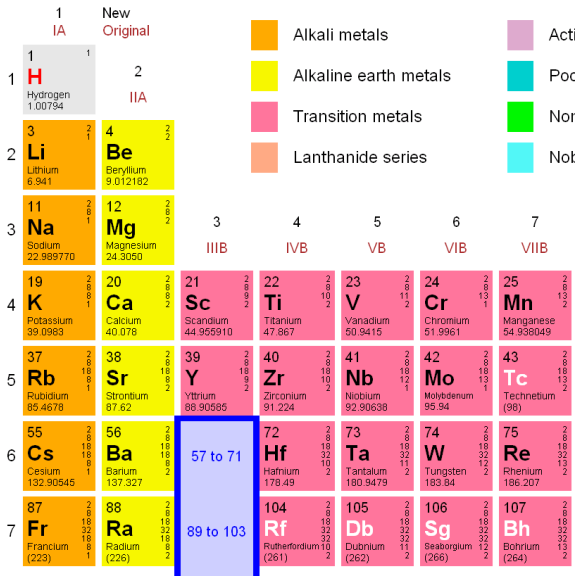
Hafnium

- **Controls:**
  - HTS 2825.90, 2850.00, 8112
  - NSG DUL 2.C.8
    - *Metal, alloys containing > 60% Hf by weight*
    - *Compounds, manufactures, waste, or scrap of any of the foregoing*
  - EU 1C231



Hafnium – nuclear uses

- **Hafnium is produced for nuclear applications by the same companies that produce low-hafnium zirconium, but for opposite nuclear purposes**
  - Hafnium possesses the same desirable properties as zirconium except that it has a very high thermal neutron absorption cross section (~600x that of Zr), making it ideal for use as control rods in fission reactors
  - Hf control rods have a very long life as many of the Hf isotopes produced by the absorption of neutrons are also strong neutron absorbers
- **Hf oxide is often used in the production of shields for nuclear reactors**



Hafnium – non-nuclear uses

- **Commercial uses of Hf**
  - Small quantities of hafnium added to nickel-base superalloys create aerospace metals of exceptional strength, ductility and resistance to heat and oxidation
  - Hafnium-based alloys, which readily form a hard, smooth, adherent oxide surface, are also well-suited for use as surgical implants.
  - Hafnium wire is used worldwide as tip material in air arc cutting torches.

Beryllium Controls

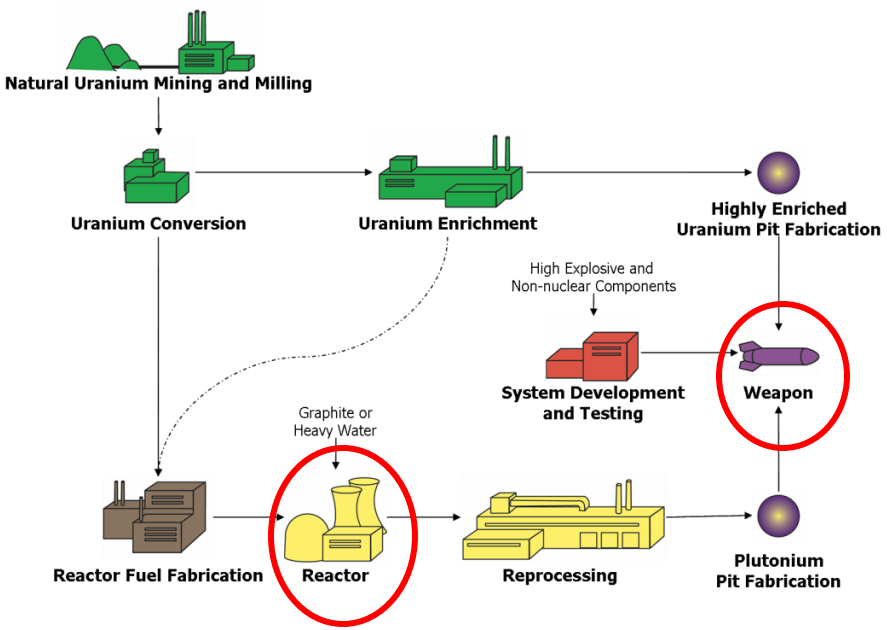
- **EU: 1C230**
- **NSG DUL: 2.C.2**
  - Beryllium metal, alloys containing more than 50% beryllium by weight, beryllium compounds, manufactures thereof, and waste or scrap of any of the foregoing
  - Exceptions:
    - *Metal windows for X-ray machines, or for bore-hole logging devices*
    - *Oxide shapes in fabricated or semi-fabricated forms specially designed for electronic component parts or as substrates for electronic circuits*
    - *Beryl (silicate of beryllium and aluminium) in the form of emeralds or aquamarines*

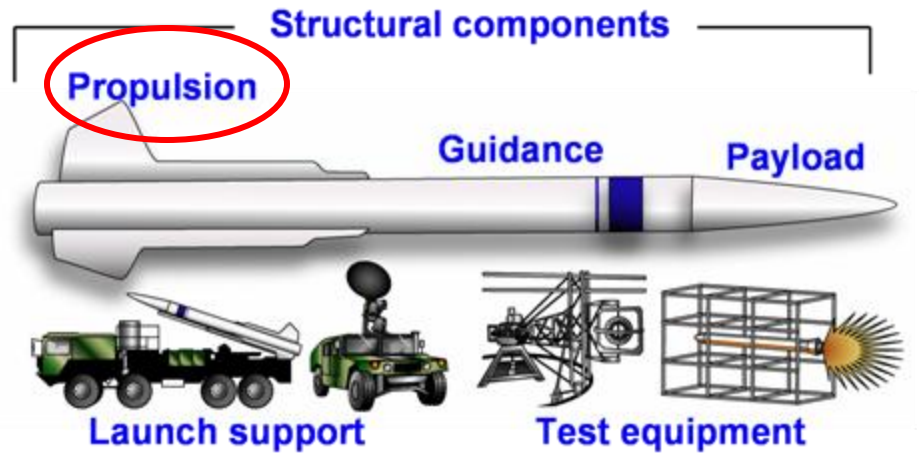
- **MTCR: 4.C.2.d**
  - Zirconium (CAS 7440-67-7), beryllium (CAS 7440-41-7), magnesium (CAS 7439-95-4) and alloys of these in particle size less than 60 x 10-6 m (60 µm), whether spherical, atomised, spheroidal, flaked or ground, consisting of 97% by weight or more of any of the above mentioned metals

- **HS 2825.90, 2833.29, 2834.29, 2836.99, 8112.11-19**

Beryllium
Definition and Reasons for Control

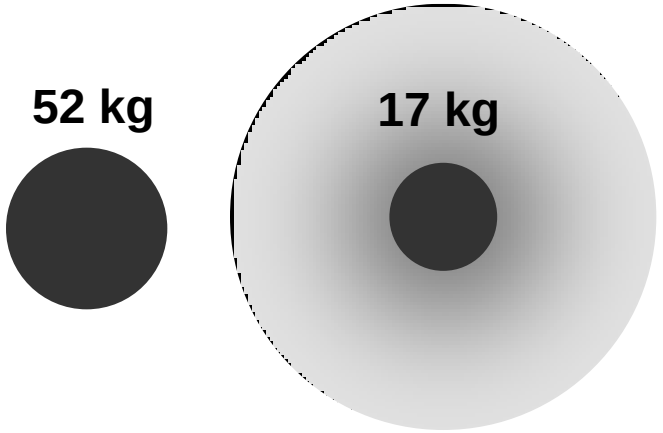
- **Definition**
  - Steel grey metal known for being both high strength and light-weight
- **Nuclear uses**
  - Neutron reflector
  - Initiator devices
- **Missile uses**
  - Beryllium powder can be used as a fuel substance for propulsion



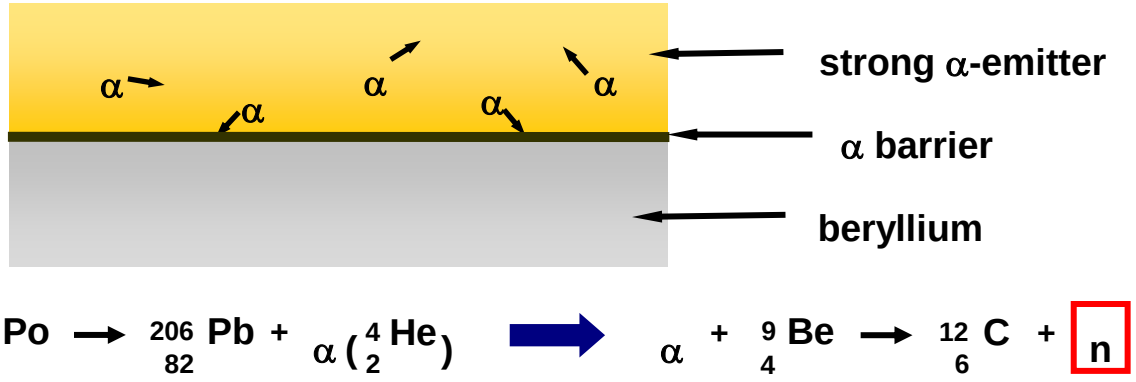


Beryllium Nuclear Uses

- **Reactors and Weapons**
  - Neutron reflector or moderator
  - Initiator devices
    - *(α,n) Initiator – based on the reaction in which α particles from a radioactive isotope (e.g., polonium-210) interact with a light element (e.g., beryllium), thereby releasing neutrons*



^{235}U critical mass with and without thick Be reflector



Beryllium
Unique and Interesting Properties

- **Lighter than aluminium yet stiffer than steel**
  - density about 30% less than that of aluminium, about one tenth that of steel
  - specific stiffness (Youngs modulus/density) is 6 times greater than its nearest rival.
- **High heat capacity AND high heat conductivity**
- **High melting point (>2000°C)**
- **Transparent to X-rays**
  - used to make windows for X-ray generators and detectors
- **Reflects neutrons**
  - high neutron scattering cross section, low neutron absorption cross section

These unique properties make beryllium very attractive for many aerospace structures and for precision instrumentation such as inertial guidance systems, space telescopes, targeting systems and spinning optics. Many parts of supersonic aircraft are made of beryllium alloys because of their lightness, stiffness, and dimensional stability.

Beryllium Commercial Uses

- **Beryllium-copper is one of the most common beryllium alloys**
  - Account for about three-quarters of all the beryllium produced. They conduct heat and electricity almost as well as pure copper but are stronger, harder, and more resistant to fatigue and corrosion.
  - Used in circuit boards, radar, computers, home appliances, aerospace applications, automatic systems in factories, automobiles, aircraft landing systems, oil and gas drilling equipment, and heavy machinery.
  - As the Beryllium content is <2%, this alloy is NOT controlled

- **Beryllium-aluminum alloys**
  - Combine beryllium's light weight and high stiffness with aluminum's excellent processing characteristics and low cost
  - Often contain more than 50% Be and so typically do meet the control specification

- **Beryllium oxide (Beryllia) is unique among ceramic materials, since it combines an extremely high electrical resistivity and dielectric constant with a large thermal conductivity and extremely high melting point (2530°C)**
  - Used in many high-performance semiconductor parts
  - Used as a structural ceramic for high-performance vacuum tubes, magnetrons, and gas lasers
  - Used as a heat dissipation medium in a wide range of miniaturized high-power circuitry applications in the defense, aerospace and commercial markets