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**COMMUNICATIONS RECEIVED FROM MEMBER STATES  
REGARDING GUIDELINES FOR THE EXPORT OF NUCLEAR MATERIAL,  
EQUIPMENT AND TECHNOLOGY**

1. The Director General has received notes verbales relating to the export of nuclear material, equipment and technology from the following Permanent Missions to the International Atomic Energy Agency: notes verbales dated 1 March 1994 from the Permanent Missions of Australia, Austria, Belgium, Bulgaria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Japan, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland, the United Kingdom of Great Britain and Northern Ireland, and the United States of America; and a note verbale dated 12 March 1994 from the Permanent Mission of Romania.
2. The purpose of these notes verbales is to provide further information on these Governments' nuclear export policies and practices.
3. In the light of the wish expressed at the end of each note verbale, the analogous text of the notes verbales is attached hereto. The enclosure of these notes verbales ("Annex A: Trigger List Referred to in Guidelines" and "Annex B: Clarification of Items on the Trigger List") is reproduced in the Annex.

## NOTE VERBALE

The Permanent Mission of [Member State] to the International Atomic Energy Agency presents its compliments to the Director General of the International Atomic Energy Agency and has the honour to refer to its [relevant previous communication(s)] concerning the decision of the Government of [Member State] to act in accordance with the Guidelines for nuclear transfers originally published as document INFCIRC/254.

Developments in nuclear technology have brought about the need to further clarify and amend parts of the trigger list which is incorporated in Annex A and Annex B to the Guidelines currently published in document INFCIRC/254/Rev.1/Part.1. Specifically:

- Section 5 of Annex B of INFCIRC/254/Rev.1/Part.1 concerning equipment especially designed or prepared for the separation of isotopes of uranium has been clarified and amended;
- Annex A and Annex B of INFCIRC/254/Rev.1/Part.1 have been amended to include a new entry for plants for the conversion of uranium and equipment especially designed or prepared therefor; and
- Item 1.7 of Section 1 of Annex B of INFCIRC/254/Rev.1/Part.1 concerning primary coolant pumps has been amended.

In the interest of clarity, the complete text of the resultant modified Annex A and Annex B is reproduced in the attachment.

The Government of [Member State] has decided to act in accordance with the Guidelines so revised.

In reaching this decision, the Government of [Member State] is fully aware of the need to contribute to economic development while avoiding contributing in any way to the dangers of a proliferation of nuclear weapons or other nuclear explosive devices, and of the need to remove non-proliferation assurances from the field of commercial competition.

[The Government of (Member State), so far as trade within the European Union is concerned, will implement this decision in the light of its commitments as a Member State of the Union.]<sup>1</sup>

The Government of [Member State] requests that the Director of the International Atomic Energy Agency circulate the text of this note and its enclosure to all Member States for their information.

The Permanent Mission of [Member State] avails itself of this opportunity to renew to the Director General of the International Atomic Energy Agency the assurances of its highest consideration.

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<sup>1</sup> This paragraph is included only in the letters sent by the Governments of Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal, Spain, the United Kingdom of Great Britain and Northern Ireland.

## ANNEX A

### TRIGGER LIST REFERRED TO IN GUIDELINES

#### PART A. Material and equipment

#### 1. Source and special fissionable material

As defined in Article XX of the Statute of the International Atomic Energy Agency:

##### 1.1. "Source material"

The term "source material" means uranium containing the mixture of isotopes occurring in nature; uranium depleted in the isotope 235; thorium; any of the foregoing in the form of metal, alloy, chemical compound, or concentrate; any other material containing one or more of the foregoing in such concentration as the Board of Governors shall from time to time determine; and such other material as the Board of Governors shall from time to time determine.

##### 1.2. "Special fissionable material"

i) The term "special fissionable material" means plutonium-239; uranium-233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing; and such other fissionable material as the Board of Governors shall from time to time determine; but the term "special fissionable material" does not include source material.

ii) The term "uranium enriched in the isotopes 235 or 233" means uranium containing the isotopes 235 or 233 or both in an amount such that the abundance ratio of the sum of these isotopes to the isotope 238 is greater than the ratio of the isotope 235 to the isotope 238 occurring in nature.

However, for the purposes of the Guidelines, items specified in subparagraph (a) below, and exports of source or special fissionable material to a given recipient country, within a period of 12 months, below the limits specified in subparagraph (b) below, shall not be included:

(a) Plutonium with an isotopic concentration of plutonium-238 exceeding 80%.

Special fissionable material when used in gram quantities or less as a sensing component in instruments; and

Source material which the Government is satisfied is to be used only in non-nuclear activities, such as the production of alloys or ceramics;

(b) Special fissionable material	50 effective grams;
Natural uranium	500 kilograms;
Depleted uranium	1000 kilograms; and
Thorium	1000 kilograms.

## **2. Equipment and Non-nuclear Materials**

The designation of items of equipment and non-nuclear materials (hereafter referred to as the "Trigger List") adopted by the Government is as follows (quantities below the levels indicated in the Annex B being regarded as insignificant for practical purposes):

- 2.1. Reactors and equipment therefor (see Annex B, section 1.);**
- 2.2. Non-nuclear materials for reactors (see Annex B, section 2.);**
- 2.3. Plants for the reprocessing of irradiated fuel elements, and equipment especially designed or prepared therefor (see Annex B, section 3.);**
- 2.4. Plants for the fabrication of fuel elements (see Annex B, section 4.);**
- 2.5. Plants for the separation of isotopes of uranium and equipment, other than analytical instruments, especially designed or prepared therefor (see Annex B, section 5.);**
- 2.6. Plants for the production of heavy water, deuterium and deuterium compounds and equipment especially designed or prepared therefor (see Annex B, section 6.);**
- 2.7. Plants for the conversion of uranium and equipment especially designed or prepared therefor (See Annex B, Section 7.).**

### **PART B. Common criteria for technology transfers under paragraph 6 of the Guidelines**

- (1) "Technology" means technical data in physical form designated by the supplying country as important to the design, construction, operation, or maintenance of enrichment, reprocessing, or heavy water production facilities or major critical components thereof, but excluding data available to the public, for example, in published books and periodicals, or that which has been made available internationally without restrictions upon its further dissemination.
- (2) "Major critical components" are:
  - (a) in the case of an isotope separation plant of the gas centrifuge type: gas centrifuge assemblies, corrosion-resistant to UF<sub>6</sub>;
  - (b) in the case of an isotope separation plant of the gaseous diffusion type: diffusion barrier;
  - (c) in the case of an isotope separation plant of the jet nozzle type: the nozzle units;
  - (d) in the case of an isotope separation plant of the vortex type: the vortex units.
- (3) For facilities covered by paragraph 6 of the Guidelines for which no major critical component is described in paragraph 2 above, if a supplier nation should transfer in the aggregate a significant fraction of the items essential to the operation of such a facility, together with the knowhow for construction and operation of that facility, that transfer should be deemed to be a transfer of "facilities or major critical components thereof".

- (4) The definitions in the preceding paragraphs are solely for the purposes of paragraph 6 of the Guidelines and this Part B, which differ from those applicable to Part A of this Trigger List, which should not be interpreted as limited by such definition.
- (5) For the purposes of implementing paragraph 6 of the Guidelines, the following facilities should be deemed to be "of the same type (i.e. if their design, construction or operating processes are based on the same or similar physical or chemical processes)":

Where the technology transferred is such as to make possible the construction in the recipient State of a facility of the following type, or major critical components thereof:

The following will be deemed to be facilities of the same type:

- |  |   |
|--|---|
| (a) an isotope separation plant of the gaseous diffusion type .....      | any other isotope separation plant using the gaseous diffusion process. |
| (b) an isotope separation plant of the gas centrifuge type .....         | any other isotope separation plant using the gas centrifuge process.    |
| (c) an isotope separation plant of the jet nozzle type .....             | any other isotope separation plant using the jet nozzle process.        |
| (d) an isotope separation plant of the vortex type .....                 | any other isotope separation plant using the vortex process.            |
| (e) a fuel reprocessing plant using the solvent extraction process ..... | any other fuel reprocessing plant using the solvent extraction process. |
| (f) a heavy water plant using the exchange process .....                 | any other heavy water plant using the exchange process.                 |
| (g) a heavy water plant using the electrolytic process .....             | any other heavy water plant using the electrolytic process.             |
| (h) a heavy water plant using the hydrogen distillation process .....    | any other heavy water plant using the hydrogen distillation process.    |

**Note:** In the case of reprocessing, enrichment, and heavy water facilities whose design, construction, or operation processes are based on physical or chemical processes other than those enumerated above, a similar approach would be applied to define facilities "of the same type", and a need to define major critical components of such facilities might arise.

- (6) The reference in paragraph 6(b) of the Guidelines to "any facilities of the same type constructed during an agreed period in the recipient's country" is understood to refer to such facilities (or major critical components thereof), the first operation of which commences within a period of at least 20 years from the date of the first operation of (1) a facility which has been transferred or incorporates transferred major critical components or of (2) a facility of the same type built after the transfer of technology. It is understood that during that period there would be a conclusive presumption that any facility of the same type utilized transferred technology. But the agreed period is not intended to limit the duration of the safeguards imposed or the duration of the right to identify facilities as being constructed or operated on the basis of or by the use of transferred technology in accordance with paragraph 6(b)(2) of the Guidelines.

## ANNEX B

### CLARIFICATION OF ITEMS ON THE TRIGGER LIST (as designated in Section 2 of Part A of Annex A)

#### 1. Reactors and equipment therefor

##### 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.

##### EXPLANATORY NOTE

A "nuclear reactor" basically includes the items within or attached directly to the reactor vessel, the equipment which controls the level of power in the core, and the components which normally contain or come in 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 grams of plutonium per year. Reactors designed for sustained operation at significant power levels, regardless of their capacity for plutonium production, are not considered as "zero energy reactors".

##### EXPORTS

The export of the whole set of major items within this boundary will take place only in accordance with the procedures of the Guidelines. Those individual items within this functionally defined boundary which will be exported only in accordance with the procedures of the Guidelines are listed in paragraphs 1.2. to 1.7. The Government reserves the right to apply the procedures of the Guidelines to other items within the functionally defined boundary.

##### 1.2. Reactor pressure vessels

Metal vessels, as complete units or as major shop-fabricated parts therefor, which are especially designed or prepared to contain the core of a nuclear reactor as defined in paragraph 1.1. above and are capable of withstanding the operating pressure of the primary coolant.

##### EXPLANATORY NOTE

A top plate for a reactor pressure vessel is covered by item 1.2. as a major shop-fabricated part of a pressure vessel.

Reactor internals (eg support columns and plates for the core and other vessel internals, control rod guide tubes, thermal shields, baffles, core grid plates, diffuser plates, etc.) are normally supplied by the reactor supplier. In some cases, certain internal support components are included in the fabrication of the pressure vessel. These items are sufficiently critical to the safety and reliability of the operation of the reactor (and, therefore, to the guarantees and liability of the reactor supplier), so that their supply, outside the basic supply arrangement for the reactor itself, would not be common practice. Therefore, although the separate supply of these unique, especially designed and prepared, critical, large and expensive items would not necessarily be considered as falling outside the area of concern, such a mode of supply is considered unlikely.

##### 1.3. Reactor fuel charging and discharging machines

Manipulative equipment especially designed or prepared for inserting or removing fuel in a nuclear reactor as defined in paragraph 1.1. above capable of on-load operation or employing technically sophisticated positioning or alignment features to allow complex off-load fuelling operations such as those in which direct viewing of or access to the fuel is not normally available.

**1.4. Reactor control rods**

Rods especially designed or prepared for the control of the reaction rate in a nuclear reactor as defined in paragraph 1.1. above.

**EXPLANATORY NOTE**

This item includes, in addition to the neutron absorbing part, the support or suspension structures therefor if supplied separately.

**1.5. Reactor pressure tubes**

Tubes which are especially designed or prepared to contain fuel elements and the primary coolant in a reactor as defined in paragraph 1.1. above at an operating pressure in excess of 5.1 MPa (740 psi).

**1.6. Zirconium tubes**

Zirconium metal and alloys in the form of tubes or assemblies of tubes, and in quantities exceeding 500 kg in any period of 12 months, especially designed or prepared for use in a reactor as defined in paragraph 1.1. above, and in which the relation of hafnium to zirconium is less than 1:500 parts by weight.

**1.7. Primary coolant pumps**

Pumps especially designed or prepared for circulating the primary coolant for nuclear reactors as defined in paragraph 1.1. above.

**EXPLANATORY 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. This definition encompasses pumps certified to NC-1 or equivalent standards.

**2. Non-nuclear materials for reactors**

**2.1. Deuterium and heavy water**

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 as defined in paragraph 1.1. above in quantities exceeding 200 kg of deuterium atoms for any one recipient country in any period of 12 months.

**2.2. Nuclear grade graphite**

Graphite having a purity level better than 5 parts per million boron equivalent and with a density greater than 1.50 g/cm<sup>3</sup> in quantities exceeding 3·10<sup>4</sup> kg (30 metric tons) for any one recipient country in any period of 12 months.



### **3. Plants for the reprocessing of irradiated fuel elements, and equipment especially designed or prepared therefor**

#### **INTRODUCTORY NOTE**

Reprocessing irradiated nuclear fuel separates plutonium and uranium from intensely radioactive fission products and other transuranic elements. Different technical processes can accomplish this separation. However, over the years Purex has become the most commonly used and accepted process. Purex involves the dissolution of irradiated nuclear fuel in nitric acid, followed by separation of the uranium, plutonium, and fission products by solvent extraction using a mixture of tributyl phosphate in an organic diluent.

Purex facilities have process functions similar to each other, including: irradiated fuel element chopping, fuel dissolution, solvent extraction, and process liquor storage. There may also be equipment for thermal denitration of uranium nitrate, conversion of plutonium nitrate to oxide or metal, and treatment of fission product waste liquor to a form suitable for long term storage or disposal. However, the specific type and configuration of the equipment performing these functions may differ between Purex facilities for several reasons, including the type and quantity of irradiated nuclear fuel to be reprocessed and the intended disposition of the recovered materials, and the safety and maintenance philosophy incorporated into the design of the facility.

A "plant for the reprocessing of irradiated fuel elements" includes the equipment and components which normally come in direct contact with and directly control the irradiated fuel and the major nuclear material and fission product processing streams.

These processes, including the complete systems for plutonium conversion and plutonium metal production, may be identified by the measures taken to avoid criticality (eg by geometry), radiation exposure (eg by shielding), and toxicity hazards (eg by containment).

#### **EXPORTS**

The export of the whole set of major items within this boundary will take place only in accordance with the procedures of the Guidelines.

The Government reserves to itself the right to apply the procedures of the Guidelines to other items within the functionally defined boundary as listed below.

Items of equipment that are considered to fall within the meaning of the phrase "and equipment especially designed or prepared" for the reprocessing of irradiated fuel elements include:

#### **3.1. Irradiated fuel element chopping machines**

##### **INTRODUCTORY NOTE**

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 a reprocessing plant as identified above and intended to cut, chop or shear irradiated nuclear fuel assemblies, bundles or rods.

#### **3.2. Dissolvers**

##### **INTRODUCTORY NOTE**

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 removed from the process stream.

Critically safe tanks (eg 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

#### INTRODUCTORY NOTE

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.

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

#### INTRODUCTORY NOTE

Three main process liquor streams result from the solvent extraction step. Holding or storage vessels are used in the further processing of all three streams, as follows:

- (a) The pure uranium nitrate solution is concentrated by evaporation and passed to a denitration process where it is converted to uranium oxide. This oxide is re-used in the nuclear fuel cycle.
- (b) The intensely radioactive fission products solution is normally concentrated by evaporation and stored as a liquor concentrate. This concentrate may be subsequently evaporated and converted to a form suitable for storage or disposal.
- (c) The pure plutonium nitrate solution is concentrated and stored pending its transfer to further process steps. In particular, holding or storage vessels for plutonium solutions are designed to avoid criticality problems resulting from changes in concentration and form of this stream.

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 two per cent, or
- (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.

### 3.5. Plutonium nitrate to oxide conversion system

#### INTRODUCTORY NOTE

In most reprocessing facilities, this final process involves the conversion of the plutonium nitrate solution to plutonium dioxide. The main functions involved in this process are: process feed storage and adjustment, precipitation and solid/liquor separation, calcination, product handling, ventilation, waste management, and process control.

Complete systems especially designed or prepared for the conversion of plutonium nitrate to plutonium oxide, in particular adapted so as to avoid criticality and radiation effects and to minimize toxicity hazards.

### 3.6. Plutonium oxide to metal production system

#### INTRODUCTORY NOTE

This process, which could be related to a reprocessing facility, 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 (eg involving equipment fabricated or lined with a precious metal), metal reduction (eg employing ceramic crucibles), slag recovery, product handling, ventilation, waste management and process control.

Complete systems especially designed or prepared for the production of plutonium metal, in particular adapted so as to avoid criticality and radiation effects and to minimize toxicity hazards.

### 4. Plants for the fabrication of fuel elements

A "plant for the fabrication of fuel elements" includes the equipment:

- (a) Which normally comes in direct contact with, or directly processes, or controls, the production flow of nuclear material, or
- (b) Which seals the nuclear material within the cladding.

#### EXPORTS

The export of the whole set of items for the foregoing operations will take place only in accordance with the procedures of the Guidelines. The Government will also give consideration to application of the procedures of the Guidelines to individual items intended for any of the foregoing operations, as well as for other fuel fabrication operations such as checking the integrity of the cladding or the seal, and the finishing treatment of the sealed fuel.

### 5. Plants for the separation of isotopes of uranium and equipment, other than analytical instruments, especially designed or prepared therefor

Items of equipment that are considered to fall within the meaning of the phrase "equipment, other than analytical instruments, especially designed or prepared" for the separation of isotopes of uranium include:

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

##### INTRODUCTORY NOTE

The gas centrifuge normally consists of a thin-walled cylinder(s) of between 75 mm (3 in) and 400 mm (16 in) diameter contained in a vacuum environment and spun at high peripheral speed of the order of 300 m/s or more with its central axis vertical. In order to achieve high speed the materials of construction for the rotating components have to be of a high strength to density ratio and 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 a rotating disc-shaped baffle(s) and a stationary tube arrangement for feeding and extracting the UF<sub>6</sub> 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 nor are they fabricated out of unique materials. A centrifuge facility however requires a large number of these components, so that quantities can provide an important indication of end use.

##### 5.1.1. Rotating components

- (a) Complete rotor assemblies:

Thin-walled cylinders, or a number of interconnected thin-walled cylinders, manufactured from one or more of the high strength to density ratio materials described in the EXPLANATORY NOTE to this Section. If interconnected, the cylinders are joined together by flexible bellows or rings as described in section 5.1.1.(c) following. The rotor is fitted with an internal baffle(s) and end

caps. as described in section 5.1.1.(d) and (e) following, if in final form. However the complete assembly may be delivered only partly assembled.

(b) Rotor tubes:

Especially designed or prepared thin-walled cylinders with thickness of  $\pm 2$  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 of the high strength to density ratio materials described in the EXPLANATORY NOTE to this Section.

(c) Rings or Bellows:

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 (0.12 in) or less, a diameter of between 75 mm (3 in) and 400 mm (16 in), having a convolute, and manufactured from one of the high strength to density ratio materials described in the EXPLANATORY NOTE to this Section.

(d) 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  $UF_6$  gas circulation within the main separation chamber of the rotor tube, and manufactured from one of the high strength to density ratio materials described in the EXPLANATORY NOTE to this Section.

(e) Top caps/Bottom caps:

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  $UF_6$  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), and manufactured from one of the high strength to density ratio materials described in the EXPLANATORY NOTE to this Section.

#### EXPLANATORY NOTE

The materials used for centrifuge rotating components are:

- (a) Maraging steel capable of an ultimate tensile strength of  $2.05 \cdot 10^8$  N/m<sup>2</sup> (300,000 psi) or more;
- (b) Aluminium alloys capable of an ultimate tensile strength of  $0.46 \cdot 10^8$  N/m<sup>2</sup> (67,000 psi) or more;
- (c) Filamentary materials suitable for use in composite structures and having a specific modulus of  $12.3 \cdot 10^6$  m or greater and a specific ultimate tensile strength of  $0.3 \cdot 10^6$  m or greater ('Specific Modulus' is the Young's Modulus in N/m<sup>2</sup> divided by the specific weight in N/m<sup>3</sup>; 'Specific Ultimate Tensile Strength' is the ultimate tensile strength in N/m<sup>2</sup> divided by the specific weight in N/m<sup>3</sup>).

### 5.1.2. Static components

(a) Magnetic suspension bearings:

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  $UF_6$ -resistant material (see EXPLANATORY NOTE to Section 5.2.). The magnet couples with a pole piece or a second magnet fitted to the top cap described in Section 5.1.1.(e). 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 CGS units) or more, or a remanence of 98.5% or more, or an energy product of greater than 80 kJ/m<sup>3</sup> ( $10^7$  gauss-oersteds). In addition to the usual material properties, it is a prerequisite that the deviation of the magnetic axes from the geometrical axes is limited to very small tolerances (lower than 0.1 mm or 0.004 in) or that homogeneity of the material of the magnet is specially called for.

(b) 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 described in section 5.1.1.(e) at the other. The shaft may however 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.

(c) 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 (0.4 in) 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 (0.08 in) or more in depth.

(d) 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 layers typically 2.0 mm (0.08 in) thick or less.

(e) 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 0.05 degrees or less. The housing may also be a honeycomb type structure to accommodate several rotor tubes. The housings are made of or protected by materials resistant to corrosion by  $UF_6$ .

(f) Scoops:

Especially designed or prepared tubes of up to 12 mm (0.5 in) internal diameter for the extraction of  $UF_6$  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 bending 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  $UF_6$ .

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

### INTRODUCTORY NOTE

The auxiliary systems, equipment and components for a gas centrifuge enrichment plant are the systems of plant needed to feed  $UF_6$  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'  $UF_6$  from the centrifuges, together with the equipment required to drive the centrifuges or to control the plant.

Normally  $UF_6$  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'  $UF_6$  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:

Feed autoclaves (or stations), used for passing  $UF_6$  to the centrifuge cascades at up to 100 kPa (15 psi) and at a rate of 1 kg/h or more;

Desublimers (or cold traps) used to remove  $UF_6$  from the cascades at up to 3 kPa (0.5 psi) pressure. The desublimers are capable of being chilled to 203 K (-70°C) and heated to 343 K (70°C);

Product' and 'Tails' stations used for trapping  $UF_6$  into containers.

This plant, equipment and pipework is wholly made of or lined with  $UF_6$ -resistant materials (see EXPLANATORY NOTE to this section) and is fabricated to very high vacuum and cleanliness standards.

### 5.2.2. Machine header piping systems

Especially designed or prepared piping systems and header systems for handling  $UF_6$  within the centrifuge cascades. The piping network is normally of 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  $UF_6$ -resistant materials (see EXPLANATORY NOTE to this section) and is fabricated to very high vacuum and cleanliness standards.

### 5.2.3. $UF_6$ 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  $UF_6$  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 isotopic analysis.

### 5.2.4. Frequency changers

Frequency changers (also known as converters or invertors) especially designed or prepared to supply motor stators as defined under 5.1.2.(d), 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%); and
4. An efficiency of greater than 80%.

#### EXPLANATORY NOTE

The items listed above either come into direct contact with the  $UF_6$  process gas or directly control the centrifuges and the passage of the gas from centrifuge to centrifuge and cascade to cascade.

Materials resistant to corrosion by  $UF_6$  include stainless steel, aluminium, aluminium alloys, nickel or alloys containing 60% or more nickel.

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

#### **INTRODUCTORY NOTE**

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 ( $UF_6$ ), all equipment, pipeline and instrumentation surfaces (that come in contact with the gas) must be made of materials that remain stable in contact with  $UF_6$ . 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**

(a) Especially designed or prepared thin, porous filters, with a pore size of 100 - 1,000 Å (angstroms), a thickness of 5 mm (0.2 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  $UF_6$ , and

(b) especially prepared compounds or powders for the manufacture of such filters. Such compounds and powders include nickel or alloys containing 60 per cent or more nickel, aluminium oxide, or  $UF_6$ -resistant fully fluorinated hydrocarbon polymers having a purity of 99.9 per cent 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.

#### **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  $UF_6$ -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 1 m<sup>3</sup>/min or more of  $UF_6$ , and with a discharge pressure of up to several hundred kPa (100 psi), designed for long-term operation in the  $UF_6$  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  $UF_6$ .

#### **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  $UF_6$ . Such seals are normally designed for a buffer gas in-leakage rate of less than 1000 cm<sup>3</sup>/min (60 in<sup>3</sup>/min).

#### **5.3.5. Heat exchangers for cooling $UF_6$**

Especially designed or prepared heat exchangers made of or lined with  $UF_6$ -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 (0.0015 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

##### INTRODUCTORY NOTE

The auxiliary systems, equipment and components for gaseous diffusion enrichment plants are the systems of plant needed to feed  $UF_6$  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"  $UF_6$  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  $UF_6$  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"  $UF_6$  gaseous streams flowing from exit points are passed by way of cascade header pipework to either cold traps or to compression stations where the  $UF_6$  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.

##### 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:

Feed autoclaves (or systems), used for passing  $UF_6$  to the gaseous diffusion cascades;

Desublimers (or cold traps) used to remove  $UF_6$  from diffusion cascades;

Liquefaction stations where  $UF_6$  gas from the cascade is compressed and cooled to form liquid  $UF_6$ ;

"Product" or "tails" stations used for transferring  $UF_6$  into containers.

##### 5.4.2. Header piping systems

Especially designed or prepared piping systems and header systems for handling  $UF_6$  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<sup>3</sup>/min (175 ft<sup>3</sup>/min) or more.

(b) Vacuum pumps especially designed for service in  $UF_6$ -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 and 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  $UF_6$ -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. $UF_6$ 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  $UF_6$  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. Collector system suitable for isotopic analysis.

##### EXPLANATORY NOTE

The items listed above either come into direct contact with the  $UF_6$  process gas or directly control the flow within the cascade. All surfaces which come into contact with the process gas are wholly made of, or lined with,  $UF_6$ -resistant materials. For the purposes of the sections relating to gaseous diffusion items the materials resistant to corrosion by  $UF_6$  include stainless steel, aluminium, aluminium alloys, aluminium oxide, nickel or alloys containing 60% or more nickel and  $UF_6$ -resistant fully fluorinated hydrocarbon polymers.

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

##### INTRODUCTORY NOTE

In aerodynamic enrichment processes, a mixture of gaseous  $UF_6$  and light gas (hydrogen or helium) is compressed and then passed through separating elements wherein isotopic 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. Since aerodynamic processes use  $UF_6$ , all equipment, pipeline and instrumentation surfaces (that come in contact with the gas) must be made of materials that remain stable in contact with  $UF_6$ .

##### EXPLANATORY NOTE

The items listed in this section either come into direct contact with the  $UF_6$  process gas or directly control the flow within the cascade. All surfaces which come into contact with the process gas are wholly made of or protected by  $UF_6$ -resistant materials. For the purposes of the section relating to aerodynamic enrichment items, the materials resistant to corrosion by  $UF_6$  include copper, stainless steel, aluminium, aluminium alloys, nickel or alloys containing 60% or more nickel and  $UF_6$ -resistant fully fluorinated hydrocarbon polymers.

##### 5.5.1. Separation nozzles

Especially designed or prepared separation nozzles and assemblies thereof. The separation nozzles consist of slit-shaped, curved channels having a radius of curvature less than 1 mm (typically 0.1 to 0.05 mm), resistant to corrosion by  $UF_6$  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 or tapered, made of or protected by materials resistant to corrosion by  $UF_6$ , having a diameter of between 0.5 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.

##### EXPLANATORY NOTE

The feed gas enters the vortex tube tangentially at one end or through swirl vanes or at numerous tangential positions along the periphery of the tube.

### 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 materials resistant to corrosion by  $UF_6$  and with a suction volume capacity of 2 m<sup>3</sup>/min or more of  $UF_6$ /carrier gas (hydrogen or helium) mixture.

#### EXPLANATORY NOTE

These compressors and gas blowers 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 of air or seal gas into the inner chamber of the compressor or gas blower which is filled with a  $UF_6$ /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  $UF_6$ .

### 5.5.6. Separation element housings

Especially designed or prepared separation element housings, made of or protected by materials resistant to corrosion by  $UF_6$ , for containing vortex tubes or separation nozzles.

#### EXPLANATORY NOTE

These 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  $UF_6$ , including:

- (a) Feed autoclaves, ovens, or systems used for passing  $UF_6$  to the enrichment process;
- (b) Desublimers (or cold traps) used to remove  $UF_6$  from the enrichment process for subsequent transfer upon heating;
- (c) Solidification or liquefaction stations used to remove  $UF_6$  from the enrichment process by compressing and converting  $UF_6$  to a liquid or solid form;
- (d) 'Product' or 'tails' stations used for transferring  $UF_6$  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  $UF_6$ , for handling  $UF_6$  within the aerodynamic cascades. This piping network is normally of the 'double' header design with each stage or group of stages connected to each of the headers.

### 5.5.9. Vacuum systems and pumps

(a) Especially designed or prepared vacuum systems having a suction capacity of 5 m<sup>3</sup>/min or more, consisting of vacuum manifolds, vacuum headers and vacuum pumps, and designed for service in UF<sub>6</sub>-bearing atmospheres.

(b) Vacuum pumps especially designed or prepared for service in UF<sub>6</sub>-bearing atmospheres and made of or protected by materials resistant to corrosion by UF<sub>6</sub>. 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 UF<sub>6</sub> with a diameter of 40 to 1500 mm for installation in main and auxiliary systems of aerodynamic enrichment plants.

### 5.5.11. UF<sub>6</sub> 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 UF<sub>6</sub> 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 isotopic analysis.

### 5.5.12. UF<sub>6</sub>/carrier gas separation systems

Especially designed or prepared process systems for separating UF<sub>6</sub> from carrier gas (hydrogen or helium).

#### EXPLANATORY NOTE

These systems are designed to reduce the UF<sub>6</sub> 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, or
- (b) Cryogenic refrigeration units capable of temperatures of -120 °C or less, or
- (c) Separation nozzle or vortex tube units for the separation of UF<sub>6</sub> from carrier gas, or
- (d) UF<sub>6</sub> 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 the isotopes of uranium causes small changes in chemical reaction equilibria that 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.

In the liquid-liquid chemical exchange process, immiscible liquid phases (aqueous and organic) are countercurrently 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 fluorocarbon polymers) and/or glass-lined columns and piping are therefore used.

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 adsorbent. For a continuous process, a reflux system is necessary to release the uranium from the adsorbent back into the liquid flow so that 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 isotopic 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 fluorocarbon 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 are 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.

##### EXPLANATORY NOTE

The cell cathodic compartment must be designed to prevent re-oxidation of uranium to its higher valence state. To keep the uranium in the cathodic compartment, the cell may 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.

##### EXPLANATORY NOTE

These systems consist of solvent extraction equipment for stripping the  $U^{+4}$  from the organic stream into an aqueous solution, evaporation and/or other equipment to accomplish solution pH adjustment and control, and pumps or other transfer devices for feeding to the electrochemical reduction cells. A major design concern is to avoid contamination of the aqueous stream with certain metal ions. Consequently, for those parts in contact with the process stream, the system is constructed of equipment made of or protected by suitable materials (such as glass, fluorocarbon polymers, polyphenyl sulfate, 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.

##### EXPLANATORY NOTE

These systems consist of dissolution, solvent extraction and/or ion exchange equipment for purification and electrolytic cells for reducing the uranium  $U^{+4}$  or  $U^{+6}$  to  $U^{+3}$ . These systems produce uranium chloride solutions having only a few parts per million of metallic impurities such as chromium, iron, vanadium, molybdenum and other bivalent or higher multivalent cations. Materials of construction for portions of the system processing high-purity  $U^{+3}$  include glass, fluorocarbon 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 of  $U^{+3}$  to  $U^{+4}$  for return to the uranium isotope separation cascade in the chemical exchange enrichment process.

##### EXPLANATORY NOTE

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 resultant  $U^{+4}$  into the stripped organic stream returning from the product end of the cascade.
- (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, including porous macroporous 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 have diameters of 0.2 mm or less and must be chemically resistant to concentrated hydrochloric acid solutions as well as physically strong enough so as not to degrade in the exchange columns. The 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 of operating at a temperature in the range of 100°C to 200°C and pressures above 0.7 MPa (102 psia).

#### 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 ion exchange uranium enrichment cascades.

#### EXPLANATORY NOTE

The ion exchange enrichment process may use, for example, trivalent titanium ( $Ti^{+3}$ ) as a reducing cation in which case the reduction system would regenerate  $Ti^{+3}$  by reducing  $Ti^{+4}$ .

The process may use, for example, trivalent iron ( $Fe^{+3}$ ) as an oxidant in which case the oxidation system would regenerate  $Fe^{+3}$  by oxidizing  $Fe^{+2}$ .

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

#### INTRODUCTORY NOTE

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 include: 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 embrace: (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' and '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 uranium-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  $UF_6$  or a mixture of  $UF_6$  and other gases. All surfaces that come into contact with the uranium or  $UF_6$  are wholly made of or protected by corrosion-resistant materials. For the purposes of the section relating 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  $UF_6$  include copper, stainless steel, aluminium, aluminium alloys, nickel or alloys containing 60 % or more nickel and  $UF_6$ -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 and cooling equipment for the crucibles.

#### EXPLANATORY 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/Rev.1/Part 2, item 2.7) 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.

#### EXPLANATORY 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.

##### EXPLANATORY NOTE

These housings have 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 closure to allow refurbishment of internal components.

#### 5.7.5. Supersonic expansion nozzles (MLIS)

Especially designed or prepared supersonic expansion nozzles for cooling mixtures of  $UF_6$  and carrier gas to 150 K or less and which are corrosion resistant to  $UF_6$ .

#### 5.7.6. Uranium pentafluoride product collectors (MLIS)

Especially designed or prepared uranium pentafluoride ( $UF_5$ ) solid product collectors consisting of filter, impact, or cyclone-type collectors, or combinations thereof, and which are corrosion resistant to the  $UF_5/UF_6$  environment.

#### 5.7.7. $UF_6$ /carrier gas compressors (MLIS)

Especially designed or prepared compressors for  $UF_6$ /carrier gas mixtures, designed for long term operation in a  $UF_6$  environment. The components of these compressors that come into contact with process gas are made of or protected by materials resistant to corrosion by  $UF_6$ .

#### 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  $UF_6$ /carrier gas mixture.

#### 5.7.9. Fluorination systems (MLIS)

Especially designed or prepared systems for fluorinating  $UF_5$  (solid) to  $UF_6$  (gas).

##### EXPLANATORY NOTE

These systems are designed to fluorinate the collected  $UF_5$  powder to  $UF_6$  for subsequent collection in product containers or for transfer as 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  $UF_5$  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  $UF_6$  are used.

#### 5.7.10. $UF_6$ 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  $UF_6$  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 isotopic 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  $UF_6$ , including:

- (a) Feed autoclaves, ovens, or systems used for passing  $UF_6$  to the enrichment process;
- (b) Desublimers (or cold traps) used to remove  $UF_6$  from the enrichment process for subsequent transfer upon heating;
- (c) Solidification or liquefaction stations used to remove  $UF_6$  from the enrichment process by compressing and converting  $UF_6$  to a liquid or solid form;
- (d) 'Product' or 'tails' stations used for transferring  $UF_6$  into containers.

#### 5.7.12. $UF_6$ /carrier gas separation systems (MLIS)

Especially designed or prepared process systems for separating  $UF_6$  from carrier gas. The carrier gas may be nitrogen, argon, or other gas.

##### EXPLANATORY NOTE

These systems may incorporate equipment such as:

- (a) Cryogenic heat exchangers or cryoseparators capable of temperatures of  $-120\text{ }^\circ\text{C}$  or less, or
- (b) Cryogenic refrigeration units capable of temperatures of  $-120\text{ }^\circ\text{C}$  or less, or
- (c)  $UF_6$  cold traps capable of temperatures of  $-20\text{ }^\circ\text{C}$  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.

##### EXPLANATORY NOTE

The lasers and laser components of importance in laser-based enrichment processes include those identified in item 3.6 of INFCIRC/254/Rev.1/Part 2. 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  $CO_2$  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  $^{235}\text{U}$  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  $^{235}\text{U}$ . 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 superconducting magnet (see item 3.10 of INFCIRC/254/Rev.1/Part 2), 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 coils 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.

##### **EXPLANATORY 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/Rev.1/Part 2, item 2.7) 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.

##### **EXPLANATORY 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 ionization of a salt feed material (typically  $UCl_4$ ) 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**

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 plates 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.

#### **EXPLANATORY 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.

## **6. Plants for the production of heavy water, deuterium and deuterium compounds and equipment especially designed or prepared therefor**

#### **INTRODUCTORY NOTE**

Heavy water can be produced by a variety of processes. However, 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.

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 sulphide 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.

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 to 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 the 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.

Many of the key equipment items for heavy water production plants using GS or the ammonia-hydrogen exchange processes 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-shell". 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 specifications 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.

Finally, it should be noted that, in both the GS and the 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 production 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.

The items of equipment which are especially designed or prepared for the production of heavy water utilizing either the water-hydrogen sulphide exchange process or the ammonia-hydrogen exchange process include the following:

#### **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.

#### **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% H<sub>2</sub>S) 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<sup>3</sup>/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 H<sub>2</sub>S 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.

#### **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 contactors which 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.

**7. 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 transformations from one uranium chemical species to another, including: conversion of uranium ore concentrates to  $UO_2$ , conversion of  $UO_2$  to  $UO_3$ , conversion of uranium oxides to  $UF_4$  or  $UF_6$ , conversion of  $UF_4$  to  $UF_6$ , conversion of  $UF_6$  to  $UF_4$ , conversion of  $UF_6$  to uranium metal, and conversion of uranium fluorides to  $UO_2$ . 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 ( $HF$ ,  $F_2$ ,  $ClF_3$ , and uranium fluorides). Finally, it should be noted that, in all of the uranium conversion processes, items of equipment which individually are not especially designed or prepared for uranium conversion can be assembled into systems which are especially designed or prepared for use in uranium conversion.*

**7.1. Especially designed or prepared systems for the conversion of uranium ore concentrates to  $UO_3$**

**EXPLANATORY NOTE**

Conversion of uranium ore concentrates to  $UO_3$  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  $UO_3$  either by concentration and denitration or by neutralization with gaseous ammonia to produce ammonium diuranate with subsequent filtering, drying, and calcining.

**7.2. Especially designed or prepared systems for the conversion of  $UO_3$  to  $UF_6$**

**EXPLANATORY NOTE**

Conversion of  $UO_3$  to  $UF_6$  can be performed directly by fluorination. The process requires a source of fluorine gas or chlorine trifluoride.

**7.3. Especially designed or prepared systems for the conversion of  $UO_3$  to  $UO_2$**

**EXPLANATORY NOTE**

Conversion of  $UO_3$  to  $UO_2$  can be performed through reduction of  $UO_3$  with cracked ammonia gas or hydrogen.

**7.4. Especially designed or prepared systems for the conversion of  $UO_2$  to  $UF_4$**

**EXPLANATORY NOTE**

Conversion of  $UO_2$  to  $UF_4$  can be performed by reacting  $UO_2$  with hydrogen fluoride gas (HF) at 300-500 °C.

**7.5. Especially designed or prepared systems for the conversion of  $UF_4$  to  $UF_6$**

**EXPLANATORY NOTE**

Conversion of  $UF_4$  to  $UF_6$  is performed by exothermic reaction with fluorine in a tower reactor.  $UF_6$  is condensed from the hot effluent gases by passing the effluent stream through a cold trap cooled to -10 °C. The process requires a source of fluorine gas.

**7.6. Especially designed or prepared systems for the conversion of  $UF_4$  to U metal**

**EXPLANATORY NOTE**

Conversion of  $UF_4$  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).

**7.7. Especially designed or prepared systems for the conversion of  $UF_6$  to  $UO_2$**

**EXPLANATORY NOTE**

Conversion of  $UF_6$  to  $UO_2$  can be performed by one of three processes. In the first,  $UF_6$  is reduced and hydrolyzed to  $UO_2$  using hydrogen and steam. In the second,  $UF_6$  is hydrolyzed by solution in water, ammonia is added to precipitate ammonium diuranate, and the diuranate is reduced to  $UO_2$  with hydrogen at 820°C. In the third process, gaseous  $UF_6$ ,  $CO_2$ , and  $NH_3$  are combined in water, precipitating ammonium uranyl carbonate. The ammonium uranyl carbonate is combined with steam and hydrogen at 500-600°C to yield  $UO_2$ .

$UF_6$  to  $UO_2$  conversion is often performed as the first stage of a fuel fabrication plant.

**7.8. Especially designed or prepared systems for the conversion of  $UF_6$  to  $UF_4$**

**EXPLANATORY NOTE**

Conversion of  $UF_6$  to  $UF_4$  is performed by reduction with hydrogen.