
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 denitrification of uranium nitrate, conversion of plutonium nitrate to oxide metal, and treatment of fissile 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 of 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.

1. Fuel element chopping machines, i.e., remotely operated equipment especially designed or prepared to cut, chop, or shear irradiated nuclear reactor fuel assemblies, bundles, or rods.

2. Critically safe tanks, i.e., small diameter, annular or slab tanks specially designed or prepared for the dissolution of irradiated nuclear reactor fuel.

3. Solvent extraction equipment. Especially designed or prepared solvent extractors such as packed or pulse columns, mixer settlers or centrifugal contactors for use in a plant for the reprocessing of irradiated fuel. Because solvent extractors must be resistant to the corrosive effect of nitric acid, they are normally fabricated of materials such as low carbon stainless steels, titanium, zirconium, or other high quality materials.

4. Chemical holding or storage vessels. Especially designed or prepared holding or storage vessels for use in a plant for the reprocessing of irradiated fuel. Because 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 or storage vessels may be designed for remote operation and maintenance and may have the following features for control of nuclear criticality:

   (i) Walls or internal structures with a boron equivalent of at least 2 percent, or

   (ii) A maximum diameter of 7 inches (17.78 cm) for cylindrical vessels, or

   (iii) A maximum width of 3 inches (7.62 cm) for either a slab or annular vessel.

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

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

7. Process control instrumentation especially designed or prepared for monitoring or controlling the processing of material in a reprocessing plant.


APPENDIX J TO PART 110—ILLUSTRATIVE LIST OF URANIUM CONVERSION PLANT EQUIPMENT AND PLUTONIUM CONVERSION PLANT EQUIPMENT UNDER NRC EXPORT LICENSING AUTHORITY

Note—Uranium conversion plants and systems may perform one or more transformations from one uranium chemical species to another, including: conversion of uranium ore concentrates to UO3, conversion of UO3 to UO2, conversion of uranium oxides to UF4 or UF6, conversion of UF4 to UF6, conversion of UP6 to UP4, conversion of UF4 to uranium metal, and conversion of uranium fluorides to UO2. Many key equipment items for uranium conversion plants are common to several segments of the chemical process industry, including 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 customer requirements and specifications. Some require special design and construction considerations to address the corrosive properties of the chemicals handled (HF, F2, CLF3, and uranium fluorides). In all of the uranium conversion processes, equipment which individually is not especially designed or prepared for uranium conversion can be assembled into systems which are especially designed or prepared for uranium conversion.

(a) Uranium Conversion Plant Equipment.
Conversion of uranium ore concentrates to UF6 can be performed by first dissolving the ore in nitric acid and extracting purified uranium nitrate using a solvent such as tributyl phosphate. Next, the uranyl nitrate is converted to UF6 either by concentration and desiccation or by neutralization with gaseous ammonia to produce ammonium diuranate with subsequent filtering, drying, and calcining.

Conversion of UF6 to UO2 can be performed directly by fluorination. The process requires a source of fluorine gas or chlorine trifluoride.

Conversion of UF6 to UF4 can be performed through reduction of UF6 with cracked ammonia gas or hydrogen.

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

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

Conversion of UF6 to UO2 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).

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

Conversion of UF6 to UF4 can be performed by one of three processes. In the first, UF6 is reduced and hydrolyzed to UF2 using hydrogen and steam. In the second, UF6 is hydrolyzed by solution in water, ammonia is added to precipitate ammonium diuranate, and the diuranate is reduced to UF2 with hydrogen at 820°C. In the third process, gaseous UF6, CO2, and NH3 are combined in water, precipitating ammonium uranyl carbonate. The ammonium uranyl carbonate is combined with steam and hydrogen at 500–600°C to yield UF2. UF6 to UF2 conversion is often performed as the first stage of a fuel fabrication plant.

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

Conversion of UF4 to UF6 is performed by reacting UO2 with hydrogen fluoride gas.

Conversion of UF4 to U metal is performed by reacting UF4 with hydrogen fluoride gas.

Conversion of UO2 to UF4 can be performed directly by fluorination. The process requires a source of fluorine gas or chlorine trifluoride.

Conversion of UO2 to UF6 can be performed directly by fluorination. The process requires a source of fluorine gas or chlorine trifluoride.

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

Conversion of UO3 to UF4 can be performed by reduction of UO3 with cracked ammonia gas or hydrogen.

Conversion of UO3 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).

Conversion of UO3 to UO2 can be performed by reduction of UO3 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UO3 to UF6 can be performed by reduction of UO3 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UO2 to UF4 can be performed by reduction of UO2 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UF4 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UO2 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF2 to UF4 can be performed by reduction of UF2 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF2 to UF6 can be performed by reduction of UF2 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UO2 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UO2 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF2 to UF4 can be performed by reduction of UF2 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF2 to UF6 can be performed by reduction of UF2 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UF4 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UF6 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF2 to UF6 can be performed by reduction of UF2 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF2 to UF4 can be performed by reduction of UF2 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UO2 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UF4 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UF6 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UF4 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UF6 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UF4 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UF6 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UF4 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UF6 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF6 to UF4 can be performed by reduction of UF6 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.

Conversion of UF4 to UF6 can be performed by reduction of UF4 with highly corrosive hydrogen fluoride, to produce plutonium fluoride, which is subsequently reduced using high purity calcium metal to produce metallic plutonium and plutonium dioxide.
calcium fluoride slag. The main functions involved in this process are the following: fluorination (e.g., involving equipment fabricated or lined with a precious metal), metal reduction (e.g., employing ceramic crucibles), slag recovery, product handling, ventilation, waste management and process control. The process systems are particularly adapted so as to avoid criticality and radiation hazards as well as to minimize toxicity hazards. Other processes include the fluorination of plutonium oxalate or plutonium oxide.

C.1. Much of the key equipment for heavy water production plants using the water-hydrogen sulphide exchange process (GS process) or the ammonia-hydrogen exchange process are common to several segments of the chemical and petroleum industries; particularly in small plants using the GS process. However, few items are available “off-the-shelf.” Both processes require the handling of large quantities of flammable, corrosive and toxic fluids at elevated pressures. Thus, in establishing the design and operating standards for plants and equipment using these processes, careful attention to materials selection and specifications is required to ensure long service life with high safety and reliability factors. The choice is primarily a function of economics and need. Most equipment, therefore, is prepared to customer requirements.

In both processes, equipment which individually is not especially designed or prepared for heavy water production can be assembled into especially designed or prepared systems for producing heavy water. Examples of such systems are the catalyst production systems used in the ammonia-hydrogen exchange process and the water distillation systems used for the final concentration of heavy water to reactor-grade in either process.

C.2. Equipment especially designed or prepared for the production of heavy water utilizing either the water-hydrogen sulphide exchange process or the ammonia-hydrogen exchange process:

(i) Water-hydrogen Sulphide Exchange Towers

Exchange towers fabricated from 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 psig) and with a corrosion allowance of 16 mm or greater.

(ii) Blowers and Compressors

Single stage, low head (i.e., 0.2 MPa or 30 psig) centrifugal blowers or compressors for hydrogen-sulphide gas circulation (i.e., gas containing more than 70 percent H₂S). The blowers or compressors have a throughput capacity greater than or equal to 56 m³/sec (120,000 SCFM) while operating at pressures greater than or equal to 1.8 MPa (260 psig) suction and have seals designed for wet H₂S service.

(iii) Ammonia-Hydrogen Exchange Towers

A. The water-hydrogen sulphide exchange process (GS process) is based upon the exchange of hydrogen and deuterium between water and hydrogen sulphide within a series of towers which are operated with the top section cold and the bottom section hot. Water flows down the towers while the hydrogen sulphide gas circulates from the bottom to the top of the towers. A series of perforated trays are used to promote mixing between the gas and the water. Deuterium migrates to the water at low temperatures and to the hydrogen sulphide at high temperatures. Gas or water, enriched in deuterium, is removed from the first stage towers at the junction of the hot and cold sections and the process is repeated in subsequent stages.

B. 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 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.

APPENDIX K TO PART 110—ILLUSTRATIVE LIST OF EQUIPMENT AND COMPONENTS UNDER NRC EXPORT LICENSING AUTHORITY FOR USE IN A PLANT FOR THE PRODUCTION OF HEAVY WATER, DEUTERIUM AND DEUTERIUM COMPOUNDS

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

A. The water-hydrogen sulphide exchange process (GS process) is based upon the exchange of hydrogen and deuterium between water and hydrogen sulphide within a series of towers which are operated with the top section cold and the bottom section hot.

B. The ammonia-hydrogen exchange process (GS process) and the ammonia-hydrogen exchange process or the ammonia-hydrogen exchange process:

(i) Ammonia-Hydrogen Exchange Towers

Exchange towers fabricated from 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 psig) and with a corrosion allowance of 16 mm or greater.

(iii) Blowers and Compressors

Single stage, low head (i.e., 0.2 MPa or 30 psig) centrifugal blowers or compressors for hydrogen-sulphide gas circulation (i.e., gas containing more than 70 percent H₂S). The blowers or compressors have a throughput capacity greater than or equal to 56 m³/sec (120,000 SCFM) while operating at pressures greater than or equal to 1.8 MPa (260 psig) suction and have seals designed for wet H₂S service.

(iv) Ammonia-Hydrogen Exchange Towers

Exchange towers fabricated from 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 psig) and with a corrosion allowance of 16 mm or greater.

(iii) Blowers and Compressors

Single stage, low head (i.e., 0.2 MPa or 30 psig) centrifugal blowers or compressors for hydrogen-sulphide gas circulation (i.e., gas containing more than 70 percent H₂S). The blowers or compressors have a throughput capacity greater than or equal to 56 m³/sec (120,000 SCFM) while operating at pressures greater than or equal to 1.8 MPa (260 psig) suction and have seals designed for wet H₂S service.