ANNEX III[*]
Restricted Nuclear Goods, Commodities, and Technologies

Pursuant to paragraph 5 (b) of resolution 2087 (2013), the items contained in this document are subject to the provisions of paragraph 8 (a), 8 (b) and 8 (c) of resolution 1718 (2006) under the DPRK sanctions regime;
and pursuant to resolution 1929 (2010) under the Iran sanctions regime
(corresponding with document INFCIRC/254/Rev.11/Part1-1)

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[*] Annex III to Enrico Carisch and Loraine Rickard-Martin, "United Nations Sanctions on Iran and North Korea: An Implementation Manual," New York: International Peace Institute. March 2014.

SPECIAL FISSIONABLE MATERIAL

INFCIRC/254/Rev.11/Part1 ANNEX B

Plutonium-239

For plutonium to reach this state it has to be processed from U-238. Plutonium in this form has gone through a nuclear reactor.

Varies based on level of enrichment and portion of Pu-240 inherent in the metal. ~5 kg of very pure Pu-239 is enough for a strategic nuclear weapon.

This metal is extremely heavy per unit of volume.

This is a radioactive isotope of plutonium; it generally will be transported in ways to minimize radioactive exposure—lead-lined containers, etc.

Uranium-233

Made from thorium-232. It has never been used to generate power or in nuclear weapons, but it has been used in research reactors.

Production costs alone have been estimated at 2–4 million per kilogram during the Cold War.

This metal is extremely heavy per unit of volume.

This is a radioactive isotope of uranium; it generally will be transported in ways to minimize radioactive exposure—lead-lined containers, etc.

Uranium-235

U-235 is the only naturally-found isotope of uranium that can sustain a fission reaction. It makes up 0.72% of all naturally found uranium.

~7 kg of U-235 can be used to make an atomic bomb. 1 kg can produce the same amount of energy as 3000 metric tons of coal in civilian use. Price would vary by level of enrichment—that is, the percentage of the uranium sold that is U-235 vs U-238 (the “standard” isotope).

This metal is extremely heavy per unit of volume.

This is a radioactive isotope of uranium; it generally will be transported in ways to minimize radioactive exposure—lead lined containers, etc.

NUCLEAR REACTORS AND ESPECIALLY DESIGNED OR PREPARED EQUIPMENT AND COMPONENTS

INFCIRC/254/Rev.11/Part1 ANNEX B Section 1

1.1 Complete nuclear reactors

Nuclear reactors capable of operation so as to maintain a controlled self-sustaining fission chain reaction, excluding zero energy reactors, the latter being defined as reactors with a designed maximum rate of production of plutonium not exceeding 100 grams per year. Note: A "nuclear reactor" basically includes the items within or attached directly to the reactor vessel, the equipment which controls the power level in the fore, and the components which normally contain or come into direct contact with or control the primary coolant of the reactor core. It is not intended to exclude reactors which could reasonably be capable of modification to produce significantly more than 100 gram of plutonium per year. Reactions designed for sustained operation at significant power levels, regardless of their capacity for plutonium production are not considered as "zero energy reactors."

Rosatom, a Russian state-owned nuclear company, has sold reactors to Turkey, Vietnam, China, and India.

Size varies widely by reactor; research reactors can be rather small while power reactors are generally massive and too large to ship as an assembled entity.

1.2 Nuclear reactor vessels

Metal vessels, or major shop-fabricated parts therefor, especially designed or prepared to contain the core of a nuclear reactor (see 1.1), as well as relevant reactor internals (see 1.8). The image to the right is of a reactor vessel in Finland (source: http://us.arevablog.com/tag/finland/).

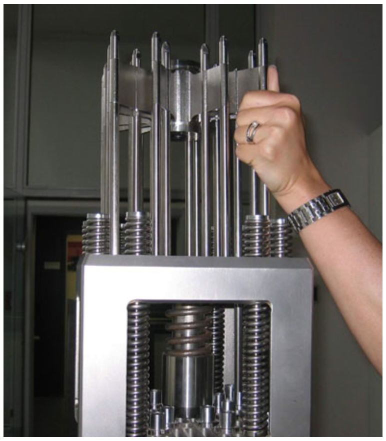
Vessels are usually cylindrical in shape. In commercial power reactors, they can be 5 m or more high and 2 m or more in diameter; research reactors may be smaller. A reactor pressure vessel intended for commercial power production recently built in China was over 13 m long and weighed over 320 metric tons.

1.3 Nuclear reactor fuel charging and discharging machines

Manipulative equipment especially designed or prepared for inserting or removing fuel in a nuclear reactor (see 1.1). Note: the items noted are capable of on-load operation or of employing technically sophisticated positioning or alignment features to allow complex off-load fueling operations such as those in which direct viewing or access to the fuel is not normally available.

More than fifty companies worldwide manufacture or distribute this type of equipment, according to Kompass.

1.4 Nuclear reactor control rods and equipment



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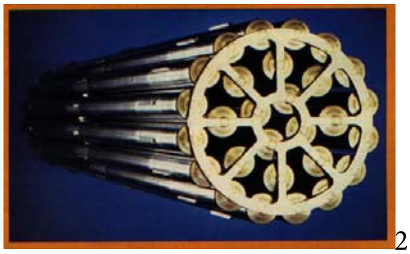
Especially designed or prepared rods, support or suspension structures therefor, rod drive mechanisms or rod guide tubes to control the fission process in a nuclear reactor. They are generally made of alloys of metal with extremely high neutron-absorption cross-sections: Cadmium, Hafnium, Indium, and Silver are some of the commonly used metals, but there are many different possibilities. Individual rods are combined into assemblies of multiple rods—usually groups of 20 for actual use. Image taken from http://en.wikipedia.org/wiki/File:PWR_control_rod_assemby.jpg

Many large power companies are involved in the nuclear control rod supply chain. Some companies involved at various points in the supply chain can be found here: http://en.wikipedia.org/wiki/List_of_companies_in_the_nuclear_sector

Note that there are few materials or manufacturing companies on this list, which is counterintuitive—it is entirely possible that the majority of companies listed here may be on the end of the supply chain rather than direct manufacturers.

1.5 Nuclear reactor pressure tubes

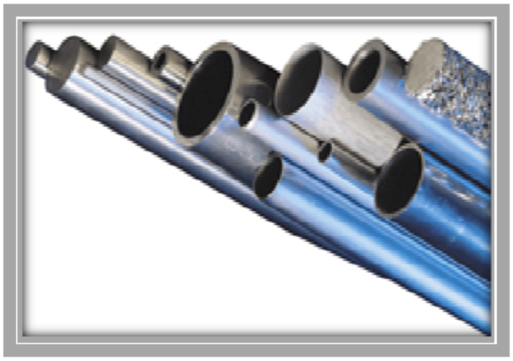
1.   2.

1. http://www.nuclearfaq.ca/bundle.jpg
2. http://upload.wikimedia.org/wikipedia/commons/5/57/CANDU_fuel_bundles.jpg

Nuclear reactor pressure tubes are designed to allow for the flow of nuclear coolant at a pressure exceeding 50 atmospheres. Various super alloys may be involved in their chemical composition.

Tubes for a PWR, the most common type of power reactor, are often individually small (~2 cm in diameter) but are generally needed in extremely large quantities for even a single reactor.

1.6 Zirconium tubes



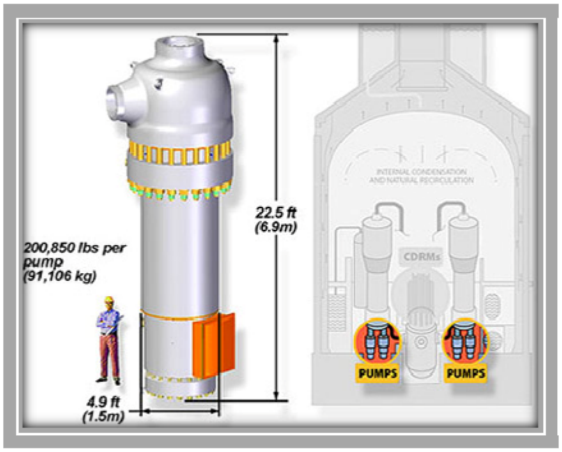
Zirconium metal and alloys in the form of tubes or assemblies of tubes, and in quantities exceeding 500 kg for any one recipient country in any period of 12 months, especially designed or prepared for use in a reactor, and in which the relation of hafnium to zirconium is less than 1:500 by weight.

Source: http://www.atimetals.com/products/Pages/zirconium.aspx.

There are many industrial tubing manufacturers that use Zirconium alloys in their products. Nuclear-grade zirconium tubing is generally 95%+ zirconium by mass. Commercial non-nuclear grade zirconium typically contains 1–5% of hafnium; for nuclear use hafnium must therefore be almost entirely removed (less than 1:5000 of the tubing by mass). At least two major companies in the USA, ATI Materials and Sandvik Materials Technology, produce Zirconium tubing for nuclear use.

Individual tubes designed for nuclear use tend to be between a third of an inch and two inches in diameter.

1.7 Primary coolant pumps



Pumps designed or prepared for circulating the primary coolant for nuclear reactors. Note: Especially designed or prepared pumps may include elaborate sealed or multi-sealed systems to prevent leakage of primary coolant, canned-driven pumps, and pumps with inertial mass systems. Below image taken from the Curtiss-Wright Corporation's website: http://www.cwfc.com/news/spokes/PressReleaseArchive2009-10.htm. As noted below, they are considered an industry leader in this field.

A *Business Wire* report dated May 07, 2013, listed the following companies as industry leaders: Curtiss-Wright Corporation, KSG AG, Shanghai Electric Group Company Limited, Sulzer AG, Toshiba Corporation, Mitsubishi Heavy Industries, Hitachi, Flowserve Corporation, Ebara Corporation, Dongfang Electric Corporation, Areva SA, and Andritz AG.

Pumps vary by size and type of reactor, generally fairly large for conventional power reactors. See image above for an idea of the scale.

1.8 Nuclear reactor internals

This is a category of items that are housed inside the nuclear reactor vessel. This category includes support columns for the core, fuel channels, thermal shields, baffles, core grid plates, and diffuser plates.

1.9 Heat exchangers

Heat exchangers are components in nuclear power reactors that transfer the heat generated by the reactor into the water, which turns into steam for power generation. They can also be used in fast breeder reactors that use liquid metal based cooling systems.

Some key companies in this sector include Joseph Oat Corporation, Bharat Heavy Electricals Limited (BHEL), Larsen & Toubro Limited, AREVA NP, Doosan Heavy Industries & Construction Co., Ltd, and Mitsubishi

Heavy Industries, Ltd. Source: http://www.graftel.com/heat-exchanger-testing.html

These are generally fairly large objects—the image above can provide an idea of the general scale involved for commercial power production. However, as with reactors themselves, sizes will vary according to a multitude of factors, including the type and intended use of the reactor.

1.10 Neutron detection and measuring instruments

Source: http://www.kwdnuclearinstruments.se/self-powered-neutron-detectors

Source: http://www.photonis.com/en/ism/31-nuclear-components.html
Especially designed or prepared neutron detection and measuring instruments for determining neutron flux levels within the core of a reactor. Note: This entry encompasses in-core and ex-core instrumentation which measures flux levels in a large range, typically from 10^4 neutrons per cm^2 per second to 10^{10} neutrons per cm^2 per second or more. Ex-core refers to those instruments outside the core of a reactor, but located within the biological shielding.

NON-NUCLEAR MATERIALS FOR REACTORS

INFCIRC/254/Rev.11/Part1 ANNEX B Section 2

2.1 Deuterium and heavy water

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Deuterium, heavy water (deuterium oxide) and any other deuterium compound in which the ratio of deuterium to hydrogen atoms exceeds 1:5000 for use in a nuclear reactor (reactor as defined above under 1.1) in quantities exceeding 200 kg of deuterium atoms for any one recipient country in any period of 12 months.

Physically and chemically, it resembles water, except it is denser—approximately 11% denser at high deuterium levels. It is not radioactive, but can be harmful if ingested.

One of the few ways to quickly demonstrate heavy water's physical differences from normal water is to freeze it and drop it into normal water. It should sink. Heavy water also has a higher freezing temperature than normal water—3.8 degrees Celsius. Note that these tests are less reliable if the water is "barely" heavy. It takes a very large amount of deuterium relative to hydrogen for the differences to be easily identifiable physically.

2.2 Nuclear grade graphite

Source: http://www.apservicesinc.com/products/product.php?pid=36

Source: http://china-sealing.cn/en/proinfo.asp?NID=69

The determination of what is "nuclear-grade" graphite vs. normal graphite is primarily based on the purity of the graphite. Nuclear-grade graphite has boron-equivalent content of less than 5 ppm and a density greater than 1.5 grams per cubic centimeter as per the NRC definition.

Graphite/carbon and materials companies generally will be typical suppliers of nuclear grade graphite; GrafTech (USA) is a prominent company that produces nuclear-grade graphite.

Nuclear-grade graphite is similar to normal graphite in many ways. Determination of nuclear grade graphite is primarily measured by its neutron-absorption cross-section, which is not visible to the naked eye.

PLANTS FOR THE REPROCESSING OF IRRADIATED FUEL ELEMENTS, AND EQUIPMENT ESPECIALLY DESIGNED OR PREPARED

INFCIRC/254/Rev.11/Part1 ANNEX B Section 3

3.1 Irradiated fuel element chopping machines

This equipment breaches the cladding of the fuel to expose the irradiated nuclear material to dissolution. Especially designed metal cutting shears are the most commonly employed, although advanced equipment, such as lasers, may be used. Remotely operated equipment especially designed or prepared for use in reprocessing plant as identified above and intended to cut, chop, or shear irradiated nuclear fuel assemblies, bundles, or rods.

3.2 Dissolvers

Dissolvers normally receive the chopped-up spent fuel. In these critically safe vessels, the irradiated nuclear material is dissolved in nitric acid, and the remaining hulls are removed from the process stream. Critically safe tanks (e.g., small diameter, annular, or slab tanks) especially designed or prepared for use in a reprocessing plant as identified above, intended for dissolution of irradiated nuclear fuel and which are capable of withstanding hot, highly corrosive liquid, and which can be remotely loaded and maintained.

3.3 Solvent extractors and solvent extraction equipment

Source: Power Reactor and Nuclear Fuel Development Corporation (PNC), Tokyo, Japan

Solvent extractors both receive the solution of irradiated fuel from the dissolvers and the organic solution which separates the uranium, plutonium, and fission products. Solvent extraction equipment is normally designed to meet strict operating parameters, such as long operating lifetimes with no maintenance requirements or adaptability to easy replacement, simplicity of operation and control, and flexibility for variations in process conditions. There are especially designed or prepared solvent extractors such as packed or pulse columns, mixer settlers, or centrifugal contactors for use in a plant for the reprocessing of irradiated fuel. Solvent extractors must be resistant to the corrosive effect of nitric acid. Solvent extractors are normally fabricated to extremely high standards (including special welding and inspection and quality assurance and quality control techniques) out of low carbon stainless steels, titanium, zirconium, or other high quality materials.

3.4 Chemical holding or storage vessels

Especially designed or prepared holding or storage vessels for use in a plant for the reprocessing of irradiated fuel. The holding or storage vessels must be resistant to the corrosive effect of nitric acid. The holding or storage vessels are normally fabricated of materials such as low carbon stainless steels, titanium, or zirconium, or other high quality materials. Holding or storage vessels may be designed for remote operation and maintenance and may have the following features for control of nuclear criticality:

(1) walls or internal structures with a boron equivalent of at least 2 %,
(2) a maximum diameter of 175 mm (7 in) for cylindrical vessels, or
(3) a maximum width of 75 mm (3 in) for either a slab or annular vessel.

PLANTS FOR THE FABRICATION OF NUCLEAR REACTOR FUEL ELEMENTS, AND EQUIPMENT ESPECIALLY DESIGNED OR PREPARED

Nuclear fuel elements are manufactured from one or more of the source or special fissionable materials mentioned in MATERIAL AND EQUIPMENT of this annex. For oxide fuels, the most common type of fuel, equipment for pressing pellets, sintering, grinding and grading will be present. Mixed oxide fuels are handled in glove boxes (or equivalent containment) until they are sealed in the cladding. In all cases, the fuel is hermetically sealed inside a suitable cladding which is designed to be the primary envelope encasing the fuel so as to provide suitable performance and safety during reactor operation. Also, in all cases, precise control of processes, procedures and equipment to extremely high standards is necessary in order to ensure predictable and safe fuel performance.

Items of equipment that are considered to fall within the meaning of the phrase "and equipment especially designed or prepared" for the fabrication of fuel elements include equipment which:
(a) normally comes in direct contact with, or directly processes, or controls, the production flow of nuclear material;
(b) seals the nuclear material within the cladding;

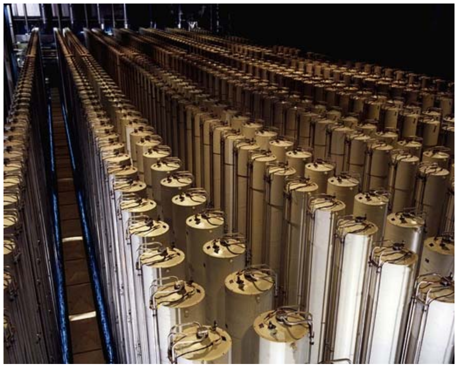
(c) checks the integrity of the cladding or the seal; or
(d) checks the finish treatment of the sealed fuel.

Such equipment or systems of equipment may include, for example:
1) fully automatic pellet inspection stations especially designed or prepared for checking final dimensions and surface defects of the fuel pellets;
2) automatic welding machines especially designed or prepared for welding end caps onto the fuel pins (or rods);
3) automatic test and inspection stations especially designed or prepared for checking the integrity of completed fuel pins (or rods). Item 3 typically includes equipment for: a) x-ray examination of pin (or rod) end cap welds, b) helium leak detection from pressurized pins (or rods), and c) gamma-ray scanning of the pins (or rods) to check for correct loading of the fuel pellets inside.

PLANTS FOR THE SEPARATION OF ISOTOPES OF NATURAL URANIUM, DEPLETED URANIUM OR SPECIAL FISSIONABLE MATERIAL AND EQUIPMENT, OTHER THAN ANALYTICAL INSTRUMENTS, ESPECIALLY DESIGNED OR PREPARED

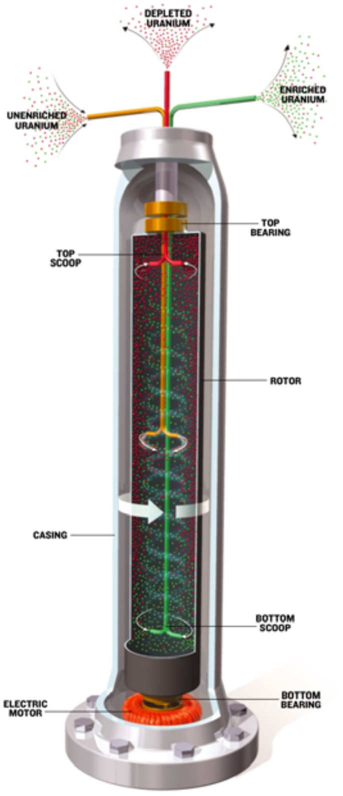
INFCIRC/254/Rev.11/Part1 ANNEX B Section 5

5.1. Gas centrifuges and assemblies and components especially designed or prepared for use in gas centrifuges



http://en.wikipedia.org/wiki/File:Gas_centrifuge_cascade.jpg

Uranium Centrifuge: Gaseous unenriched uranium with both U-238 (red dots) and U-235 (green dots) flows into the rotor through a stationary pipe. An electric motor induces a rotating electromagnetic field at the bottom of the rotor, which begins to spin. Most centrifuges use a needlelike metal bearing to support the rotor at the bottom. Centrifugal force pushes the heavier U-238 close to the walls of the rotors, while the lighter U-235 tends to collect at the center. Scoops suck out the enriched and depleted streams. To produce reactor fuel, the process is repeated through thousands of centrifuges until U-235 concentration reaches at least 3 percent.



HOW URANIUM CENTRIFUGES WORK: Gaseous unenriched uranium with both U-238 [red dots] and U-235 [green dots] flows into the rotor through a stationary pipe. A special electric motor induces a rotating electromagnetic field at the bottom of the rotor, which begins to spin. Most centrifuges use a needlelike metal bearing to support the rotor at the bottom. In the Brazilian model, actively controlled electromagnetic bearings at the top and bottom keep the rotor levitating. Centrifugal force pushes the heavier U-238 close to the walls of the rotors, while the lighter U-235 tends to collect at the center. Scoops suck out the enriched and depleted streams. To produce reactor fuel, the process is repeated through thousands of centrifuges until U-235 concentration reaches at least 3 percent.

Source: http://spectrum.ieee.org/energy/nuclear/how-brazil-spun-the-atom

5.1.1 Rotating Components

The gas centrifuge normally consists of thin-walled cyclinder(s) of between 75 mm (3 in) and 400 mm (16 in) in diameter contained in a vacuum environment and spun at a high peripheral speed of the order of 300 m/s or more with its central axis vertical. In order to achieve the high speed, the materials of construction have to be of a high strength to density ratio. The rotor assembly, and hence its individual components, have to be manufactured to very close tolerances in order to minimize the unbalance. In contrast to other centrifuges, the gas centrifuge for uranium enrichment is characterized by having within the rotor chamber rotating disc-shaped baffle(s) and a stationary tube arrangement for feeding and extracting the UF6 gas and featuring at least 3 separate channels, of which 2 are connected to scoops extending from the rotor axis towards the periphery of the rotor chamber. Also contained within the vacuum environment are a number of critical items which do not rotate and which although they are especially designed, are not difficult to fabricate, and are not fabricated out of unique materials. A centrifuge facility, however, requires a large number of these components, so quantities can provide an indication of end use.

Complete rotor assemblies:

Source: http://isis-online.org/isis-reports/detail/irans-new-centrifuge-what-do-we-know-about-it/8

Thin-walled cylinders, or a number of interconnected thin-walled cylinders, manufactured from one or more high strength to density ratio materials. If interconnected, the cylinders are joined together by flexible bellows or rings. The rotor is fitted with an internal baffle(s) and end caps if in final form. However, the complete assembly may be delivered only partially assembled. Note: high strength to density materials used for centrifuge rotating components referred to here and in the few subsequent entries are

(a) Maraging steel capable of an ultimate tensile strength of 300,000 psi or more,
(b) Aluminium alloys capable of an ultimate tensile strength of 67,000 psi or more,
(c) Filamentary materials suitable for use in composite structures and having a specific modulus of 3.18×10^6 m or greater and a specific ultimate tensile strength of 7.62×10^4 m or greater.

Note: For all gas centrifuge components, the manufacture and supply is highly regulated and generally done directly by governments or government-owned corporations.

As per the introductory note, centrifuges are typically thin-walled cylinder(s) of between 75 mm (3 in) and 400 mm (16 in), so completed rotor assemblies will usually be slightly smaller than this.

Rotor tubes:

Especially designed or prepared thin-walled cylinders with thickness of 12 mm (0.5 in) or less, a diameter of between 75 mm (3 in) and 400 mm (16 in), and manufactured from one or more high strength to density ratio materials.

As per above, rotor tubes are cylinders with between 75 mm (3 in) and 400 mm (16 in), with thin walls.

Rings or bellows:

Source: http://isis-online.org/isis-reports/detail/irans-new-centrifuge-what-do-we-know-about-it/8

Components especially designed or prepared to give localized support to the rotor tube or to join together a number of rotor tubes. The bellows is a short cylinder of wall thickness 3 mm (.12 in) or less, a diameter between 75 mm (3 in) and 400 mm (16 in), having a convolute, and manufactured from one or more high strength to density ratio materials.

As per above, the bellows is a short cylinder of wall thickness 3 mm (.12 in) or less, a diameter between 75 mm (3 in) and 400 mm (16 in).

Baffles:

Disc-shaped components of between 75 mm (3 in) and 400 mm (16 in) diameter especially designed or prepared to be mounted inside the centrifuge rotor tube, in order to isolate the take-off chamber from the main separation chamber and, in some cases, to assist the UF6 gas circulation from within the main separation chamber of the rotor tube. Manufactured from one or more high strength to density ratio materials.

As per description above, disc-shaped components of between 75 mm (3 in) and 400 mm (16 in) diameter.

Top cap/bottom cap:

Disc-shaped components of between 75 mm (3 in) and 400 mm (16 in) diameter especially designed or prepared to fit to the ends of the rotor tube, and so contain the UF6 within the rotor tube, and in some cases to support, retain, or contain as an integrated part an element of the upper bearing (top cap) or to carry the rotating elements of the motor and lower bearing (bottom cap). Manufactured from one or more high strength to density ratio materials.

As per description above, disc-shaped components of between 75 mm (3 in) and 400 mm (16 in) diameter.

5.1.2 Static Components

Magnetic suspension bearings:

Source: http://www.synchrony.com/support/documents/090109_Fusion.pdf

Especially designed or prepared bearing assemblies consisting of an annular magnet suspended within a housing containing a damping medium. The housing will be manufactured from a UF6-resistant material. The magnet couples with a pole piece or second magnet fitted to the top cap. The magnet may be ring-shaped with a relation between outer and inner diameter smaller or equal to 1.6:1. The magnet may be in a form having an initial permeability of 0.15 H/m (120,000 in GS units) or more, or a remanence of 98.5% or more, or an energy product of greater than 80 Kj/m^3. In addition to the usual material properties, the deviation of the magnetic axes from the geometrical axes is limited to very small tolerances (lower than 0.1 mm or .004 in) or homogeneity of the material of the magnet is specifically called for.

Bearings/dampers:

Especially designed or prepared bearings comprising a pivot/cup assembly mounted on a damper. The pivot is normally a hardened steel shaft with a hemisphere at one end with a means of attachment to the bottom cap. The shaft may have a hydrodynamic bearing attached. The cup is pellet-shaped with a hemispherical indentation in one surface. These components are often supplied separately to the damper.

Molecular pumps:

Especially designed or prepared cylinders having internally machined or extruded helical grooves and internally machined bores. Typical dimensions are as follows: 75 mm (3 in) to 400 mm (16 in) internal diameter, 10 mm (.4 min) or more wall thickness, with the length equal to or greater than the diameter. The grooves are typically rectangular in cross-section and 2 mm (.08 in) or more in depth.

As above: Typical dimensions are as follows: 75 mm (3 in) to 400 mm (16 in) internal diameter, 10 mm (.4 min) or more wall thickness, with the length equal to or greater than the diameter. The grooves are typically rectangular in cross-section and 2 mm (.08 in) or more in depth.

Motor stators:

Especially designed or prepared ring-shaped stators for high speed multiphase AC hysteresis (or reluctance) motors for synchronous operation within a vacuum in the frequency range of 600–2000 Hz and a power range of 50–1000 VA. The stators consist of multi-phase windings on a laminated low loss iron core comprised of thin laters typically 2.0 mm (.08 in) thick or less.

Centrifuge housing/recipients:

Components especially designed or prepared to contain the rotor tube assembly of a gas centrifuge. The housing consists of a rigid cylinder of wall thickness up to 30 mm (1.2 in) with precision machined ends to locate the bearings and with one or more flanges for mounting. The machined ends are parallel to each other and perpendicular to the cylinder's longitudinal axis to within .05 degrees or less. The housing may also be a honeycomb tree type structure to accommodate several rotor tubes. The housings are made of or protected by materials resistant to corrosion by UF6.

Scoops:

Especially designed or prepared tubes up to 12 mm (.5 in) internal diameter for the extraction of UF6 gas from within the rotor tube by a Pitot tube action (that is, with an aperture facing into the circumferential gas flow within the rotor tube, for example by behind the end of a radially disposed tube) and capable of being fixed to the central gas extraction system. The tubes are made of or protected by materials resistant to corrosion by UF6

5.2. Especially designed or prepared auxiliary systems, equipment and components for gas centrifuge enrichment plants

Autoclave system for UF6 feeding
Source: http://www.platom.fi/uf6-equipments/

The auxiliary systems, equipment, and components for a gas centrifuge enrichment plant are the systems of plant needed to feed UF6 to the centrifuges, to link the individual centrifuges to each other to form cascades (or stages) to allow for progressively higher enrichments and to extract the "product" and "tails" UF6 from the centrifuges, together with the equipment required to drive the centrifuges or to control the plant. Normally, UF6 is evaporated from the solid using heated autoclaves and is distributed in gaseous form to the centrifuges by way of cascade header pipework. The "product" and "tails" UF6 gaseous streams flowing from the centrifuges are also passed by way of cascade header pipework to cold traps (operating at about 203 K [-70° C]) where they are condensed prior to onward transfer into suitable containers for transportation or storage. Because an enrichment plant consists of many thousands of centrifuges arranged in cascades there are many kilometers of cascade header pipework, incorporating thousands of welds with a substantial amount of repetition of layout. The equipment, components, and piping systems are fabricated to very high vacuum and cleanliness standards.

5.2.1 Feed systems/product and tails withdrawal systems

Especially designed or prepared process systems including:

(a) Feed autoclaves (or stations), used for passing UF6 to centrifuge cascades at up to 100 kPa (15 psi) and at a rate of 1 kg/h or more,
(b) Desublimers (or cold traps) used to remove UF6 from the cascades at up to 3 kPa (.5 psi) pressure. The desublimers are capable of being chilled to 203 K (-70° C) and heated to 343 K (70° C),
(c) "Product" and "Tails" stations used for trapping UF6 into containers. Plant, equipment, and pipework will be wholly made of or lined with UF6-resistant materials and is fabricated to very high vacuum and cleanliness standards.

Note: Materials resistant to corrosion by UF6 include stainless steel, aluminium, aluminium alloys, nickel or alloys containing 60% or more nickel.

5.2.2 Machine header piping systems

Especially designed or prepared piping systems and header systems for handling UF6 within the centrifuge cascades. The piping network is normally the "triple" header system with each centrifuge connected to each of the headers. There is thus a substantial amount of repetition in its form. It is wholly made of or lined with UF6-resistant materials and is fabricated to very high vacuum and cleanliness standards. Note: Materials resistant to corrosion by UF6 include stainless steel, aluminium, aluminium alloys, nickel or alloys containing 60% or more nickel.

5.2.3 Special shut-off and control valves

Especially designed or prepared bellows-sealed valves, manual or automated, shut-off or control, made of or protected by materials resistant to corrosion by UF6, with a diameter of 10 to 160 mm, for use in the main or auxiliary systems of gas centrifuge enrichment plants. Note: Materials resistant to corrosion by UF6 include stainless steel, aluminium, aluminium alloys, nickel or alloys containing 60% or more nickel.

As per above, valves have typical diameter of 10 to 160 mm.

5.2.4 UF6 mass spectrometers/ion sources

Source: http://www.directindustry.com/prod/inprocess-instruments-gmbh/quadrupole-mass-spectrometers-qms-33978-887589.html

Especially designed or prepared magnetic or quadrupole mass spectrometers capable of taking "on-line" samples of feed, product or tails, from UF6 gas streams and having all of the following characteristics:

(1) Unit resolution for atomic mass unit greater than 320,
(2) Ion sources constructed of or lined with nichrome or monel or nickel plated,
(3) Electron bombardment ionization sources,
(4) Having a collector system suitable for isotropic analysis.

5.2.5 Frequency changers

Frequency changers (also known as convertors or invertors) especially designed or prepared to supply motor stators; or parts, components, and sub-assemblies of such frequency changers having all of the following characteristics:

(1) A multiphase output of 600 to 2000 Hz,
(2) High stability (with frequency control better than 0.1%),
(3) Low harmonic distortion (less than 2%),
(4) An efficiency of greater than 80%.

Note: These items either come into direct contact with the UF6 process gas or directly control the centrifuges and the passage of the gas from centrifuge to centrifuge and cascade to cascade.

5.3. Especially designed or prepared assemblies and components for use in gaseous diffusion enrichment

Gaseous Diffusion Plant
Source: https://www3.orau.gov/CEDR/site-information.aspx

In the gaseous diffusion method of uranium isotope separation, the main technological assembly is a special porous gaseous diffusion barrier, heat exchanger for cooling the gas (which is heated by the process of compression), seal valves and control valves, and pipelines. Inasmuch as gaseous diffusion technology uses uranium hexafluoride (UF6), all equipment, pipeline and instrumentation surfaces (that come into contact with the gas) must be made of materials that remain stable in contact with UF6. A gaseous diffusion facility requires a number of these assemblies, so that quantities can provide an important indication of end use.

5.3.1 Gaseous diffusion barriers

Source: http://www.laradioactivite.com/en/site/pages/Gaseous_Diffusion.htm

(a) Especially designed or prepared thin, porous filters, with a pore size of 100–1000 Å (angstroms), and a thickness of 5 mm (.2 in) or less, and for tubular forms, a diameter of 25 mm (1 in) or less, made of metallic, polymer, or ceramic materials resistant to corrosion by UF6.

(b) [E]specially prepared compounds or powders for the manufacture of such filters described in (a). Such compounds and powders include nickel or alloys of nickel containing 60% or more nickel, aluminium oxide, or UF6-resistant fully florinated hydrocarbon polymers having a purity of 99.9% or more, a particle size less than 10 microns, and a high degree of particle size uniformity, which are especially prepared for the manufacture of gaseous diffusion barriers.

Per Jeffrey Lewis (arms control expert) in a 2007 article, the methods governments use to produce gaseous diffusion barriers are classified.

5.3.2 Diffuser housings

Especially designed or prepared hermetically sealed cylindrical vessels greater than 300 mm (12 in) in diameter and greater than 900 mm (35 in) in length, or rectangular vessels of comparable dimensions, which have an inlet connection and two outlet connections all of which are greater than 50 mm (2 in) in diameter, for containing the gaseous diffusion barrier, made of or lined with UF6-resistant materials and designed for horizontal or vertical installation.

5.3.3 Compressors and gas blowers

Especially designed or prepared axial, centrifugal, or positive displacement compressors, or gas blowers with a suction volume capacity of 1m^3/min or more of UF6, and with a discharge pressure of up to several hundred kPa (100 psi), designed for long-term operation in the UF6 environment with or without an electrical motor of appropriate power, as well as separate assemblies of such compressors and gas blowers. These compressors and gas blowers have a pressure ratio between 2:1 and 6:1 and are made of or lined with materials resistant to UF6. The image and diagram below are taken from the USNRC's training manual on gaseous diffusion enrichment.

5.3.4 Rotary shaft seals

Especially designed or prepared vacuum seals, with seal feed and seal exhaust connections, for sealing the shaft connecting the compressor or the gas blower rotor with the driver motor so as to ensure a reliable seal against in-leaking of air into the inner chamber of the compressor or gas blower which is filled with UF6. Such seals are normally designed for a buffer of in-gas leakage rate of less than 1000 cm^3/min (60in^3/min). Image: http://www.hayley-group.co.uk/catalogue/rotary-shaft-seals/

5.3.5 Heat exchangers for cooling UF6

Especially designed or prepared heat exchangers made of or lined with UF6-resistant materials (except stainless steel) or with copper or any combination of those metals, and intended for a leakage pressure change rate of less than 10 Pa (.0015 psi) per hour under a pressure difference of 100 kPa (15 psi).

5.4. Especially designed or prepared auxiliary systems, equipment and components for use in gaseous diffusion enrichment

The auxiliary systems, equipment and components for gaseous diffusion enrichment plants are the systems of plant needed to feed UF6 to the gaseous diffusion assembly, to link the individual assemblies to each other to form cascades (or stages) to allow for progressively higher enrichments and to extract the “product” and “tails” UF6 from the diffusion cascades. Because of the high inertial properties of diffusion cascades, any interruption in their operation, and especially their shut-down, leads to serious consequences. Therefore, a strict and constant maintenance of vacuum in all technological systems, automatic protection from accidents, and precise automated regulation of the gas flow is of importance in a gaseous diffusion plant. All this leads to a need to equip the plant with a large number of special measuring, regulating, and controlling systems. Normally, UF6 is evaporated from cylinders placed within autoclaves and is distributed in gaseous form to the entry point by way of cascade header pipework. The “product” and “tails” UF6 gaseous streams flowing from exit points are passed by way of cascade header pipework to either cold traps or to compression stations where the UF6 gas is liquefied prior to onward transfer into suitable containers for transportation or storage. Because a gaseous diffusion enrichment plant consists of a large number of gaseous diffusion assemblies arranged in cascades, there are many kilometers of cascade header pipework, incorporating thousands of welds with substantial amounts of repetition of layout. The equipment, components and piping systems are fabricated to very high vacuum and cleanliness standards. Explanatory note: The items in this section (5.5) either come into direct contact with UF6 or directly control the flow within the cascade. As such, they are either wholly made of or lined with UF6-resistant materials. For these purposes, UF6-resistant materials include stainless steel, aluminium, aluminium alloys, aluminium oxide, nickel or alloys containing 20% or more nickel and UF6-resistant fully fluorinated hydrocarbon polymers.

5.4.1 Feed systems/product and tails withdrawal systems

Especially designed or prepared process systems, capable of operating at pressures of 300 kPa (45 psi) or less, including:

(a) Feed autoclaves (or systems), used for passing UF6 to the gaseous diffusion cascades,
(b) Desublimers (or cold traps) used to remove UF6 from the diffusion cascades,
(c) Liquefaction stations where UF6 gas from the cascade is compressed and cooled to form liquid UF6,
(d) "Product" or "tails" stations used for transferring UF6 into containers.

5.4.2 Header piping systems

Especially designed or prepared piping systems and header systems for handling UF6 within the gaseous diffusion cascades. This piping network is normally of the “double” header system with each cell connected to each of the headers.

5.4.3 Vacuum systems

(a) Especially designed or prepared large vacuum manifolds, vacuum headers and vacuum pumps having a suction capacity of 5 m^3/min (175 ft^3/min) or more, and
(b) Vacuum pumps especially designed for service in UF6-bearing atmospheres made of, or lined with, aluminium, nickel, or alloys bearing more than 60% nickel. These pumps may be either rotary or positive, may have displacement or fluorocarbon seals, and may have special working fluids present.

5.4.4 Special shut-off and control valves

Especially designed or prepared manual or automated shut-off and control bellows valves made of UF6-resistant materials with a diameter of 40 to 1500 mm (1.5 to 59 in) for installation in main and auxiliary systems of gaseous diffusion enrichment plants.

5.4.5 UF6 mass spectrometers/ion sources

Especially designed or prepared magnetic or quadrupole mass spectrometers capable of taking “on-line” samples of feed, product or tails, from UF6 gas streams and having all of the following characteristics:

(1) Unit resolution for atomic mass greater than 320,
(2) Ion sources constructed of or lined with nichrome or monel or nickel plated,
(3) Electron bombardment ionization sources, and
(4) Collector system suitable for isotopic analysis.

5.5. Especially designed or prepared systems, equipment and components for use in aerodynamic enrichment plants

Introductory and Explanatory Notes

In the aerodynamic enrichment process, a mixture of gaseous UF6 and light gas (hydrogen or helium) is compressed and then passed through separating elements wherein isotropic separation is accomplished by the generation of high centrifugal forces over a curved-wall geometry. Two processes of this type have been successfully developed: the separation nozzle process and the vortex tube process. For both processes the main components of a separation stage include cylindrical vessels housing the special separation elements (nozzles or vortex tubes), gas compressors and heat exchangers to remove the heat of compression. An aerodynamic plant requires a number of these stages, so that quantities can provide an important indication of end use. Explanatory note: The items that follow in this section (5.5) either come into direct contact with UF6 or directly control the flow within the cascade. As such, they are either wholly made of or lined with UF-resistant materials. For these purposes, UF6-resistant materials include stainless steel, aluminium, aluminium alloys, aluminium oxide, nickel or alloys containing 20% or more nickel and UF6-resistant fully fluorinated hydrocarbon polymers.

5.5.1 Separation nozzles

Especially designed or prepared separation nozzles or assemblies thereof. The separation nozzles consist of slit-shaped, curved channels having a radius of curvature less than 1 mm (typically .1 to 0.05 mm), resistant to corrosion by UF6 and having a knife-edge within the nozzle that separates the gas flowing through the nozzle into two fractions.

5.5.2 Vortex tubes

Especially designed or prepared vortex tubes and assemblies thereof. The vortex tubes are cylindrical and tapered, made of and protected by materials resistant to corrosion by UF6, having a diameter of between .5 cm and 4 cm, a length to diameter ratio of 20:1 or less and with one or more tangential inlets. The tubes may be equipped with nozzle-type appendages at either or both ends.

5.5.3 Compressors and gas blowers

Especially designed or prepared axial, centrifugal or positive displacement compressors or gas blowers made of or protected by material resistant to corrosion by UF6 and with a suction volume capacity of 2 m^3/min or more of UF6/carrier gas (hydrogen or helium) mixture. Typically have a pressure ratio between 1.2:1 and 6:1.

5.5.4 Rotary shaft seals

Especially designed or prepared rotary shaft seals, with seal feed and seal exhaust connections, for sealing the shaft connecting the compressor rotor or the gas blower rotor with the driver motor so as to ensure a reliable seal against out-leakage of process gas or in-leakage or air or seal gas into the inner chamber of the compressor or gas blower which is filled with a UF6 carrier gas mixture.

5.5.5 Heat exchangers for gas cooling

Especially designed or prepared heat exchangers made of or protected by materials resistant to corrosion by UF6.

5.5.6 Separation element housings

Especially designed or prepared separation element housings, made of or protected by materials resistant to corrosion by UF6, for containing vortex tubes or separation nozzles.

Housings may be cylindrical vessels greater than 300 mm in diameter and greater than 900 mm in length, or may be rectangular vessels of comparable dimensions, and may be designed for horizontal or vertical installation.

5.5.7 Feed systems/product and tails withdrawal systems

Especially designed or prepared process systems or equipment for enrichment plants made of or protected by materials resistant to corrosion by UF6, including:

(a) Feed autoclaves, ovens, or systems used for passing UF6 to the enrichment process,
(b) Desublimers (or cold traps) used to remove UF6 from the enrichment process for subsequent transfer upon heating,
(c) Solidification or liquefaction stations used to remove UF6 from the enrichment process by compressing and converting UF6 to a liquid or solid form, and
(d) "Product" or "tails" sections used for transferring UF6 into containers.

5.5.8 Header piping systems

Especially designed or prepared header piping systems, made of or protected by materials resistant to corrosion by UF6, for handling UF6 within the aerodynamic cascades. This piping network is normally of the "double" header design with each stage or group of stages connected to one of the headers.

5.5.9 Vacuum systems and pumps

(a) Especially designed or prepared vacuum systems having a suction capacity of 5 m^3/min or more, consisting of vacuum manifolds, vacuum headers, and vacuum pumps, and designed for service in UF6-bearing atmospheres, and
(b) Vacuum pumps especially designed or prepared for service in UF6-bearing atmospheres and made of or protected by materials resistant to corrosion by UF6. These pumps may use fluorocarbon seals and special working fluids.

5.5.10 Special shut-off and control valves

Especially designed or prepared manual or automated shut-off and control bellows valves made of or protected by materials resistant to corrosion by UF6 with a diameter of 40 to 1500 mm for installation in the main and auxiliary systems of aerodynamic enrichment plants.

5.5.11 UF6 mass spectrometers/ion sources

Especially designed or prepared magnetic or quadrupole mass spectrometers capable of taking "on-line" samples of feed, product or tails, from UF6 gas streams and having all of the following characteristics:

(1) Unit resolution for atomic mass greater than 320,

(2) Ion sources constructed of or lined with nichrome or monel or nickel plated,
(3) Electron bombardment ionization sources,
(4) Collector system suitable for isotopic analysis.

5.5.12 UF6/carrier gas separation systems

Especially designed or prepared process systems for separating UF6 from carrier gas (hydrogen or helium). These systems are designed to reduce the UF6 content in the carrier gas to 1 ppm or less and may incorporate equipment such as:

(a) Cryogenic heat exchangers and cryoseparators capable of temperatures of -120° C or less,
(b) Cryogenic refrigeration units capable of temperatures of -120° C or less,
(c) Separation nozzles or vortex tube units for the separation of UF6 from carrier gas, and
(d) UF6 cold traps capable of temperatures of -20° C or less.

5.6. Especially designed or prepared systems, equipment and components for use in chemical exchange or ion exchange enrichment plants.

Introductory Note

The slight difference in mass between isotopes of uranium causes small changes in chemical reaction equilibria than can be used as a basis for separation of the isotopes. Two processes have been successfully developed: liquid-liquid chemical exchange and solid-liquid ion exchange.

(1) In the liquid-liquid process, immiscible liquid phases (aqueous and organic) are counter-currently contacted to give the cascading effect of thousands of separation stages. The aqueous phase consists of uranium chloride in hydrochloric acid solution; the organic phase consists of an extractant containing uranium chloride in an organic solvent. The contactors employed in the separation cascade can be liquid-liquid exchange columns (such as pulsed columns with sieve plates) or liquid centrifugal contactors. Chemical conversions (oxidation and reduction) are required at both ends of the separation cascade in order to provide for the reflux requirements at each end. A major design concern is to avoid contamination of the process streams with certain metal ions. Plastic, plastic-lined (including use of flurocarbon polymers) and/or glass-lined columns and piping are therefore used;
(2) In the solid-liquid ion-exchange process, enrichment is accomplished by uranium adsorption/desorption on a special, very fast-acting, ion-exchange resin or adsorbent. A solution of uranium in hydrochloric acid and other chemical agents is passed through cylindrical enrichment columns containing packed beds of the absorbent. For a continuous process, a reflux system is necessary to release the uranium from the absorbent back into the liquid flow so that the “product” and “tails” can be collected. This is accomplished with the use of suitable reduction/oxidation chemical agents that are fully regenerated in separate external circuits and that may be partially regenerated within the isotropic separation columns themselves. The presence of hot concentrated hydrochloric acid solutions in the

process requires that the equipment be made of or protected by special corrosion-resistant materials.

5.6.1 Liquid-liquid exchange columns (Chemical exchange)

Countercurrent liquid-liquid exchange columns having mechanical power input (i.e., pulsed columns with sieve plates, reciprocating plate columns, and columns with internal turbine mixers), especially designed or prepared for uranium enrichment using the chemical exchange process. For corrosion resistance to concentrated hydrochloric acid solutions, these columns and their internals are made of or protected by suitable plastic materials (such as flurocarbon polymers) or glass. The stage residence time of the columns is designed to be short (30 seconds or less.)

5.6.2 Liquid-liquid centrifugal contactors (Chemical exchange)

Liquid-liquid centrifugal contactors especially designed or prepared for uranium enrichment using the chemical exchange process. Such contactors use rotation to achieve dispersion of the organic and aqueous streams and then centrifugal force to separate the phases. For corrosion resistance to concentrated hydrochloric acid solutions, the contactors are made of or lined with suitable plastic materials (such as fluorocarbon polymers) or are lined with glass. The stage residence time of the centrifugal contactors is designed to be short (30 seconds or less).

5.6.3 Uranium reduction systems and equipment (Chemical exchange)

(a) Especially designed or prepared electrochemical reduction cells to reduce uranium from one valence state to another for uranium enrichment using the chemical exchange process. The cell materials in contact with process solutions must be corrosion resistant to concentrated hydrochloric acid solutions. Note that the cell must have an impervious diaphragm membrane constructed of special cation exchange material. The cathode consists of a suitable solid conductor such as graphite,

(b) Especially designed or prepared systems at the product end of the cascade for taking the U+4 out of the organic stream, adjusting the acid concentration and feeding to the electrochemical reduction cells. Note that a major design concern is to avoid the contamination of the aqueous stream with certain metal ions, so parts in contact with the process stream are constructed of equipment made of or protected by suitable materials (such as glass, fluorocarbon polymers, polyphenyl sulphate, polyether sulfone, and resin-impregnated graphite.)

5.6.4 Feed preparation systems (Chemical exchange)

Especially designed or prepared systems for producing high-purity uranium chloride feed solutions for chemical exchange uranium isotope separation plants. These systems consist of dissolution, solvent extraction and/or ion exchange equipment for purification and electrolytic cells for reducing the U+6 or U+4 to U+3. These systems produce uranium chloride solutions having only a few parts per million of metallic impurities. Materials of construction for portions of the system processing high-purity U+3 include glass, flurocarbon polymers, polyphenyl sulfate or polyether sulfone plastic-lined and resin-impregnated graphite.

5.6.5 Uranium oxidation systems (Chemical exchange)

Especially designed or prepared systems for oxidation or U+3 to U+4 for return to the uranium isotope separation cascade in the chemical exchange enrichment process. These systems may incorporate equipment such as:

(a) Equipment for contacting chlorine and oxygen with the aqueous effluent from the isotope separation equipment and extracting the resulting U+4 into the stripped organic stream returning from the product end of the cascade, and
(b) Equipment that separates water from hydrochloric acid so that the water and the concentrated hydrochloric acid may be reintroduced to the process at the proper locations.

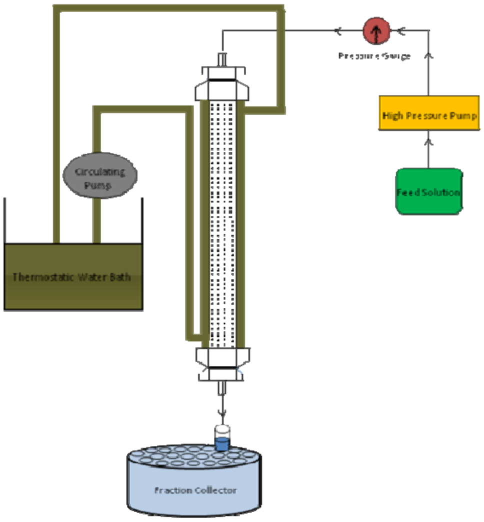
5.6.6 Fast-reacting ion exchange resins/adsorbents (Ion exchange)

Fast-reacting ion-exchange resins or adsorbents especially designed or prepared for uranium enrichment using the ion exchange process, using porous macroreticular resins, and/or pellicular structures in which the active chemical exchange groups are limited to a coating on the surface of an inactive porous support structure, and other composite structures in any suitable form including particles or fibers. These ion exchange resins/adsorbents are especially designed to achieve very fast uranium isotope exchange kinetics (exchange rate half-time of less than 10 seconds) and are capable of operating at a temperature in the range of 100° C to 200° C.

5.6.7 Ion exchange columns (Ion exchange)

Cylindrical columns greater than 1000 mm in diameter for containing and supporting packed beds of ion exchange resin/adsorbent, especially designed or prepared for uranium enrichment using the ion exchange process. These columns are made of or protected by materials (such as titanium or fluorocarbon plastics) resistant to corrosion by concentrated hydrochloric acid solutions and are capable or operating at a temperature in the range of 100° C to 200° C and pressures above .7 MPa (102 psi).

Greater than 1 m in diameter, as noted above.



5.6.8 Ion exchange reflux systems (Ion exchange)

(a) Especially designed or prepared chemical or electrochemical reduction systems for regeneration of the chemical reducing agent(s) used in ion exchange uranium enrichment cascades.
(b) Especially designed or prepared chemical or electrochemical oxidation systems for regeneration of the chemical oxidizing

agent(s) used in the ion exchange uranium enrichment cascades. Image adjacent: “Schematic diagram of the apparatus for ion exchange separation” from Xingcheng Ding and Xunyue Liu, “Nitrogen Isotope Separation by Ion Exchange Chromatography” in *Ion Exchange Technologies*, edited by Ayben Kilislioğlu, (Institute of Nuclear Agricultural Science, Zhejiang University, Hangzhou, P.R.China), p. 347.

5.7. Especially designed or prepared systems, equipment and components for use in laser-based enrichment plants.

Introductory and Explanatory Notes

Present systems for enrichment processes using lasers fall into two categories: those in which the process medium is atomic uranium vapor and those in which the process medium is the vapor of a uranium compound. Common nomenclature for such processes includes: first category— atomic vapor laser isotope separation (AVLIS or SILVA); second category—molecular laser isotope separation (MLIS or MOLIS) and chemical reaction by isotope selective laser activation (CRISLA). The systems, equipment, and components for laser enrichment plants include:

(a) devices to feed uranium-metal vapor (for selective photo-ionization) or devices to feed the vapor of a uranium compound (for photo-dissociation or chemical activation);
(b) devices to collect enriched and depleted uranium metal as “product” or “tails” in the first category, and devices to collect dissociated or reacted compounds as “product” and unaffected material as “tails” in the second category;
(c) process laser systems to selectively excite the U-235 species, and
(d) feed preparation and product conversion equipment. The complexity of the spectroscopy of uranium atoms and compounds may require incorporation of any of a number of available laser technologies.

Explanatory Note: Many of the items listed in this section come into direct contact with uranium metal vapor or liquid or with process gas consisting of UF6 or a mixture of UF6 and other gases. All surfaces that come into contact with the uranium or UF6 are wholly made of or protected by corrosion-resistant materials. For the purposes of the section related to laser-based enrichment items, the materials resistant to corrosion by the vapor or liquid of uranium metal or uranium alloys include yttria-coated graphite and tantalum; and the materials resistant to corrosion by UF6 include copper, stainless steel, aluminium, aluminium alloys, nickel or alloys containing 60% or more nickel and UF6-resistant fully fluorinated hydrocarbon polymers.

5.7.1 Uranium vaporization systems (AVLIS)

Especially designed or prepared uranium vaporization systems which contain high-power strip or scanning electron beam guns with a delivered power on the target of more than 2.5 kW/cm.

5.7.2 Liquid uranium metal handling systems (AVLIS)

Especially designed or prepared liquid metal handling systems for molten uranium or uranium alloys, consisting of crucibles or cooling equipment for the crucibles. Note: The crucibles and other parts of this system that come into contact with molten uranium or uranium alloys are made of or protected by materials of suitable corrosion and heat resistance. Suitable materials include tantalum, yttria-coated graphite, graphite coated with other rare earth oxides (See INFCIRC/254/Part 2 as amended), or mixtures thereof.

5.7.3 Uranium metal “product” and “tails” collector assemblies (AVLIS)

Especially designed or prepared “product” and “tails” collector assemblies for uranium metal in liquid or solid form. Note: Components for these assemblies are made of or protected by materials resistant to the heat and corrosion of uranium metal vapor or liquid (such as yttria-coated graphite or tantalum) and may include, pipes, valves, fittings, “gutters,” feed-throughs, heat exchangers and collector plates for magnetic, electrostatic or other separation methods.

5.7.4 Separator module housings (AVLIS)

Especially designed or prepared cylindrical or rectangular vessels for containing the uranium metal vapor source, the electron beam gun, and the “product” and “tails” collectors. Note: These housings have a multiplicity of ports for electrical and water feed-throughs, laser beam windows, vacuum pump connections and instrumentation diagnostics and monitoring. They have provisions for opening and closing to allow refurbishment of internal components.

5.7.5 Supersonic expansion nozzles (MLIS)

Especially designed or prepared supersonic expansion nozzles for cooling mixtures of UF6 and carrier gas to 150 K or less and which are resistant to UF6.

5.7.6 Uranium pentafluoride product collectors (MLIS)

Especially designed or prepared uranium pentafluoride (UF5) solid product collectors consisting of filter, impact, or cyclone-type collectors, or combinations thereof, and which are corrosion resistant to the UF5/UF6 environment.

5.7.7 UF6/carrier gas compressors (MLIS)

Especially designed or prepared compressors for UF6/carrier gas mixtures, designed for long-term operation in a UF6 environment. The components of these compressors that come into contact with process gas are made of or protected by materials resistant to corrosion by UF6.

5.7.8 Rotary shaft seals (MLIS)

Especially designed or prepared rotary shaft seals, with seal feed and seal exhaust connections, for sealing the shaft connecting the compressor rotor with the driver motor so as to ensure a reliable seal against out-leakage of process gas or in-leakage of air or seal gas into the inner chamber of the compressor which is filled with a UF6/carrier gas mixture.

5.7.9 Fluorination systems (MLIS)

Especially designed or prepared systems for fluorinating UF5 (solid) to UF6 (gas). Note: These systems are designed to fluorinate the collected UF5 powder to UF6 for subsequent collection in product containers or for transfer feed to MLIS units for additional enrichment. In one approach, the fluorination reaction may be accomplished within the isotope separation system to react and recover directly off the "product" collectors. In another approach, the UF5 powder may be removed/transferred from the "product" collectors into a suitable reaction vessel (e.g., fluidized-bed reactor, screw reactor or flame tower) for fluorination. In both approaches, equipment for storage and transfer of fluorine (or other suitable fluorinating agents) and for collection and transfer of UF6 are used.

5.7.10 UF6 mass spectrometers/ion sources (MLIS)

Especially designed or prepared magnetic or quadrupole mass spectrometers capable of taking "on-line" samples of feed, "product" or "tails," from UF6 gas streams and having all of the following characteristics:

(1) Unit resolution for mass greater than 320,
(2) Ion sources constructed of or lined with nichrome or monel or nickel plated,
(3) Electron bombardment ionization sources,
(4) Collector system suitable for isotropic analysis.

5.7.11 Feed systems/product and tails withdrawal systems (MLIS)

Especially designed or prepared process systems or equipment for enrichment plants made of or protected by materials resistant to corrosion by UF6, including:

(a) Feed autoclaves, ovens, or systems used for passing UF6 to the enrichment process,
(b) Desublimers (cold traps) used to remove UF6 from the enrichment process for subsequent transfer upon heating,
(c) Solidification or liquefaction stations used to remove UF6 from the enrichment process by compressing and converting UF6 to a liquid or solid form, and
(d) "Product" or "tails" stations used for transferring UF6 into containers.

5.7.12 UF6/carrier gas separation systems (MLIS)

Especially designed or prepared process systems for separating UF6 from carrier gas. The carrier gas may be nitrogen, argon, or other gas. Note: These systems may incorporate equipment such as:

(a) Cryogenic heat exchangers or cryoseparators capable of temperatures of -120° C or less,
(b) Cryogenic refrigeration units capable of temperatures of -120° C or less,
(c) UF6 cold traps capable of temperatures of -20° C or less.

5.7.13 Laser systems (AVLIS, MLIS and CRISLA)

Lasers or laser systems especially designed or prepared for the separation of uranium isotopes. Note: The lasers and laser components of importance in laser-based enrichment processes include those identified in INFCIRC/253/Part 2 (as amended). The laser system for the AVLIS process usually consists of two lasers: a copper vapor laser and a dye laser. The laser system for MLIS usually consists of a CO2 or excimer laser and a multi-pass optical cell with revolving mirrors at both ends. Lasers or laser systems for both processes require a spectrum frequency stabilizer for operation over extended periods of time.

5.8. Especially designed or prepared systems, equipment and components for use in plasma separation enrichment plants.

Introductory Note

In the plasma separation process, a plasma of uranium ions passes through an electric field tuned to the U235 ion resonance frequency so that they preferentially absorb energy and increase the diameter of their corkscrew-like orbits. Ions with a large-diameter path are trapped to produce a product enriched in U235. The plasma, which is made by ionizing uranium vapor, is contained in a vacuum chamber with a high-strength magnetic field produced by a superconducting magnet. The main technological systems of the process include the uranium plasma generation system, the separator module with the superconducting magnet (see INFCIRC/254/Part 2 (as amended)), and metal removal systems for the collection of “product” and “tails.”

5.8.1 Microwave power sources and antennae

Especially designed or prepared microwave power sources and antennae for producing or accelerating ions and having the following characteristics: greater than 30 GHz frequency and greater than 50 kW mean power output for ion production.

5.8.2 Ion excitation coils

Especially designed or prepared radio frequency ion excitation cells for frequencies of more than 100 kHz and capable of handling more than 40 kW mean power.

5.8.3 Uranium plasma generation systems

Especially designed or prepared systems for the generation of uranium plasma, which may contain high-power strip or scanning electron beam guns with a delivered power on the target of more than 2.5 kW/cm.

5.8.4 Liquid uranium metal handling systems

Especially designed or prepared liquid metal handling systems for molten uranium or uranium alloys, consisting of crucibles and cooling equipment for the crucibles. Note: The crucibles and other parts of this system that come into contact with molten uranium or uranium alloys are made of or protected by materials of suitable corrosion and heat resistance. Suitable materials include tantalum, yttria-coated graphite, graphite coated with other rare earth oxides (see INFCIRC/254/Part 2 (as amended)) or mixtures thereof.

5.8.5 Uranium metal “product” and “tails” collector assemblies

Especially designed or prepared “product” and “tails” collector assemblies for uranium metal in solid form. These collector assemblies are made of or protected by materials resistant to the heat and corrosion of uranium metal vapor, such as yttria-coated graphite or tantalum.

5.8.6 Separator module housings

Cylindrical vessels especially designed or prepared for use in plasma separation enrichment plants for containing the uranium plasma source, radio-frequency drive coil and the “product” and “tails” collectors. Note: These housings have a multiplicity of ports for electrical feed-throughs, diffusion pump connections and instrumentation diagnostics and monitoring. They have provisions for opening and closure to allow for refurbishment of internal components and are constructed of a suitable non-magnetic material such as stainless steel.

5.9. Especially designed or prepared systems, equipment and components for use in electromagnetic enrichment plants.

Introductory Note

In the electromagnetic process, uranium metal ions produced by the ionization of a salt feed material (typically UCl4) are accelerated and passed through a magnetic field that has the effect of causing the ions of different isotopes to follow different paths. The major components of an electromagnetic isotope separator include: a magnetic field for ion-beam diversion/separation of the isotopes, an ion source with its acceleration system, and a collection system for the separated ions. Auxiliary systems for the process include the magnet power supply system, the ion source high-voltage power supply system, the vacuum system, and extensive chemical handling systems for recovery of product and cleaning/recycling of components.

5.9.1 Electromagnetic isotope separators (Note: Ion sources, Ion collectors, vacuum housings, magnet pole pieces)

Electromagnetic isotope separators especially designed or prepared for the separation of uranium isotopes, and equipment and components therefor, including:

(a) Ion sources: Especially designed or prepared single or multiple uranium ion sources consisting of a vapor source, ionizer, and beam accelerator, constructed of suitable materials such as graphite, stainless steel, or copper, and capable of providing a total ion beam current of 50 mA or greater;
(b) Ion collectors: Collector players consisting of two or more slits and pockets especially designed or prepared for collection of enriched and depleted uranium ion beams and constructed of suitable materials such as graphite or stainless steel;
(c) Vacuum housings: Especially designed or prepared vacuum housings for uranium electromagnetic separators, constructed of suitable non-magnetic materials such as stainless steel and designed for operation at pressures of 0.1 Pa or lower. Note: The housings are specially designed to contain the ion sources, collector plates and water-cooled liners and have provision for diffusion pump connections and opening and closure for removal and reinstallation of these components;
(d) Magnet pole pieces: Especially designed or prepared magnet pole pieces having a diameter greater than 2 m used to maintain a constant magnetic field within an electromagnetic isotope separator and to transfer the magnetic field between adjoining separators.

5.9.2 High voltage power supplies

Especially designed or prepared high-voltage power supplies for ion sources, having all of the following characteristics: capable of continuous operation, output voltage of 20,000 V or greater, output current of 1 A or greater, and voltage regulation of better than 0.01% over a time period of 8 hours.

5.9.3 Magnet power supplies

Especially designed or prepared high-power, direct current magnet power supplies having all of the following characteristics: capable of continuously producing a current output of 500 A or greater at a voltage of 100 V or greater and with a current or voltage regulation better than 0.01% over a period of 8 hours.

PLANTS FOR THE PRODUCTION OR CONCENTRATION OF HEAVY WATER, DEUTERIUM AND DEUTERIUM COMPOUNDS AND EQUIPMENT ESPECIALLY DESIGNED OR PREPARED

INFCIRC/254/Rev.11/Part1 ANNEX B Section 6

Introductory Note

Heavy water can be produced by a variety of processes. The two processes that have proven to be commercially viable are the water-hydrogen sulphide exchange process (GS process) and the ammonia-hydrogen exchange process:

(1) The GS process is based upon the exchange of hydrogen and deuterium between water and hydrogen sulphide within a series of towers which are operated with the top section cold and the bottom section hot. Water flows down the towers while the hydrogen sulphide gas circulates from the bottom to the top of the towers. A series of perforated trays are used to promote mixing between the gas and the water. Deuterium migrates to the water at low temperatures and to the hydrogen sulplhide at high temperatures. Gas or water, enriched in deuterium, is removed from the first stage towers at the junction of the hot and cold sections and the process is repeated in subsequent stage towers. The product of the last stage, water enriched up to 30% in deuterium, is sent to a distillation unit to produce reactor grade heavy water; i.e., 99.75% deuterium oxide;

(2) The ammonia-hydrogen exchange process can extract deuterium from synthesis gas through contact with liquid ammonia in the presence of a catalyst. The synthesis gas is fed into exchange towers and to an ammonia converter. Inside the towers the gas flows from the bottom to the top while the liquid ammonia flows from the top the bottom. The deuterium is stripped from the hydrogen in the synthesis gas and concentrated in the ammonia. The ammonia then flows into an ammonia cracker at the bottom of the tower while gas flows into an ammonia converter at the top. Further enrichment takes place in subsequent stages and reactor grade heavy water is produced through final distillation. The synthesis gas feed can be provided by an ammonia plant that, in turn, can be constructed in association with a heavy water ammonia-hydrogen exchange plant. The ammonia-hydrogen exchange process can also use ordinary water as a feed source of deuterium;

(3) Many of the key equipment items for heavy water production plants using GS or ammonia-hydrogen exchange process are common to several segments of the chemical and petroleum industries. This is particularly so for small plants using the GS process. However, few of the items are available "off-the-shelf." The GS and ammonia-hydrogen processes require the handling of large quantities of flammable, corrosive, and toxic fluids at elevated pressures. Accordingly, in establishing the design and operating standards for plants and equipment using these processes, careful attention to the materials selection and specification is required to ensure long service life with high safety and reliability factors. The choice of scale is primarily a function of economics and need. Thus, most of the equipment items would be prepared according to the requirements of the customer;

(4) Finally, it should be noted that in both the GS and ammonia-hydrogen exchange processes, items of equipment which individually are not especially designed or prepared for heavy water production can be assembled into systems which are especially designed or prepared for producing heavy water. The catalyst system used in the ammonia-hydrogen exchange process and water distillation systems used for the final concentration of heavy water to reactor-grade in either process are examples of such systems.

6.1 Water-Hydrogen Sulphide Exchange Towers

Exchange towers fabricated from fine carbon steel (such as ASTM A516) with diameters of 6 m (20 ft) to 9 m (30 ft), capable of operating at pressures greater than or equal to 2 MPa (300 psi) and with a corrosion allowance of 6 mm or greater, especially designed or prepared for heavy water production utilizing the water-hydrogen sulphide exchange process.

Diameter of 6–9 m, as per description.

6.2 Blowers and Compressors

Single-stage, low head (i.e., 0.2 MPa or 30 psi) centrifugal blowers or compressors for hydrogen-sulphide gas circulation (i.e., gas containing more than 70% H2S), especially designed or prepared for heavy water production utilizing the water-hydrogen sulphide exchange process. These blowers or compressors have a throughput capacity greater than or equal to 56 m^3/second (120,000 SCFM) while operating at pressures greater than or equal to 1.8 MPa (260 psi) suction and have seals designed for wet H2S service.

6.3 Ammonia-Hydrogen Exchange Towers

Ammonia-hydrogen exchange towers greater than or equal to 35 m (114.3 ft) in height with diameters of 1.5 m (4.9 ft) to 2.5 m (8.2 ft) capable of operating at pressures greater than 15 MPa (2225 psi) especially designed or prepared for heavy water production utilizing the ammonia-hydrogen exchange process. These towers also have at least one flanged, axial opening of the same diameter as the cylindrical part through which the tower internals can be inserted or withdrawn. Image: hydrogen-ammonia exchange towers at a heavy water plant in India. source: http://www.hwb.gov.in/htmldocs/plants/Thal.asp
See relevant dimensional information and note the axial opening as described above.

6.4 Tower Internals and Stage Pumps

Tower internals and stage pumps especially designed or prepared for towers for heavy water production utilizing the ammonia-hydrogen exchange process. Tower internals include especially designed stage contractors that promote intimate gas/liquid contact. Stage pumps include especially designed submersible pumps for circulation of liquid ammonia within a contacting stage internal to the stage towers.

6.5 Ammonia Crackers

Ammonia crackers with operating pressures greater than or equal to 3 MPa (450 psi) especially designed or prepared for heavy water production utilizing the ammonia-hydrogen exchange process.

6.6 Infrared Absorption Analyzers

Infrared absorption analyzers capable of “on-line” hydrogen/deuterium ratio analysis where deuterium concentrations are equal to or greater than 90%.

6.7 Catalytic Burners

Catalytic burners for the conversion of enriched deuterium gas into heavy water especially designed or prepared for heavy water production utilizing the ammonia-hydrogen exchange process.

6.8 Complete heavy water upgrade systems or columns therefor

Complete heavy water upgrade systems, or columns therefor, especially designed or prepared for the upgrade of heavy water to reactor-grade deuterium concentration. Note: These systems, which usually employ water distillation to separate heavy water from light water, are especially designed and prepared to produce reactor-grade heavy water (i.e., typically 99.75% deuterium oxide) from heavy water feedstock of lesser concentration.

PLANTS FOR THE CONVERSION OF URANIUM AND PLUTONIUM FOR USE IN THE FABRICATION OF FUEL ELEMENTS AND THE SEPARATION OF URANIUM ISOTOPES AS DEFINED IN SECTIONS 4 AND 5 RESPECTIVELY, AND EQUIPMENT ESPECIALLY DESIGNED OR PREPARED

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7.1. Plants for the conversion of uranium and equipment especially designed or prepared therefor

Introductory Note

Uranium conversion plants and systems may perform one or more transformation from one uranium chemical species to another, including: conversion of uranium ore concentrates to UO3, conversion of UO3 to UO2, conversion of uranium oxides to UF4, UF6, or UCl4, conversion of UF4 to UF6, conversion of UF6 to UF4, conversion of UF4 to uranium metal, and conversion of uranium fluorides to UO2. Many of the key equipment items for uranium conversion plants are common to several segments of the chemical process industry. For example, the types of equipment employed in these processes may include: furnaces, rotary kilns, fluidized bed reactors, flame tower reactors, liquid centrifuges, distillation columns, and liquid-liquid extraction columns. However, few of the items are available "off-the-shelf"; most would be prepared according to the requirements and specifications of the customer. In some instances, special design and construction considerations are required to address the corrosive properties of some of the chemicals handled (HF, F2, CIF3, and uranium fluorides) as well as nuclear criticality concerns. Finally, it should be noted that, in all of the uranium conversion processes, items of equipment which individually are not especially designed or used for uranium conversion can be assembled into systems which are especially designed or prepared for use in uranium conversion.

7.1.1 Especially designed or prepared systems for the conversion of uranium ore concentrates to UO3

Note: Conversion of uranium ore concentrates to U03 can be performed by first dissolving the ore in nitric acid and extracting purified uranyl nitrate using a solvent such as tributyl phosphate. Next, the uranyl nitrate is converted to U03 either by concentration and denitration or by neutralization with gaseous ammonia to produce ammonium diuranate with subsequent filtering, drying, and calcining.

7.1.2 Especially designed or prepared systems for the conversion of UO3 to UF6

Note: Conversion of UO3 to UF6 can be performed directly by fluorination. The process requires a source of fluorine gas or chlorine trifluoride.

7.1.3 Especially designed or prepared systems for the conversion of UO3 to UO2

Note: Conversion of UO3 to UO2 can be performed from reduction of UO3 with cracked ammonia gas or hydrogen.

7.1.4 Especially designed or prepared systems for the conversion of UO2 to UF4

Note: Conversion of UO2 to UF4 can be performed by reacting UO2 with hydrogen fluoride gas (HF) at 300-500C.

7.1.5 Especially designed or prepared systems for the conversion of UF4 to UF6

Note: Conversion of UF4 to UF6 is performed by exothermic reaction with fluorine in a tower reactor. UF6 is condensed from the hot effluent gas by passing the effluent stream through a cold trap to -10° C. The process requires a source of fluorine gas.

7.1.6 Especially designed or prepared systems for the conversion of UF4 to U metal

Note: Conversion of UF4 to U metal is performed by reduction with magnesium (large batches) or calcium (small batches). The reaction is carried out at temperatures above the melting point of uranium (1130° C).

7.1.7 Especially designed or prepared systems for the conversion of UF6 to UO2

Note: Conversion of UF6 to UO2 can be performed by one of three processes.

1. UF6 is reduced and hydrolyzed to UO2 using hydrogen and steam,
2. UF6 is hydrolyzed by solution in water, ammonia is added to precipitate ammonium diuranate, and the diuranate is reduced to UO2 with hydrogen at 820° C,
3. Gaseous UF6, CO2, and NH3 are combined in water, precipitating ammonium uranyl carbonate. The ammonium uranyl carbonate is combined with steam and hydrogen at 500–600° C to yield UO2.

7.1.8 Especially designed or prepared systems for the conversion of UF6 to UF4

Note: Conversion of UF6 to UF4 is performed by reduction with hydrogen.

7.1.9 Especially designed or prepared systems for the conversion of UO2 to UCl4

Note: Conversion of UO2 to UCl4 can be performed by one of two processes:

1. UO2 is reacted with carbon tetrachloride (CCl4) at approximately 400° C,
2. UO2 is reacted to at approximately 700° C in the presence of carbon black (CAS 1333-86-4), carbon monoxide, and chlorine to yield UCl4.

7.2. Plants for the conversion of plutonium and equipment especially designed or prepared therefor

Introductory Note

Plutonium conversion plants and systems perform one or more transformations from one plutonium chemical species to another, including: conversion of plutonium nitrate to PuO2, conversion of PuO2 to PuF4, and conversion of PuF4 to plutonium metal. Plutonium conversion plants are usually associated with reprocessing facilities, but may also be associated with plutonium fuel fabrication facilities. Many of the key equipment items for plutonium conversion plants are common to several segments of the chemical process industry. For example, the types of equipment employed in these processes may include: furnaces, rotary kilns, fluidized bed reactors, flame tower reactors, liquid centrifuges, distillation columns and liquid-liquid extraction columns. Hot cells, glove boxes and remote manipulators may also be required. However, few of the items are available “off-the-shelf”; most would be prepared according to the requirements and specifications of the customer. Particular care in designing for the special radiological, toxicity and criticality hazards associated with plutonium is essential. In some instances, special design and construction considerations are required to address the corrosive properties of some of the chemicals handled (e.g., HF). Finally, it should be noted that, for all plutonium conversion processes, items of equipment that individually are not especially designed or prepared for plutonium conversion can be assembled into systems which are especially designed or prepared for use in plutonium conversion.

7.2.1 Especially designed or prepared systems for the conversion of plutonium nitrate to oxide

Note: The main functions involved in this process are: process feed storage and adjustment, precipitation and solid/liquid separation, calcination, product handling, ventilation, waste management, and process control. The process systems are particularly adapted so as to avoid criticality and radiation effects and to minimize toxicity hazards. In most reprocessing facilities, this process involves the conversion of plutonium nitrate to plutonium dioxide. Other processes can involve the precipitation of plutonium oxalate or plutonium peroxide.

7.2.2 Especially designed or prepared systems for plutonium metal production

Note: This process usually involves the fluorination of plutonium dioxide, normally with highly corrosive hydrogen fluoride, to produce plutonium fluoride which is subsequently reduced using high purity calcium metal to produce metallic plutonium and a calcium fluoride slag. The main functions involved in this process are fluorination (e.g., involving equipment fabricated or lined with a precious metal), metal reduction (e.g., employing ceramic crucibles) slag recovery, product handling, ventilation, waste management, and process control. The process systems are particularly adapted so as to avoid criticality and radiation effects and to minimize toxicity hazards. Other processes include the fluorination of plutonium oxalate or plutonium peroxide followed by a reduction to metal.