ANNEX 3

LIST OF ITEMS TO BE REPORTED TO IAEA

*Items marked * and shaded are prohibited to Iraq under Resolution 687.*

The notation (SC II) *or* (SC IV) *indicates that items of the same type/category are also listed in one of the Annexes (2 or 4, respectively) of the UN Special Commission Plan.*

NUCLEAR MATERIALS

1. Source and special fissionable material as follows:

1.1. 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 and any other goods containing one or more of the foregoing.

1.2. Low Enriched Uranium (LEU), or plutonium as follows:

Uranium enriched to less than 20% of the isotopes 233, 235, or both; plutonium with an isotopic concentration of Pu-238 exceeding 80%; any of the foregoing in the form of metal, alloy, chemical compound or concentrate and any other goods containing one or more of the foregoing.

1.3. *Highly Enriched Uranium (HEU) or plutonium, as follows:

Uranium enriched to 20% or more in isotopes 233, 235, or both; plutonium containing less than 80% plutonium 238; any of the foregoing in the form of metal, alloy, chemical compound or concentrate and any other goods containing one or more of the foregoing

except for the following items which are not prohibited, but are controlled:

Sub-gram amounts of the special fissionable material specified in 1.3 above in the form of:

(a) certified reference material;

(b) instrument calibration source; or

(c) sensing component in instruments.

1.4. *Irradiated nuclear fuel

EXPLANATORY NOTE:
The prohibition applies only to the transfer of irradiated nuclear fuel to Iraq.

NON-NUCLEAR MATERIALS

2. Zirconium (SC IV)

2.1. Zirconium metal and alloys in the form of tubes, or assemblies of tubes, specially designed or prepared for use in a nuclear reactor and in which the relation of hafnium to zirconium is less than 1:500 parts by weight.

2.2. Zirconium as follows: metal, alloys containing more than 50% zirconium by weight, and compounds in which the ratio of hafnium content to zirconium content is less than 1 part to 500 parts by weight, and manufactures wholly thereof; except zirconium in the form of foil having a thickness not exceeding 0.10 mm (0.004 in).

TECHNICAL NOTE:
This applies to waste and scrap containing zirconium as defined here.

3. Aluminum alloys

Aluminum alloys capable of an ultimate tensile strength of 460 MPa (0.46 x 10^9 N/m^2) or more at 293 K (20°C), in the form of tubes or solid forms (including forgings) having an outside diameter or more than 75 mm (3 in).

TECHNICAL NOTE:
The phrase "capable of" encompasses aluminum alloys before or after heat treatment.

4. Fibrous or filamentary materials (SC IV)

4.1. Carbon or aramid fibrous or filamentary materials having a specific modulus of 12.7 x 10^6 m or greater or a specific tensile strength of 23.5 x 10^4 m or greater; or

4.2. Glass fibrous or filamentary materials having a specific modulus of 3.18 x 10^6 m or greater and a specific tensile strength of 7.62 x 10^4 m or greater;

4.3. *Composite structures in the form of tubes with an inside diameter of between 75 mm (3 in) and 400 mm (16 in) made with fibrous or filamentary materials described in 4.1 and 4.2 above.

TECHNICAL NOTE:
The term "fibrous or filamentary materials" includes continuous monofilaments, continuous yarns, and tapes;

(i) "Specific modulus" is the Young's modulus in N/m2 divided by the specific weight in N/m3 when measured at a temperature of 23±2°C and a relative humidity of 50±5%

(ii) "Specific tensile strength" is the ultimate tensile strength in N/m2 divided by the specific weight in N/m3 when measured at a temperature of 23±2°C and a relative humidity of 50±5%.

5. *Maraging steel (SC IV)

Maraging steel capable of an ultimate tensile strength of 2050 MPa (2.050 x 10^9 N/m^2) (300,000 lb/in^2) or more at 293 K (20°C) except forms in which no linear dimension exceeds 75 mm (3 in).

TECHNICAL NOTE:
The phrase "capable of" encompasses maraging steel before or after heat treatment.

6. Titanium

Titanium alloys capable of an ultimate tensile strength of 900 MPa (0.9 x 10^9 N/m^2) or more at 293 K (20°C) in the form of tubes or solid forms (including forgings) with an outside diameter more than 75 mm (3 in).

TECHNICAL NOTE:
The phrase "capable of" encompasses titanium alloys before or after heat treatment.

7. Chlorine trifluoride (SC IV)

8. *Fast-reacting ion-exchange resins/adsorbents

Fast-reacting ion-exchange resins or adsorbents specially designed or prepared for uranium enrichment using the ion exchange process, including 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 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 specially 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.

9. Beryllium (SC IV)

Beryllium as follows: metal, alloys containing more than 50% of beryllium by weight, compounds containing beryllium and manufactures thereof;

except:

9.1. Metal windows for X-ray machines;

9.2. Oxide shapes in fabricated or semi-fabricated forms specially designed for electronic component parts or as substrates for electronic circuits;

9.3. Naturally occurring compounds containing beryllium.

TECHNICAL NOTE:
This entry includes waste and scrap containing beryllium as defined here.

10. Calcium

Calcium metal containing both equal to or less than 0.2% by weight of impurities other than magnesium and less than 20 ppm of boron.

11. Magnesium (SC IV)

Magnesium metal containing both equal to or less than 0.2% by weight of impurities other than calcium and less than 20 ppm of boron.

12. Tantalum (SC IV)

Tantalum sheets with a thickness of 2.5 mm or greater from which a circle of 200 mm diameter can be obtained.

13. Tungsten, as follows: (SC IV)

Parts made of tungsten, tungsten carbide, or tungsten alloys (greater than 90% tungsten) having a mass greater than 20 kg and a hollow cylindrical symmetry (including cylinder segments) with an inside diameter greater than 100 mm (4 in) but less than 300 mm (12 in).

14. Hafnium

Hafnium as follows: metal, alloys, and compounds of hafnium containing more than 60% hafnium by weight and manufactures thereof.

15. Boron

Boron and boron compounds, mixtures and loaded materials in which the boron-10 isotope is more than 20% by weight of the total boron content.

16. Bismuth

High Purity (99.99% or greater) bismuth with very low silver content (less than 10 parts per million).

17. Lithium

Isotopically enriched in lithium-6; as follows:

17.1. *Metal, hydrides or alloys containing lithium enriched in the lithium-6 isotope (^{6}Li) to a concentration higher than the one existing in nature (7.5% on an atom percentage basis);

17.2. *Any other materials containing lithium enriched in the lithium-6 isotope (including compounds, mixtures and concentrates);

17.3. ^{6}Li incorporated in thermoluminescent dosimeters.

18. ***Helium-3**

Helium in any form isotopically enriched in the helium-3 isotope, whether or not mixed with other materials or contained in any equipment or device,

except for the following items which are not prohibited, but are controlled:

Products or devices containing less than 1 g of helium-3.

19. Tritium

19.1. *Tritium, including compounds and mixtures, containing tritium in which the ratio of tritium to hydrogen by atoms exceeds 1 part in 1000 .

19.2. Tritium in luminescent devices (e.g. safety devices installed in aircraft, watches, runway lights) containing more than 40 Ci of tritium in any chemical or physical form.

19.3. Tritium labeled organic compounds

20. 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.

21. 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^3.

*PLANTS FOR THE SEPARATION OF ISOTOPES OF URANIUM AND EQUIPMENT, OTHER THAN ANALYTICAL INSTRUMENTS, SPECIALLY DESIGNED OR PREPARED THEREFOR

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

22. *Gas centrifuges and assemblies and components specially 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 indivdual components have to be manufactured to very close tolerances in order to minimize the imbalance. 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_6 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 specially 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.

22.1. *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 (c) following. The rotor is fitted with an internal baffle(s) and end caps, as described in section (d) and (e) following, if in final form. However, the complete assembly may be delivered only partly assembled.

(b) Rotor tubes:

Specially 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 of the high strength to density ratio materials described in the explanatory note to this section.

(c) Rings or bellows:

Components specially 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 or more 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) in diameter specially 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 or more 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) in diameter specially 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 notes to this section.

EXPLANATORY NOTE:

The materials used for centrifuge rotating components are:

(i) Maraging steel capable of an ultimate tensile strength of 2.05×10^9 N/m^2 (300,000 psi) or more;

(ii) Aluminum alloys capable of an ultimate tensile strength of 0.46×10^9 N/m^2 (67,000 psi) or more;

(iii) Filamentary materials suitable for use in composite structures and having a specific modulus of 12.3×10^6 m or greater and a specific ultimate tensile strength of 0.3×10^6 m or greater ('Specific Modulus' is the 'Young Modulus in N/m^2 divided by the specific weight in N/m^3; 'Specific Ultimate Tensile Strength' is the ultimate tensile strength in N/m^2 divided by the specific weight in N/m^3.)

22.2. *Static components

(a) Magnetic suspension bearings:

Specially designed or prepared bearing assemblies consisting of an annular magnet suspended within a housing containing a damping medium. The housing is manufactured from a UF_6-resistant material (see explanatory note to Section 23). The magnet couples with a pole piece or a second magnet fitted to the top cap described in Section 22.1.(e). The magnet may be ring-shaped with a relation between the 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^3 (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:

Specially 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 22.1.(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:

Specially 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:

Specially 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 specially 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:

Specially 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.

23. *Specially 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 the plant needed to feed UF_6 to the centrifuges, to link the individual centrifuge 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 centrifuge 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 centrifuge by way of cascade header pipework. The 'product' and 'tails' UF_6 gaseous streams flowing from the centrifuge 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.

23.1. *Feed systems/'product' and 'tails' withdrawal systems

Specially designed or prepared process systems including:

(a) 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;

(b) 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); and

(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 at the end of this section) and is, fabricated to very high vacuum and cleanliness standards.

23.2. *Machine header piping systems

Specially 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 at the end of this section) and is fabricated to very high vacuum and cleanliness standards.

23.3. *UF_6 mass spectrometers/ion sources

Specially 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:

(a) Unit resolution for atomic mass unit greater than 320;

(b) Ion sources constructed of or lined with nichrome or monel or nickel plated;

(c) Electron bombardment ionization sources; and

(d) A collector system suitable for isotopic analysis.

23.4. *Frequency changers

Frequency changers (also known as converters or invertors) specially designed or prepared to supply motor stators as defined under 22.2.(d), or parts, components, and sub-assemblies of such frequency changers having all of the following characteristics:

(a) A multiphase output of 600 to 2000 Hz;

(b) High stability (with frequency control better than 0.1%); and

(c) Total harmonic distortion less than 2%.

EXPLANATORY NOTE:

The items listed in section 23 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, aluminum, aluminum alloys, nickel, or alloys containing 60% or more nickel.

24. *Specially 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. In as much 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.

24.1. *Gaseous diffusion barriers

(a) Specially designed or prepared thin, porous filters, with a pore size of 100 - 1000 Å (ångstroms), 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) Specially prepared compounds or powders for the manufacture of such filters. Such compounds and powders include nickel or alloys containing 60% or more nickel, aluminum oxide, or UF_6-resistant fully fluorinated 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 specially prepared for the manufacture of gaseous diffusion barriers.

24.2. *Diffuser housings

Specially 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.

24.3. *Compressors and gas blowers

Specially designed or prepared axial, centrifugal, or positive displacement compressors, or gas blowers with a suction volume capacity of 1 m^3/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.

24.4. *Rotary shaft seals

Specially 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^3/min (60 in^3/min).

24.5. *Heat exchangers for cooling UF_6

Specially 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).

25. ***Specially 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 specially their shut-down, leads to serious consequences. Therefore, a strict and constant maintenance of vacuum in all technological systems, automatic protection from accidents, the 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.

25.1. *Feed systems/'product' and 'tails' withdrawal systems

Specially 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 UF_6 to the gaseous diffusion cascade;

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

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

(d) 'Product' or 'tails' stations used for transferring UF_6 into containers.

25.2. *Header piping systems

Specially designed or prepared piping systems and header systems, for handling UF_6 within the gaseous diffusion cascade. This piping network is normally of the 'double' header system with each stage or group of stages connected to each of the headers.

25.3. *Vacuum systems

(a) Specially 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 specially designed for service in UF_6-bearing atmospheres made of, or lined with, aluminum, 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.

25.4. *Special shut-off and control valves

Specially 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.

25.5. *UF_6 mass spectrometers/ion sources

Specially 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:

(a) Unit resolution for atomic mass unit greater than 320;

(b) Ion sources constructed of or lined with nichrome or monel or nickel plated;

(c) Electron bombardment ionization sources; and

(d) Collector system suitable for isotopic analysis.

EXPLANATORY NOTE:

The items listed in section 25 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, aluminum, aluminum alloys, aluminum oxide, nickel or alloys containing 60% or more nickel and UF_6-resistant fully fluorinated hydrocarbon polymers.

26. *Specially 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 (nozzle 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 are 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, aluminum, aluminum alloys, nickel or alloys containing 60% or more nickel and UF_6-resistant fully fluorinated hydrocarbon polymers.

26.1. *Separation nozzles

Specially 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.

26.2. *Vortex tubes

Specially 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.

26.3. *Compressors and gas blowers

Specially 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^3/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.

26.4. *Rotary shaft seals

Specially 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.

26.5. *Heat exchangers for gas cooling

Specially designed or prepared heat exchangers made of, or protected by, materials resistant to corrosion by UF_6.

26.6. *Separation element housings

Specially 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.

26.7. *Feed systems/'product' and 'tails' withdrawal systems

Specially 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; and

(d) 'Product' or 'tails' stations used for transferring UF_6 into containers

26.8. *Header piping systems

Specially 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.

26.9. *Vacuum systems and pumps

(a) Specially 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 UF_6 bearing atmospheres; and

(b) Vacuum pumps specially designed or prepared for service in UF_6-bearing atmospheres and made of, or protected by, materials resistant to corrosion by UF_6. These pumps may use fluorocarbon seals and special working fluids.

26.10. *Special shut-off and control valves

Specially designed or prepared manual or automated shut-off and control bellows valves made of, or protected by, materials resistant to corrosion by UF_6 with a diameter of 40 to 1500 mm for installation in main and auxiliary systems of aerodynamic enrichment plants.

26.11. *UF_6 mass spectrometers/ion sources

Specially 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:

(a) Unit resolution for mass greater than 320;

(b) Ion sources constructed of or lined with nichrome or monel or nickel plated;

(c) Electron bombardment ionization sources; and

(d) Collector system suitable for isotopic analysis.

26.12. *UF_6/carrier gas separation systems

Specially designed or prepared process systems for separating UF_6 from carrier gas (hydrogen or helium).

EXPLANATORY NOTE:

These systems are designed to reduce the UF_6 content in the carrier gas to 1 ppm or less, and may incorporate equipment such as:

(i) cryogenic heat exchangers and cryoseparators capable of temperatures of -120°C or less, or

(ii) cryogenic refrigeration units capable of temperatures of -120°C or less, or

(iii) separation nozzle or vortex tube units for the separation of UF_6 from carrier gas, or

(iv) UF_6 cold traps capable of temperatures of -20°C or less.

27. *Specially 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 requirement 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 continuos process, a reflux system is necessary to release the uranium from the adsorbent back into the liquid flow so that 'products' 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 partly 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.

27.1. *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), specially 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).

27.2. *Liquid-liquid centrifugal contactors (Chemical exchange)

Liquid-liquid centrifugal contactors specially 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).

27.3. *Uranium reduction systems and equipment (Chemical exchange)

(a) Specially 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) Specially 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).*

27.4. *Feed preparation systems (Chemical exchange)

Specially 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^{+6} *or* U^{+4} *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 multi-valent 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*

27.5. *Uranium oxidation systems (Chemical exchange)

Specially 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:

(i) 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; and.*

(ii) 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 location.

27.6. *Ion exchange columns (Ion exchange)

Cylindrical columns greater than 1000 mm in diameter for containing and supporting packed beds of ion exchange resin/adsorbent, specially 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 psi). *See also item 8 for ion exchange resins/adsorbents.*

27.7. *Ion exchange reflux systems (Ion exchange)

(a) Specially designed or prepared chemical or electrochemical reduction systems for regeneration of the chemical reducing agent(s) used in ion exchange uranium enrichment cascades; and

(b) Specially 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 action 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}.

28. *Specially designed or prepared systems, equipment and components for use in laser based enrichment plants.

INTRODUCTORY NOTE

Present systems for enrichment processes using laser 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 (CRISLA).

The systems, equipment and components for laser enrichment plants embrace:

(i) 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);

(ii) devices to collect enriched and depleted uranium metals as 'product' and 'tails' in the first category, and devices to collect dissociated or reacted compounds as 'products' and unaffected material as 'tails' in the second category;

(iii) process laser systems to selectively excite the uranium-235 species; and

(iv) 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 vapor or liquid uranium metal or uranium alloys include yttria-coated graphite and tantalum; and the materials resistant to corrosion by UF_6 include copper, stainless steel, aluminum, , aluminum alloys, nickel or alloys containing 60% or more nickel and UF_6-resistant fully fluorinated hydrocarbon polymers.

28.1. *Uranium vaporization systems (AVLIS)

Specially 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.

28.2. *Liquid uranium metal handling systems (AVLIS)

Specially 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 alloy are made of, or protected by, material of suitable corrosion and heat resistance. Suitable materials include tantalum, yttria-coated graphite, graphite coated with other rare earth oxides or mixtures thereof.

28.3. *Uranium metal 'product' and 'tails' collector assemblies (AVLIS)

Specially 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.

28.4. *Separator module housings (AVLIS)

Specially 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 disclosure to allow refurbishment of internal components.

28.5. *Supersonic expansion nozzles (MLIS)

Specially 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.

28.6. *Uranium pentafluoride product collectors (MLIS)

Specially 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.

28.7. *UF_6/carrier gas compressors (MLIS)

Specially 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.

28.8. *Rotary shaft seals (MLIS)

Specially 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.

28.9. *Fluorination systems (MLIS)

Specially 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 isotopic 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.

28.10. *UF_6 mass spectrometers/ion sources (MLIS)

Specially 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 the following characteristics:

(a) Unit resolution for mass greater than 320;

(b) Ion sources constructed of or lined with nichrome or monel or nickel plated;

(c) Electron bombardment ionization sources; and; and;;;;;;;;;;l;

(d) Collector system suitable for isotopic analysis.

28.11. *Feed systems/’product’ and ‘tails’ withdrawal systems (MLIS)

Specially 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; and

(d) 'Product' or ‘tails' stations used for transferring UF_6 into containers.

28.12. *UF_6/carrier gas separation systems (MLIS)

Specially 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:

(i) Cryogenic heat exchangers or cryoseparators capable of temperatures of -120°C or less, or

(ii) Cryogenic refrigeration units capable of temperatures of -120°C or less, or

(iii) UF_6 cold traps capable of temperatures of -20°C or less.

28.13. *Laser systems (AVLIS, MLIS and CRISLA) as follows:

Laser systems specially designed or prepared for the separation of uranium isotopes.

EXPLANATORY NOTE:

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. Laser or laser systems for both processes require a spectrum frequency stabilizer for operation over extended periods of time.

28.14. Lasers, as follows:

(a) Copper vapor lasers with 40 W or greater average output power operating at wavelengths between 500 nm and 600 nm;

(b) Argon ion lasers with greater than 40 W average output power operating at wavelengths between 400 nm and 515 nm;

(c) Neodymium-doped (other than glass) lasers as follows:

(i) Having an output wavelength between 100 nm and 1100 nm, being pulse-excited and Q-switched with a pulse duration equal to or greater than 1 ns, and having either of the following:

(A) A single-transverse mode output having an average output exceeding 40 W; or

(B) A multiple-transverse mode output having an average output power exceeding 50 W;

(ii) Operating at a wavelength between 1000 nm and 1100 nm incorporating frequency doubling giving an output wavelength between 500 nm and 550 nm with an average power at the doubled frequency (new wavelength) of greater than 40 W;

(d) Tunable pulsed single-mode dye oscillators capable of an average power output of greater than 1 W, a repetition rate greater than 1 kHz, a pulse width less than 100 ns, and a wavelength between 300 nm and 800 nm;

(e) Tunable pulsed dye amplifiers and oscillators, except single-mode oscillators, with an average power output of greater than 30 W, a repetition rate greater than 1 kHz a pulse width less than 100 ns, and a wavelength between 300 nm and 800 nm;

(f) Alexandrite lasers with a bandwidth of 0.005 nm or less, a repetition rate of greater than 125 Hz, and an average power output greater than 30 W operating at wavelengths between 720 nm and 800 nm;

(g) Pulsed carbon dioxide lasers with a repetition rate greater than 250 Hz, an average power output of greater than 500 W, and a pulse of less than 200 ns operating at wavelengths between 9000 nm and 11,000 nm;

NOTE:

This specification is not intended to control the higher power (typically 1 to 5 kW) industrial CO_2 lasers used in applications such as cutting and welding, as these latter lasers are either continuous wave or are pulsed with a pulse width more than 200 ns.

(h) Pulsed excimer lasers (XeF, XeCl, KrF) with a repetition rate greater than 250 Hz, an average power output of greater than 500 W, and a pulse of less than 200 ns operating at wavelengths between 240 and 360 nm;

(i) Para-hydrogen Raman shifters designed to operate at 16 nm output wavelength and at a repetition rate greater than 250 Hz; and

(j) Free electron lasers.

29. * 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}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}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, and metal removal systems for the collection of 'product' and 'tails'.

29.1. *Microwave power sources and antennae

Specially designed or prepared microwave power sources and antennae for producing or accelerating ions and having the following characteristics:

(a) greater than 30 GHz frequency; and

(b) greater than 50 kW mean power output for ion production.

29.2. *Ion excitation coils

Specially 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.

29.3. *Uranium plasma generation systems

Specially 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.

29.4. *Liquid uranium metal handling systems

Specially 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 or mixtures thereof.

29.5. *Uranium metal 'product' and ‘tails' collector assemblies

Specially 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.

29.6. *Separator module housings

Cylindrical vessels specially 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.

29.7. *Superconducting electromagnets

Superconducting solenoidal electromagnets with all of the following characteristics:

(a) Capable of creating magnetic fields of more than 2 teslas (20 kilogauss);

(b) With a L/D (length divided by inner diameter) greater than 2;

(c) With an inner diameter of more than 300 mm; and

(d) With a magnetic field uniform to better than 1% over the central 50% of the inner volume.

NOTE:
This item does not cover magnets specially designed for and used as parts of medical nuclear magnetic resonance (NMR) imaging systems.

30. * 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 pass 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.

30.1. *Electromagnetic isotope separators

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

(a) Ion sources:

Specially 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 specially 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:

Specially 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 openings and closures for removal and reinstallation of these components.

(d) Magnet pole pieces:

Specially 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.

30.2. *Electromagnetic isotope separators other than those specified in 30.1 above, designed for or equipped with single or multiple ion sources capable of providing a total ion beam current of 50 mA or greater.

30.3. *High voltage power supplies

Specially designed or prepared high-voltage power supplies for ion sources,capable of continuously producing, over a time period of 8 hours, the following:

(a) Output voltage of 20,000 V or greater;

(b) Output current of 1 A or greater; and

(c) Voltage regulation of better than 0.1%.

30.4. *High current power supplies

Direct current high-power supplies capable of continuously producing, over a period of 8 hours, the following:

(a) Output voltage of 100 V or greater, with a current output of 500 A or greater; and

(b) Current or voltage regulation better than 0.1%.

30.5. Vacuum pumps

Vacuum pumps with an input throat size of 380 mm or greater with a pumping speed of 15,000 liters/second or greater and capable of producing an ultimate vacuum better than 10^{-4} Torr (0.76 x 10^{-4} mbar).

TECHNICAL NOTE:
The ultimate vacuum is determined at the input of the pump with the input of the pump blocked off.

ANALYTICAL INSTRUMENTS AND PROCESS CONTROL SYSTEMS USED IN URANIUM ENRICHMENT

31. Mass spectrometers

Mass spectrometers capable of measuring ions of 230 atomic mass units or greater and having a resolution of better than 2 parts in 230, as follows, and ion sources therefor;

31.1. Inductively coupled plasma mass spectrometers (ICP/MS);

31.2. Glow discharge mass spectrometers (GDMS);

31.3. Thermal ionization mass spectrometers (TIMS);

31.4. *Electron bombardment mass spectrometers which have a source chamber constructed from or lined with or plated with materials resistant to UF_6.

31.5. Molecular beam mass spectrometers as follows:

(a) Which have a source chamber constructed from or lined with or plated with stainless steel or molybdenum and have a cold trap capable of cooling to 193K (-80°C) or less; or

(b) *Which have a source chamber constructed from or lined with or plated with materials resistant to UF_6

31.6. *Mass spectrometers equipped with a microfluorination ion source designed for use with actinides or actinide fluorides.

32. Instrumentation and process control systems for use in enrichment (SC II)

Instrumentation for monitoring temperature, pressure, pH, fluid level or flow rate specially designed to be corrosion resistant to UF_6 by being made of, or protected by, any of the following materials:

(a) Stainless steel;

(b) Aluminum;

(c) Aluminum alloys;

(d) Nickel; and

(e) Alloys containing 60% or more nickel.

33. ***Software specially designed for the control of uranium enrichment plant or facilities.**

OTHER ISOTOPE SEPARATION PLANTS

34. Plants for the production of heavy water, deuterium and deuterium compounds and equipment 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 sulfide 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 sulfide 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 sulfide 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 sulfide 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 then 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 the 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-shelf". The GS and the 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 standard 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 process, items of equipment which individually are not specially designed or prepared for heavy water production can be assembled into systems which are specially 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 specially designed or prepared for the production of heavy water utilizing either the water-hydrogen sulfide exchange process or the ammonia-hydrogen exchange process include the following:

34.1. Water-Hydrogen Sulfide 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, specially designed or prepared for heavy water production utilizing the water-hydrogen sulfide exchange process.

34.2. Blowers and Compressors

Single stage, low head (i.e., 0.2 MPa or 30 psi) centrifugal blowers or compressors for hydrogen-sulfide gas circulation (i.e., gas containing more than 70% H_2S) specially designed or prepared for heavy water production utilizing the water-hydrogen sulfide 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 H_2S service.

34.3. 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) specially 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.

34.4. Tower Internals and Stage Pumps

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

34.5. Ammonia Crackers

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

34.6. Infrared Absorption Analyzers

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

34.7. Catalytic Burners

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

34.8. Specialized Packing

Specialized packing for use in separating heavy water from ordinary water and made of phosphor bronze mesh or copper (both chemically treated to improve wettability) and designed for use in vacuum distillation towers;

34.9. Circulating Pumps

Pumps circulating solutions of diluted or concentrated potassium amide catalyst in liquid ammonia (KNH_2/NH_3) with all of the following characteristics:

(a) Airtight (i.e. hermetically sealed);

(b) For concentrated potassium amide solutions (1% or greater), operating pressure of 1.5-60 MPa; for dilute potassium amide solutions (less than 1%) operating pressure of 20-60 MPa; and

(c) A capacity greater than 8.5 m^3/h;

34.10. Ammonia synthesis converters

Ammonia synthesis units in which the synthesis gas (nitrogen and hydrogen) is withdrawn from an ammonia/hydrogen high-pressure exchange column and the synthesized ammonia is returned to said column;

34.11. Platinized catalysts

Platinized catalysts specially designed or prepared for promoting the hydrogen isotope exchange reaction between hydrogen and water for the recovery of tritium from heavy water or for the production of heavy water.

34.12. Hydrogen-cryogenic distillation columns having all of the following applications:

(a) designed to operate with internal temperatures of -238^{o}C (35 K) or less;

(b) designed to operate at internal pressure of 0.5 to 5 MPa (5 to 50 atmospheres);

(c) constructed of fine-grain stainless steels of the 300 series with low sulfur content or equivalent cryogenic and H_2-compatible materials; and

(d) with internal diameters of 1 m or greater and effective lengths of 5 m or greater.

35. *__Plants and specially designed equipment for the separation of lithium-6__

36. *__Facilities or plants for the production, recovery, extraction, concentration, or handling of tritium, and equipment and materials therefor, as follows:__

36.1. Tritium storage, separation, purification, and pumping systems using metal hydrides as the storage, pumping or purification medium;

36.2. Hydrogen or helium refrigeration units capable of cooling to 23 K (-250°C) or less, with heat removal capacity greater than 150 watts.

NOTE:
See also item 19.

PLANTS AND EQUIPMENT FOR THE CONVERSION OF URANIUM

INTRODUCTORY NOTE

Uranium conversion plants and systems may perform one or more transformations from one uranium chemical species to another, including:

(i) conversion of uranium ore concentrates to UO_3;

(ii) conversion of UO_3 to UO_2;

(iii) conversion of uranium oxides to UF_4 or UF_6;

(iv) conversion of UF_6 to UF_4;

(v) conversion of UF_4, to UF_6;

(vi) conversion of UF_4, to uranium metal;,

(vii) conversion of uranium fluorides to UO_2; and

(viii) conversion of uranium oxides to UCl_4.

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 specially designed or prepared for uranium conversion can be assembled into systems which are specially designed or prepared for use in uranium conversion.

37. Specially designed or prepared systems for the conversion of uranium ore concentrates to $U0_3$

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

38. *Specially 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.

39. Specially 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.

40. Specially 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.

41. *Specially 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 (263 K). The process requires a source of fluorine gas.

42. Specially 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).

43. *Specially 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.

44. *Specially 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.

45. *Specially designed or prepared systems for the conversion of UO_2 to UCl_4.

EXPLANATORY NOTE:

Conversion of UO_2 to UCl_4 can be performed by reacting UO_2 with CCl_4 at high temperature.

46. Electrolytic cells for fluorine production with a production capacity greater than 250 grams of fluorine per hour and specially designed parts and accessories therefor (SC II)

NUCLEAR REACTORS AND EQUIPMENT THEREFOR

47. Complete nuclear reactors

Nuclear reactors capable of operation so as to maintain a controlled self sustaining fission chain reaction.

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.

47.1. Reactor Vessels

Metal vessels, as complete units or as major shop-fabricated parts therefor, which are specially designed or prepared to contain the core of a nuclear reactor as defined in paragraph 47 above and are capable of withstanding the operating pressure of the primary coolant.

EXPLANATORY NOTE:

A top plate for a reactor vessel is covered by item 47.1 as a major shop-fabricated part.

Reactor internals (e.g. 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 reactor vessel. These items are sufficiently critical to the safety and reliability of the operation of the reactor (and, therefore, to the guarantees and the 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, specially 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.

47.2. Reactor fuel charging and discharging machines

Manipulative equipment specially designed or prepared for inserting or removing fuel in a nuclear reactor capable of on-load operation or 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.

47.3. Reactor control rods

Rods specially designed or prepared for the control of the reaction rate in a nuclear reactor.

EXPLANATORY NOTE:

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

47.4. Reactivity control mechanisms, devices and systems

EXPLANATORY NOTE:
Reactivity control mechanisms, devices, and systems may be manual, electro-mechanical, hydraulic, pneumatical and chemical injection/removal type.

47.5. Reactor pressure tubes

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

47.6. Primary coolant pumps

Pumps specially designed or prepared for circulating the primary coolant for nuclear reactors.

EXPLANATORY NOTE:
Specially designed or prepared pumps may include elaborate sealed or multi-sealed system 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.

47.7. Reactor process monitoring measurement and process control systems

Reactor process monitoring , measurement and control systems, sub-systems and components. All analog and digital process control computers and hydraulic and pneumatic process monitoring and control instruments and equipment.

NUCLEAR FUEL FABRICATION PLANTS

48. Plants for the fabrication of fuel elements

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

48.1. Which normally comes in direct contract with, or directly processes, or controls, the production flow of nuclear material; or

48.2. Which seals the nuclear material within the cladding; or

48.3. Which checks the integrity of the cladding or the seal; or

48.4. Which provides for the finishing surface treatment of the sealed fuel.

49. *Plants and equipment for the reprocessing of irradiated fuel elements

INTRODUCTORY NOTE

Reprocessing irradiated 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 (e.g. by geometry), radiation exposure (e.g. by shielding), and toxicity hazards (e.g. by containment).

49.1. *Irradiated fuel element chopping machines

INTRODUCTORY NOTE

This equipment breaches the cladding of the fuel to expose the irradiated nuclear material to dissolution. Specially designed metal cutting shears are the most commonly employed, although advanced equipment, such as lasers, may be used.

Remotely operated equipment specially 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.

49.2. *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 are removed from the process stream.

Critically safe tanks (e.g. small diameter, annular, or slab tanks) specially 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.

49.3. *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.

Specially 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.

49.4. *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:

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.

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 form suitable for storage or disposal.

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.

Specially 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. They are normally fabricated of materials such as low carbon stainless steels, titanium, or zirconium, or other high quality materials. Holding and storage vessels may be designed for the remote operation and maintenance and may have the following features for control of nuclear criticality:

(a) *Walls or internal structures with a boron equivalent of a least 2%; or

(b) *A maximum diameter of 175 mm (7 in) for cylindrical vessels; or

(c) *A maximum width of 75 mm (3 in) for either a slab or annular vessel.

49.5. *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/liquid separation, calcination, product handling, ventilation, waste management, and process control.

Complete systems specially 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.

49.6. *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 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.

Complete systems specially 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.

49.7. *Hot cells and related equipment specially designed or prepared for the handling and processing of irradiated nuclear material

EXPLANATORY NOTE:

Small scale chemical separation of plutonium or uranium or both from irradiated nuclear material requires radiation protection from fission products' gamma activity and from plutonium toxicity. This separation is normally conducted in specially designed or prepared lead- or concrete- shielded cells provided with viewing ports made of high density glass and remote manipulators. Protection from plutonium toxicity is obtained with an air-tight internal lining of the hot the cell normally made of low-carbon steel. Hot cells are provided with air extraction system capable of maintaining a slightly negative pressure and equipped with high efficiency particulate air filters which prevent the release of aerosols from the hot cell into the environment.

49.8. Hot cells related equipment specially designed or prepared for the handling or processing of radioisotopes or radiation sources in medical and industrial applications as follows:

(a) Remote manipulators that provide mechanical translation of human operator actions by electrical, hydraulic, or mechanical means to an operating arm and terminal fixture, that can be used to provide remote actions in radiochemical separation operations and hot cells as follows:

(i) Having a capability of penetrating 0.6 m or more of cell wall ('through the wall' operation); or

(ii) Having a capability of bridging over the top of a cell wall with a thickness of 0.6 m or more ('over the wall' operation);

NOTE:
Remote manipulation may be of a 'master/slave' type or operated by a joystick or keypad.

(b) High-density (lead glass or other) radiation shielding windows greater than 0. 3 m on a side and with a density greater than 3 g/cm^3 and a thickness of 100 mm or greater and specially designed frames therefor;

(c) Radiation hardened TV cameras specially designed or rated as radiation hardened to withstand greater than 5 x 10^4 grays (SI) (5 x 10^6 rad) without operational degradation and specially designed lenses used therein;

(d) Casks designed for transportation or storage of nuclear reactor fuel or irradiated fuel elements.

INDUSTRIAL EQUIPMENT AND MACHINE TOOLS

50. * Rotor fabrication and assembly equipment and bellows forming mandrels and dies, as follows:

50.1. Rotor assembly equipment for assembly of rotor tube sections, baffles, and end caps including associated precision mandrels, clamps and shrink fit machines;

50.2. Rotor straightening equipment for alignment of rotor tube sections to a common axis;

NOTE:
Normally such equipment will consist of precision measuring probes linked to a computer that subsequently controls the action of, for example, pneumatic rams used for aligning the rotor tube sections.

50.3. Bellows forming mandrels and dies for producing single-convolution bellows i.e., bellows made of high strength aluminum alloys, maraging steel or high-strength filamentary materials. The bellows have all of the following dimensions:

(a) 75 mm to 400 mm (3 in to 16 in) inside diameter;

(b) 12.7 mm (0.5 in) or more in length; and

(c) Single convolution depth more than 2 mm (0.08 in)

NOTE:
Items under (c) are two-piece cylindrical with a single indented circumferential convolution bisected by the two halves.

51. *Centrifugal balancing machines

Centrifugal multi-plane balancing machines, fixed or portable, horizontal or vertical, as follows; and specially designed software therefor:

51.1. Centrifugal balancing machines designed for balancing flexible rotors having a length of 400 mm or more and having all the following characteristics:

(a) A swing or journal diameter of 75 mm or more;

(b) Mass capability of from 0.9 to 23 kg; and

(c) Capable of balancing speed of revolution more that 5000 rpm;

51.2. Centrifugal balancing machines designed for balancing hollow cylindrical rotor components and having all the following characteristics:

(a) A journal diameter of 75 mm or more;

(b) Mass capability of from 0.9 to 23 kg;

(c) Capable of balancing to a residual imbalance of 0.010 kg mm/kg per plane or better; and

(d) Belt drive type.

52. *Filament winding machines (SC IV)

Filament winding machines in which the motions for positioning, wrapping and winding fibers are coordinated and programmed in two or more axes, specially designed to fabricate composite structures or laminates from fibrous or filamentary materials and capable of winding cylindrical rotors of diameter between 75 mm and 400 mm and lengths of 400 mm or greater; coordinating and programming controls therefor; precision mandrels; and specially designed software therefor.

53. Spin-forming and flow-forming machines (SC IV)

Spin-forming and flow-forming machines and precision rotor-forming mandrels designed to form cylindrical rotors of inside diameter between 75 mm and 400 mm; and specially designed software therefor, which:

53.1. According to the manufacturer's technical specification, can be equipped with numerical control units or a computer control; and

53.2. Have two or more axes that can be coordinated simultaneously for contouring control.

NOTE:
The only spin-forming machines included into this entry are those combining the function of spin-forming and flow-forming.

54. Dimensional inspection machines

Dimensional inspection machines, devices or systems, as follows, and specially designed software therefor.

54.1. Computer controlled or numerically controlled dimensional inspection machines having both of the following characteristics:

(a) Two or more axes; and

(b) A one-dimensional length measurement uncertainty equal to or less (better) than (6 ± L/1000) µm (L is the measured length in millimeters) (Ref.VDI/VDE 2617 parts 1 and 2).

54.2. Linear and angular displacement measuring devices, as follows:

(a) Linear measuring instruments having any of the following characteristics:

(i) Non-contact type measuring systems with a "resolution" equal to or less (better) than 0.2 µm within a measuring range up to 0.2 mm; or

(ii) Linear voltage differential transformer (LVDT) systems having both of the following characteristics:

(A) Linearity equal to or less (better) than 0.1% within a measuring range up to 5 mm; and

(B) Drift equal to or less (better) than 0.1% per day at a standard ambient test room temperature ± 1K; or

(iii) Measuring systems that have both of the following characteristics:

(A) Contain a laser; and

(B) Maintain for at least 12 hours, over a temperature range of ± 1K around a standard temperature and a standard pressure:

(I) A resolution over their full scale of 0.1 µm or better; and

(II) A "measurement uncertainty" equal to or less (better) than (0.2 ±L/2000) µm (L is the measured length in millimeters); except measuring interferometer systems, without closed or open loop feedback, containing a laser to measure slide movement errors of machine tools, dimensional inspection machines, or similar equipment;

(b) Angular measuring instruments having an angular position deviation equal to or less (better) than 0.00025°;

NOTE:
This item does not include optical instruments, such as autocollimators, using collimated light to detect angular displacement of a mirror.

(c) *Systems for simultaneous linear-angular inspection of hemishells, having both of the following characteristics:*

(i) "Measurement uncertainty" along any linear axis equal to or less (better) than 3.5 µm per 5 mm; and

(ii) Angular position deviation equal to or less than 0.02°.

NOTE:
Specially designed software for the systems described in paragraph (c) of this item includes software for simultaneous measurement of wall thickness and contour.

TECHNICAL NOTE 1:
Machine tools that can be used as measuring machines are included if they meet or exceed the criteria specified for the machine tool function or the measuring machine function.

TECHNICAL NOTE 2:
A machine described in paragraph 54 is included if it exceeds the control threshold anywhere within its operating range.

TECHNICAL NOTE 3:
The probe used in determining the "measurement uncertainty" of a dimensional inspection system shall be as described in VDI/VDE 2617 parts 2, 3 and 4.

TECHNICAL NOTE 4:
All parameters of measurement values in this item represent plus/minus, i.e. not total band.

> *"Measurement uncertainty"*
> *The characteristic parameter which specifies in what range around the output value the correct value of the measurable variable lies with a confidence level of 95%. It includes the uncorrected systematic deviations, the uncorrected backlash, and the random deviations (Reference: VDI/VDE 2617).*
>
> *"Resolution"*
> *The least increment of a measuring device; on digital instruments, the least significant bit (Reference:ANSI B-89.1.12).*
>
> *"Linearity"*
> *(Usually measured in terms of non-linearity) is the maximum deviation of the actual characteristic (average of upscale and downscale readings), positive or negative, from a straight line so positioned as to equalize and minimize the maximum deviations.*
>
> *"Angular position deviation"*
> *The maximum difference between angular position and the actual, very accurately measured angular position after the workpiece mount of the table has been turned out of its initial position. (Reference: VD1/VDE 2617. Draft: "Rotary table on coordinate measuring machines").*

55. Electron beam welding machines

Electron beam welding machines with a chamber of 0.5 m^3 or more.

56. Plasma spray systems

Plasma spray systems, atmospheric or vacuum.

57. Oxidation furnaces

Vacuum oxidation furnaces with all of the following characteristics:

(a) Having a steam supply capable of introducing slightly superheated steam into the bottom of the furnace at a controlled rate;

(b) Capable of containing a retort of working diameter of 600 mm or more and a workable height of 1200 mm or more; and

(c) Having a radiant heater to uniformly heat the retort to a temperature of 673 K (400^{o}C) or more.

TECHNICAL NOTE:
Oxidation furnaces are used to deposit a controlled oxide layer on the surface of the centrifuge components made from maraging steel.

58. High temperature furnaces

58.1. *Vacuum or controlled environment (inert gas) induction furnaces capable of operation above 1123K (850°C) and having induction coils 600 mm or less in diameter, and power supplies specially designed for induction furnaces with a power supply of 5 kW or more.

TECHNICAL NOTE:
This entry does not include furnaces designed for the processing of semiconductor wafers.

58.2. *Vacuum or controlled environment metallurgical melting and casting furnaces as follows; and specially configured computer control and monitoring systems and specially designed software therefor:

(a) Arc remelt and casting furnaces with consumable electrode capacities between 1000 cm^3 and 20,000 cm^3 and capable of operating with melting temperatures above 1973 K (1700°C); and

(b) Electron beam melting and plasma atomization and melting furnaces with a power of 50 kW or greater and capable of operating with melting temperatures above 1473 K (1200°C).

59. Isostatic presses (cold and hot) (SC IV)

Isostatic presses capable of achieving a maximum working pressure of 69 MPa or greater and having a chamber cavity with an inside diameter in excess of 152 mm; and specially designed dies and molds, components, accessories and controls; and specially designed software therefor.

TECHNICAL NOTE 1:
Isostatic presses are presses capable of pressurizing a closed cavity through various media (gas, liquid, solid particles) to create equal pressure in all directions within the cavity upon a workpiece of material.

TECHNICAL NOTE 2:
The inside chamber dimension is that of the chamber in which both the working temperature and the working pressure are achieved and does not include fixtures. That dimension is smaller of either the inside diameter of the pressure chamber or the inside diameter of the insulated furnace chamber, depending on which of the two chambers is located inside the other.

60. Machine tools (SC IV)

60.1. Numerical control units, specially designed motion control boards for numerical control applications on machine tools, numerically controlled machine tools, specially designed software, and related technology. Detailed specifications of the equipment are set out in the Appendix to Annex 3.

60.2. *Turning, milling and grinding machines having any of the following characteristics:

(a) Vacuum chucks suitable for holding hemispherical parts;

(b) Machines installed within glove boxes or equivalent containment facilities; and

(c) Explosion-proofing features.

61. Vibration test equipment (SC IV)

Vibration test systems, equipment, components and software therefor, as follows:

61.1. Vibration test systems, employing feedback or closed loop control techniques and incorporating a digital controller, capable of vibrating a system at 10 g RMS or more anywhere in the range 20 Hz to 2000 Hz and imparting forces of 50 kN (11,250 lbs), measured 'bare table', or greater;

61.2. Digital controllers, combined with "specially designed software" for vibration testing, with a real-time bandwidth greater than 5 kHz and being designed for use with the systems controlled in 61.1.above;

61.3. Vibration thrusters (shaker units), with or without associated amplifiers, capable of imparting a force of 50 kN (11,250 lbs), measured "bare table", or greater, which are usable for the systems controlled in 61.1.above;

61.4. Test piece support structures and electronic units designed to combine multiple shaker units into a complete shaker system capable of providing an effective combined force of 50 kN, measured 'bare table', or greater, which are usable for the systems controlled in 61.1 above.

EXPLANATORY NOTE:
The term 'bare table' refers to a flat table or surface with no fixtures or fittings.

61.5. "Specially designed software" for use with the systems controlled in 61.1.above or for the electronic units controlled in 61.4.above.

62. "Robots" and "end-effectors" having any of the following characteristics; and specially designed controllers and software therefor:

62.1. Specially designed to comply with national safety standards applicable to explosive environments (for example, meeting electrical code ratings for explosive environments);

62.2. Specially designed or rated as radiation hardened more than necessary to withstand normal industrial (i.e. non-nuclear industry) ionizing radiation.

NOTE:
See Appendix to Annex 3 for definitions.

IMPLOSION SYSTEMS DEVELOPMENT EQUIPMENT

63. *Specialized equipment for hydrodynamic experiments, as follows:

63.1. Velocity interferometers for measuring velocities in excess of 1 km per second during time intervals less than 10µs (VISARs, Doppler laser interferometers, DLIs, etc.);

63.2. Manganin gauges for pressures greater than 100 kilobars;

63.3. Quartz pressure transducers for pressures greater than 100 kilobars;

63.4. Pindomes; or

63.5. Schliering systems.

64. Flash X-ray equipment

Flash X-ray generators or pulsed electron accelerators with peak energy of 500 keV or greater as follows, except accelerators that are component parts of devices designed for purposes other than electron beam or x-ray radiation (electron microscopy, for example) and those designed for medical purposes:

64.1. Having an accelerator peak electron energy of 500 keV or greater, but less than 25 MeV and with a figure of merit (K) of 0.25 or greater, where K is defined as:

$$K=1.7 \times 10^{3} V^{2.65} Q$$

where V is the peak electron energy in million electron volts and ***Q*** is the total accelerated charge in coulombs if the accelerator beam pulse duration is less than or equal to 1 µs; if the accelerator beam pulse duration is greater than 1 µs, ***Q*** is the maximum accelerated charge in 1 µs [***Q*** equals the integral of i with respect to ***t***, over the lesser of 1 µs or the time duration of the beam pulse ($Q = \int i dt$), where i is the beam current in amperes and ***t*** is the time in seconds] or,

64.2. Having an accelerator peak electron energy of 25 MeV or greater and a peak power greater than 50 MW. [Peak power = (peak potential in volts) x (peak beam current in amperes).]

TECHNICAL NOTE:

Time duration of the beam pulse In machines, based on microwave accelerating cavities, the time duration of the beam pulse is the lesser of 1 µs or the duration of the bunched beam packet resulting from one microwave modulator pulse.

Peak beam current In machines based on microwave accelerating cavities, the peak beam current is the average current in the time duration of a bunched beam packet.

65. *Gun systems

Multistage gas guns or other high-velocity gun systems (coil, electromagnetic, electrothermal, or other advanced systems) capable of accelerating projectiles to 2 km per second or greater.

66. * Mechanical rotating mirror cameras

Mechanical framing cameras with recording rates greater than 225,000 frames per second; streak cameras with writing speeds greater than 0.5 mm per microsecond; and parts and accessories thereof, including synchronizing electronics specially designed for this purpose and specially designed rotor assemblies (consisting of turbines, mirrors, and bearings).

67. *Electronic streak and framing cameras and tubes as follows:

67.1. Electronic streak cameras capable of 50 ns or less time resolution and streak tubes therefor;

67.2. Electronic (or electronically shuttered) framing cameras capable of 50 ns less frame exposure time including single frame cameras;

67.3. Framing tubes and solid-state imaging devices for use with cameras controlled in 67.2 above, as follows:

(a) proximity focused image intensifier tubes having the photocathode deposited on a transparent conductive coating to decrease photocathode sheet resistance;

(b) gate silicon intensifier target (SIT) vidicon tubes, where a fast system allows gating the photoelectons from the photocathode before they impinge on the SIT plate;

(c) Kerr or pockel cell electro-optical shuttering; or

(d) Other framing tubes and solid-state imaging devices having a fast-image gating time of less than 50 ns specially designed for cameras controlled in 67.2 above.

68. *Computer codes for nuclear explosives

Hydrodynamics codes, neutronic codes, and/or equation-of-state and related nuclear data files usable for calculating implosion or gun type weapons.

NOTE:
These items include software, equations or data in any form usable for calculating implosion or gun type weapons.

69. Detonators and multi-point initiator systems

Detonators and multipoint initiation systems:

69.1. Electrically driven explosive detonators as follows:

- **(a)** Exploding bridge (EB);
- **(b)** Exploding bridge wire (EBW);
- **(c)** Slapper; and
- **(d)** Exploding foil initiators (EFI).

69.2. Arrangements using single or multiple detonators designed to nearly simultaneously initiate an explosive surface (over greater than 5000 mm^2) from a single firing signal (with an initiation timing spread over the surface of less than 2.5 μs).

TECHNICAL NOTE:

The detonators of concern all utilize a small electrical conductor (bridge, bridge wire, or foil) that explosively vaporizes when a fast, high-current electrical pulse is passed through it. In non-slapper types, the exploding conductor starts a chemical detonation in a contacting high-explosive material such as PETN (pentaerythritoltetranitrate). In slapper detonators, the explosive vaporization of the electrical conductor drives a "flyer" or "slapper" across a gap, and the impact of the slapper on the explosive starts a chemical detonation . The slapper in some designs is driven by magnetic force. The term "exploding foil" detonator may refer to either an EB or a slapper-type detonator. Also, the word "initiator" is sometimes used in place of the word "detonator".
Detonators using only primary explosives, such as lead azide, are not subject to control.

70. *Explosive lenses.

Explosive lenses designed to uniformly initiate the detonation of the surface of a high explosive charge.

71. *Firing sets and equivalent high-current pulse generators (for controlled detonators)

71.1. Explosive detonator firing sets designed to drive multiple controlled detonators covered under item 69 above;

71.2. Modular electrical pulse generators (pulsers) designed for portable, mobile or ruggedized use (including xenon flashlamp drivers), with the following characteristics:

- **(a)** Capable of delivering their energy in less than 15 microseconds;
- **(b)** Having an output greater than 100 A;

(c) Having a rise time of less that 10 microseconds into loads of less than 40 ohms. (Rise time is defined as the time interval from 10% to 90% current amplitude when driving a resistive load);

(d) Enclosed in a dust-tight enclosure;

(e) No dimension greater than 25.4 cm (10 in);

(f) Weight less than 25 kg (55 lb); and

(g) Specified for use over an extended temperature range (-50°C to 100°C) or specified as suitable for aerospace use.

72. Switching devices, as follows:

72.1. Cold-cathode tubes (including gas krytron tubes and vacuum sprytron tubes), whether gas filled or not, operating similarly to a spark gap, containing three or more electrodes, and having all of the following characteristics:

(a) Anode peak voltage rating of 2500 V or more;

(b) Anode peak current rating of 100 A or more; and

(c) Anode delay time of 10 microseconds or less;

72.2. Triggered spark-gaps having an anode delay time of 15 microseconds or less and rated for a peak current of 500 A or more;

72.3. Modules or assemblies with a fast switching function having all of the following characteristics:

(a) Anode peak voltage rating greater than 2000V;

(b) Anode peak current rating of 500 A or more; and

(c) Turn-on time of 1 µs or less.

73. Capacitors with either of the following sets of characteristics:

73.1. Voltage rating greater than 1.4 kV, energy storage greater than 10J, capacitance greater than 0.5 µF, and series inductance less than 50 nH; or

73.2. Voltage rating greater than 750 V, capacitance greater than 0.25 µF, and series inductance less than 10 nH.

74. High explosives (SC IV)

High explosive, in any form, including shells and hollow spheres, as follows:

74.1. Cyclotetramethylenetetranitroamine (HMX);

74.2. Cyclotrimethylenetrinitroamine (RDX);

74.3. Triaminotrinitrobenzene (TATB);

74.4. Pentaerythritoltetranitrate (PETN); except when contained in pharmaceuticals;

74.5. Hexanitrostilbene (HNS), except when contained in pharmaceuticals; and

74.6. Any explosive with a crystal density greater than 1.8 g/cm^3 and having a detonation velocity greater than 8000 m/s.

OTHER EQUIPMENT

75. Crucibles, as follows:

75.1. *Crucibles made of any of the following materials:

- **(a)** Calcium fluoride (CaF_2);
- **(b)** Calcium zirconate (metazirconate) (Ca_2ZrO_3);
- **(c)** Cerium sulfide (Ce_2S_3);
- **(d)** Erbium oxide (erbia) (Er_2O_3);
- **(e)** Hafnium oxide (hafnia) (HfO_2);
- **(f)** Magnesium oxide (MgO);
- **(g)** Nitrided niobium-titanium-tungsten alloy (approximately 50% Nb, 30% Ti, 20%W);
- **(h)** Yttrium oxide (yttria) (Y_2O_3); or
- **(i)** Zirconium oxide (zirconia) (ZrO_2);

75.2. *Crucibles made of or lined with tantalum, having a purity of 99.9% or greater;

75.3. *Crucibles made of or lined with tantalum (having a purity of 98% or greater) coated with tantalum carbide, nitride or boride (or any combination of these)

76. Alpha sources

Alpha-emitting radionuclides, as follows; and equipment containing such alpha-emitting radionuclides

(a) Radionuclides, including compounds and mixtures, which:

(i) Have an half-life of 10 days or greater, but less than 200 years; and

(ii) Have a total alpha activity of 37 Gbq per kilogram (1 curie per kilogram) or greater;

except:

devices containing less than 100 millicuries (3.7 Gbq) of alpha activity per device;

(b) Radium-226 in any form;

except:

when contained in medical applicators

77. Neutron generator systems

77.1. *Neutron generator systems, including tubes, designed for operation without an external vacuum system and utilizing electrostatic acceleration to induce a tritium-deuterium reaction, capable of producing more than 3 x 10^3 neutron/µs.

77.2. Neutron generator systems to utilize dense plasma focus for deuterium-deuterium or tritium-deuterium reaction.

78. Electronic digital computers (SC IV)

Electronic digital computers with a composite theoretical performance (CTP) of 12.5 million theoretical operations per second (Mtops) or greater

except:

computers essential for medical applications and incorporated in equipment or systems designed or modified for identifiable and dedicated medical applications.

79. Electronic equipment for time delay generation or time interval measurement, as follows:

79.1. Digital time delay generators with a resolution of 50 nanoseconds or less over time intervals of 1 microsecond or greater;

79.2. Multi-channel (three or more) or modular time interval meter and chronometry equipment with time resolution less than 50 nanoseconds over time ranges greater than 1 microsecond.

80. Oscilloscopes

Oscilloscopes and transient recorders as follows; and specially designed components therefor:

80.1. Non-modular analog oscilloscopes having a bandwidth of 1 GHz or greater;

80.2. Modular analog oscilloscope systems having either of the following characteristics;

(a) A mainframe with a bandwidth of 1 GHz or greater; or

(b) Plug-in modules with an individual bandwidth of 4 GHz or greater.

80.3. Analog sampling oscilloscopes for the analysis of recurring phenomena with an effective bandwidth greater than 4 GHz;

80.4. Digital oscilloscopes and transient recorders, using analog-to digital conversion techniques, capable of storing transients by sequentially sampling single-shot inputs at successive intervals of less than 1 ns (greater than 1 giga-sample per second), digitizing to 8 bits or greater resolution and storing 256 or more samples.

NOTE 1:

Specially designed components for analog oscilloscopes, are:

(i) Plug-in units;

(ii) External amplifiers;

(iii) Pre-amplifiers;

(iv) Sampling devices; and

(v) Cathode ray tubes;

NOTE 2:

"Bandwidth" is defined as the band of frequencies over which the deflection on the cathode ray tube does not fall below 70.7% of that at the maximum point measured with a constant input voltage to the oscilloscope amplifier.

81. High-speed pulse generators

High-speed pulse generators with output voltages greater than 6 V into a less than 55-ohm resistive load, and with pulse transition times less than 500 ps (defined as the time interval between 10% and 90% voltage amplitude).

82. Pulse amplifiers

Pulse amplifiers with gain greater than 6 decibels and with a baseband bandwidth greater than 500 megahertz (having the low frequency half-power point at less than 1 MHz and the high frequency half-powered point greater than 500 MHz) and output voltage greater than 2 volts into 55 ohms or less (this corresponds to an output greater than 16 dBm in a 50 ohm system).

83. Photomultiplier tubes

Photomultiplier tubes,with the following characteristics; a photocathode area of greater than 20 cm^2; and an anode pulse rise time of less than 1 ns.

84. Frequency changers

Frequency changers (also known as converters or invertors), other than those specified in item 23.4, having all of the following characteristics:

(a) A multiphase output capable of providing a power of 40W or more;

(b) Capable of operating in the frequency range between 600 and 2000 Hz;

(c) Total harmonic distortion below 10%; and

(d) Frequency control better than 0.1%.

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ANNEX 3

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NON-NUCLEAR MATERIALS

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