IAEA-TECDOC-771

Manual on safe production, transport, handling and storage of uranium hexafluoride

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MANUAL ON
SAFE PRODUCTION, TRANSPORT, HANDLING AND STORAGE OF
URANIUM HEXAFLUORIDE

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FOREWORD

This document has been prepared for people dealing with UF_6. It is intended to be a single source of basic material on the properties and potential problems associated with UF_6. As such, all people who intend to produce, handle, transport, or store UF_6 should find in this volume an extensive description of the processes and the properties of the material with which they will be dealing. This document should also be valuable not only for those who do not yet deal with UF_6, but also for those who wish to review aspects of their programmes, such as quality assurance, safety and emergency preparedness. The materials presented include: UF_6 properties; properties of associated products and waste materials; safety concerns in production, handling, transport and storage of UF_6; and descriptive materials of quality assurance programmes, safety analysis programmes, and emergency preparedness and response programmes.

Uranium hexafluoride occupies a key position in the nuclear fuel cycle because of its use in the most common enrichment processes. Efforts to promote the safe transport of UF_6 have been made by the IAEA in the framework of transportation of radioactive materials. However, the operations involving UF_6 (production in the conversion plants, management in the enrichment plants, handling in fuel fabrication facilities and storage of significant quantities of the depleted material) are numerous and have very different characteristics.

The purpose of this document is to provide guidance to technical personnel and facility operators. The radiological and toxicological properties of the materials involved in UF_6 production and use are known. The hazards and risks to workers, the public and the environment, are also known. However, a comprehensive single document collecting all this information on UF_6 has not existed. The information contained in this publication will also help the public to understand that nuclear fuel cycle operations are conducted safely.

Work on this subject was initiated by a Consultants meeting convened in November 1988, followed by an Advisory Group meeting in June 1989 and another Consultants meeting in April 1990. Consultants from Argentina, Canada, France, Japan, the Netherlands, Sweden, the United Kingdom, the USA and the former USSR attended the meetings and prepared a draft of this document.

The IAEA wishes to express its gratitude to those who took part in the preparation of this document and in particular to Mr. J.P. Didyk (Canada), Chairman of the Group of Consultants, Mr. R.T. Tanaka (Canada), Mr. J. Amamoto (Japan), Mr. B.G. Dekker (Netherlands), Mr. T.J. Hayes (United Kingdom), and Ms. H. Henson and Mr. W.E. Sykes (USA) for their valuable contribution.

The IAEA officers responsible for this publication were Mr. J.L. Rojas and Mr. J. Finucane, of the Division of Nuclear Fuel Cycle and Waste Management.

EDITORIAL NOTE

CONTENTS

Chapter 1

INTRODUCTION

Uranium hexafluoride (UF_6) is a uranium compound used during the enrichment of uranium to make fuel for nuclear reactors. At room temperature it is a solid but it can readily undergo changes in state and exist as a gas, or a liquid at slightly elevated temperatures. Since fluorine exists naturally in only one isotopic form (^{19}F), the physical processes widely used for enrichment of ^{235}U (diffusion, centrifugation) increase only the concentrations of U isotopes. It is radioactive because of its uranium content and is chemically reactive because of its high fluorine content. The chemical hazards are more significant than the radiological hazards.

Several of the most important steps in the nuclear fuel cycle, namely, uranium refining, conversion and enrichment, involve the production, handling, transportation and waste management of UF_6 and related products. Due to the hazardous properties of UF_6, these operations must be carried out in a safe manner to protect plant workers, the public and the environment. Advances in the technology of UF_6 processing have been significant in the last twenty-five years and development of safety techniques and protective measures have improved accordingly.

Although the hazardous properties (radioloactive, corrosive and toxic) of the materials involved in UF_6 production are well known, a comprehensive document providing safety guidance from production to waste management has not previously existed in a single publication. The purpose of the document is to provide information to technical personnel and facility operators on the hazards associated with UF_6 operations to ensure that the workers, the public and the environment are adequately protected.

This document includes a description of the physical, chemical and radiological properties of UF_6 and related products, including information concerning their production, handling, storage and transportation and the management of the wastes which result. All the operations of UF_6 management are considered from a safety point of view. Special attention has been given to the production of UF_6 in the conversion from ore concentrate through uranium dioxide (UO_2) and tetrafluoride (UF_4) to UF_6. The handling operations in the conversion facilities, in the uranium enrichment plants and in the fuel fabrication plants have also been considered. Transport of UF_6 is analysed considering the different modalities of transport using the publications of the IAEA[1]. The IAEA organized a series of meetings to consider the hazards of UF_6 transport since considerable quantities of depleted, natural and enriched UF_6 are transported between nuclear fuel sites. Storage of depleted UF_6 is another important issue. Factors affecting long term storage are presented, especially site choice and cylinder corrosion. Other topics such as waste management, quality assurance and emergency preparedness which contribute to the overall safety of UF_6 handling, are included. The intention of this document is to provide analysis of the safety implications of all stages of UF_6 operations and to draw attention to specific features and properties of importance. References are given to the regulations, recommendations and advice which govern these operations and which have been prepared by the United Nations, the IAEA, and national and international organizations.

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[1] IAEA-TECDOC-423 [1] and Safety Series No.6 [2] (several revisions) of the IAEA are a very valuable reference for UF_6 Transport Regulations.

Chapter 2

PROPERTIES OF UF_6 AND OTHER URANIUM COMPOUNDS

2.1. PHYSICAL PROPERTIES

At ambient temperature, UF_6 is a colourless, high molecular weight solid with a significant but less than atmospheric vapour pressure. It is readily transformed into a gas at atmospheric pressure by raising its temperature above 56.4°C and into a liquid by raising the temperature above 64°C and increasing the pressure above 1.5 atmospheres. In the nuclear industry UF_6 is handled in all three states during processing stages in the fuel cycle. As processes are conducted in sealed metal containers, UF_6 is not directly observable. In order to interpret the indirect observations from instrumentation it is important to understand the properties of UF_6 .

All three phases, solid, liquid and gas, coexist at 64°C (the triple point). Only the gaseous phase exists above 230°C (the critical temperature) at which temperature the critical pressure is 46.1 atmospheres. The vapour pressure above the solid reaches 1 atmosphere at 56°C, the sublimation temperature. A complete phase diagram and vapour pressure/temp relationships are detailed in Figure 2.1.

A large decrease in UF_6 density occurs in changing from the solid to the liquid state. Figure 2.2 shows that the expansion of the liquid with increasing temperature is also high.

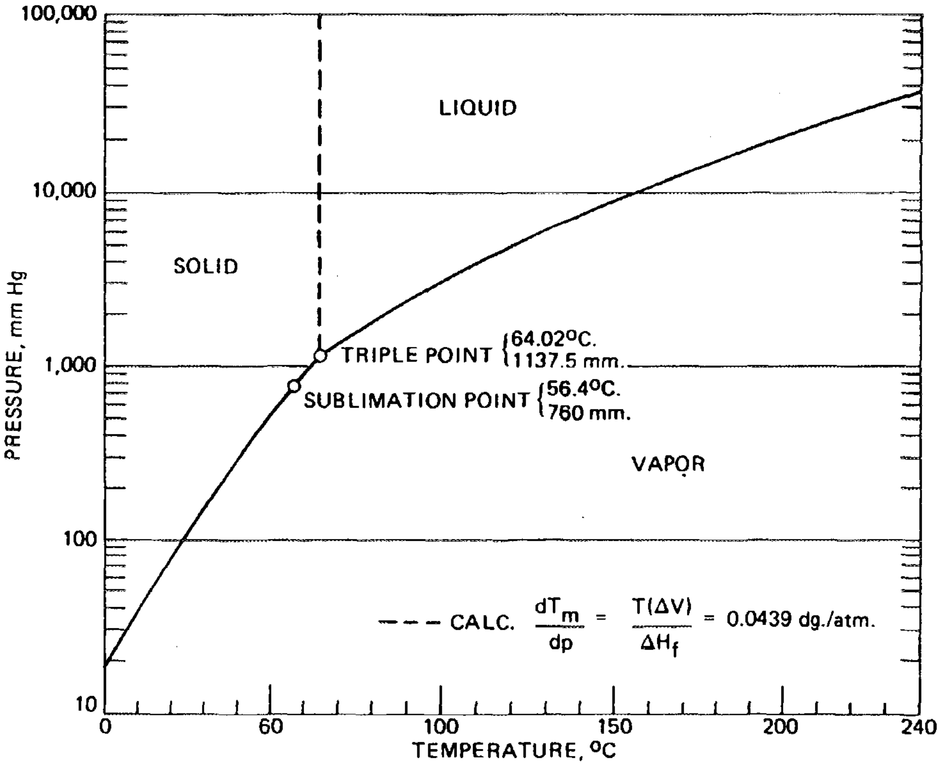

FIG. 2.1. Phase diagram of UF_6 (a more detailed and comprehensive description of the properties and characteristics of UF_6 is given in Ref. [11]).

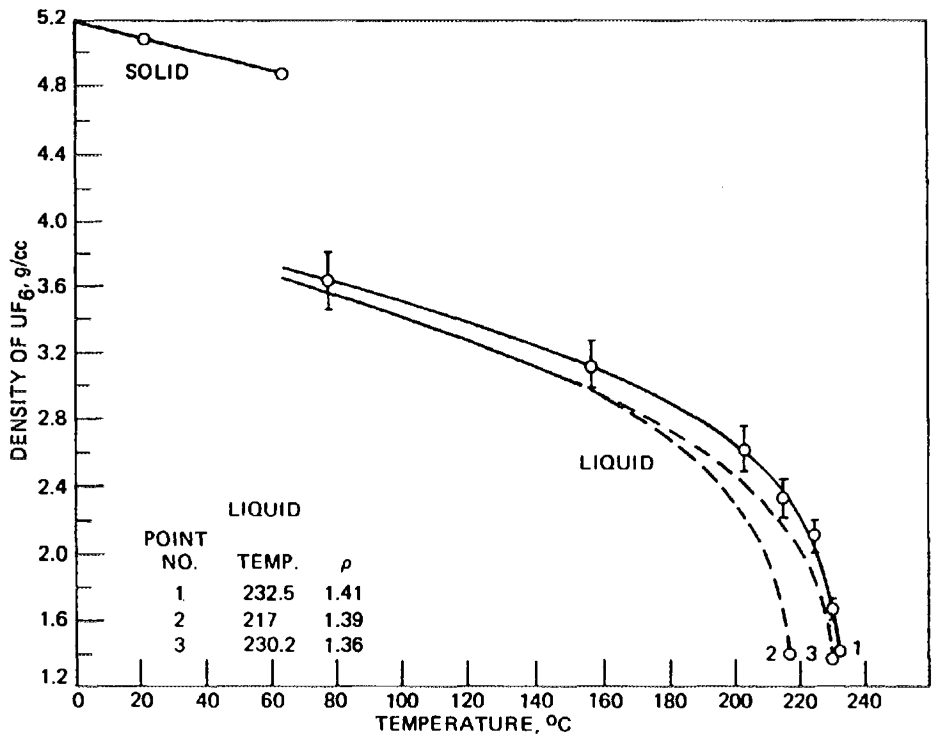

FIG. 2.2. Density of solid and liquid UF_6

It is essential to control the physical state of UF_6 at all times. When restricted volumes such as traps and containers are filled with UF_6, allowance must be made for the volume changes which arise over the working temperature range to avoid rupture. Data relating the volumes of several different masses in a Model 48 cylinder are presented in Table 2.1.

The relatively small value for the heat of vaporization implies that sublimation and condensation occur readily. Unexpected material transfer and plugging of lines can result. Since the sublimation temperature lies below the triple point, the pressure must be in excess of 1.5 atmospheres and the temperature must be above 64°C for UF_6 to be a liquid.

2.2. CHEMICAL PROPERTIES

Uranium hexafluoride is a highly reactive material under conditions in which stable uranyl (UO_2^{++}) species can be formed or in which UF_6 can behave as an oxidizing agent. An important UF_6 reaction is that which occurs with water to form the soluble reaction products uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF), both of which are very toxic. These reactions are strongly exothermic.

(a) In the solid state:

$$UF_6(s) + 2H_2O(l) \rightarrow UO_2F_2(s) + 4HF(g) + \Delta H$$

where $\Delta H = +36.2$ kJ/mole UF_6.[1]

In the solid state the reaction of UF_6 with water may be hindered by the formation of hydrated UO_2F_2 which covers the UF_6 surface, thereby slowing further reaction.

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[1] Energy figures derived from US Bureau of Standards Data.

TABLE 2.1. VARIATION OF VOLUME OCCUPIED BY UF_6 IN MODEL 48Y CYLINDER[a] WITH TEMPERATURE

T°C	UF_6 density g/cm³	Volume occupied by UF_6					
		Filled 12.5 tonne		Filled 13 tonne		Filled 13.5 tonne	
		m³	%	m³	%	m³	%
20	5.090(solid)	2.456	60.7	2.554	63.2	2.652	65.6
65	3.624(liquid)	3.449	85.3	3.587	88.8	3.725	92.2
80	3.532(liquid)	3.539	87.6	3.680	91.1	3.822	94.6
95	3.437(liquid)	3.636	90.0	3.782	93.6	3.927	b
112	3.316(liquid)	3.769	93.3	3.920	b	4.071	b
120	3.263(liquid)	3.830	94.8	3.984	b	4.137	b
125	3.225(liquid)	3.875	95.9	4.031	b	4.186	b

[a] Model 48Y cylinder volume 4.040 m³.
[b] Overfilled.

(b) In the gas phase:

$$UF_6(g) + 2H_2O(g) \rightarrow UO_2F_2(s) + 4HF(g) + \Delta H$$

where $\Delta H = -101.7$ kJ/mole HF_6.[1]

When released to the atmosphere, gaseous UF_6 reacts with humidity to form $HF \cdot UO_2F_2$. The reaction is very fast and is limited by the availability of water. To hydrolyse 1000 kg of UF_6 requires 100 kg of water; at 25°C and 70% relative humidity, this amount of water is contained in 6000 m³ of air. Following a large scale release of UF_6 outside, the dispersion is governed by meteorological conditions. The plume could still contain unhydrolysed UF_6 even after travelling a distance of several hundred meters. After hydrolysis, uranyl fluoride (UO_2F_2), usually as a hydrate, can be deposited as a finely divided solid while HF continues as part of the gas plume. Indoors, the reaction products form a dense fog seriously reducing visibility and hindering evacuation and emergency response. Fog can also occur in unconfined areas if the humidity is high. Reaction of UF_6 with water, which occurs rapidly in the ambient environment, is accelerated in a fire because of the large quantities of H_2O formed in combustion. Reaction of liquid UF_6 with hydrocarbon vapours is extremely exothermic with formation of UF_4 and low molecular weight fluorinated compounds (CF_4, C_2F_6, etc.). More heat is generally released in hydrocarbon reactions with UF_6 than is released in similar reactions with O_2.

2.3. HAZARDS AND PRECAUTIONS ASSOCIATED WITH RELEASE OF UF_6

The hazards from release of UF_6 are mainly inhalation of and ingestion of HF and UO_2F_2. The hazards of exposure to unhydrolysed UF_6 are greater than those involved in the combined exposure to UO_2F_2 and HF because the UF_6 hydrolysis reaction occurs at sensitive tissues. Currently, there is no data available that demonstrates the extent of damage to humans caused by this reaction. The control of UF_6 releases requires preplanning with respect to emergency procedures and equipment. Respiratory protective equipment, wooden plugs, patches, a detection and alarm system, and some type of cooling mechanism should be available in areas where UF_6 is processed. Entry into dense clouds from UF_6 requires the use of protective clothing and breathing apparatus capable of preventing inhalation of HF and particulates. Skin protection is necessary to prevent burns. It is essential that all persons not properly trained and protected be evacuated from

[1] Energy figures derived from US Bureau of Standards Data.

areas affected by the release. The wooden plugs should be designed to be inserted into holes which might occur as a result of broken or defective valves, line breakage, etc. Patches should be shaped to fit contours of the UF_6 cylinders to seal a leak.

A UF_6 release may be terminated by using patches and plugs depending on the pressure within the system. In some circumstances the release will be terminated by freezing the UF_6 at the leak in the system with appropriate cooling. This cooling is usually provided by a water stream. In no case should water be streamed directly into a cylinder opening. Dry ice or pressurized CO_2 from a large-capacity source may be used safely to freeze off leaks. If the cylinder content is liquid, extended freeze off periods will be required. It is not practical to attempt to seal a large opening in a liquid UF_6 system. When dealing with enriched UF_6, nuclear criticality and safety evaluations should be made beforehand to assure the absence of unsafe accumulations of uranium.

If the hole or tear in a cylinder is small, the application of wet towels or sponges can plug the hole with hydrolysis products. This works for both solid and liquid UF_6. Hydrolysis products will develop immediately and provide an effective plug sooner than by freezing the UF_6. Also, the hydrolysis products will not melt.

2.4. HAZARDS OF URANYL FLUORIDE

In accidental releases of UF_6, UO_2F_2 as a solid particulate material may deposit on the ground over a large area. There are no internationally accepted values for uranium contamination levels for uncontrolled access. However, the value of 0.38 Bq/cm^2 (10^{-5} μCi/cm^2) is accepted in many countries [3] for unlimited occupancy of uncontrolled areas. This is equivalent to a ground concentration of approximately 0.1 g/m^2 for natural uranium and to 0.003g/m^2 for 50% enriched uranium. Uranyl fluoride (UO_2F_2) is a yellow hygroscopic solid which is very soluble in water. The hazards associated with UO_2F_2 relate to its radiological, toxic and fissile properties. Fissile properties of UO_2F_2 are comparable to those of UF_6 from which it is produced by hydrolysis. The most important factors are the enrichment level of uranium and the accident conditions. However, in the case of released gaseous UF_6 it is highly improbable that UO_2F_2 will develop as a critical system due to the dilution of the uranium by the dispersion into a greater volume. The radiological effects of UO_2F_2 can arise from direct inhalation of aerosols of UO_2F_2 or from secondary intake associated with environmental contamination from deposition of UO_2F_2 as a solid around the incident. UO_2F_2 is very soluble in water. In lung fluid it is classified as Type D by the International Commission on Radiological Protection (ICRP); for Type D materials the annual limit of intake (ALI) for uranium is 5×10^4 Bq. This value is based on limiting committed dose to the bone surfaces to 500 mSv. The inhalation model upon which the dosimetric considerations are based applies to aerosols in the particle size range 02–10 μ which is appropriate for atmospheric releases of UF_6.

The change of specific activity for uranium upon enrichment is mainly attributable to the increase in ^{234}U content. For this reason the uranium mass intake for 1 ALI ranges from 2000 mg for natural uranium to 20 mg for a 90% ^{235}U enrichment (enrichment of ^{235}U also enriches ^{234}U, but to a greater factor — see Section 3.3 below). The toxic daily limit of intake (TDLI) for soluble uranium compounds is about 2 mg. The comparable radiological daily derived limit of intake (ALI/250) exceeds the toxic restriction only for enrichments greater than 5% ^{235}U In routine daily operations, the exposure limit should be based on toxicological considerations, for enrichments of up to 5% ^{235}U. It has been estimated that intakes of 10–25 mg UO_2F_2 within a short period (30 min) can induce renal damage in a normal adult, while 50% lethality is expected for an intake of 200 mg (Table 2.2) [4].

The toxicological effects of soluble uranium compounds have been discussed by Just [5]. Their findings are summarized in Figure 2.3. In order to obtain the amounts of material

TABLE 2.2. COMPARISON OF CHEMICAL TOXICITY AND RADIOTOXICITY OF SOLUBLE URANIUM[a]

Absorbed dose of soluble uranium (mg U/kg)[b]	Equivalent radiation dose (Bq)	Acute health effects	
		Chemical toxicity	Radiotoxicity
0.03	5.92.10³	No effect	No effect
0.058	1.11.10⁴	Renal injury	No effect
1.63	3.13.10⁵	50% lethality	No effect
19.29	3.70.10⁶	Lethal	Onset of radiological effects

[a] At 97.5% U-235 and 1.14% U-234 enrichment.
[b] Absorbed dose of soluble uranium per kilogram of body weight.

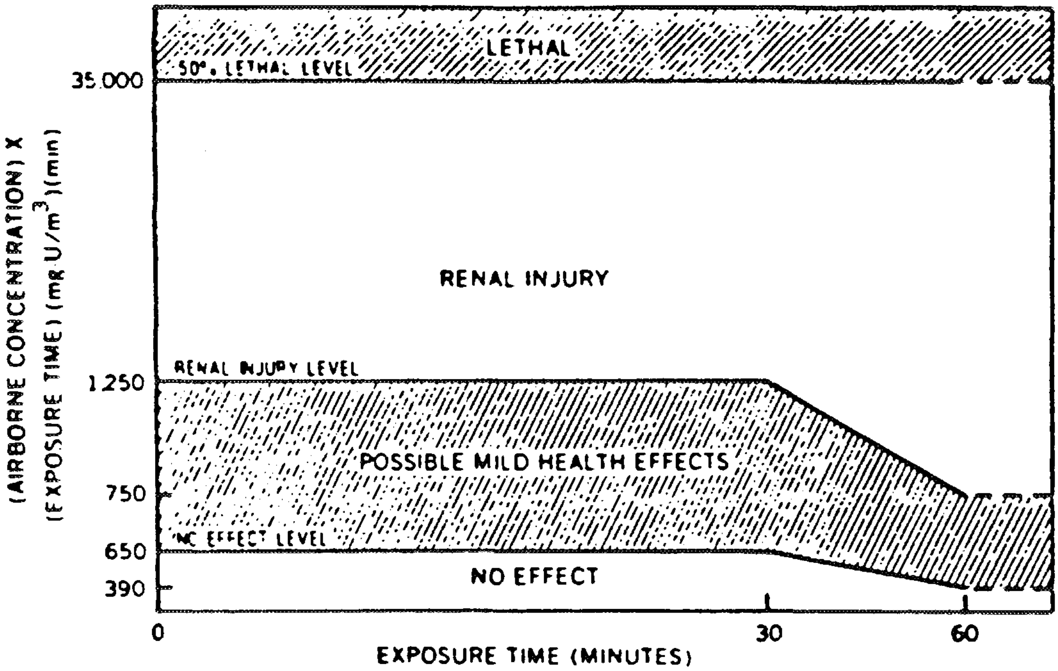

FIG. 2.3. Toxicity of acute exposures to soluble uranium.

inhaled, one multiplies [the integrated exposure expressed as U concentration (mg U/m³)] by [exposure duration (minutes)] by [the normal breathing rate (0.02m³/min)]. For example, the Renal Injury Level for exposures shorter than or equal to 30 minutes is 1250 (mg U/m³)(min) x 0.02m³/min = 25 mg. An alternative approach to assessing the toxic implications of a UF_6 release in accident conditions has been proposed by Ringot et al. [6] and is illustrated in Table 2.3.

2.5. HAZARDS OF HYDROGEN FLUORIDE

Hydrogen fluoride is a colourless fuming corrosive liquid which boils at 20°C. It is one of the strongest oxidizing agents known and it is considered to be one of the most destructive inorganic agents to human tissue. A distinction is made between anhydrous

TABLE 2.3. TOXICITY EFFECTS

Enrichment % ^{235}U	Specific activity	Mass equivalent to 1 ALI		
		Uranium	UF_6	HF
	Bq/g U	mg	mg	mg
Natural	2.6×10^4	1900	2800	950
1	2.9×10^4	1750	2600	900
5	1.0×10^5	500	750	250
10	1.7×10^5	300	450	150
20	3.5×10^5	145	220	75
50	1.0×10^6	50	75	23
90	2.3×10^6	20	30	9

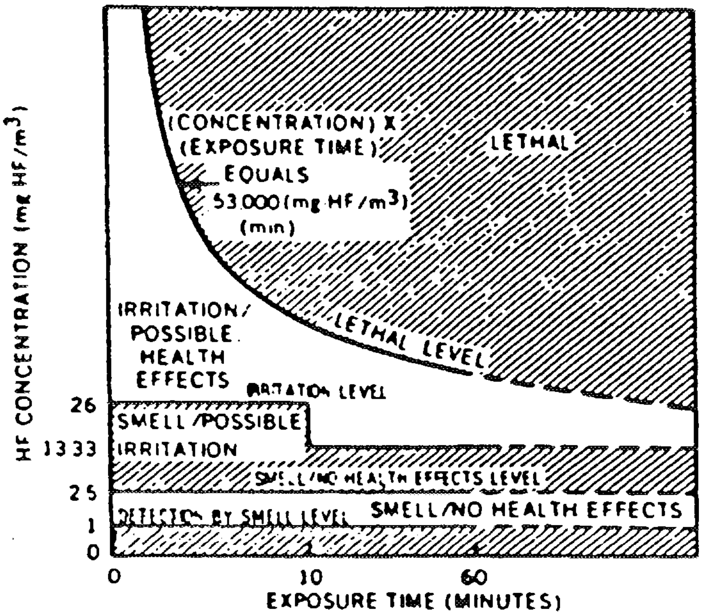

FIG. 2.4. Toxicity of acute exposures to hydrogen fluoride [1].

hydrogen fluoride (UN[2] Number 1052) and an aqueous solution of hydrofluoric acid (UN Number 1790) which may be less dangerous, depending upon its concentration. The toxicology of hydrogen fluoride is discussed, e.g., by Just [7]. The findings are summarized in Figure 2.4 and Table 2.4.

Table 2.4 refers to different kinds of exposure, because persons can be exposed to HF in normal or accidental conditions. The 2nd, 3rd and 4th values of air concentration of HF are applicable to workers exposed in routine conditions, such as workers at F_2 production facilities or UF_6 production or enrichment facilities in normal conditions of

[2] For complete information on the materials classification system, the related hazardous properties, the special and general recommendations relating to specific classes of materials, please see "Recommendations on the Transport of Dangerous Goods", Eighth revised edition, United Nations, New York (1993), ST/SG/AC.10/1/Rev.8 (The Orange Book) [8].

TABLE 2.4. SUMMARY OF ESTIMATES OF HYDROGEN FLUORIDE TOXICITY

	Source	Effect	Concentration in air (mg HF/m³)	Exposure time (min)
		Threshold of detection by smell	0.02 to 1	–
CHRONIC EXPOSURE	National Institute for Occupational Safety and Health (NIOSH)	Short term exposure limit (STEL)	5	15
	NIOSH	Threshold limit value (TLV)	2.5	480
	Occupational Safety and Health Administration (OSHA)	Permissible exposure limit (PEL)	2	480
ACUTE EXPOSURE	National Research Council	Emergency exposure limit	13.3	10
	NIOSH/OSHA	Immediately dangerous to life or health (IDLH)	13.3	30

operation. In these cases the problem is chronic exposure to HF. The 5th and 6th values of Table 2.4 refer to acute exposure to HF for short periods of time. These values could be used as guidance in emergency planning as well as for making safety decisions (e.g. if accident analysis indicates that the exposure of the most exposed person can exceed the value given, more stringent safety conditions would be required). In case of acute exposure to HF, the health hazards are the induction of pneumonitis and pulmonary oedema. The last value of Table 2.4 indicates that significant health effects can be expected after an integrated exposure of an adult in excess of 13 mg HF/m^3 for over 30 minutes.

2.6. COMPATIBILITY

Due to the oxidizing properties of UF_6, the reaction of liquid UF_6 with some organic materials is unpredictable and may be explosive. Small quantities of hydrocarbon oil have been known to react violently, resulting in an explosion. As a result extreme caution should be used to ensure that all equipment is clean and free from organic contamination. This is particularly important in operational circumstances involving UF_6, for example when transferring UF_6 or reducing its pressure using oil based vacuum pumps. When using such pumps, a reservoir or trap large enough to hold the entire oil contents of the pump should be included between the pump and any UF_6 to prevent the backflow of oil into the UF_6 system. The use of UF_6 compatible oils is recommended.

Reaction of UF_6 with fully fluorinated hydrocarbons is very low. However, UF_6 can be soluble in such fluids so caution is necessary. UF_6 does not react with oxygen, nitrogen or dry air. Aluminium, copper, monel, nickel and aluminium bronze are usually suitable materials for UF_6 at elevated temperatures, since UF_6 forms protective fluoride films on the surface of these metals. Physical or chemical conditions (mechanical turbulence, erosion, or chemical complex formation) which interfere with this protection mechanism may result

TABLE 2.5. SPECIFIC ACTIVITY AND ALI OF SOLUBLE URANIUM NUCLIDES AND DAUGHTERS

Species	Specific activity	ALI[a]
	Bq/g	Bq
U-232	8.3×10^{11}	8×10^{3}
U-234	2.31×10^{8}	5×10^{4}
U-235	8.0×10^{4}	5×10^{4}
U-236	2.4×10^{6}	5×10^{4}
U-238	1.2×10^{4}	5×10^{4}
Th-228	3.0×10^{13}	4×10^{2}
Th-230	7.6×10^{8}	2×10^{2}
Th-232	4.0×10^{3}	40
Th-234	8.6×10^{14}	7×10^{6}

[a] Basic Safety Standards for Radiation Protection, IAEA Safety Series No. 9 (1982) [10].

in unexpected, degradation of the performance of these materials. It is therefore essential that design criteria for vessels and process equipment take into consideration the purity of the UF_6 and velocity and turbulence conditions likely to exist during normal operations.

2.7. RADIOACTIVITY OF UF_6

The radioactivity of a mass of UF_6 is dependent upon several factors:

- origin of uranium, natural or reprocessed,
- degree of enrichment in ^{235}U,
- time elapsed since processing,
- radioactive impurities.

The specific activity and annual limits of intake (ALI) for inhalation of soluble species of uranium nuclides and daughters are listed in Table 2.5. The corresponding specific activity of UF_6 may be calculated from the ANSI N14.1 formula:

$$\text{Specific activity (millicuries/lb } UF_6) = 18.90W_4 + 0.028W_5 + 0.0001W_8$$

$$\text{Specific activity}^3 \text{ (Bq/kg } UF_6) = 1.54 \times 10^9 W_4 + 2.28 \times 10^6 W_5 + 8.15 \times 10^4 W_8$$

where W_4, W_5 and W_8 are the weight % of the isotopes ^{234}U, ^{235}U and ^{238}U. This equation is based upon a specification for UF_6 which includes 0.110 parts ^{232}U and 500 parts ^{233}U per million parts of ^{235}U. If these nuclides are not present, subtract $0.022 \times W_5$ from the equation. The maximum anticipated activity levels in UF_6 shipping containers are given in ANSI N14.1 (1987) [9].

2.8. NATURAL UF_6

The radioactivity of unirradiated UF_6 is governed by ^{235}U enrichment. Natural uranium has a specific activity of 2.6×10^4 Bq/g U. The isotopes ^{234}U and ^{235}U each contribute about half of this activity. With the enrichment of the ^{235}U isotope, the contribution to activity from ^{234}U which enriches more rapidly than ^{235}U (see Section 3.3), becomes

[3] $1 \text{ mCi} = 10^{-3} \text{ Ci} = 10^{-3} \times 3.70 \times 10^{10} \text{ Bq} = 3.70 \times 10^7 \text{ Bq}$

$$1 \text{ mCi/lb } UF_6 = \frac{3.70 \times 10^7 \text{ Bq}}{0.454 \text{ kg}} = 8.15 \times 10^7 \text{ Bq/kg } UF_6.$$

dominant. At 5% ^{235}U, 80% of the activity is attributable to the ^{234}U content. Alpha activity from uranium presents no hazard as UF_6 is always contained in sealed vessels because of its chemical properties. The chemotoxicity exceeds the radiological for all common enrichments.

The decay products of uranium include nuclides which emit more penetrating beta and gamma radiation. When UF_6 is vaporized from a vessel or transport cylinder these non volatile decay products remain and can concentrate on surfaces. Without the shielding and absorption of the bulk of UF_6, the gamma radiation level will be much higher than for the filled vessel and may be as high as 2 mGy/hour. The highest radiation levels occur immediately after emptying. They then rapidly decay.

The neutron flux arising from the interaction of alpha radiation with fluorine atoms (α,n) (which rises with increasing enrichment) is of minor significance. The gamma activity arising from ^{235}U (186 keV) can be used with appropriate detectors and multichannel analyzers to derive the ^{235}U assay of materials within vessels and cylinders.

2.9. UF_6 FROM IRRADIATED URANIUM

UF_6 produced from irradiated and reprocessed uranium can contain, in addition to ^{234}U, ^{235}U, ^{238}U, significant concentrations of:

- other uranium isotopes, e.g. ^{232}U, ^{233}U, ^{236}U, ^{237}U,
- transuranic nuclides, e.g. ^{237}Np, ^{239}Pu,
- fission product impurities, e.g. ^{106}Ru, ^{99}Tc,
- daughter products of these species, e.g. ^{228}Th, ^{208}Tl.

Since the chemical processes do not affect the isotopic composition of uranium, the ratios existing at reprocessing continue through subsequent stages of conversion to UF_6. An exception is ^{237}U which has a very short half-life (6.75 d) and is a daughter of ^{241}Pu. Removal of Pu and Np can occur during conversion to UF_6 especially during the fluorination stage where the stabilities of PuF_6 and NpF_6 differ from UF_6.

Uranium-234, which occurs naturally in unirradiated uranium, is of great significance to the specific activity of reprocessed uranium. The ^{234}U concentration of uranium is increased during enrichment of ^{235}U (see Section 3.3 below) by larger factors than is ^{235}U. During burnup in the reactor, ^{234}U is consumed at only half the rate of ^{235}U by neutron interactions. As a consequence ^{234}U contributes proportionately more to the specific activity in reprocessed uranium than in the fresh fuel. After re-enrichment, the ^{234}U is most important in calculating the A_2 value for transport and in determining the ALI of the material.

Uranium-236 is of no special safety concern, but the presence of this isotope is a useful indicator of contamination by irradiated materials. Specification for natural UF_6 usually limits this isotope to less than 20 parts per million. This isotope also parasitically absorbs neutrons and is therefore undesirable in nuclear fuel.

The significance of ^{232}U arises from the decay chain through ^{228}Th to the gamma emitting nuclide ^{208}Tl. The chain can be broken by chemical processes such as solvent extraction or volatilization of members of the chain, but as ^{232}U continues to decay, equilibrium is subsequently re-established with over 30% regrowth in one year. As a consequence, operations following reprocessing should take place as rapidly as possible to minimize gamma radiation dose.

The composition of reprocessed uranium will depend upon the reactor type, the burnup, and cooling history, the efficiency of impurity removal in reprocessing and conversion, and the time elapsed since these operations occurred. The conversion of uranium oxide to UF_6 concentrates impurities in the waste stream. In addition, any process in which UF_6 is transferred in the gas phase will concentrate non volatile species in residues. Volatile species such as ^{106}Ru and ^{99}Tc can contribute to activity in process vessels and cylinders and can contaminate effluent streams from wet scrubbing processes. Pu and Np can be volatilized in a flame reactor. Neptunium will volatilize in fluidized beds to a degree while Pu is retained in Ca F_2. As a result, provision should be made to include such species in site regulation and monitoring procedures.

2.10. CRITICALITY

The distinguishing characteristic of a fissile nuclide such as ^{235}U is that it is capable of initiating a self sustaining neutron chain reaction. A fission chain is propagated by neutrons. Since a chain reaction is dependent upon the behaviour of neutrons, fissile materials are handled, packaged and shipped under requirements designed to control neutron behaviour in a manner to ensure subcriticality and, thus, provide criticality safety.

There are three possible fates for a neutron in fissile material: it may encounter a fissile nuclide and induce fission, producing neutrons to continue the chain; it may be absorbed by other materials or by a fissile nuclide without fissioning; it may leak out of the system. Criticality is achieved when there is a balance between neutron production by fission and loss by neutron absorption in and leakage from the fissile material. The three possible outcomes for a neutron are controlled to provide criticality control. The fraction of neutrons leaking is affected by the geometric configuration, both of the individual package and of the spacing between packages. Neutrons leaking from a vessel may enter other similar containers and produce a fission. Neutron interaction can be influenced by package dimensions, which determine the spacing of the fissile material. Neutrons may also be removed from the system by the use of neutron absorbers. Good design embodies a balance of many parameters and assures subcriticality. This goal is accomplished by employing specific limits on ^{235}U enrichment, mass, volume, geometry, moderation and

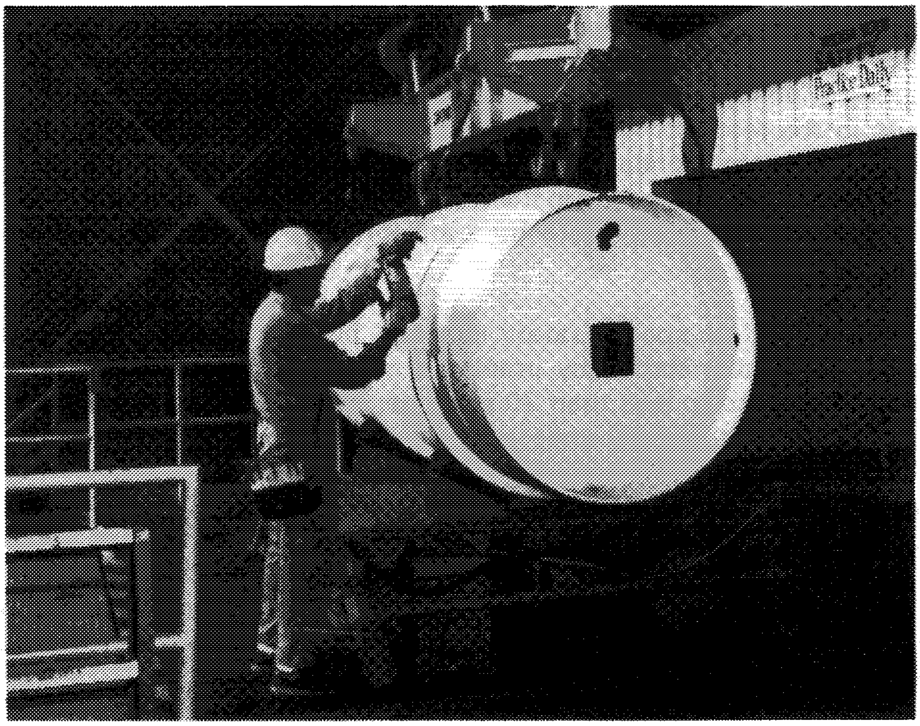

FIG. 2.5. UF_6 handling.

FIG. 2.6. UF_6 handling with crane.

spacing, and, in some instances, utilizing the neutron absorption characteristics of the vessel and cylinder walls.

Figure 2.5 shows a model of a 48 x cylinder which incorporates most of the above nuclear criticality safety limitations. These same limitations, including temperature control to prevent rupture in process operations, are specified throughout this report. The amount of UF_6 which may be contained in an individual vessel or cylinder and the total number of vessels or cylinders accumulated as a group are determined by the nuclear properties of the UF_6 (see Figure 2.6). Spacing of cylinders of enriched UF_6 in transit is assured through the use of IAEA approved packages.

The use of Models 30 and 48 cylinders at ^{235}U enrichments of 5.0% and 4.5% respectively is dependent upon limiting the availability of hydrogen — a neutron moderator. A hydrogen-to-uranium atomic ratio of less than 0.088, which is equivalent to a specification of greater than 99.5% UF_6 (assuming the impurity is hydrogen). This is required by ASTM specifications C787 and C996 (see also Figure 2.7).

The shipment of UF_6 of enrichment greater than 1% but less than 5% ^{235}U requires the use of an approved overpack. For enrichments above 5% ^{235}U, geometric and mass limits are employed as well as overpack protection.

Changes in the quantity, form, arrangement, physical or chemical state, or changes in the packaging could affect the neutron multiplication factor and invalidate the Transport Index[4] of the package. The requirements set forth in the certificate of approval for a

[4] The Transport Index relates to a package, overpack, tank, or freight container which is used to provide control over both nuclear criticality safety and radiation exposure.

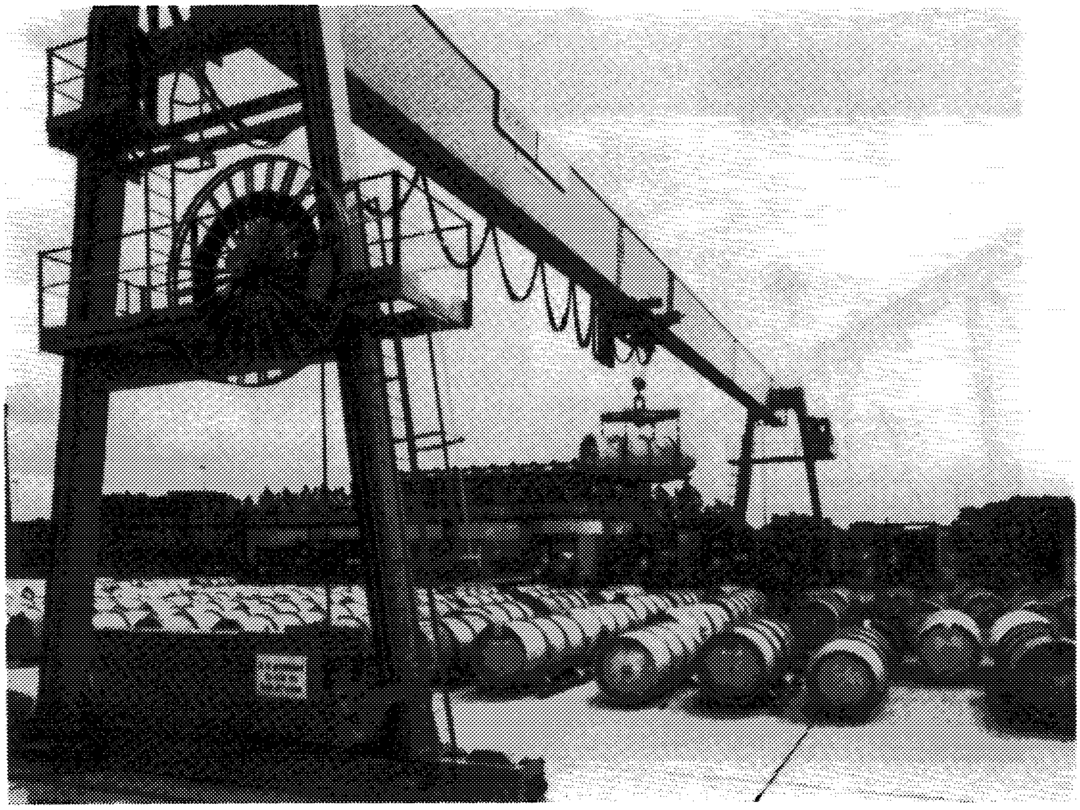

FIG. 2.7. Loading and unloading UF_6 cylinders.

package are necessary to assure safety during transport. The criticality safety assessment performed includes a range of parameters. These parameter ranges should be described in the application for transportation approval.

Chapter 3

PRODUCTION AND HANDLING

3.1. INTRODUCTION

An overview of the sequences of operations involving UF_6 from uranium ore to nuclear fuel showing the main process operations as well as the supporting operations is given below.

Main process operation	Supporting operations for processing of UF_6
Conversion process ($U_3O_8 \rightarrow UF_6$)	UF_6-withdrawal UF_6-sampling and transfer UF_6-cylinder weighing UF_6-storage
Enrichment process ($UF_6 \rightarrow UF_6$-enriched + UF_6-depleted)	UF_6-feeding UF_6-withdrawal UF_6-sampling and transfer UF_6-cylinder weighing UF_6-storage
Reconversion process ($UF_6 \rightarrow UO_2$ or U_3O_8 or UF_4)	UF_6-feeding UF_6-sampling and transfer UF_6-cylinder weighing UF_6-storage

The main process operations — conversion, enrichment and reconversion — are described in Sections 3.2, 3.3 and 3.4 respectively. The supporting operations are described in Section 3.5.

Section 3.6 describes the safety concerns with handling and processing of UF_6 and is relevant to all the three main process operations. In conversion and reconversion, materials other than UF_6 are involved; the safety concerns with regard to those materials are addressed in Section 3.7. The typical appearance of the different uranium products is shown in Figure 3.1. Since conversion, enrichment and reconversion are not carried out at one location, inter-site transportation of UF_6 is unavoidable. Transportation of UF_6 is covered in Chapter 5. Storage of UF_6 may be necessary in support of the process operations at each site. The storage of UF_6 is covered in Chapter 6.

3.2. URANIUM REFINING AND CONVERSION ($U_3O_8 \rightarrow UF_6$)

There are many facilities operating to convert uranium ore concentrate (yellow-cake) to uranium hexafluoride UF_6. The uranium ore concentrate is usually an impure compound of ammonium NH_4, sodium (Na) or magnesium (Mg) diuranate. The various unit operations in the conversion facilities are illustrated in Table 3.1. As can be seen in the flow diagrams, regardless of the process, the common elements are: the conversion of yellow-cake

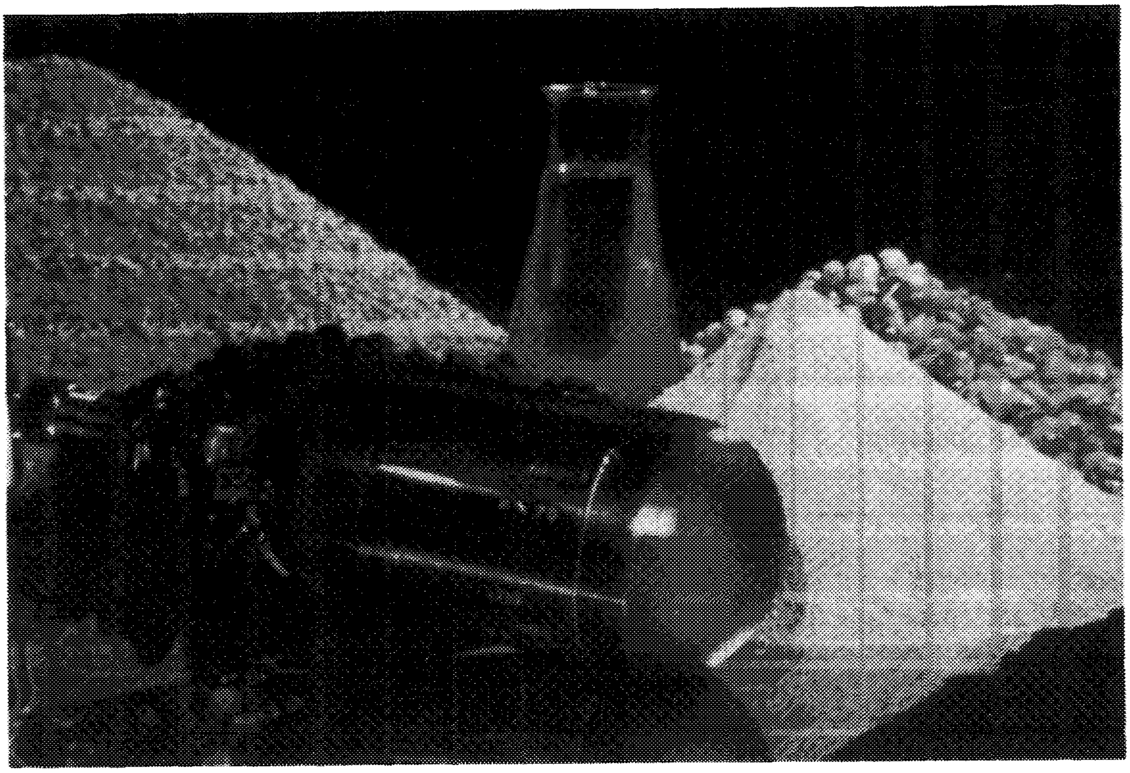

FIG. 3.1. Typical appearance of uranium products.

concentrate to uranium dioxide UO_2, hydrofluorination of UO_2 to uranium tetrafluoride UF_4 and fluorination of UF_4 to uranium hexafluoride UF_6 with elemental fluorine. One process exception is the direct precipitation of UF_4 from aqueous acidic solution.

In the "wet process" the impurities are removed from concentrate using solvent extraction. The concentrate is dissolved in nitric acid to form uranyl nitrate solution and this crude solution is purified using 20–25 vol/% tributyl phosphate in organic diluent chemical such as hexane or kerosene. The process is carried out using pulsed columns or mixer settlers. The purified uranium in the solvent phase is re-extracted or "stripped" with hot water to form a dilute uranyl nitrate solution. Then the "stripped" solvent is treated and recycled to the solvent extraction process again. The aqueous or raffinate waste from the first extraction operation is either treated to recover the nitric acid for recycle to the initial dissolution operation and neutralized for disposal or directly neutralized for disposal. The dilute uranyl nitrate product stream is then concentrated and denitrated to uranium trioxide (UO_3) or precipitated with an alkali. In all cases, the uranium is ultimately reduced to UO_2 using either cracked ammonia or pure hydrogen.

In the "dry-process" the concentrate is first calcined to U_3O_8 and/or reduced to UO_2 in its impure state. The reduction step is usually carried out with hydrogen using fluid bed or rotary kiln reactors. The excess hydrogen gas is filtered or scrubbed prior to being discharged to the atmosphere.

UO_2 is converted to UF_4 with anhydrous hydrofluoric acid either via dry or wet processes. Normal equipment used in the dry process are fluid beds or kilns. In the "wet" process UO_2 is reacted with anhydrous and aqueous hydrofluoric acid mixture to produce UF_4 and then the resultant UF_4 slurry is dried. The off-gas streams from both wet and dry processes are scrubbed before discharge to the atmosphere.

The UF_4 is fed in a dry powder state into either tower or fluidized bed fluorination reactors and reacted with preheated fluorine gas to produce the gaseous UF_6 product. The fluorine used in the production of UF_6 is generated by the electrolysis of anhydrous hydrofluoric acid in potassium bifluoride. Each converter produces fluorine on site. A typical fluorine cell-room consist of the number of cells of the required current to provide the required fluorine production capacity. The actual number and size of cells varies but normally, cells of 6000 to 12 000 amps each are used. Both fluorine and hydrogen are generated during electrolysis. Normally hydrogen is "scrubbed" and flared-off. The rate of fluorine generation is controlled by the demand on the UF_6 reactors.

The product UF_6 in the gaseous state is usually filtered to remove the particulates and condensed as a solid in cold traps. As required, UF_6 is heated to achieve liquefaction and is allowed to drain directly into shipping cylinders where it solidifies. In the process where the concentrate is directly reduced, hydrofluorinated and fluorinated to UF_6, initially produced impure UF_6 is vaporized and fed into distillation columns where fractional distillation removes the remaining impurities. Following purification, UF_6 is collected in a cold trap and then fed directly to shipping cylinders as noted above. After sampling, the cylinder is stored ready for shipment to the various enrichment facilities. All UF_6 produced and shipped should meet a standard feed specification (e.g. ASTM C787) [12].

The waste resulting from the refining and conversion of uranium concentrates to UF_6 are generally common to all facilities. Waste arises from two sources, waste products originating from the concentrates and waste products originating from the process reagents. In general, wastes are handled by treatment and recycle or treatment and disposal. All conversion processes use hydrofluoric acid (HF). Because of the environmental and health impact of this chemical, all effluent streams must be treated to remove the HF and contaminant uranium. In the case of off-gases, HF and uranium removal are achieved with potassium hydroxide (KOH) scrubbing. The scrub liquor is subsequently filtered to remove the precipitated potassium diuranate and then the filtrate is treated with lime to regenerate KOH and to precipitate the fluoride as calcium fluoride (CaF_2). The slurry of calcium fluoride/potassium hydroxide (CaF_2/KOH) is filtered to remove the CaF_2 solids for disposal and the resultant KOH is recycled.

$$KOH + HF \rightarrow KF + H_2O$$

$$14KOH + 2UF_6 \rightarrow K_2U_2O_7 + 12KF + 7H_2O$$

$$2KF + Ca(OH)_2 \rightarrow 2KOH + CaF_2$$

3.3. ENRICHMENT

3.3.1. Introduction

A key step in the nuclear fuel cycle is changing the concentration or assay of the ^{235}U isotope. A higher assay level of ^{235}U than the 0.71% in natural uranium (generally in the range of three to four percent) is required. This is accomplished through enrichment. At present there are two principal processes in commercial use. Gaseous diffusion is the oldest and represents most of the present capacity. The second method is the gas centrifuge process. In both these enrichment processes, enrichment is accomplished by taking advantage of the slight difference in the atomic masses of the ^{235}U and ^{238}U isotopes. Both of these methods require a gaseous form for uranium — hence our interest in UF_6. Because each of the enrichment methods described below use the slight difference in mass between ^{238}U and ^{235}U to drive the process, ^{234}U will be enriched by even larger factors than will be ^{235}U (driven by slightly larger mass differences).

TABLE 3.1. CONVERSION PROCESSES

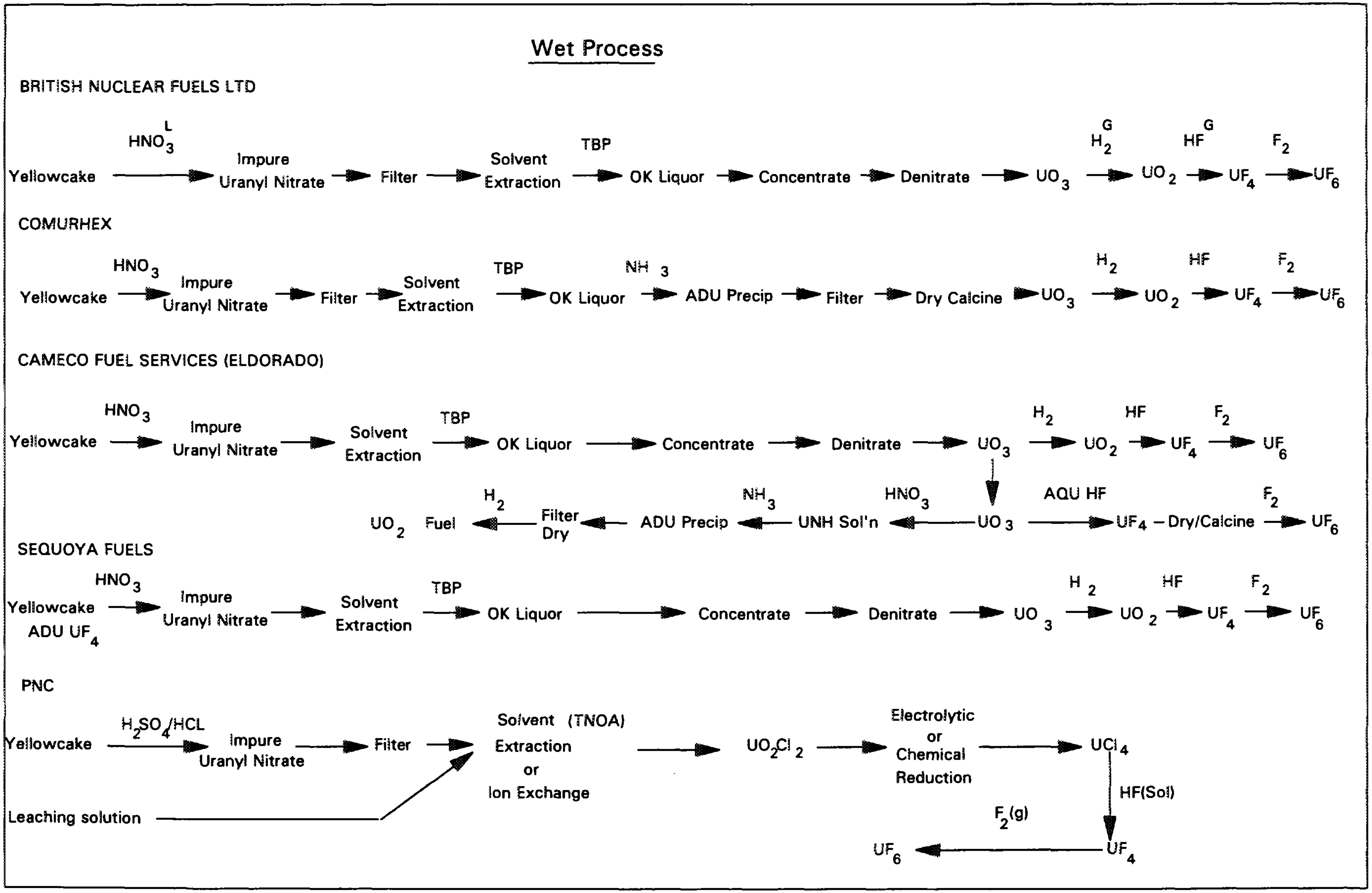

TABLE 3.1. (cont.)

Dry Process

ALLIED SIGNAL

Yellowcake $\xrightarrow{H_2}$ UO_2 $\xrightarrow{HF}$ UF_4 $\xrightarrow{F_2}$ UF_6 → Distillation → UF_6

COMURHEX

Yellowcake ADU → Calcine → UO_3 $\xrightarrow{H_2}$ UO_2 $\xrightarrow{HF}$ UF_4 $\xrightarrow{F_2}$ UF_6 → Distillation → UF_6

FIG. 3.2. Gaseous diffusion stages.

3.3.2. Gaseous diffusion process

In the gaseous diffusion process uranium containing ^{238}U and ^{235}U, is introduced as gaseous uranium hexafluoride and pumped to higher pressure. The chamber containing the UF_6 gas is connected with a similar chamber by barrier tubes — hundreds of millions of uniformly sized, submicroscopic openings per square inch. The gas molecules containing the lighter ^{235}U move slightly faster than those containing ^{238}U. Consequently, the gas diffusing through the barrier tubes is slightly enriched in ^{235}U. The diffused gas, representing about one-half of the stream, is then fed to the next higher stage where the process is repeated. The remaining gas flowing within the chamber is recycled to the next lower stage. Because of the very small amount of separation occurring in one stage, the process must be repeated hundreds of times in a series arrangement called a cascade (Figure 3.2).

A gaseous diffusion stage contains a compressor to pump the UF_6 gas, an electric motor to drive the compressor, a process cooler to remove heat created from gas compression, a process control valve to control pressure, and interconnecting piping. The process can be operated at above or below atmospheric pressure. In addition, a uranium enrichment plant also has: UF_6 feed system, UF_6 withdrawal system, UF_6 cylinder handling, UF_6 cylinder weighing, UF_6 transfer and sampling systems. These supporting operations are described in Section 3.5.

3.3.3. Centrifuge process

The centrifuge process separates isotopes of uranium by making use of the principle of centrifugal force. When gaseous UF_6 is fed into a centrifuge machine which rotates very

FIG. 3.3. View of centrifuges in a cascade hall of an enrichment plant.

rapidly, the lighter molecules containing ^{235}U gather along the central axis of the rotor and the heavier molecules containing ^{238}U move to the outside. The UF_6 gas in which ^{235}U is slightly concentrated is drawn from near the axis and is fed to the next stage of the cascade. The UF_6 stream containing a higher concentration of ^{238}U is removed from the periphery and is fed to the next downstage centrifuge. Since the amount of actual isotope separation accomplished by a single centrifuge machine is small, many stages must operate in a cascade configuration (Figure 3.3). Since the centrifuge itself functions as a pump, a compressor is not necessary to move the gas to the next stage in the cascade. The centrifuge enrichment process operates at sub-atmospheric pressures. Supporting operations are the same as for a gaseous diffusion plant.

3.4. RECONVERSION PROCESSES ($UF_6 \rightarrow UO_2$ or U_3O_8 or UF_4)

3.4.1. Introduction

UF_6 is converted either to UO_2 for fuel fabrication purposes, or to U_3O_8 or UF_4 for long term storage, or to UF_4 for production of uranium metal. These processes have common requirements for handling UF_6. Brief descriptions are given below of the overall operations.

3.4.2. Conversion to UO_2

Enriched UO_2 for fuel fabrication is produced from enriched UF_6 using either aqueous processing routes through precipitation of ammonium diuranate (ADU) or ammonium uranyl

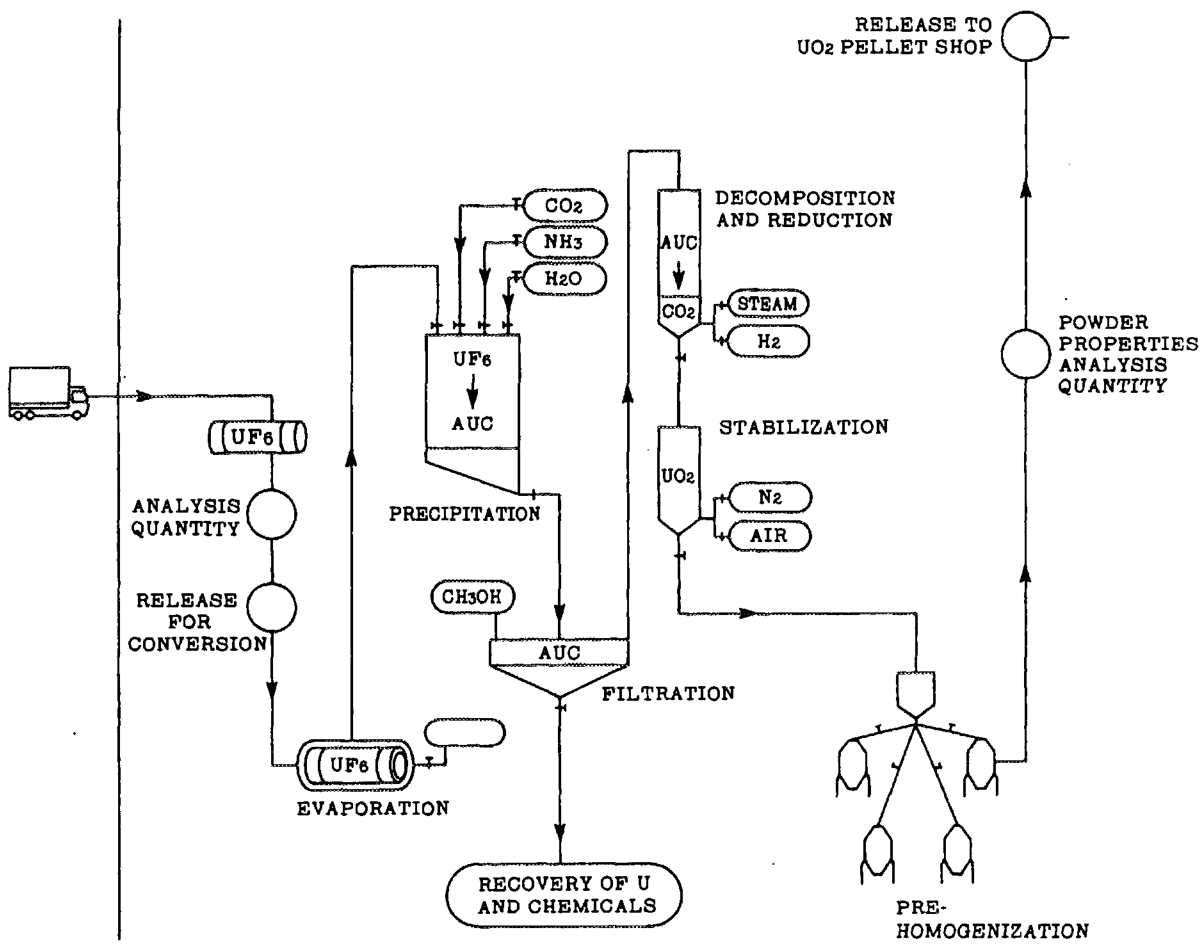

FIG. 3.4. AUC process.

carbonate (AUC) or alternatively through gas phase reactions of UF_6 with steam and hydrogen using so called dry routes.

3.4.2.1. The AUC process

In the AUC conversion process, gaseous UF_6 is fed into a stirred aqueous system at the same time as gaseous CO_2 and NH_3 (see Figure 3.4). The resulting reaction is:

$$UF_6 + 5H_2O + 10NH_3 + 3CO_2 \rightarrow (NH_4)_4\,UO_2\,(CO_3)_3 + 6NH_4F$$

The ammonium uranyl carbonate precipitate is filtered then subsequently decomposed in a fluidized bed reactor to UO_2. Chemical reactions which take place in a fluidized bed are:

$$(NH_4)_4UO_2(CO_3)_3 \rightarrow UO_3 + 4NH_3 + 3CO_2 + 2H_2O$$

$$UO_3 + H_2 \rightarrow UO_2 + H_2O$$

For the vaporization of UF_6 the low enriched feed cylinders are sealed in autoclaves which can be electrically or steam heated (see Figure 3.5). The UF_6 cylinder valve can be remotely driven and the line from autoclave to precipitation vessel is electrically heated. The precipitator is usually a critically safe vessel with a circulating loop. The process gases are fed into this vessel through nozzles within the loop. Off-gases are taken to a jet scrubber then to a spray scrubber and filter system.

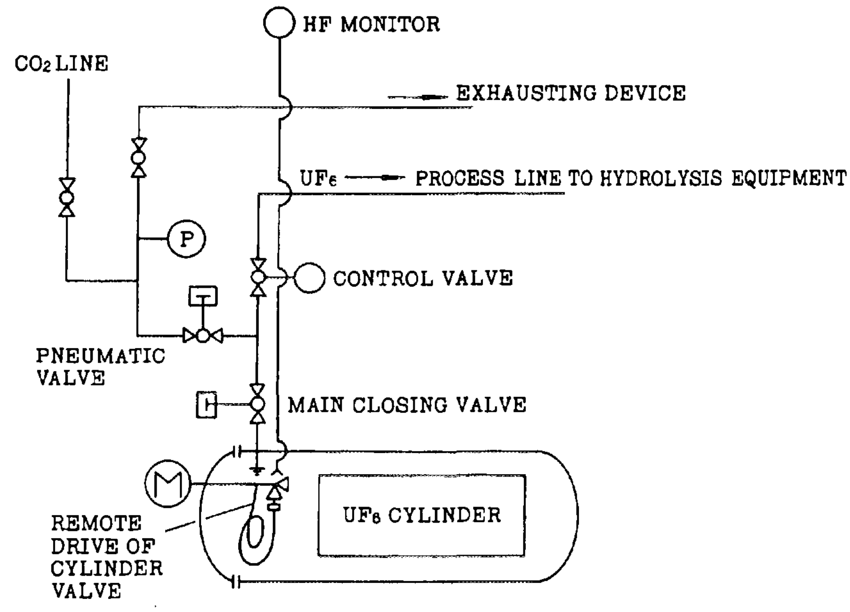

FIG. 3.5. Evaporating equipment.

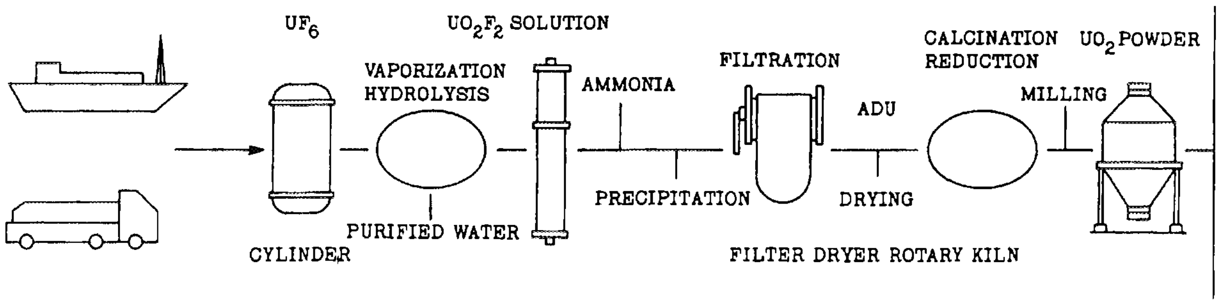

FIG. 3.6. ADU process.

3.4.2.2. The ADU process

In the ADU conversion process (see Figure 3.6), UF_6 is fed into water to produce a solution of uranyl fluoride (UO_2F_2) and dilute hydrofluoric acid. This solution is treated with gaseous or aqueous ammonia to precipitate ammonium diuranate. The ADU is filtered and washed with hot water and then converted to UO_2 using hydrogen or cracked ammonia. Some processes calcine to U_3O_8 before reduction. The overall reactions are:

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

$$2UO_2F_2 + 6NH_4OH \rightarrow (NH_4)_2U_2O_7 + 4NH_4F + 3H_2O$$

$$3(NH_4)_2U_2O_7 \rightarrow 2U_3O_8 + 6NH_3 + 3H_2O + O_2$$

$$(NH_4)_2U_2O_7 \rightarrow 2UO_3 + 2NH_3 + H_2O$$

$$U_3O_8 + 2H_2 \rightarrow 3UO_2 + 2H_2O$$

$$UO_3 + H_2 \rightarrow UO_2 + H_2O$$

The fluoride containing filtrate is treated with a calcium salt to precipitate calcium fluoride (CaF_2) and regenerate ammonia.

$$2NH_4F + Ca(OH)_2 \rightarrow CaF_2 + 2NH_4OH$$

The ammonia is recycled to the process. The CaF_2 may either be stored or used industrially.

In the modified ADU conversion process (see Figure 3.7), hydrolysis of UF_6 in aluminium nitrate solution is followed by TP solvent extraction. The aluminium nitrate solution is provided to complex the fluorine. Uranium, is then precipitated as ADU. Fluorine transferred into raffinate at the solvent extraction step is recovered as aluminium fluoride for industrial reuse. The overall reaction of the modified ADU conversion process is as follows:

$$UF_6 + 2Al(NO_3)_3 + 2H_2O \rightarrow UO_2(NO_3)_2 + 2AlF_3 + 4HNO_3$$

$$UO_2(NO_3)_2 + 2TBP \rightarrow UO_2(NO_3)_2 2TBP$$

$$2UO_2(NO_3)_2 + 6NH_3 + 3H_2O \rightarrow (NH_4)_2U_2O_7 + 3NH_4NO_3$$

3.4.2.3. The IDR process

In the integrated dry route (IDR) process (see Figure 3.8), UF_6 is converted directly to a ceramic grade UO_2 powder by interaction of UF_6 vapour with steam and hydrogen in a rotary Inconel kiln. The kiln is operated with counter current gas-solids flow, UF_6 vapour being fed concurrently with steam into the base of a filter hopper at the gas outlet end of

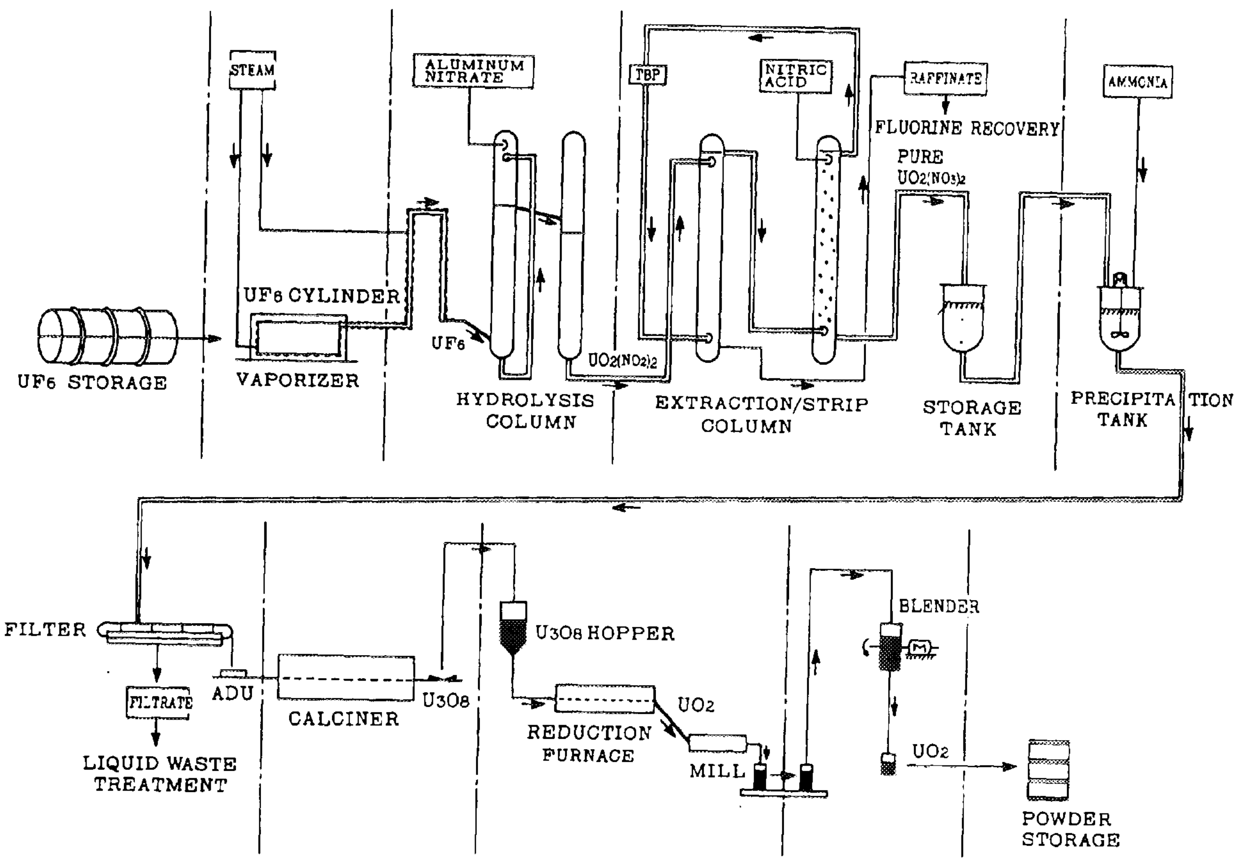

FIG. 3.7. Modified ADU process.

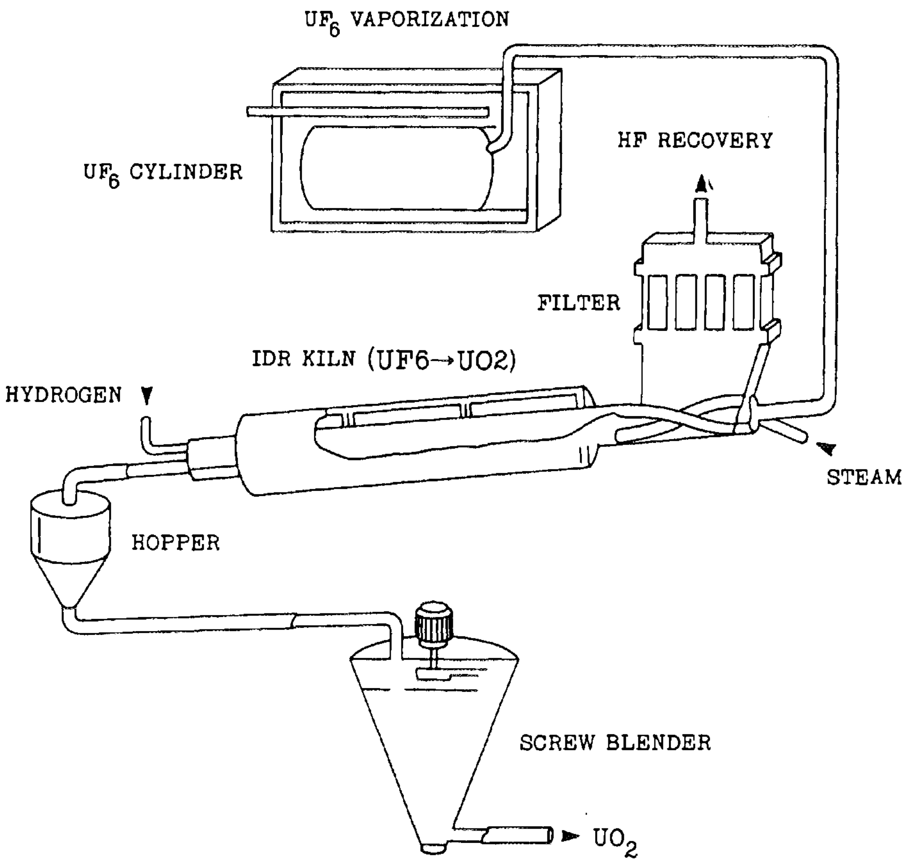

FIG. 3.8. IDR process.

the kiln (see Figure 3.8). The steam reacts with UF_6 to produce an intermediate phase of UO_2F_2 which is passed into the body of the kiln by means of a scroll feeder. The kiln temperature profile is controlled by a number of zone heaters so that the profile can be adjusted to suit the quality of product required. Pyrohydrolysis and reduction is achieved by a hydrogen and steam feed to the powder discharge end of the kiln. Effluent gases are filtered before being discharged to a condensation HF recovery and final scrubber system. The intermediate stage and overall reactions are:

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$
$$UO_2F_2 + H_2O \rightarrow UO_3 + 2HF$$
$$UO_3 + H_2 \rightarrow UO_2 + H_2O$$
$$\overline{UF_6 + 2H_2O + H_2 \rightarrow UO_2 + 6HF}$$

3.4.2.4. The GECO[1] process

In the GECO process (Figure 3.9) vaporized UF_6 is fed into a flame reactor in which U_3O_8 is formed by reaction with oxygen (air) and hydrogen. This U_3O_8 is further reduced in a kiln to produce UO_2. As in the IDR process HF is recovered for reuse. The intermediate stage and overall reactions are:

at flame reactor

$$UF_6 + 3H_2 + O_2 \rightarrow UO_2 + 6HF$$
$$3UO_2 + O_2 \rightarrow U_3O_8$$
$$U_3O_8 + 6HF + 1/2O_2 \rightarrow 3UO_2F_2 + 3H_2O$$

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[1] Registered trademark of the General Electric Company.

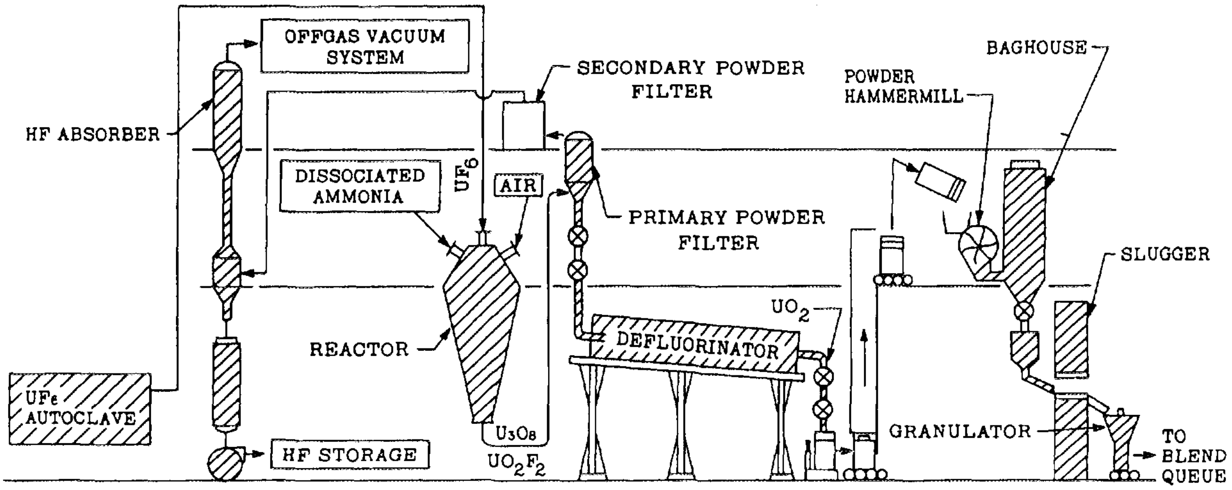

FIG. 3.9. GECO process.*

* *Registered trademark of the General Electric Company.*

at defluorinator

$$UO_2F_2 + H_2 \rightarrow UO_2 + 2HF$$
$$U_3O_8 + 2H_2 \rightarrow 3UO_2 + 2H_2O$$

3.4.2.5. The fluidized bed process

In the fluidized bed process (see Figure 3.10), UF_6 is converted to UO_2 by steam and hydrogen via UO_2F_2 at multiple fluidized bed reactors. HF bearing effluent gases are filtered by means of dry scrubbers with calcium hydroxide and HF in the gas phase is recovered as calcium fluoride. Calcium fluoride is either stored or reused. The intermediate stage and overall reactions are:

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$
$$UO_2F_2 + H_2 \rightarrow UO_2 + 2HF$$

3.4.3. Reconversion to U_3O_8

The dry route processes to UO_2 can also be used with changed operational parameters to produce U_3O_8 from UF_6. This is most useful as a form to store depleted uranium arising from the enrichment process. This U_3O_8 after mechanical densification can be stored in stainless steel containers for long times.

3.4.4. Reconversion to UF_4

Reduction of uranium hexafluoride (UF_6) to uranium tetrafluoride (UF_4) can be performed by reacting UF_6 with hydrogen at elevated temperatures in a monel reactor.

$$UF_6(g) + H_2(g) \rightarrow UF_4(g) + 2HF(g)$$

UF_6 cylinders are placed in temperature controlled heating cabinets such as autoclaves to provide a controlled vaporized UF_6 feed to a surge vessel ahead of the reduction reactors. Nitrogen gas is used to purge cylinder discharge lines and reactor feed lines. Bulk hydrogen (H_2) is fed to each cylindrical reactor and mixed with UF_6 in a conical section designed to minimize slag build-up on the reactor walls. A reactor temperature profile of

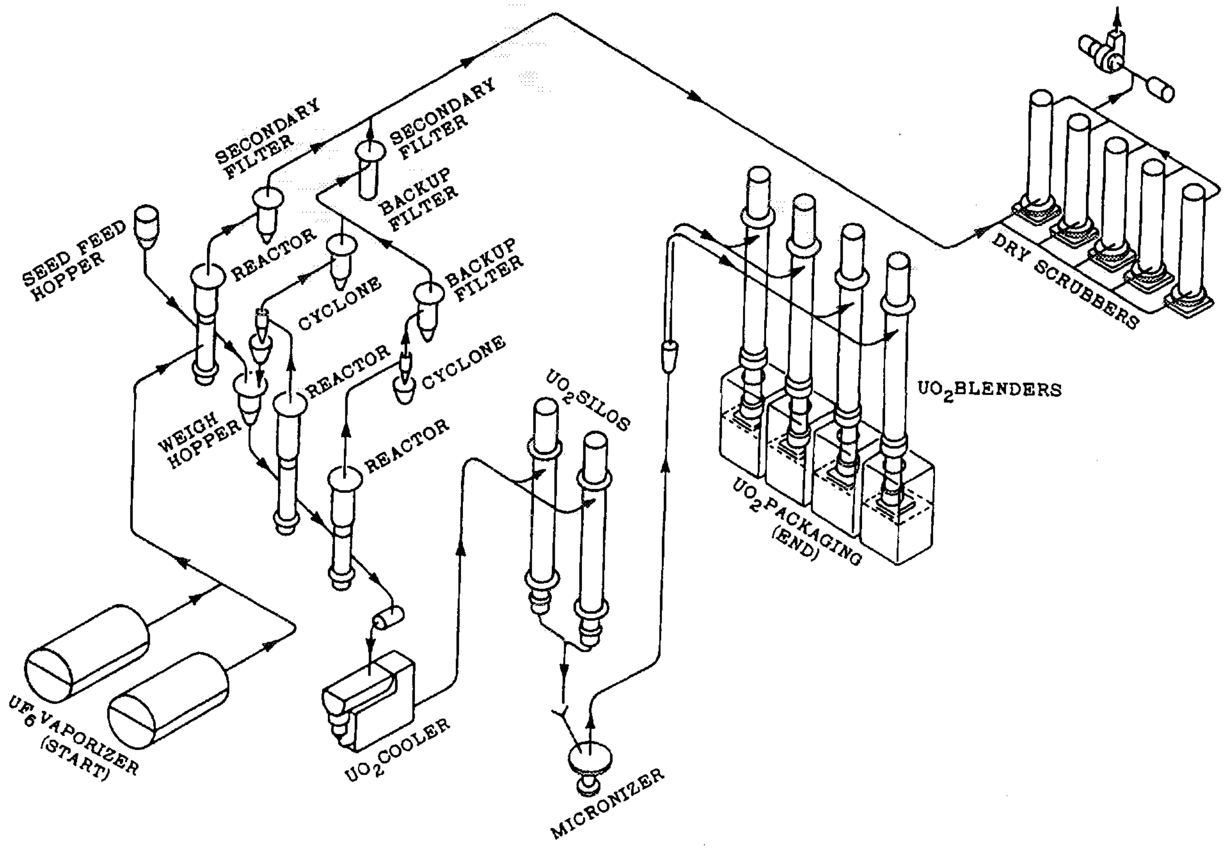

FIG. 3.10. Fluidized bed process.

650°C top–480°C bottom is maintained by electrical clam shell zone heaters. Compressed air is supplied to each zone for rapid cool-down or shutdown of the reactors. The UF_4 and gaseous reaction products pass from the bottom of the reactor to a screw-type cooling conveyor. The UF_4 discharges from the cooling conveyor to a pulverizer, through a seal hopper, product surge hopper and into product shipping drums. Improper operation of the $UF_6 + H_2 \rightarrow UF_4 + 2HF$ process may result in an excessive accumulation of UF_x, where $4 < x \leq 5$, which deposits on the system walls. This may require mechanical equipment such as a jack hammer for removal; radioactive dust may be generated during removal.

The off-gas produced in the reduction reactor (consisting of anhydrous hydrofluoric acid, hydrogen, nitrogen, trace of UF_6 and fine particles of UF_4) pass through the cooling conveyor with the UF_4 and then to primary and secondary sintered metal filters that separate UF_4 particulates from the off-gas stream. Before entering the hydrofluoric acid recovery circuit, the off-gas passes through activated charcoal chemical traps to remove any residual UF_6. The off-gas stream from the chemical traps containing HF, N_2 and H_2 is passed through a circuit consisting of a pre-cooler, a partial condenser and finally a total condenser to remove the HF. The HF is collected in storage tanks and may be recycled to a UF_6 conversion plant. The H_2 and N_2 off-gas stream from this circuit is discharged to atmosphere via a mist eliminator and a neutralization scrubber. As can be noted, the chemical components and equipment are similar to those used for the conversion of concentrate to UF_6.

3.5. SUPPORTING OPERATIONS

The following sections describe the operations that are performed in support of the main process operations.

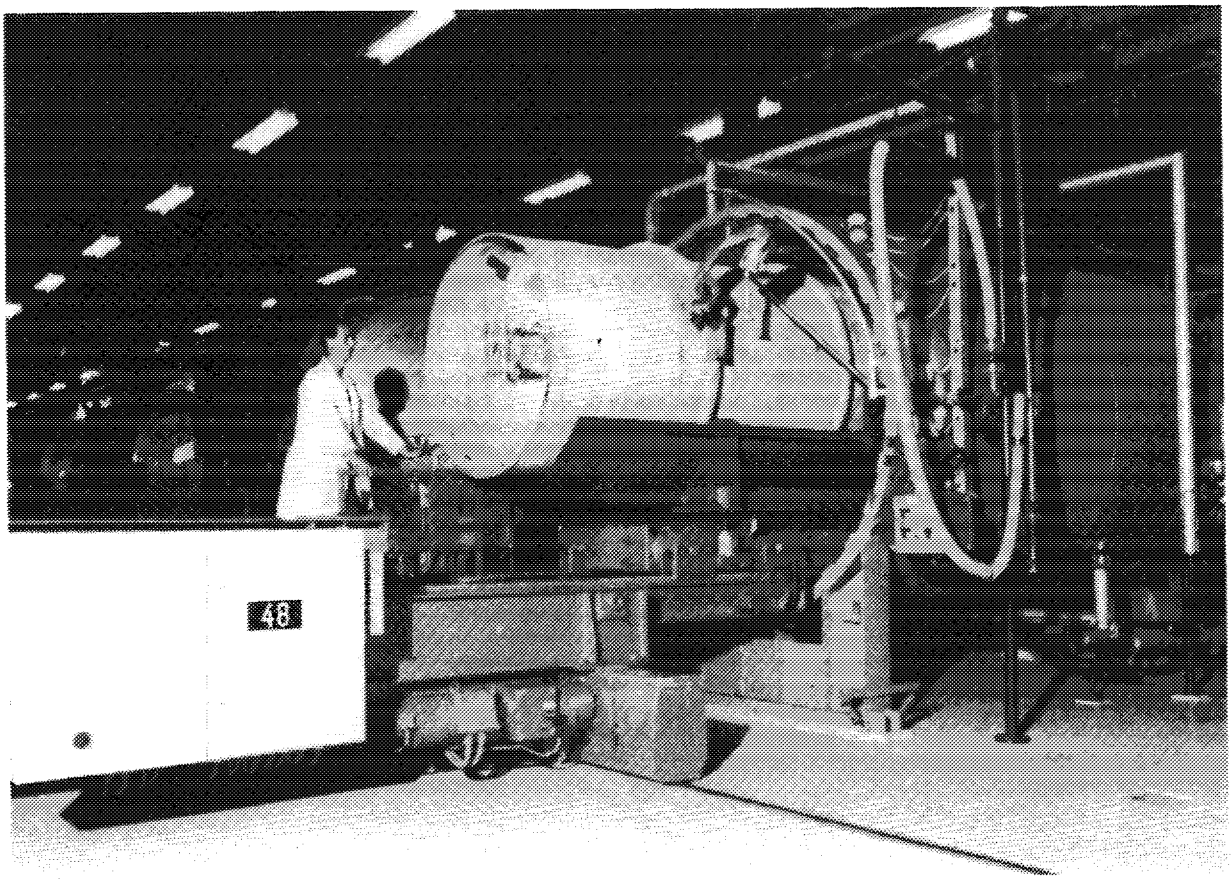

FIG. 3.11. Autoclaves being loaded with a 48 in. cylinder for heating.

3.5.1. UF_6 feeding

UF_6 can be removed from cylinders as a gas by using several methods. These include heating the cylinder with steam or hot air or by evacuation to a low pressure with a pump. Heating the cylinders with steam or hot air causes the solid UF_6 to liquify in order to create sufficient gasflow to the enrichment cascades or to the reconversion plant systems. Figure 3.11 shows feed station autoclaves. Autoclaves can be used to provide for secondary containment around the UF_6 cylinder.

3.5.2. UF_6 withdrawal

UF_6 withdrawal from the conversion process into the shipping cylinders is carried out by draining the liquid UF_6 from heated traps or feeding the UF_6 to the cylinder in gaseous form for direct solidification. From the enrichment process UF_6 may be removed using compressors or desublimer stations. Compressors increase the pressure to a point where the UF_6 gas can be transformed into a liquid and then drained into a receiving cylinder at a filling station. Alternatively, the UF_6 gas can be pumped directly into a receiving cylinder where it is desublimed. Desublimer stations utilize cold traps that can be filled and emptied by cooling and heating. The emptying of a full desublimer into a receiving cylinder at the withdrawal station can be done in the liquid or in the gaseous phase. Desublimer stations are operated by a specific sequence of valving. See Figure 3.12.

3.5.3. UF_6 cylinder handling

Movement of UF_6 cylinders within a plant site is a necessary operation supporting several phases of main process operations. Both empty and full cylinders have to be

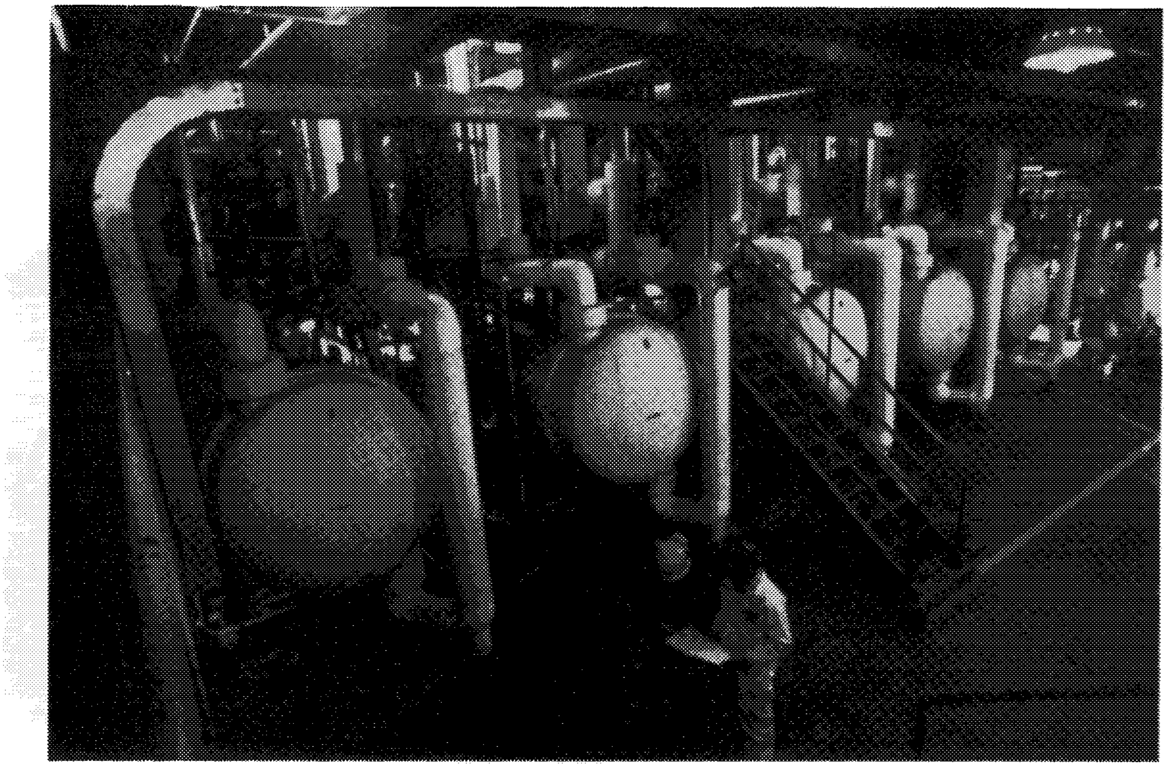

FIG. 3.12. Cold traps.

handled. Basic rules for handling heavy loads have to be applied to avoid damage to cylinders and equipment (see Figure 3.13). Cylinder movements should be carried out when the UF_6 is in the solid phase. The movement of cylinders containing liquid UF_6 is a significantly more hazardous operation and should be avoided when possible (see para. 3.6.5 "Liquid UF_6 handling"). Cranes and mobile equipment used in handling cylinders, together with the lifting fixtures and other hardware must be properly inspected and maintained (see Figures 3.14 and 3.15). UF_6 cylinder handling must be performed by qualified personnel.

3.5.4. UF_6 Cylinder weighing

Accurate weighing of UF_6 cylinders is important when handling and processing UF_6. During filling operations the cylinder weight should be frequently monitored to avoid overfilling. After the filling operation the final cylinder weight should be determined using an approved scale or weighing bridge. A similar weight verification should be carried out upon receipt of UF_6 cylinders before they are heated. Detailed examples of weighing programmes are given in ORO[2] 651 [13]. Personnel performing weighing operations should be qualified (see Figure 3.16).

3.5.5. Transferring of UF_6 from cylinder to cylinder

Uranium enrichment operations often require the transfer of UF_6 from one cylinder directly to another. Transfer of UF_6 as a liquid can be accomplished by heating the parent cylinder with steam or hot air until the entire contents are a homogenized liquid. The UF_6 is then transferred through piping by gravity to an empty evacuated receiving cylinder. This material can be liquid sampled either before or during this transfer operation. It is also

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[2] ORO refers to an Oak Ridge Operations document.

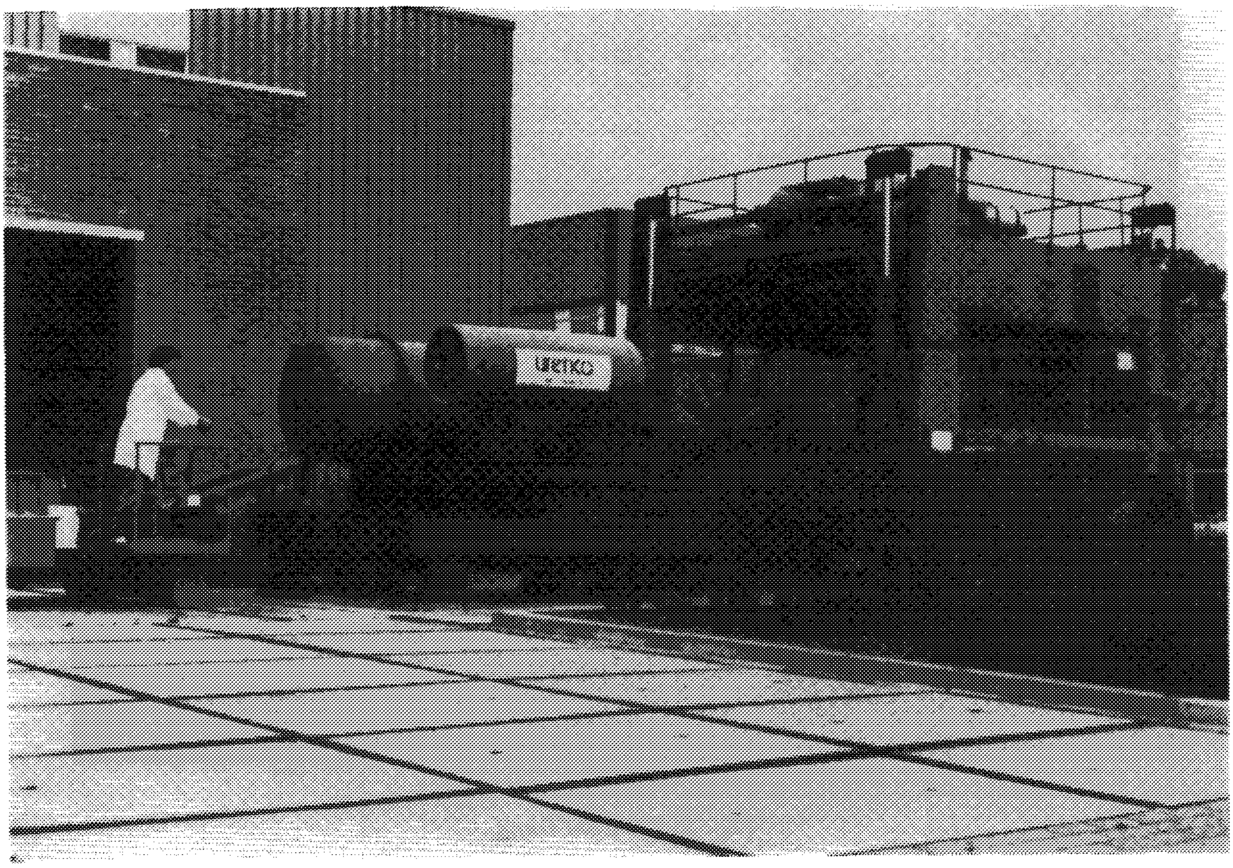

FIG. 3.13. Straddle carrier for on-site cylinder transport.

FIG. 3.14. UF_6 cylinder handling activity.

FIG. 3.15. UF_6 cylinder handling equipment.

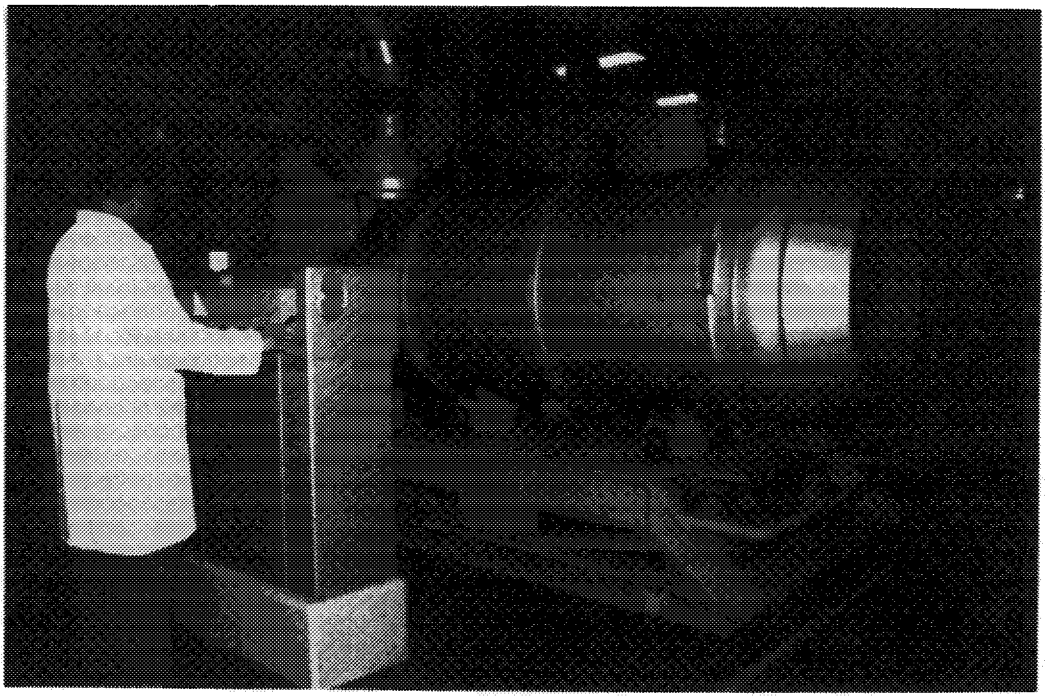

FIG. 3.16. UF_6 cylinder weighing operations.

possible to blend assays of ^{235}U from multiple parent cylinders in a transfer operation to achieve a particular assay level for a future use of customer order.

Transfer of UF_6 as a gas can also be accomplished by removal of UF_6 from the parent cylinder as described in Section 3.5.1 and then the UF_6 collected in a receiving cylinder by either one of two methods. The first method is by direct routing of the gas into a receiving cylinder which is being cooled. The receiving cylinder serves as a cold trap for either liquefaction or desublimation of the UF_6. The second method employs the use of a pump to increase the UF_6 pressure to the condensation point and then the UF_6 is drained as a liquid into the receiving cylinder or by direct desublimation in the receiving cylinder. This second method of removal of UF_6 as a gas from the parent cylinder can be at an ambient or elevated temperature. The contents of cylinders that cannot be safely heated can also be transferred as a gas without heating by using the pump. This procedure may be used in instances where cylinders are damaged or overfilled.

3.5.6. Sampling UF_6 from cylinder

Sampling of UF_6 from a cylinder can be done by removal of the sample from the liquid or gas phases. Procedures for liquid UF_6 sampling require the cylinder to be heated so its contents are totally homogenized. Heating is performed by either steam or hot air in a similar manner as described in Section 3.5.1. After homogenization, the cylinder position is changed to shift the cylinder valve below the liquid level so a small amount of UF_6 can be pored into a sample container and solidified. Figure 3.17 shows autoclaves for homogenizing 30 inch cylinders in tipped position for liquid sampling. Methods of changing the position of the cylinder containing liquid UF_6 vary depending on equipment available and procedures. Cylinders may be tipped slightly by elevating the plug end of the cylinder causing the liquid level to move above the cylinder valve or by actually rotating the cylinder to change the end valve position from the 12 o'clock point to a point below the liquid level. This is normally the 3 o'clock position. A sample taken from the homogenized liquid phase can be used for assay and impurity analysis (see Figure 3.18).

Gas phase samples can be removed from a cylinder at ambient temperature by connecting the valve to a small sample container. The gas sample can be solidified by

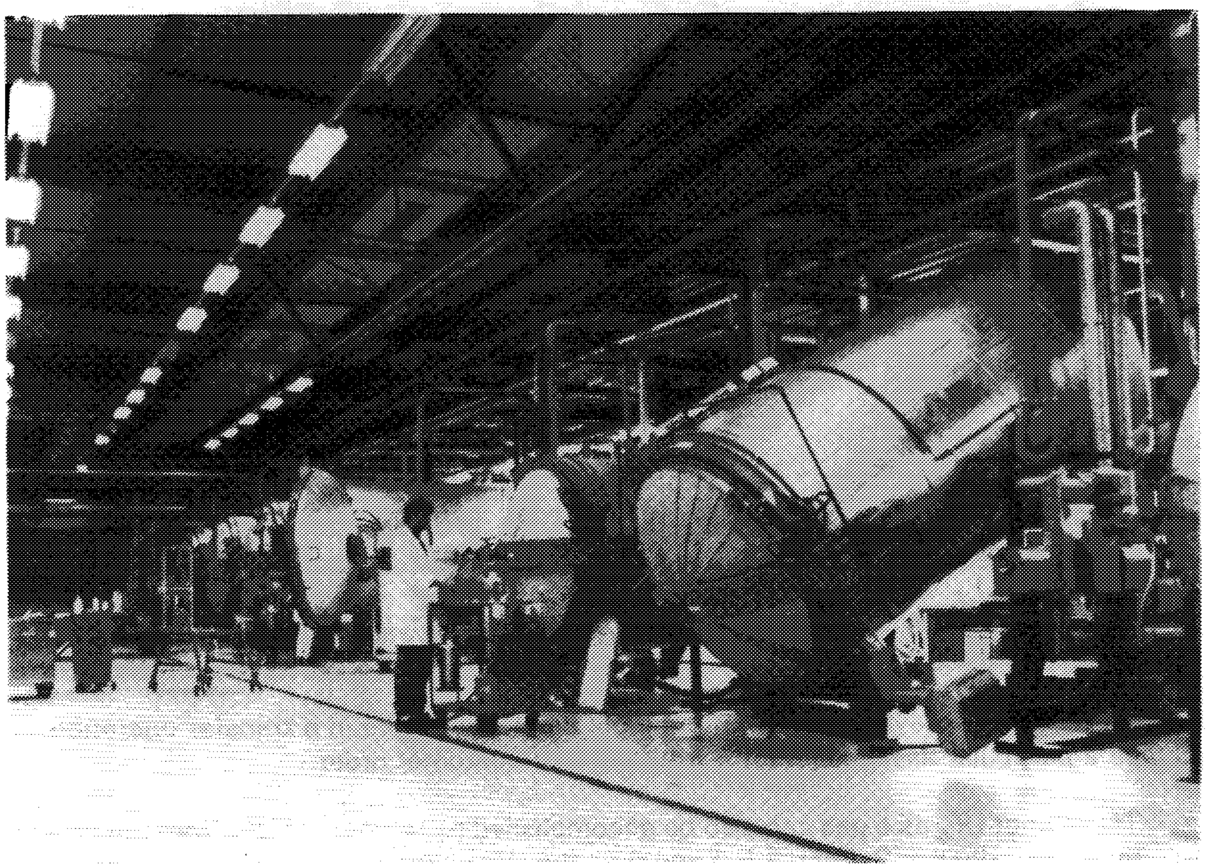

FIG. 3.17. UF_6 liquid sampling.

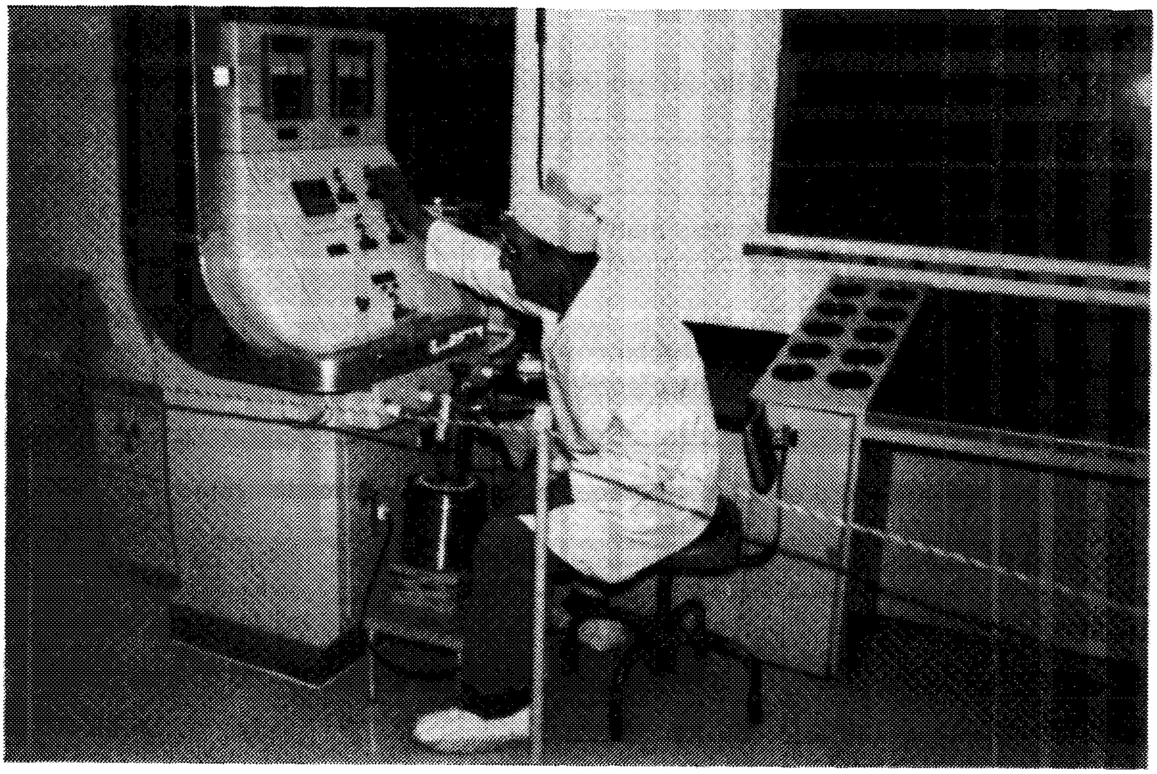

FIG. 3.18. UF_6 sampling analysis.

using either ice water or liquid nitrogen. This type of sample can only be used for quick checks of ^{235}U assay or to determine concentration levels of contaminants in the gas phase of the cylinder.

3.6. SAFETY CONCERNS WHEN HANDLING AND PROCESSING UF_6

3.6.1. General

There are many safety concerns that must be recognized and properly addressed to provide a high level of both personnel safety and protection of the environment. It is difficult to cover adequately all these concerns in detail in this document. The design, handling and treatment of UF_6 cylinders is extensively covered in documents such as ORO 651 [13], ANSI N 14.1 [9], ISO 7195 [14], IAEA-TECDOC-423 [1] and others. Such references are used in order to obtain the information to develop procedures to be followed for safe UF_6 handling operations. The following sections address several of the more significant safety concerns and recommended safety practices in UF_6 processing operations.

3.6.2. Physical state and pressure of UF_6 in process plant operations

The pressure and physical state of the UF_6 is of importance for the determination of the safety measures and procedures required. Leaks in process systems containing UF_6 at or above atmospheric pressures will result in an immediate release of UF_6, while leaks in a UF_6 process system at or below atmospheric pressure will result in a leakage of ambient air into the process system, followed by a delayed slow release of UF_6 reaction products. Systems below 1.5 atmospheres pressure can contain only solid and gaseous UF_6. Systems above 1.5 atmospheres pressure can contain any of the three physical states of UF_6. The pressure and physical states of UF_6 determine the potential hazard.

3.6.3. Categorization of building areas

Facility building areas can be categorized based on the following characteristics:

Characteristics	Category
Building areas where process plant contains UF_6 at *above atmospheric* pressures	Type I area
Building areas where process plant contains UF_6 at *below atmospheric* pressure	Type II area

Each typical area category should be given specific safety consideration.

3.6.4. Specific safety consideration for area categories

Type I areas

System failures (leaks) in Type I areas immediately result in release of UF_6 and consequently cause airborne and surface contamination. UF_6 release detector systems should be provided in these areas. Such detector systems should actuate alarms locally and in the control room. Where required, automatic systems should be activated to isolate parts of the facility affected to permit later clean-up of contaminated ventilation outlet air. By cleaning the ventilation air while maintaining a negative air pressure inside the building section, spread of contamination to the environment can be reduced or avoided. Local exhaust provision, e.g. fume extraction hoods should be available during operations when UF_6 plant systems have to be opened — for example after disconnection of UF_6 cylinders. When necessary, operating personnel should wear respiratory equipment. Appropriate protective clothing has to be worn for routine operations to minimize the spread of contamination. Personnel working in Type I area should have defined escape routes and training for emergency situations. An example is a hand rail installed to serve as a guide to direct personnel out of the immediate release area. In the case of cab-operated cranes in Type I areas respiratory masks and a means to egress should be provided. It should be possible to isolate drain and sewer systems from other general sewer systems. Facilities to check for possible contamination of waste water before disposal, should be available.

Type II areas

Safety measures like monitoring for UF_6 release are less relevant in Type II areas. The primary result of a UF_6 system failure will be an inleakage of air. No immediate releases of UF_6 are to be expected. Nevertheless, it is necessary to apply contamination control measures when disconnecting plant components. It is necessary that the process system is adequately evacuated and purged before opening. Exhaust provisions are used to protect workers against fumes and contamination when process systems are opened. The exhausted air has to be cleaned before release to the environment.

3.6.5. Liquid UF_6 handling

Liquid UF_6 has the greatest release potential, because the vapour pressure is above atmospheric and the UF_6 is at an elevated temperature ($>64°C$). When a system containing liquid UF_6 is breached and the pressure falls below 1.5 atmospheres, the liquid UF_6 immediately converts to the solid and vapour states. Because of the high transformation energy available, the solid and vaporized UF_6 will be spread considerable since the spray

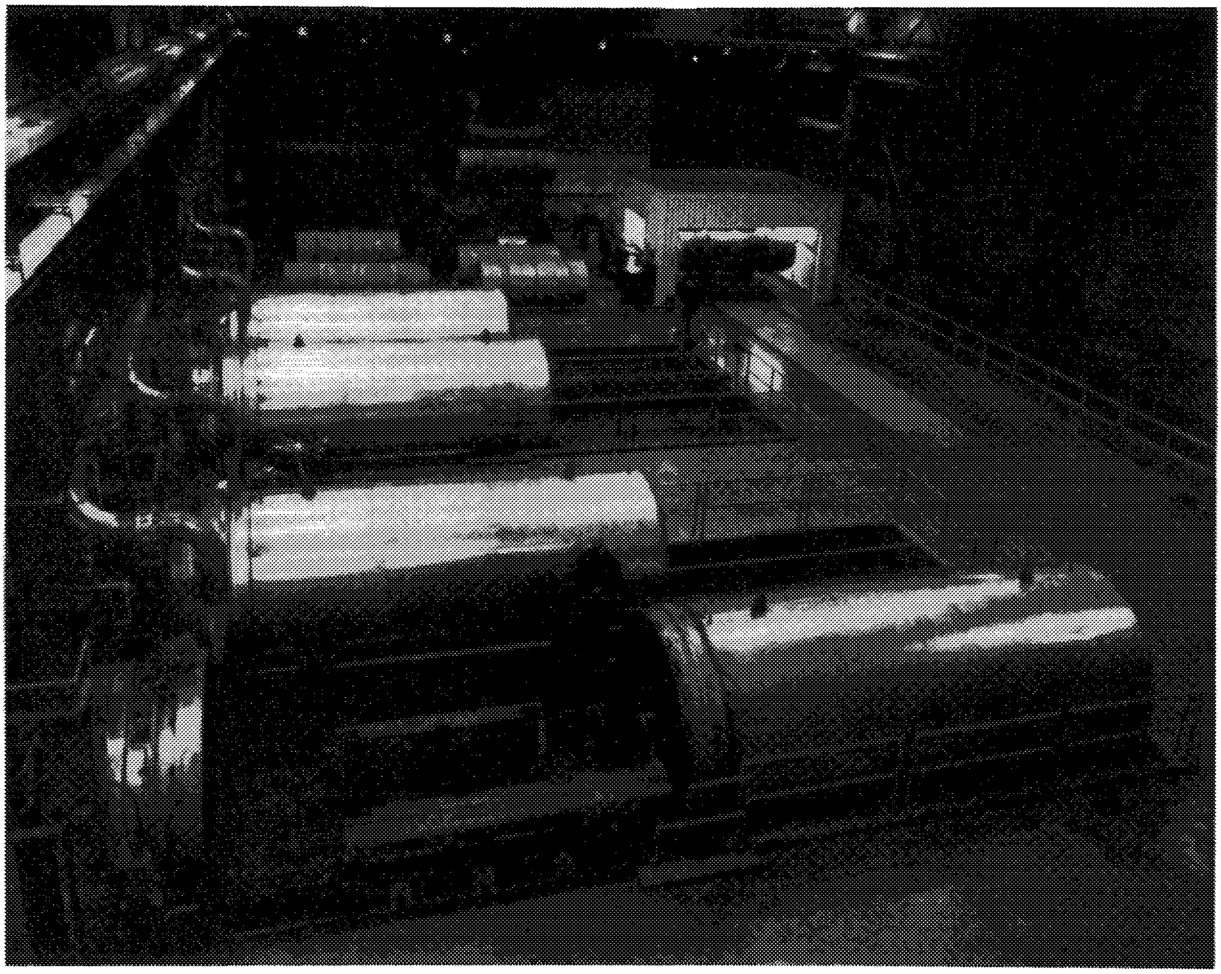

FIG. 3.19. Autoclave systems for homogenizing UF_6.

of solid particulates will be driven in all directions, unimpeded by a structure. All areas where liquid UF_6 operations are carried out are categorized as Type I and all the relevant safety considerations apply. It is recognized that the number of operations and quantity of liquid UF_6 that must be handled is, in most cases, determined by design of a facility and individual site operating procedures. New facilities design should eliminate the movement of liquid UF_6 when possible. Because of the high risk and the consequences of a system failure, liquid UF_6 handling operations should be avoided or actions taken to minimize risk. Special care should be taken when moving cylinders containing liquid UF_6 (especially with partial fillings), because surging of the liquid may result in cylinder tipping. Both lift heights and travel distances should be minimized. Systems containing liquid UF_6 must be designed to permit quick isolation of minimum volumes to reduce the quantity of liquid UF_6 released. Quick automatic operating type isolation valves are desirable in most applications. Figure 3.19 shows sampling and transfer autoclaves where liquid UF_6 is taken from cylinders. All personnel performing liquid UF_6 handling operations must receive adequate periodic training and be fully qualified. Training completion is to be documented.

3.6.6. UF_6 cylinders

UF_6 cylinders together with their valves, plugs and valve guards have to be manufactured, maintained and, if necessary, repaired following the appropriate national and international standards, e.g. ANSI N 14.1 [9], ISO 7195 [14] and ORO 651 [13]. Examples of UF_6 cylinders are given in Table 3.2. Quality assurance activities should be set up to

TABLE 3.2. EXAMPLES OF UF_6 CYLINDER DATA

Model number	Nominal diameter		Material of construction	Minimum volume		Approximate[a] tare weight		Maximum enrichment (wt% ^{235}U)	Maximum fill limit	
	(mm)	(in)		(m^3)	(ft^3)	(kg)	(lb)		(kg)	(lb)
1S	40	1.6	Nickel	.00015	0.0053	0.79	1.75	100.0	0.45	1.0
2S	90	3.5	Nickel[b]	.00072	0.0256	1.91	4.2	100.0	2.22	4.9
5A	130	5	Nickel[b]	.00804	0.284	25	55	100.0	24.95	55
5B	130	5	Nickel	.00804	0.284	25	55	100.0	24.95	55
8A	205	8	Nickel[b]	.03735	1.319	55	120	12.5	116	256
12A	305	12	Nickel	.06740	2.380	84	185	5.0	209	460
12B	305	12	Nickel[b]	.06740	2.380	84	185	5.0	209	460
30B	700	28	Steel	.73600	26.000	635	1400	5.0	2275	5020
48A	1220	48	Steel	3.08000	108.9001	2041	4500	4.5	9540	21030
48X	1220	48	Steel	3.08000	08.900	2041	4500	4.5	9540	21030
48F	1220	48	Steel	3.96000	140.000	2360	5200	4.5	12260	27030
48Y	1220	48	Steel	4.04000	142.700	2360	5200	4.5	12500	27560
48T	1220	48	Steel	3.04000	107.200	1111	2450	1.0	9390	20700
48O	1220	48	Steel	3.82000	135.000	1202	2650	1.0	11825	26070
48G	1220	48	Steel	3.96000	139.000	1202	2650	1.0	12175	26840

Note 1: Minimum volume and maximum fill limit values based on cylinder designs and water weight determinations made in the English system of measurements. The metric equivalents are approximate.

Note 2: Data are taken from original sources but limiting or qualifying notes have been omitted. The information should not be used without reference to the latest documents (ORO-651 Rev.5 and ANSI-N.14.1).

[a] Without valve protector.

[b] Or nickel-copper alloy.

ensure compliance in manufacture and provide for documentation of inspections, maintenance and repairs. Cleanliness of UF_6 cylinders is of serious concern to the nuclear industry, since the reaction of UF_6 with hydrocarbon oils and some other impurities, even in small quantities, is quite vigorous and can result in explosions. Also the purity of the UF_6 can be appreciably affected, which would create quality problems. Periodic cylinder cleaning therefore has to be carried out with great care. Evacuation of air from cylinders should not be attempted with oil vacuum pumps which have no provisions to prevent backflow of oil into the cylinder. Prior to each operational use, cylinders should be carefully inspected in order to ensure that all requirements for safe use as specified in ANSI, ISO and ORO have been met. Rejected cylinders should be clearly identified by a uniform method of weather resistant and durable markings or tags indicating the reason for rejection. Replacement of defective valves on cylinders containing UF_6 should be carried out following approved procedures based on guidelines in ORO 651 [13]. Valve rebuilding and valve testing procedures should be in compliance with ANSI.N-14.1 [9] and ORO 651 [13].

All information on UF_6 cylinders relating to safe limits for filling, storage, shipping and heating should be kept readily available for engineering and operating personnel. Relevant data should be incorporated into specific operating procedures and not be left open for interpretation. Any time new ANSI N-14.1 [9], ORO 651 [13] or ISO-revisions are issued, procedures should be updated. Each facility should keep records of the UF_6 cylinder inventory at all times.

3.6.7. Cylinder filling

For cylinder filling operations the correct UF_6 cylinder must be selected based upon the ^{235}U enrichment and planned further use of the cylinder, i.e. storage or inter site transportation. Cylinders positioned in filling stations should have means to prevent movements while connected to the process plant. Such interlocks can be electrical and/or mechanical. During sampling and liquid transfer operations the hazard of using open flame torches to prevent valve plugging should be recognized. The use of such torches or other uncontrolled heat sources should be eliminated and replaced by temperature controlled devices.

Cylinder weights should be carefully monitored during filling operations to avoid overfilling. Cylinders that are accidentally overfilled should be clearly identified by weather resistant and durable markings or tags. An overfilled cylinder should have the excess UF_6 removed as soon as possible following approved procedures (see also para. 3.5.5 "Transferring of UF_6 from cylinder to cylinder"). This operation should be conducted without heating (if possible) to avoid the possibility of rupture. If possible, overfilled cylinders should not be removed from a facility until the overfilled condition has been corrected.

3.6.8. Cylinder heating

Before cylinders are heated, they should be inspected and both the weight of the UF_6 and the internal cylinder pressure should be verified. Both values must be within safe limits. Heating of cylinders which are overfilled may result in rupture of the cylinder, and release of the UF_6 as a superheated liquid. Heating of cylinders shall only be performed by controlled heat sources. Temperatures should never exceed the cylinder design temperature. Localized heating of cylinders should never be practised because of the associated rupture hazard. During heating, the cylinder valve shall be open and cylinder pressure will be monitored. UF_6 cylinder heating facilities should have the capability of containing UF_6 releases within a secondary containment; they should be built as autoclaves (see Figure 3.20). If this capability does not exist, then assessments should be completed on probable UF_6 release accident scenarios to identify consequences to personnel and environment.

3.6.9. Plant components and connecting lines

Fixed and flexible connecting lines (such as "pig tails") should be designed, fabricated and inspected to accepted standards. Connecting lines must be inspected by qualified personnel before each use (see Figure 3.21). Upon installation of plant components and connecting lines, leak testing and functional testing should be carried out. Depending on temperature and pressure of the UF_6 contained in process lines, it may be necessary to

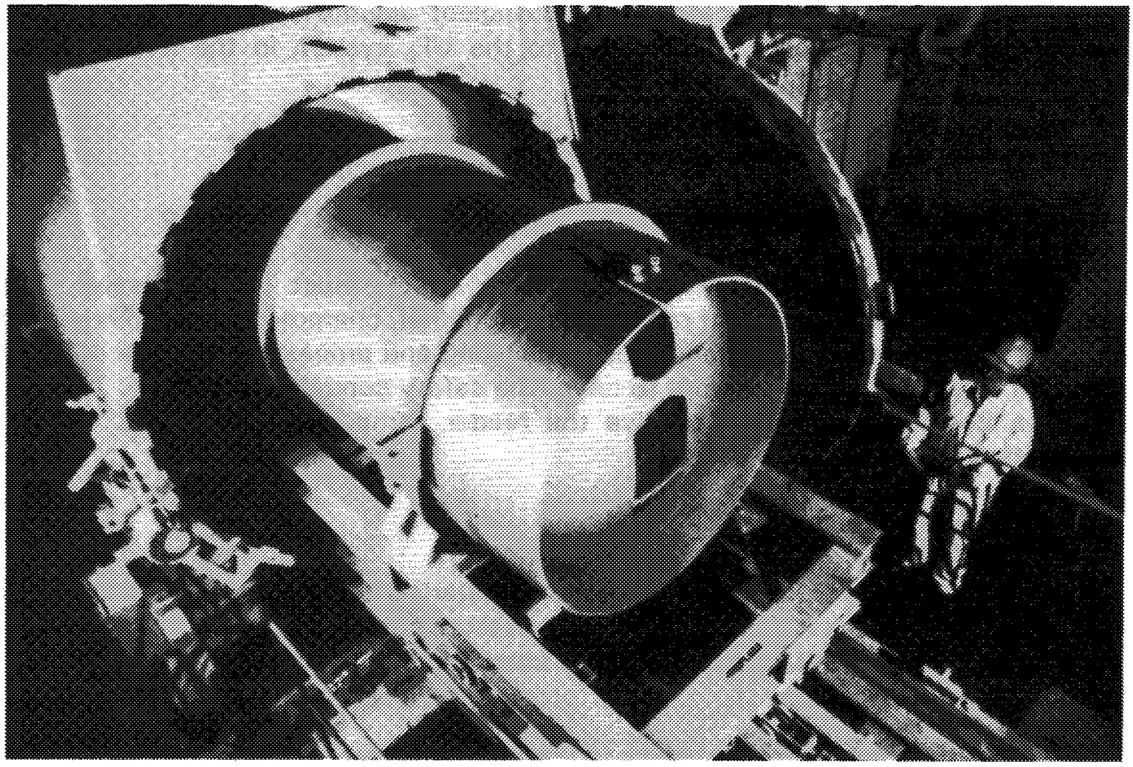

FIG. 3.20. Cylinder heating.

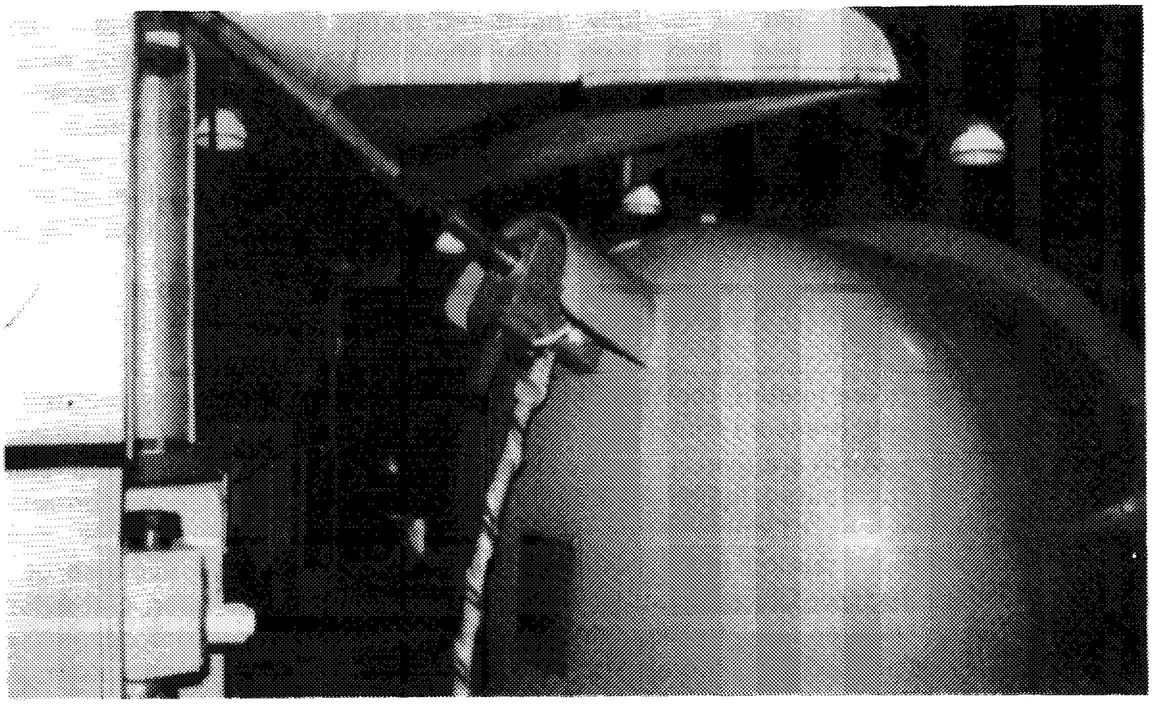

FIG. 3.21. UF_6 cylinder connected to heated pigtail.

apply heat tracing to avoid unwanted liquefaction and/or solidification of UF_6. Whenever possible trace heaters should be designed to be self limiting rather than depending upon a control device. Uncontrolled localized heat sources, such as torches, must never be applied to connecting lines or other components containing liquid or solid UF_6.

Care should be exercised in the selection of pumping systems for evacuation of UF_6 process plant and UF_6 cylinders. Vacuum pumps containing hydrocarbon oil should be equipped with an oil backflow reservoir of sufficient volume or a chemical trap (e.g. activated carbon) to prevent oil entering into the UF_6 system in the event of pump stoppage.

3.7. OTHER SAFETY CONCERNS

3.7.1. Conversion and reconversion operations

There are numerous safety considerations which must be addressed. These considerations are combinations of radiological, industrial, chemotoxic and environmental safety. Since the detailed safety analyses of handling and processing UF_6 are covered in Section 3.6, this section will attempt to cover the safety concerns in general. This is not intended to be all inclusive but to give the reader some ideas as to the variety of considerations required.

3.7.1.1. Design and equipment

It is very important that the construction materials for processing equipment are compatible with the process. Temperature and pressure conditions must be considered. An example is the use of 300 series stainless steel for nitric acid services or monel for hydrofluoric acid services.

Design of the equipment is another important safety factor. Adequate fume or dust removal systems with provisions for maintenance must be included when the process is being designed. All connections for acid fume removal systems must be welded or water-tight to avoid any leakage. Whenever practical, the design should consider "in-leakage" vs "out-leakage", i.e. the design should "pull" rather than "push" any fumes or dust through a duct.

An appropriate alarm system to detect any abnormalities in the process system is desirable. There are two types — one being process alarms and the other being the detection in the working atmosphere. Examples of the types of alarms are gaseous detectors for hydrogen, fluorine and hydrofluoric acid and conductivity alarms for liquids. Also, redundant containment is widely used for environmental and personnel protection and is recommended. Continuous monitoring systems in plant and on all emission streams is recommended as part of the plant design.

3.7.1.2. Process chemicals

These operations take place within a chemical processing plant with its chemical hazards along with the radiological concerns. Extensive literature is available for the various chemicals used in the processes. Some major ones are addressed in this section to illustrate some of the requirements for safety.

The principal chemicals used in the purification and conversion operations are nitric acid, sulphuric acid, tributyl phosphate, lime, fluorine, hydrogen, hydrofluoric acid and potassium hydroxide. Material safety data sheets are available from vendors for most of these chemicals. The properties of HF and UF_6 have been previously covered in Chapter 2.

Fluorine

Fluorine is the most hazardous chemical used in these processes, being both toxic and corrosive. Many materials combine with and burn spontaneously in fluorine as it is the most electronegative and easily the most reactive element known. Fluorine is a pale, green-yellow gas with a penetrating odour similar to ozone. Its odour is so intense it can be detected by the sense of smell at concentrations below the threshold limit value (TLV) of 0.1 ppm. Fluorine attacks skin causing a thermal burn and by reaction with moisture liberates HF (Reference 'Fluorine — The First 100 Years', Elsevier Science Publishing Co. Inc., 1986) [15].

Electrolyte

The electrolyte used to generate fluorine is usually based upon KF.2HF prepared by addition of anhydrous HF (AHF) in liquid form to potassium hydrogen fluorine (KHF_2). AHF (boiling point 19°C) can give rise to serious skin burns and tissue damage. The longer the exposure and the thinner the skin, the more rapidly do lesions appear. The subsequent pains and white necrosis can be severe. Treatment for HF burns has been based upon injection of sterile 10% calcium gluconate or topical application of iced alcoholic/aqueous solutions of quaternary ammonium compounds. In general, ingestion of fluorides must be controlled because of toxicity. A lethal quantity is 5–10 g of sodium fluoride. A threshold limit value for airborne particulate fluoride of 2.5 mg/m^3(F) has been proposed.

3.7.1.3. Personnel

For personnel protection, standard safety equipment is adequate in these process plants. Protective clothing, neoprene gloves and suits, self-contained breathing equipment, acid proof goggles, face shields, and safety shoes and helmets are worn when needed. All protective clothing must be clean and free of hydrocarbons since HF and F_2 will react with the hydrocarbons and thus could penetrate the protective equipment. Because hazards exist from the chemicals and radioactivity, extensive training of all employees is very important. The training should be comprehensive, including indoctrination and recognition of chemical and radiological hazards. Other specialized training is to be provided as necessary. To ensure proper radiological protection, dosimeters must be worn by each person while in a process area. To minimize exposure, good housekeeping is essential in maintaining low radiation and airborne contamination levels and general safety.

The medical control programme required in the uranium processing plant is similar to that in the heavy metal industry. Usually, the programme includes a pre-employment examination to detect pulmonary, renal or haemotological disease. Also periodic scheduled physical examination is carried out to monitor the health of the employees. Routine urinalysis for uranium is performed to determine the exposure level of the employee.

The following guidelines provide radiological and chemical protection to personnel involved with the handling and storage of UF_6 cylinders.

(a) On receipt, UF_6 cylinders should be monitored for radiation and contamination. UF_6 cylinders which exceed established radiation and other guidelines should be identified and isolated from other cylinders. Corrective actions should be initiated.

(b) A personnel monitoring programme should be established to assure that personnel do not receive excessive radiation exposure.

(c) Personnel handling UF_6 cylinders should have access to respiratory protective equipment that provides chemical protection from UF_6 and HF and from particulates in the event of a UF_6 release. Other protective equipment should include chemical protection suits which are resistant to UF_6 and HF.

(d) In the event of a cylinder rupture or a UF_6 release, personnel without protective equipment should promptly evacuate the area to avoid any contact with the UF_6 or HF. Assembly points should be established upwind.

The guidelines outlined previously for radiological and chemical protection to personnel involved with handling UF_6 (both monitoring and emergency) also apply to UF_6 storage.

3.7.2. Safety considerations — UO_3 to UO_2

The principal safety concerns in the UO_3 to UO_2 reduction area are the handling of ammonia, hydrogen and hazards of high operating temperatures. The safe handling of hydrogen is primarily concerned with preventing the formation of an explosive mixture with air. The following are examples of recommended safety measures:

- Ensure the integrity of seals at the inlet and outlets of the reactor system.
- Purge with inert gas and use a seal pot to avoid air entering the reduction reactors
- Hydrogen analyzers are to be located near equipment containing hydrogen.
- All major equipment should have a design pressure sufficient to withstand an explosion.
- Sprinklers should be installated in the UO_3/UO_2 baghouses in cases of fire.
- Spark detectors should also be installed in the inlet and outlet ducts from the baghouses.

3.7.3. Safety consideration – Fluorination of UF_4 to UF_6

In this process hazards are created by handling F_2, HF, UF_6 and UF_4. Gaseous F_2, HF and UF_6 are found in the UF_6 reactors and UF_6 filter areas as well as in the process piping.

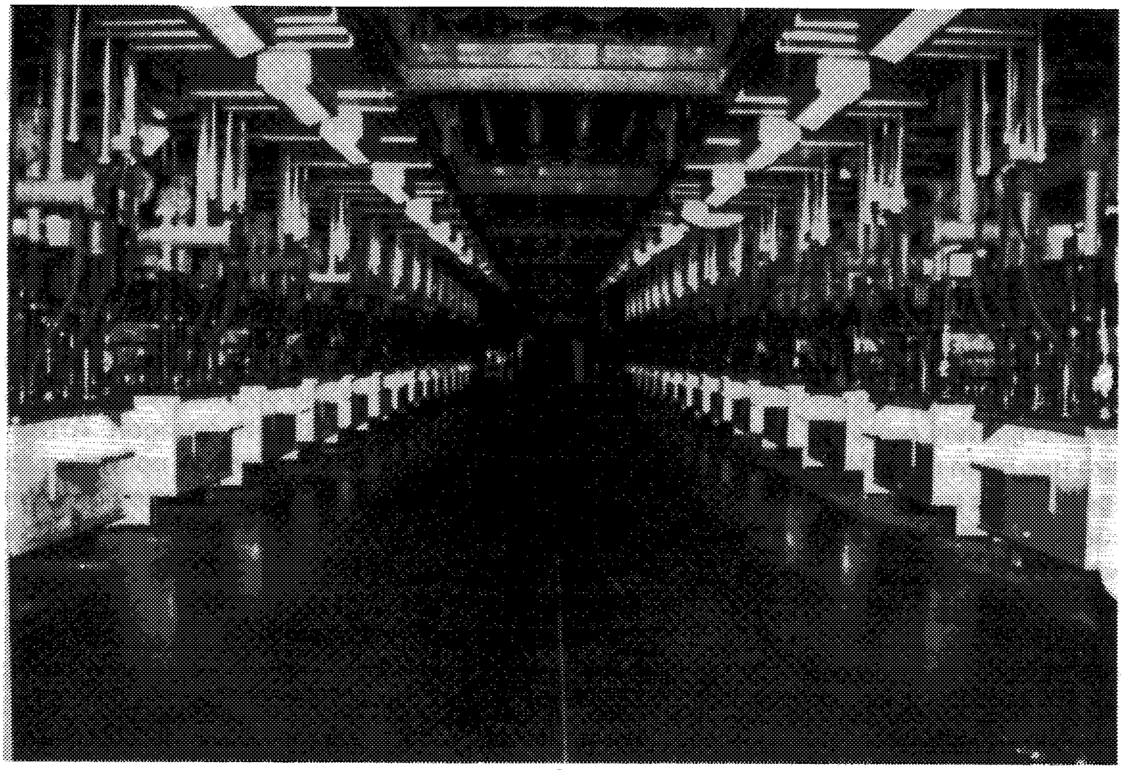

FIG. 3.22. Cells for F_2 generating.

When maintenance work is to be performed on any process equipment, lines or process vents, care must be taken to ensure that they have been previously isolated and purged. UF_4 dust is a chemical hazard as well as a radiological hazard. Exposure can result in damage to the kidneys, therefore respiratory equipment must be used at all times there is a potential for UF_4 to become airborne. The UF_6 may also contain fluorides which, in contact with the skin will produce HF, (possible burn) therefore proper personal protection must be worn. There are also some radiological concerns in the reactor areas. External exposures in the form of alpha, beta and gamma radiation can be obtained from the filters, headers, valves, reactors discharge lines, and ash collectors.

3.7.4. Safety — Cell maintenance

3.7.4.1. Cell removal

The principle hazards associated with a fluorine cell are of electrical and chemotoxic nature. Before starting to work on a cell, ensure that the cell has been electrically isolated and that the rectifier has been locked and tagged off (see Figure 3.22). When taking a cell "off-line" purge the cell using N_2 before isolation from the fluorine/hydrogen headers. Protective gloves and dust masks must be worn when cleaning out headers. The carryover is electrolyte and it contains HF.

3.7.4.2. Electrolyte transfer

This step requires the presence of a safety standby operator and the use of a protective suits, respiratory protection, face shields and gloves because of the HF content in electrolyte. Fumes will be generated during this operation which could cause burns if skin is exposed or fumes are inhaled.

3.7.5. Safety – Fluorine and fluorine passivation

The presence of fluorine in the atmosphere can be monitored but is readily noticeable at very low concentrations (1 mg/m^3) because of its characteristic odour. All leaks must be traced and immediately stopped. Fluorine is toxic and is an extremely strong oxidizing agent. Care must be taken that the equipment used to transport and store this gas is properly prepared. The corrosion resistance of a metal towards fluorine is based on the formation of a surface fluoride layer which protects against further attack by fluorine. If the equipment in which fluorine is to be used is not properly cleaned and passivated before use, reactions of the fluorine with metals can take place and can lead to the burning of the valves, manometers, reactors and the lines. The following measures are absolutely essential. All parts must be very carefully cleaned of impurities and degreased. The solvent is then completely removed by drying, and the equipment flushed with nitrogen. After the system has been completely checked for leakages, it is passivated. For this operation slow nitrogen flow is passed through the apparatus, to which an increasing proportion of fluorine is added, until finally pure fluorine flows into the apparatus. All valves are closed and time allowed for passivation. When sufficient passivation has been attained the apparatus is ready for operation. An alternative method is to evacuate the system and allow the fluorine to flow into the system slowly, till atmospheric pressure is reached. The fluorine is left in the equipment for some hours for passivation. Improved stability results if the system can be heated to a controlled temperature.

Qualified and well-trained staff should be employed for work with fluorine. Personal protection equipment should be worn at all times. If work is carried out with equipment containing fluorine, gloves made of neoprene, protective headwear with face-shield of plastic and protective clothing must be worn. Furthermore, all the standard safety measures for the handling of highly toxic gases must be applied. In emergency situations, self contained breathing apparatus is required. All protective clothing and equipment must be clean and free of hydrocarbons.

3.7.6. Safety of reconversion operations of UF_6 to UO_2, to U_3O_8 or to UF_4

Safety considerations for reconversion operation of UF_6 to either UO_2, to U_3O_8 or to UF_4 are mostly covered by those for concentrate - UF_6 conversion operation described in Section 3.4.1. Similar safety concerns are UF_6 cylinder heating, and gas phase reactions using H_2 for both wet and dry processes. HF is recovered within the dry process. The details of these items are described in 3.4. HF is recovered in the dry conversion process at concentrations between 40 to 70 wt% at which it poses a corrosion hazard. In handling this material great care must be taken in the selection of materials and in the measures to protect personnel.

3.7.7. Safety – Liquid effluent

In the liquid effluent treatment area, the hazards are mostly associated with chemical handling. Personal protective equipment such as eye protection and rubber gloves are recommended. Radiological hazards are minimal in this area except when UF_6 filters are cleaned. Normally, these filters are stored until they decay to a safe handling level. However, radiation checks should be part of a routine procedure before they are handled. Workers should wear personal dosimeters whenever the filters are cleaned.

Chapter 4

TRANSPORT

This chapter does not specify additional regulations for UF_6 transport, nor does it modify those used successfully for many years. Regulations applicable to UF_6 transport are published by the IAEA in its Regulations for the Safe Transport of Radioactive Material (Safety Series No. 6), the supplements to the Transport Regulations and its supporting documents consisting of advisory and explanatory material which should be consulted [16]. For further information on the development of these regulations see Sections 4.8 to 4.10.

4.1. GENERAL REGULATIONS FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIAL

UF_6 transport may be classified under two headings:

- transport within a nuclear site, by trained and qualified personnel, using specialized equipment, under national licensing arrangements;

- carriage on public transport networks by personnel who are not specially trained in the handling of packages of nuclear materials and making use of either specialized or standard vehicles covered by IAEA Safety Series No. 6 [16].

The first category involves less risk to the public and the environment than does the second. The primary reasons for this are shorter distances and no accessibility of the public to the site. The second category, involving greater risk, concerns transport between processing establishments which may be far apart within a country or between two countries. When being transported the design of the entire package offers the protection (see Figure 4.1). The IAEA Regulations for the Safe Transport of Radioactive Material (Safety Series No. 6) provide standards for ensuring a high level of safety of people, property and the environment against radiation and criticality hazards as well as other effects associated with the radioactive properties of materials. The basic requirements are:

- containment of radioactive material;
- control of radiation emitted from the package; and
- criticality prevention.

For meeting the basic requirements and the declared purpose of the Regulations, effective quality assurance and compliance assurance programmes are required. These ensure, for example, that:

- appropriate and sound packages are used,
- the activity of radioactive material in each package does not exceed the egulatory activity limit for that material and that package type,
- the radiation levels external to, and the contamination levels on, surfaces of packages do not exceed the appropriate limits,
- packages are properly marked and labelled and transport documents are completed,
- the number of packages containing radioactive material in a conveyance is within the regulatory limits,
- packages of radioactive material are securely stowed in conveyances and are stored at a safe distance from persons and photosensitive materials,
- only those transport and lifting devices which have been tested are used in loading, conveying and unloading packages of radioactive material, and
- packages of radioactive material are properly secured for transport (see Figure 4.2).

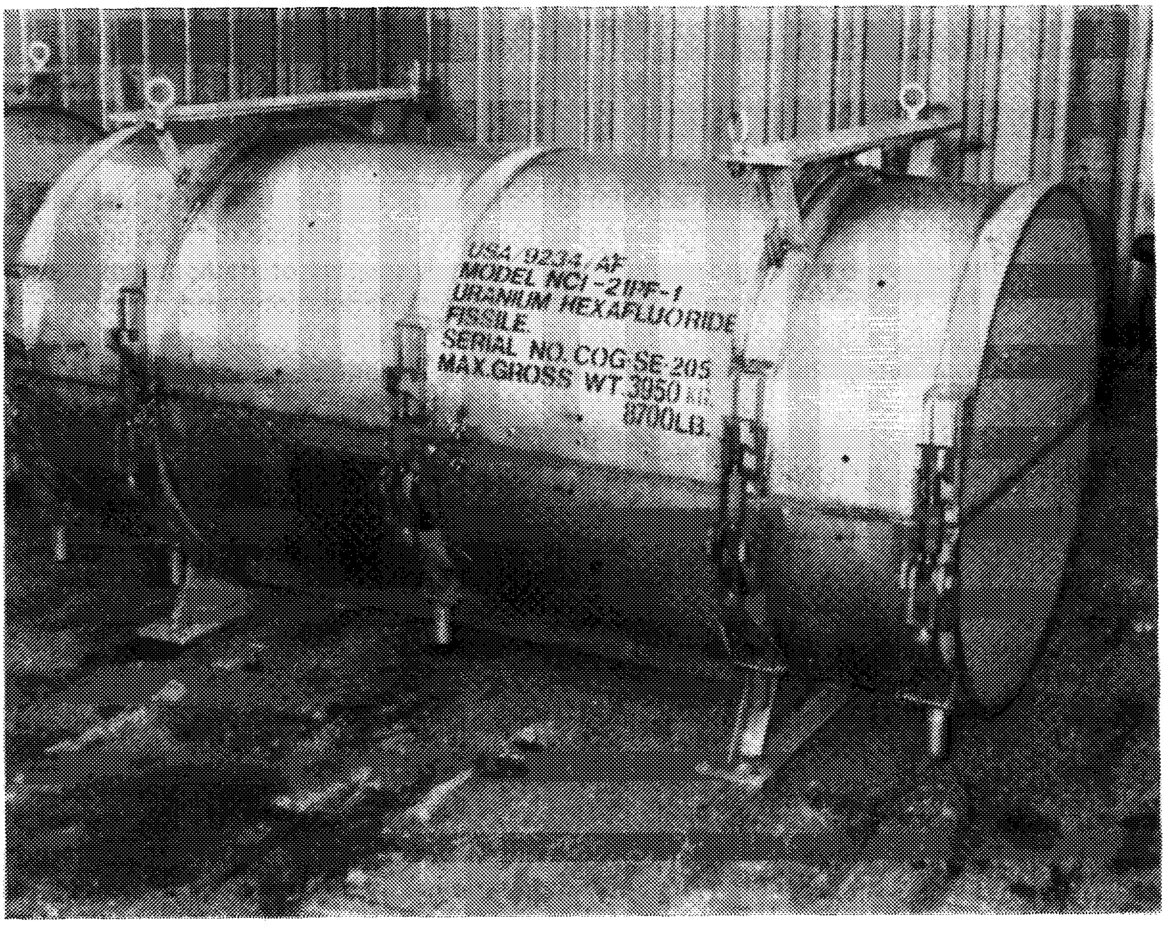

FIG. 4.1. Outer protective packaging NCI-21PF-1 (Nuclear Containers Inc.).

The control of the transport of radioactive materials may be necessary also for other reasons, e.g. safeguards control and physical protection of nuclear materials (see Figure 4.3).

4.2. THE SPECIAL CASE OF UF_6

For radioactive materials having other dangerous properties, the regulations of Member States, modal conventions and agreements, and other relevant documents of international organizations need to be applied. Generally, the other dangerous properties are controlled as subsidiary hazards. However, in the specific case of uranium hexafluoride at low enrichment levels, the subsidiary chemotoxic hazards generally override the radiological consequences (see Chapter 3). These chemical properties, combined with UF_6 radiological characteristics are not adequately covered under existing IAEA and United Nations recommendations. This situation is being corrected (see Section 4.4 below).

4.3. PRESENT PRACTICE FOR UF_6 TRANSPORT

The existing IAEA recommendations for UF_6 transport packages are summarized in Table 4.1. This information is derived from Safety Series No. 6, Regulations for the Safe Transport of Radioactive Material [16], and the table numbers refer to the relevant paragraphs. These requirements do not consider the chemotoxic properties of UF_6. Also, the table does not consider the additional radiological hazards of recycled material. Additional advisory material is available in Safety Series No. 37, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material [17], and in Safety Series No. 7, Explanatory Material for the IAEA Regulations for the Safe Transport of Radioactive Material [18].

FIG. 4.2. DOT-21-PF-1A outer protective packaging.

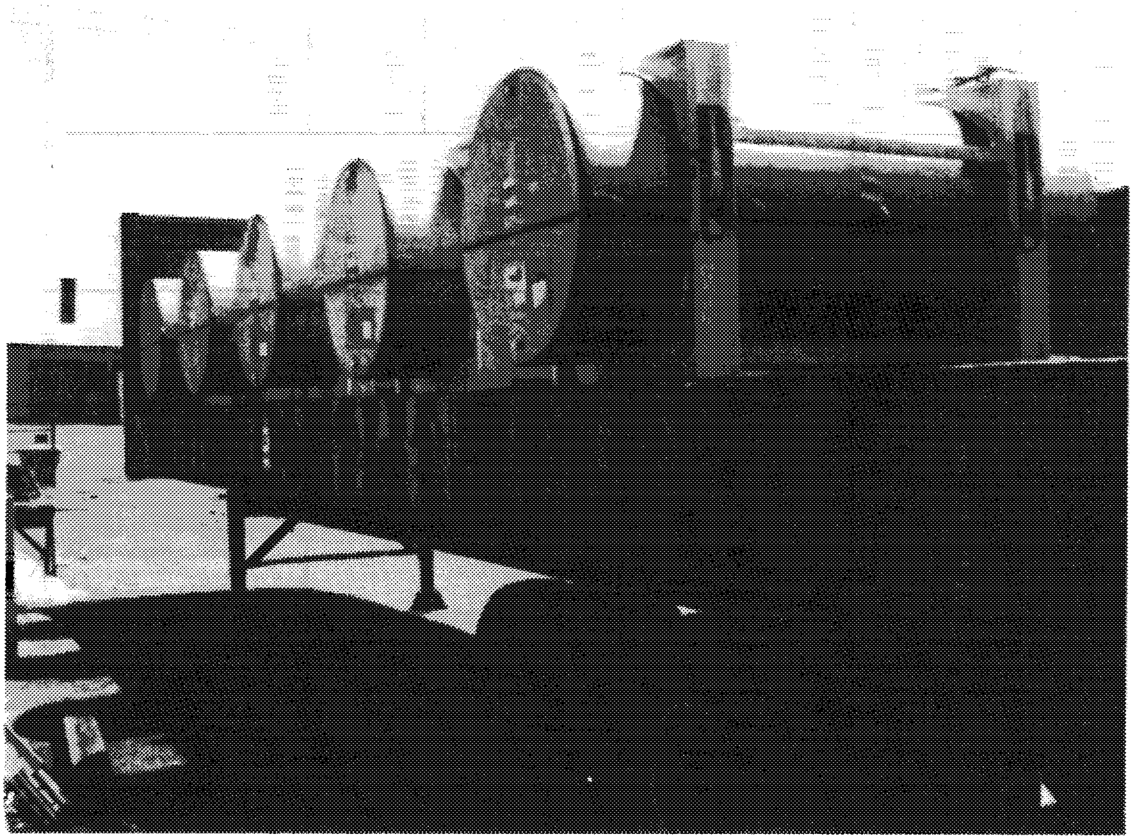

FIG. 4.3. U_x-30 outer protective packaging (Nuclear Packaging Inc).

TABLE 4.1. REQUIREMENTS IMPOSED ON UF_6 TRANSPORT PACKAGES BY IAEA SAFETY SERIES No.6
(Numbers in parentheses indicate relevant paragraph numbers from Safety Series No. 6 [16])

<table>
<tr><th>Uranium enrichment % of U-235</th><th>Maximum contents (g of U-235)</th><th>Material classification</th><th>Maximum radiation level</th><th>Fissile material classification</th><th>Fissile packaging requirements</th><th>UN number (a)</th><th>Packaging requirements</th><th>Labelling & documentation requirements</th><th>Approval requirement</th></tr>
<tr><td colspan="10">EXCEPTED PACKAGES - SEE TEXT, SECTION</td></tr>
<tr><td>≤0.72%</td><td>(b)</td><td>LSA-I(c)</td><td rowspan="5">10 mSv/h 3 m from unshielded if LSA-I or LSA-II (422), and 2 mSv/h at package surface if not under Exclusive Use (433), or 10 mSv/h at package surface if under exclusive use (434)</td><td>Non-fissile</td><td>None</td><td>2978</td><td>IP-1(426,518)</td><td>(436-453)</td><td>None</td></tr>
<tr><td>>0.72% to 1.0%</td><td>(b)</td><td>LSA-II (d)</td><td>Fissile</td><td>Fissile Excepted (560)</td><td>2978</td><td>IP-2(426,519)</td><td>(436-453)</td><td>None</td></tr>
<tr><td>>0.72%</td><td>15 g (560a)</td><td>LSA-II (e) if enrichment <5%; if enrichment >5%, LSA-II (e) if specific activity $\leq 10^5$ Bq/g, otherwise not LSA</td><td>Fissile</td><td>Fissile Excepted (560)</td><td>2978</td><td>IP-2 if LSA (426, 519, 560), or Type A if not LSA (524-538)</td><td>(436-453)</td><td>None</td></tr>
<tr><td>>1.0% to 5.0%</td><td>(b) (f)</td><td>LSA-II (e)</td><td>Fissile</td><td>Fissile (559, 561-568) (g)</td><td>2977</td><td>IP-2 (426,519); and Fissile (559)</td><td>(436-459)</td><td>Multilateral (710)</td></tr>
<tr><td>>5.0%</td><td>(f)</td><td>LSA-II (e) if specific activity $\leq 10^5$ Bq/g, otherwise not LSA</td><td>Fissile</td><td>Fissile (559, 561-568) (g)</td><td>2977</td><td>IP-2 if LSA (426,519), or, if not LSA, Type A (524-538) or Type B (549-556 or 557-558); and Fissile (559)</td><td>(436-459)</td><td>Multilateral (710)</td></tr>
</table>

(a) UN number is used internationally to assist hazard identification in emergency response (see Appendix I of Ref. [16]).

(b) Controlled by unshielded material radiation level at 3 m (422) (see para. 422 of Ref. [16]).

(c) Natural and depleted solid unirradiated uranium is classified as LSA-I (see para. 131(a)(ii) and (iii) of Ref. [16]).

(d) LSA-I cannot be fissile material (see para. 131(a)(iii) of Ref. [16]). Although the package containing uranium enriched to a maximum of 1% should be regulated as a non-fissile material package the radioactive material is still fissile. Therefore, it is classified LSA-II(e).

(e) The specific activity limit for solid LSA-II is (see para. 131(b)(ii) of Ref. [16]): $10^{-4}A_2$/g. Up to 5% enrichment level (including) the A_2 value is unlimited. Above 5% enrichment level the A_2 value is 10^{-3}TBq; thus LSA-II limit is: $10^{-4} \times 10^{-3}$ TBq/g = 10^{-7} TBq/g = 10^5 Bq/g. UF_6 enriched to levels where the specific activity exceeds 10^5 Bq/g cannot be classified as LSA-III because the requirement of para. 131(c)(ii) of Ref. [16] is not fulfilled.

(f) Controlled by package design.

(g) Fissile material shall be packaged and shipped in such a manner that subcriticality is maintained under normal conditions of transport and in accidents. For demonstrating this the packages are required to be tested as specified in paras 619–624, 626–628 and 631–633 or 619–624 and 629 (more limiting combination) of Ref. [16].

4.4. NEW RECOMMENDATIONS FOR UF_6 TRANSPORT

The IAEA recognizes the chemotoxic properties of UF_6 and has taken on the task of developing recommendations to provide protection during the transport of UF_6. These recommended requirements were published in IAEA-TECDOC-608 [19]. The provisions will be subject to further review by Member States and are intended to be included into the IAEA Safety Series Regulations No.6 in its 1996 revised edition. The requirements, insofar as they affect cylinder design specifications, have been included in the International Standard ISO/7195 [14] which closely follows ANSI N14.1–1987 [9] but requires compliance with IAEA recommendations and includes cylinders other than to United States specification.

4.5. URANIUM HEXAFLUORIDE PACKAGES

A package for the transport of UF_6 means the packaging with specified contents as presented for transport. Packaging is used to mean the assembly of the cylinder service and structural equipment.

4.5.1. Cylinders

Cylinders used for transport purposes also serve as process vessels during filling and emptying operations. The types of cylinder most frequently used are listed in Chapter 3. The design and manufacturing specifications of UF_6 cylinders are covered in detail in such publications as ANSI N 14.1 [9], and ISO/7195 [14] to which reference should be made.

4.5.2. Outer packaging

An outer protective packaging is used to provide additional protection for criticality purposes, for thermal protection and for extra resistance in potential accident conditions. Figure 4.4 shows 48 inch cylinders with outer protective packaging. A breach of an unprotected cylinder containing enriched UF_6 could allow ingress of water which could result in a criticality incident. Approved designs of outer protective packaging [e.g. DOT 21-PF1 Series (see Figure 4.2), UX-30 (see Figure 4.3)] ensure that ingress of water is prevented while providing thermal insulation and physical protection. Proper maintenance of the outer protective packaging is essential to ensure the integrity of the package as a fire and shock resistant housing. The outer protective packaging shall be kept structurally sound, provide a tight seal between the cover and base, and be protected from damage to the insulation by moisture. The minimum inspection and maintenance requirements are listed in ANSI N 14.1 (1987) [9]. National and international criteria for licensing and testing should be strictly observed.

4.5.3. Stowing and fastenings for transport

Stowing and fastening represent an important factor under the heading "safety in transport". Stowing and fastening materials must be suited to both the package and the transport vehicle. They must hold the shipment components together and act as a shock-absorber if the fastenings break during an accident.

There are two categories of devices:

- rigid devices,
- sliding devices.

Both categories can be used in the transport of all UF_6 containers. The rigid devices, however, are normally used for light weight packages (types 5, 8, 12, 30 Cylinders)

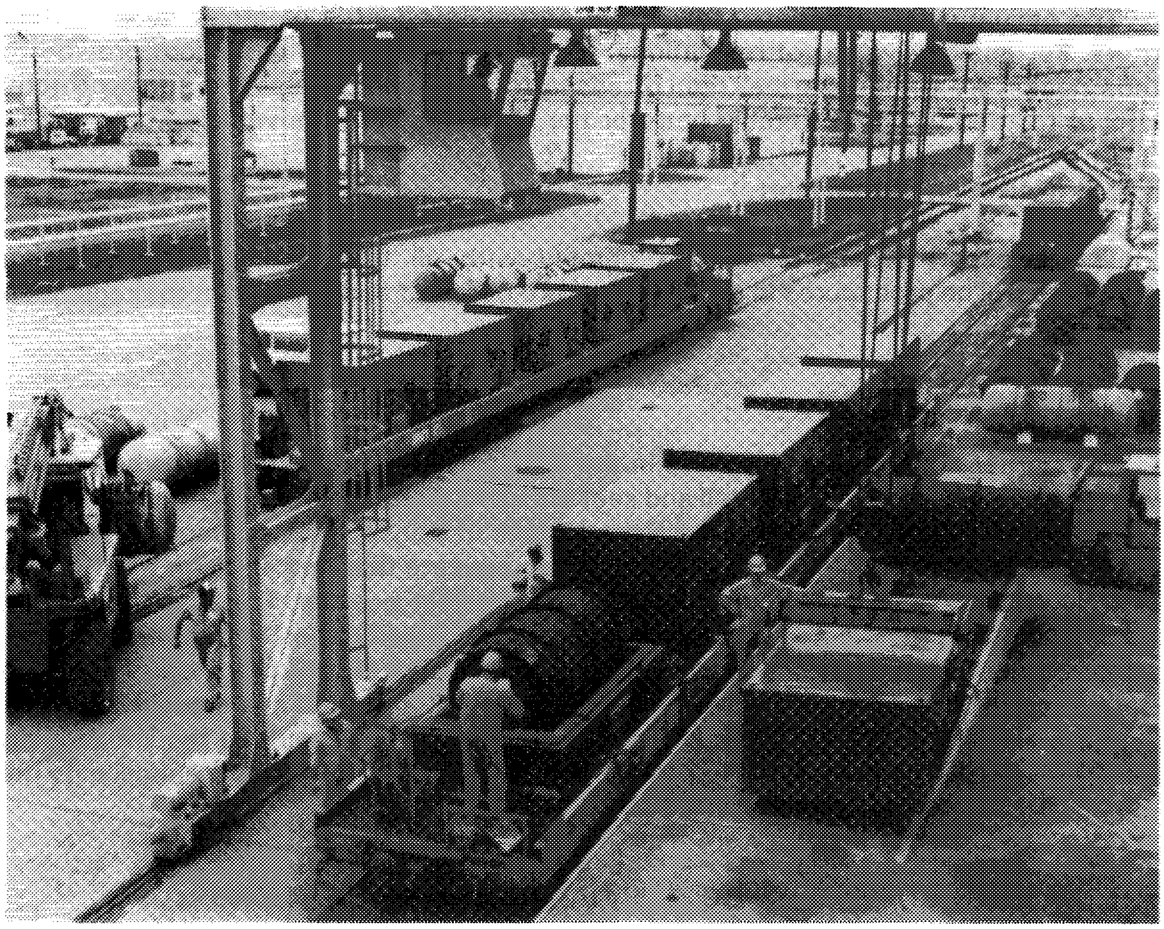

FIG. 4.4. 48 inch cylinders loaded in outer protective packaging.

equipped with outer protective packagings. These devices are intended to solidly secure the container to the floor or wall of the vehicle and to prevent any movement of the load during transport. They must resist the force of an emergency stop of a road vehicle or the buffeting of a rail car. The sliding devices are used for transport of 48 inch type cylinders by rail. These devices retard and stop, the longitudinal movement of the load after a sudden shock within a given distance. Apparatus for transportation may be chosen from a large variety of options. The most often used are:

- flats (closed or open),
- wooden or metal cradles,
- pallets,
- various jigs, frames, spreaders, fasteners, most often made of wood,
- chains, straps, ropes, tensioners, bolts, pins, serving to fix the container and its bearer to the transport vehicle.

4.6. OTHER TRANSPORT CONSIDERATIONS

Apart from the safety provided by the design of the package itself, transport safety requires:

- effective organization of transport,
- careful choice of the carrier and the means of transport,
- an appropriate system used for fixation of the packaging,
- various measures taken by the people responsible for transport.

The accumulated experience of all the parties involved is of great value in these matters. For example, a set of regulations, however comprehensive, cannot provide the criteria necessary to choose the 'right' transporter. Nor can it show the most effective means of fixation which is suitable both for the packaging and the vehicle.

4.6.1. Organization of transport

The transport organization must comply with all the administrative and legal requirements. The procedures in each country are different and depend on the regulations of the country.

4.6.2. The choice of carrier

The carrier is an important factor in the transport of UF_6, particularly when several means of transport (such as road, rail and sea) are used. The carrier's importance increases with the distance and the number of different types of transport used. Consequently, the carrier's ability, organization and experience must indicate that he can carry out the task. Economic factors cannot be the only criteria used to select a carrier. Their installations and representation and their experience, equipment and the qualification of their personnel are also important. Many countries require companies wishing to engage in transport of nuclear materials to be licensed by a government ministry. The carrier and consignee should together choose the type of transport to be used. National authorities require that civil authorities who would be involved in case of accident, be informed. This responsibility may be delegated to the carrier if permitted by regulations.

4.7. TRANSPORT DOCUMENTS OF INTERNATIONAL ORGANIZATIONS

- Recommendations on the Transport of Dangerous Goods, Committee of Experts on the Transport of Dangerous Goods, United Nations (UN)), New York.
- Technical Instructions for the Safe Transport of Dangerous Goods by Air (TI), International Civil Aviation Organization (ICAO), Montreal.
- Dangerous Goods Regulations, International Air Transport Association (IATA), Montreal.
- International Maritime Dangerous Goods (IMDG) Code, International Maritime Organization (IMO), London.
- Universal Postal Convention of Rio de Janeiro 1979, Universal Postal Union, Bern.

4.8. TRANSPORTATION DOCUMENTS OF REGIONAL OR NATIONAL ORGANIZATIONS

- European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) and Protocol of Signature, United Nations Economic Commission for Europe (ECE), Geneva (1957).
- Régiement international concernant le transport des marchandises dangereuses par chemins de fer (RID), Convention Internationale Concernant le Transport des Marchandises par Chemins de Fer (CIM), Office Central des Transports Internationaux par Chemins de Fer (OCIT), Berne.
- Regulations for the Transport of Dangerous Goods on the Rhine (ADNR), Central Commission for the Navigation of the Rhine (CCNR), Strasbourg.
- European Provisions Concerning the International Carriage of Dangerous Goods by Inland Waterway (ADN), Draft, United Nations Economic Commission for Europe, Geneva.
- Regulations for the Transport of Radioactive Substances, Annex 4 to the Agreement on International Railroad Freight Traffic (SMGS), Railroad Cooperation Organization (OSZhD), Warsaw.

Regulations for the Safe Transport of Spent Fuel from Nuclear Power Plants of CMEA Member Countries — Transport by Rail, Council for Mutual Economic Assistance (CMEA), Moscow.

Regulations of the US Nuclear Regulatory Commission (NRC), the US Department of Energy (DOE) and the US Department of Transportation (DOT).

4.9. PHILOSOPHY OF THE REGULATIONS

The basic principle underlying the IAEA's regulations is that protection against the hazards of radioactive material in transport should be provided by the packaging in which it is carried. The consignor of the radioactive material has primary responsibility for safety and must declare in the transport documents that it is packed, marked and labelled in accordance with the applicable regulations. This ensures that the person most likely to have the necessary knowledge of the special hazards presented by the radioactive material, is responsible for providing safety in the transport.

The carrier has a lesser degree of responsibility and must take appropriate precautions to protect workers and the public during transit. Where the hazard of the material being transported requires it, the protection afforded by the packaging must remain effective, even under severe accident conditions. For more hazardous contents, an independent review and approval of the transport package design by appropriate national authorities is required. The regulations also require quality assurance measures to avoid inadvertent non-compliance with safety features and appropriate emergency response arrangements to deal with the consequences of accidents or incidents. The IAEA's regulations seek to control the impact of the transport of radioactive material on workers, members of the public and the environment. The record, however, speaks for itself. In more than 40 years of transportation, there have been no known deaths or injuries due to the radioactive nature of material being transported under the provisions of the regulations. In principle, the IAEA's regulations control radiation hazards and, where these are significant, would also cover subsidiary chemical risks. Where the radioactive hazard is low (see Table 2.2), other regulations would normally apply. However, uranium hexafluoride is unique. Because UF_6 is carried solely for the nuclear energy industry, it is appropriate for the IAEA to be the focal point for setting formal requirements. IAEA-TECDOC-608 [19] includes the recommendations for inclusion in the 1996 Edition of the Transport Regulations.

Chapter 5

STORAGE OF URANIUM HEXAFLUORIDE

5.1. INTRODUCTION AND GENERAL CONSIDERATIONS

Storage of UF_6 both short-term and long-term occurs at many locations around the world. Short-term storage safety considerations involve criticality, inventory control, and safe handling. Long-term storage safety considerations include those above plus containment (container integrity). Feed stock of enriched material may experience extended pauses in its flow through the nuclear fuel cycle. Depleted UF_6 deserves special attention concerning storage because large amounts of this material are generated at enrichment plants and it is then stored for very long periods. Figure 5.1 shows a typical UF_6 staging area. It is assumed that UF_6 is stored as a solid in approved cylinders such as those described in ORO-651 [13] and ISO-2195 [20] (for examples see Table 3.1). Many factors are common to both short- and long-term storage: stacking and spacing considerations (criticality, radiological, and mechanical), accountability, security, safety, chemical activity, quality control, quality assurance, and emergency planning. For extended storage the selection and qualification of a storage site, cylinder maintenance, monitoring, control and inspection, accountability, and security, and the monitoring of corrosion of containment vessels are all important. The factors which affect short-term storage will be described separately when they differ significantly from long-term storage practices or requirements.

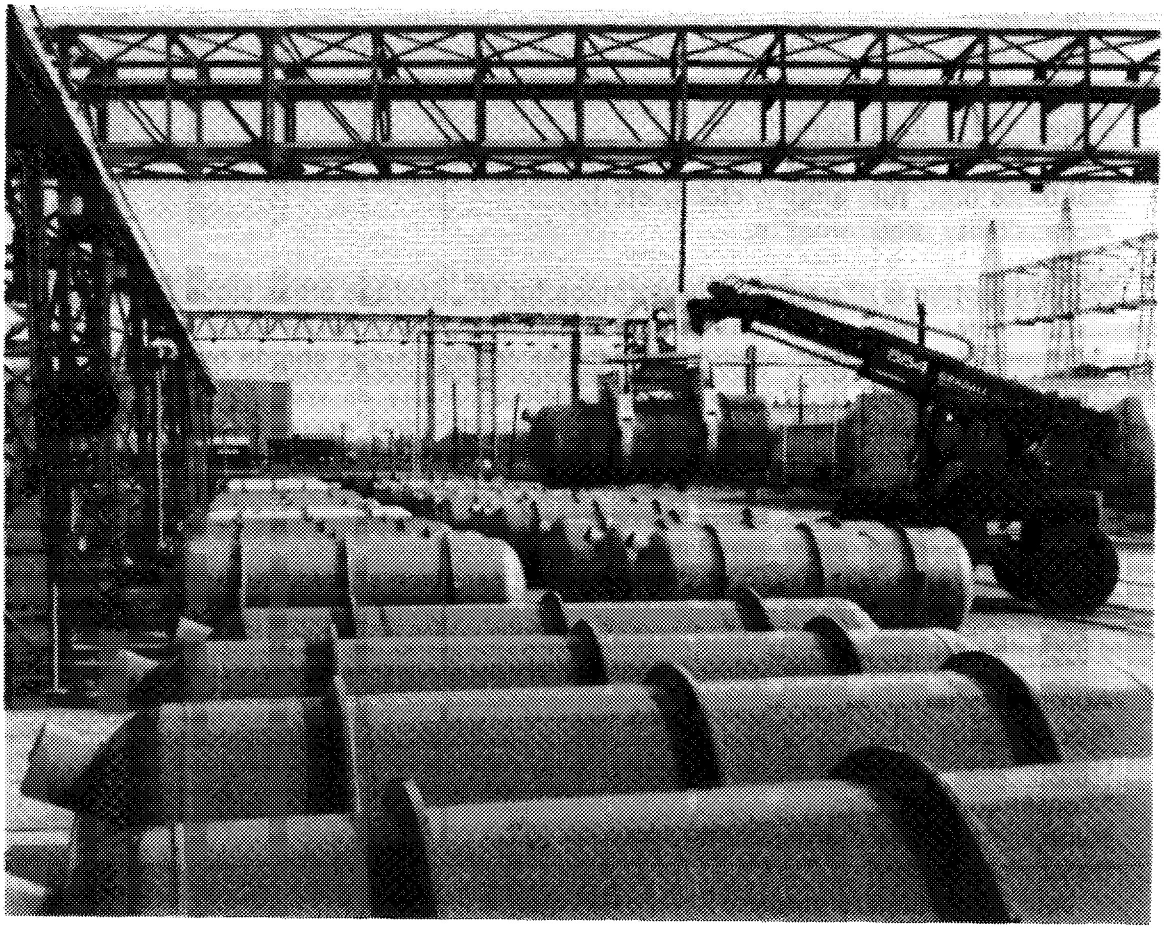

FIG. 5.1. Typical UF_6 cylinder staging area (before movement to long term storage pad).

5.1.1. General criteria for UF_6 storage

All cylinders used for the storage of UF_6 should be individually equipped with a data plate in accordance with ANSI, ORO and ISO-7195 [14] specifications. All cylinder storage should be supported by an accountability records system to identify cylinder contents as well as to maintain a history of each cylinder. This system should include the following:

- Complete fabrication data (drawings, materials of construction, applicable codes, standards deviations, date of fabrication, and certified volume when available);
- Test data;
- Transportation experience;
- Inspection results;
- IAEA competent authority certificates, domestic approvals, etc.;
- Maintenance and repair records.

All cylinders scheduled for storage of UF_6:

- Should be equipped with approved valves and plugs that are properly installed;
- Should be secured from unauthorized access;
- Should have all defects, deviations, discrepancies, dents, and damage identified (defective or damaged cylinders should be set aside for repair or other action as appropriate);
- Should have identified internal contaminants (i.e., non-UF_6) that are above UF_6 purity specifications.

Preferably UF_6 cylinders should be grouped for storage in arrays according to the following criteria:

- Cylinder model;
- ^{235}U enrichment;
- Scheduled storage period;
- Final destination of material;
- Contents (i.e., full, empty, clean, etc.);
- Accessibility requirements.

Fire prevention is of particular importance for UF_6 storage areas since fire represents an opportunity for significant material release. Flammable materials should not be stored in the proximity of cylinders. Access to cylinder storage areas should be restricted. This restriction should apply to storage of all cylinders, empty as well as filled. Figure. 5.2 shows model 48Y cylinders for storing UF_6.

5.2. ORGANIZATION

UF_6 storage is an integral part of UF_6 operations. Each storage facility for UF_6 should be organized to ensure that all responsibilities are appropriately assigned. The organization should include or interface with the following activities and report to the facility manager:

- Administration
- Procurement
- Operations
- Maintenance
- Nuclear materials management
- Safety and Health
  - Nuclear criticality safety
  - Radiological safety
  - Industrial safety
  - Safety analysis

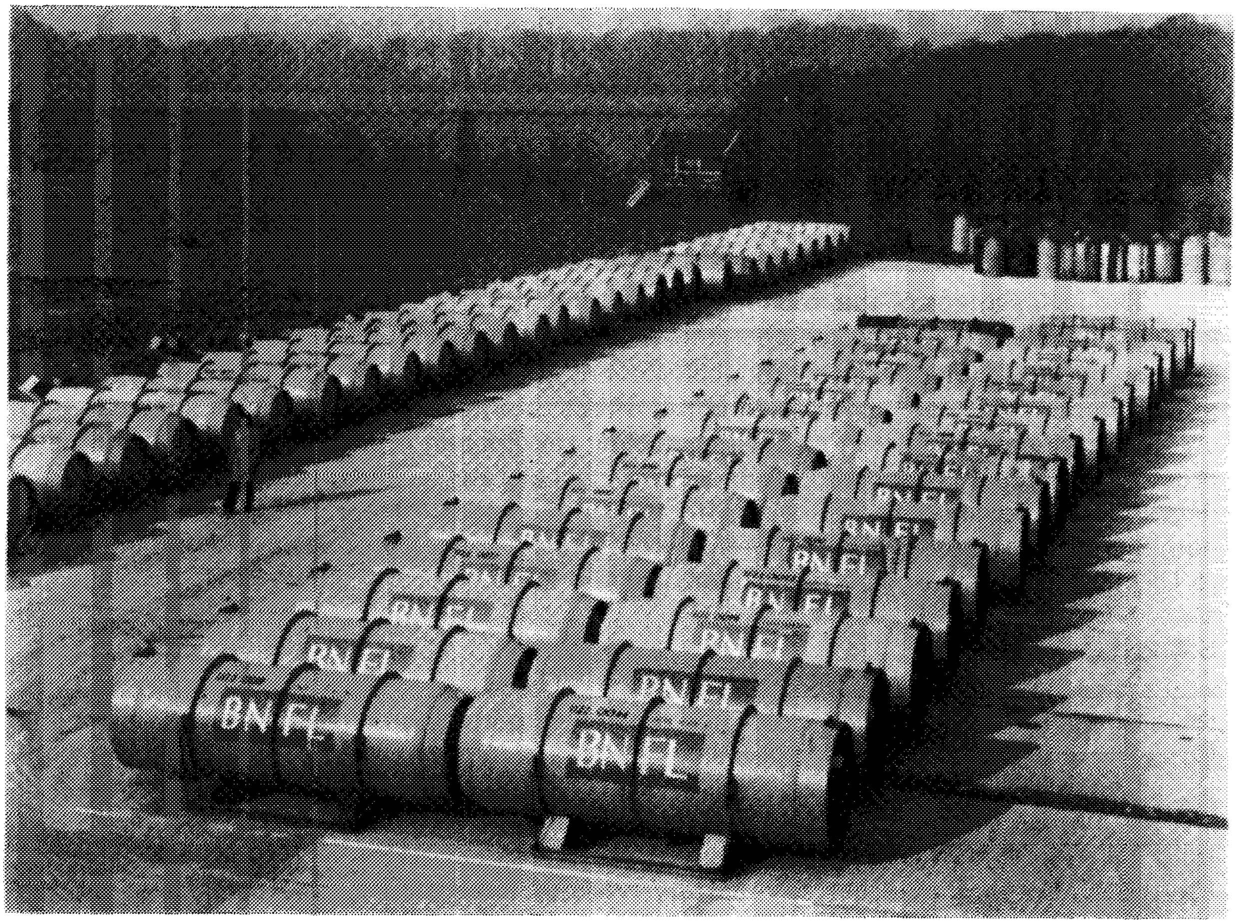

FIG. 5.2. 48Y cylinders for storing UF_6.

- Transportation/traffic
  - On-site
  - Off-site
- Quality assurance/quality control
  - Inspection
  - Tests.

5.3. QUALITY ASSURANCE AND QUALITY CONTROL ASPECTS OF UF_6 STORAGE

A quality assurance (QA) assessment or plan for a UF_6 storage facility should address material handling, cylinder safety, and storage monitoring. The assessment should consider health, safety, and monetary impacts of system failures such as cylinder leakage due to corrosion, handling damage, or damage from earthquake, storm, or other external forces. Cylinder inspections; storage monitoring; maintenance of auxiliary facilities for weighing, filling, and emptying; cylinder handling; waste management; emergency management; personnel training; and preparation and maintenance of operating procedures should also be included in a quality assessment.

5.4. SITE SELECTION AND CRITERIA

5.4.1. Selection

The choice of a site for the safe and secure storage of UF_6 cylinders is often predetermined by the location of processing facilities and the economics and safety of additional transport movements. The physical location can be characterized by factors such as local topography, hydrology, demography, geology, seismology, and climate. Associated with the site will be buildings and structures housing equipment used in receipt and storage, and the appropriate transport infrastructure. The site will usually be capable of transferring UF_6 in both the liquid and the gas phases. A storage site will require provision of services for personnel exposure protection and safety, QA, surveillance, inspection, maintenance, and security.

The assessment of the impact of the location of the site on the environment should include consideration of natural phenomena and situations that could lead to an accidental release of UF_6, including low-probability events. The presence of adjacent sources of atmospheric pollution can significantly affect storage acceptability. Exhausts from chimneys, chemical stacks, and water cooling towers can influence the pH of rainfall or provide particulate deposition which may accelerate cylinder corrosion rates. The degradation of cylinders will also be affected by coastal salt-bearing winds and the general humidity. Temperature variation, both diurnal and seasonal, must be considered in relation to UF_6 physical properties and cylinder design criteria.

5.4.2. Site criteria

(a) Site selection should consider fire, earthquake, and damage from other phenomena.
(b) The site should be well drained and should not be subject to casual flooding. Capability for temporary holding and monitoring of runoff should be provided. Figure 5.3 shows a typical UF_6 cylinder storage yard.
(c) The site should provide a stable surface for cylinder storage.
(d) Site access should be restricted by walls or fences. Security measures should be provided.
(e) The site should be served by transportation facilities suitable for its needs.

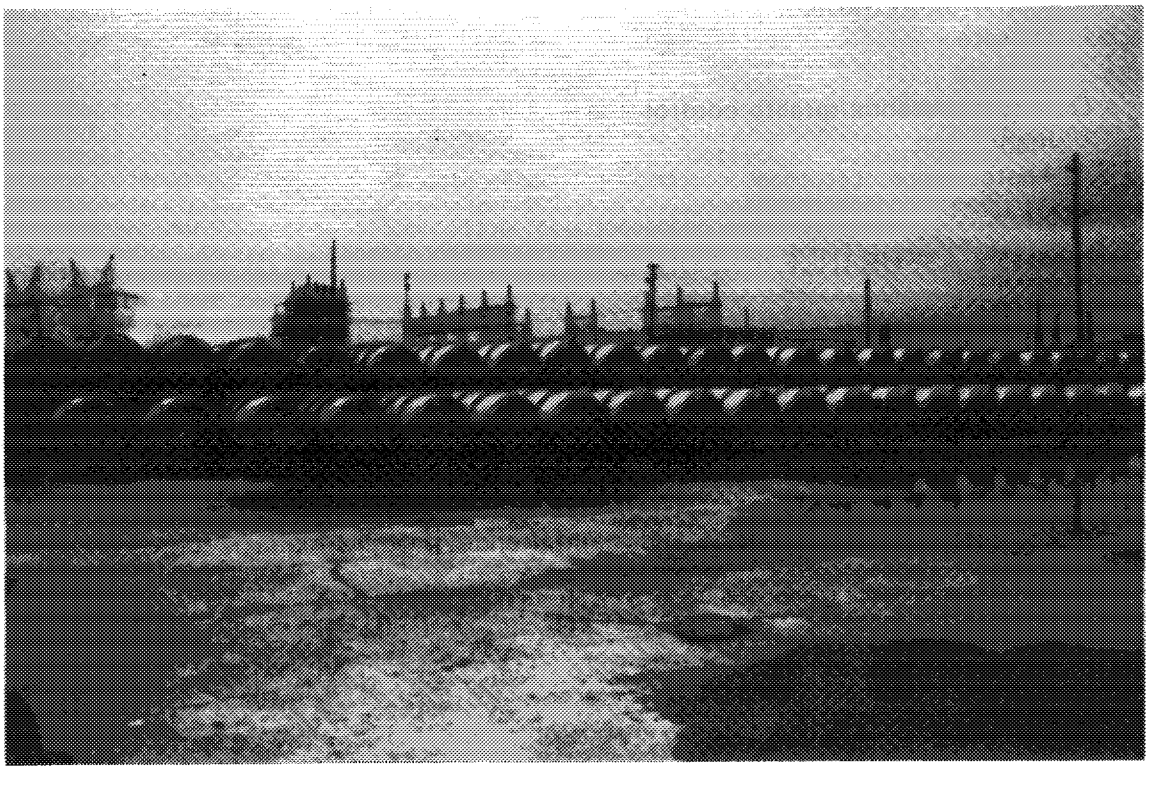

FIG. 5.3. Typical UF_6 cylinder storage yard.

(f) Reasonable containment of accidental releases of UF_6 should be possible.
(g) The site should have facilities for the transfer from one UF_6 cylinder to another, preferably in the gaseous phase.

5.5. EQUIPMENT AND CAPABILITY NEEDS FOR A STORAGE FACILITY

Maintaining a storage facility requires the concurrent maintenance of a range of auxiliary support facilities. Capabilities required for UF_6 cylinder storage include cylinder handling equipment, a system for accountability, QA (including a mechanism to correct deficiencies), and emergency response. Cylinders should be positioned on chocks. Cylinder handling capabilities such as lifting fixtures and hardware, straddle carriers, forklifts, cranes, and specialized cylinder handling machinery are needed. Cylinder damage due to handling activities and cylinder wall thinning due to corrosion processes may render a container unsuitable for transport. Therefore, capability to transfer from one cylinder to another is needed. An alternative would be to have the capability of transporting rejected cylinders to another site. The occasional need to change valves makes it necessary to have the equipment and trained personnel to make such changes. Storage facilities for UF_6 also require leak detection equipment.

5.6. SECURITY

All UF_6 storage facilities require security arrangements appropriate to the ^{235}U enrichment. The highest levels of security are required for ^{235}U enrichments greater than 20%.

Basic requirements for a security system for all UF_6 storage are:

(a) The UF_6 storage facility should be located inside a secure area;
(b) Cleaned, emptied and new UF_6 cylinders should also be stored in a secured area.
(c) UF_6 cylinders should be equipped with tamper-indicating devices during any period when they are not in a secure area.
(d) Access to UF_6 storage areas should be limited to authorized personnel.
(e) An appropriate communications system should be provided to ensure coordination with the security, safety and emergency staffs.

5.7. CRITERIA APPLICABLE TO THE STORAGE OF CYLINDERS OF UF_6 WHERE CRITICALITY IS OF CONCERN

5.7.1. Administrative criteria

(a) Operations and storage arrangements shall follow established practices to prevent accidental nuclear criticality incidents[1].
(b) Methods and practices shall be described in written procedures.
(c) Personnel involved in cylinder movement and storage shall be fully aware of the written procedures.
(d) Compliance with the procedures shall be periodically verified by inspections.

5.7.2. Nuclear criticality safety practices

(a) Experimental data and/or validated computational results shall provide the basis for approved storage arrays.

[1] For example ANSI N16.1–1975, American National Standard for Nuclear Criticality Safety in Operation with Fissionable Materials Outside Reactors [21].

(b) Individual cylinders of UF_6 shall be subcritical under conditions of total submersion in water.

(c) The design, fabrication, and maintenance of facilities and structures for storage shall be in accordance with good engineering practices. Analysis should show accidental criticality shall not result even if fire, flood, earthquake, and other natural phenomena do occur.

(d) The use of physical barriers including fixed storage positions, bird cages, etc., which are sturdy and non-combustible are to be preferred to administrative controls to preclude criticality incidents during storage.

(e) A criticality detection and alarm system should be installed to alert personnel of a nuclear criticality accident[2].

5.7.3. UF_6 enriched to greater than 5% ^{235}U

The maximum ^{235}U enrichment of the UF_6 (see Table 5.1) should not be exceeded to ensure cylinders are geometrically safe.

5.7.4. UF_6 enriched from 1.0% up to 5% ^{235}U

Moderation control is an acceptable method for nuclear criticality safety of UF_6 for enrichments of 1.0% to 5% in large cylinders. By controlling the UF_6 purity to not less than 99.5%, an equivalent moderating ratio expressed as an $H/U = 0.088$ would not be exceeded[3,4]. If moderation control is not maintained (i.e. $H/U > 0.088$), then the UF_6 in this enrichment range must be stored and transported in smaller cylinders and packages (see Table 5.2).

TABLE 5.1. MAXIMUM ENRICHMENT OF UF_6 CYLINDERS FOR SEVERAL CYLINDER DIAMETERS

Cylinder diameter		Maximum enrichment (% U-235)
(in)	(cm)	
5	12.7	100.0
8	20.3	12.5

TABLE 5.2. MODERATION RATIO REQUIREMENTS FOR SEVERAL ENRICHMENT/CYLINDER DIAMETER COMBINATIONS

With moderation control[a] (H/U ratio)	Without moderation control[a] (H/U ratio)	Cylinder diameter (in)	Cylinder diameter (cm)	Maximum enrichment (% U-235)
<0.088		30	76.2	5.0
<0.088		48	121.9	4.5
	>0.088	12	30.5	5.0

[a] A moderation control ratio (H/U) of 0.088 would not be exceeded provided the purity of the UF_6 exceeded 99.5%.

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[2] For example ANSI N16.2-1969, American National Standard Criticality Accident Alarm System [22].

[3] ANSI N14.1-1987, American National Standard for Nuclear Materials – Uranium Hexafluoride, Packaging for Transport [9].

[4] ORO-651, Rev. 5, Uranium Hexafluoride: Handling Procedures and Container Description, September 1987 [13].

5.8. CRITERIA APPLICABLE TO NON-FISSILE AND FISSILE EXCEPTED UF_6

The storage requirements for UF_6 with enrichment less than 1.0% follow the general criteria in Sections 5.1–5.6.

5.9. RADIOLOGICAL AND CHEMICAL CONSIDERATIONS

UF_6 cylinders are often emptied by evaporation (see Chapter 3). Some radioactive impurities may remain and collect at the low points in the cylinder when the UF_6 is evaporated. Thus "empty cylinders" may have a higher external radiation level (i.e., beta and gamma radiation) than full cylinders where the impurities are dispersed through the UF_6 and are shielded to some extent (see Chapter 3). Uranium is also an alpha emitter. Personnel are protected from the alpha radiation and from the chemical properties of UF_6 by the cylinder containment. The guidelines outlined previously (Chapter 3) for radiological and chemical protection of personnel involved with handling UF_6 (both monitoring and emergency) also apply to UF_6 storage.

5.10. EMERGENCY PLANNING (see also Appendix A)

In long-term storage of UF_6, there may be a need to transfer cylinder contents to other cylinders. Transfer capabilities must therefore be available at the storage site for use when corrosion processes or mechanical damage make a transfer necessary. Procedures should be developed for each storage site for monitoring cylinder condition; for recording, storing, and retrieving such data; and for correcting deficiencies as they are identified. Procedures should also be developed for emergency situations, for example handling accidents, material releases, equipment failures, breaches of security, fires or other natural disasters, or man-made situations. Procedures should be developed to respond to accidental material releases — from small leaks to major spills. Emergency procedures to respond to natural catastrophes such as earthquakes, fires, floods, and storms should be prepared. Emergency procedures should be prepared to respond to accidental or intentional damage by man, such as aircraft impact, vehicle damage, sabotage, theft, etc.

5.11. HANDLING, SHIPPING, AND RECEIVING CYLINDERS

Procedures should be prepared for all routine operations in UF_6 storage including cylinder cleaning and inspection, handling, storage, monitoring, and removal from storage. When a cylinder is removed from storage status (i.e. handled), procedures should be followed to maintain accountability and to ensure that the cylinder meets the criteria for the intended application or destination and that all safety, criticality, and environmental conditions are satisfied. The cylinder selected for shipping should be tested to ensure that the pressure within the cylinder is below atmospheric. It should then be inspected to ensure compliance with other handling and shipping criteria. When the cylinder is found to be suitable for shipping, it can then be weighed and moved to a staging area for transfer to a qualified carrier. Cylinders that do not meet internal pressure, external damage, or wall-thickness requirements should be rejected and identified. They should then be submitted for corrective action or marked and set aside for later repair of defects if appropriate.

5.11.1. Storage status

The following steps should be followed before removing cylinders from storage.

(a) A cylinder should be given an internal pressure check to ensure below atmospheric internal pressure.

(b) The cylinder should be inspected for cracks, bulges, dents, valve damage, and other defects.

(c) A weight determination should be made for reconciliation with the entry weight.
(d) Valve protection should be provided, as appropriate.

5.11.2. Storage and transport interface

A staging area may be provided for UF_6 cylinders between storage areas and transport and for their receipt upon arrival. Approved operating procedures should be established for moving cylinders within the site. These procedures should include UF_6 cylinder preparation and inspection and UF_6 cylinder receiving and inspection prior to storage. For off-site transport, requirements can be found in Chapter 4 and the documents referenced there.

5.12. ORIENTATION AND STACKING OF CYLINDERS

5.12.1. Natural and depleted material

In the storage of natural UF_6, no special storage configuration is required for criticality safety. Since inventory control is generally by cylinder serial number, storage arrays will normally be limited to double rows so that any cylinder is accessible to lifting equipment. The 30 and 48 inch cylinders must be stored horizontally with the valve in the 12 o'clock position. The cylinder contents tend to redistribute themselves over time. If this redistribution is not considered, for some types of lifting equipment (notably the H-frame with cables) can be operated outside of their safe load range with an eccentrically loaded cylinder. Long-term storage requires attention to such factors as cylinder support (chocks), visibility of the cylinder serial number, and physical condition of the cylinder (degrees of rusting, valve condition, dents, or other physical damage). Arrays should have sufficient clearance between rows to permit inspection of both ends of each cylinder for monitoring the progress of atmospheric corrosion, wall thinning, and other damage. Cylinders for natural and depleted UF_6 should be stored in orientations and arrays suited for the effective use of handling equipment.

5.12.2. Fissile UF_6

Enriched material is to be stored in cylinders of suitable geometry and/or with suitable moderation control in order to meet criticality considerations. Storage arrays should permit close visual access to the cylinder nameplate, valve, and support points as well as general access to surfaces exposed to corrosion processes. The storage arrays should allow for ease of removal of specific cylinders with a minimum of movement of other cylinders in the array.

5.13. ACCOUNTABILITY AND INVENTORY

Normally all uranium bearing materials are carefully inventoried and tracked due to their value and for safeguards purposes. Quality Assurance standards or other governmental regulations may dictate additional record-keeping requirements. Accountability for UF_6 during its movement through the fuel cycle is most readily maintained through tracking of these cylinders using their serial numbers. The following information should be added to the records recommended in Section 5.1.2:

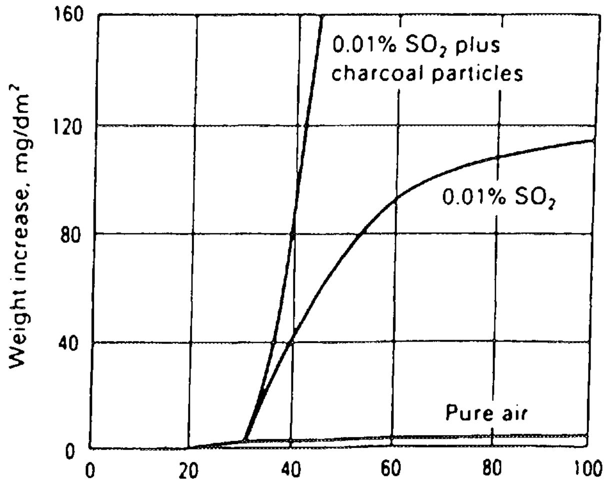
(a) physical location of cylinder;
(b) indication of conditions requiring special handling procedures.

These records should be maintained throughout cylinder lifetimes; computer data bases offer the potential for rapid retrieval and widespread distribution of such information. Responsibility for maintenance of both the cylinders and the cylinder's records should be clearly assigned and monitored. Transfer records should be kept and inventory records should be updated with each transfer. Note the following guidelines:

(a) A record of each cylinder weight and the isotopic assay of contents should be recorded when the cylinder is placed in storage.
(b) Each cylinder in storage should be physically inventoried on a regular basis in accordance with safeguards requirements.
(c) Cylinders filled for storage should be accurately weighed as part of the preparation for storage.
(d) Cylinders removed from storage should be accurately weighed to assure that there has not been a change in weight during the term of storage.
(e) Any evidence of leakage from stored cylinders should initiate corrective measures followed by a weight check to determine if significant amounts of material have been released.

5.14. CORROSION ASPECTS

Unprotected steel cylinders in outside storage are susceptible to general rusting. Corrosion rates depend on weather conditions, atmospheric acidity, (Figure 5.4) and particulate deposition (Figure 5.5). The wide variation in weather with location is illustrated in Table 5.3. It is apparent that location will directly influence anticipated storage life. Wall thinning in specific regions of cylinders may also be expected. Welds, dissimilar material junctions, contact points between cylinders, supports, shaded areas and other regions where drying might be restricted should receive special attention. Most corrosion occurs when the steel surfaces are covered with a thin film of moisture. If conditions preclude drying, accelerated corrosion is likely. Humidity control and ventilation can dramatically reduce cylinder corrosion, particularly when the cylinder surface is not rusty. Cylinder corrosion studies have concluded that UF_6 cylinders can have extremely long lives — 70 years or more. The strength of the cylinders is reduced with a decrease in wall thickness. Table 5.4 provides the minimal wall thickness for various models of UF_6 cylinders for operations and transport. Cylinders with wall thicknesses below these values which contain UF_6 will require special handling when UF_6 is removed. These cylinders should not be transported. Protective coatings, where practical, can be very effective in limiting corrosion. These work best when they incorporate galvanic protection. Adequate surface preparation prior to painting is very important in assuring integrity and promoting durability of the protective coatings (see Figure 5.6).



(L. L. Shreir, Ed., *Corrosion, Vol 1, John Wiley & Sons*)

FIG. 5.4. Effect of relative humidity.

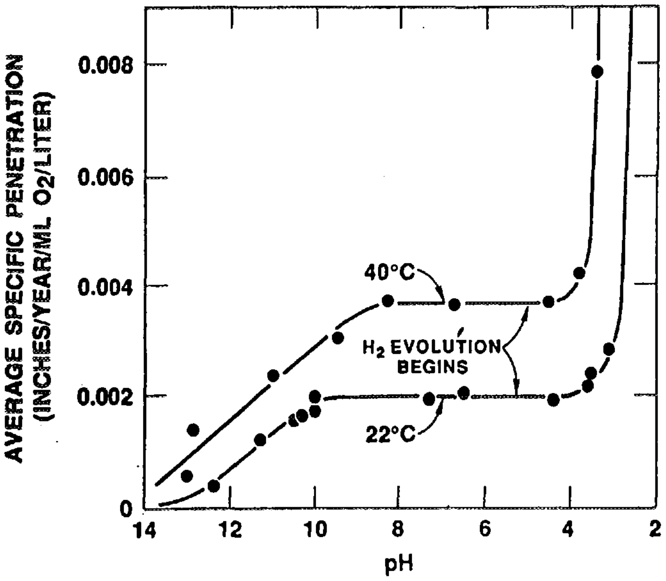


FIG. 5.5. Effect of pH on corrosion of mild steel.

TABLE 5.3. ATMOSPHERIC STEEL CORROSION BY LOCATION[a]

Location	Weight loss (gm)
Norman Wells, NWT, Canada	0.73
Phoenix, Arizona, USA	2.23
Fort Amidor Pier, Panama	7.10
Melbourne, Australia	12.7
Pittsburgh, Pennsylvania, USA	14.9
Miraflores, Panama	20.9
London (Battersea), UK	23.0
Manila, Philippine Islands	26.2
Brazos River, Texas, USA	45.4
London (Stratford), UK	54.3
Kure Beach, North Carolina, USA	71.0

[a] Taken from Corrosiveness of Various Atmospheric Test Sites as Measured by Specimens of Steel and Zinc [23]. Based on weight loss of 4 in. by 6 in. (10 cm by 15 cm) cold-rolled carbon steel coupons after two-year exposures.

TABLE 5.4. MINIMUM CYLINDER WALL THICKNESS[a,b]

Cylinder model	Designed wall thickness (mm)	Minimum wall thickness (in)	Minimum wall thickness (mm)
1S	0.0625	1/16	0.0625
2S	0.112	7/64	0.109
5A, 5B	0.150	1/8	0.125
8A	0.1875	1/8	0.125
12A, 12B	0.250	3/16	0.1875
30B	0.500	5/16	0.3125
48A, 48F, 48X, 48Y	0.625	1/2	0.500
48H[c], 48HX[c],			
48G[c], 480M[c]	0.3125	1/4	0.250

[a] ORO-651 [13].
[b] US 001 49 CFR.179.300.
[c] Low-specific-activity UF_6 cylinders.

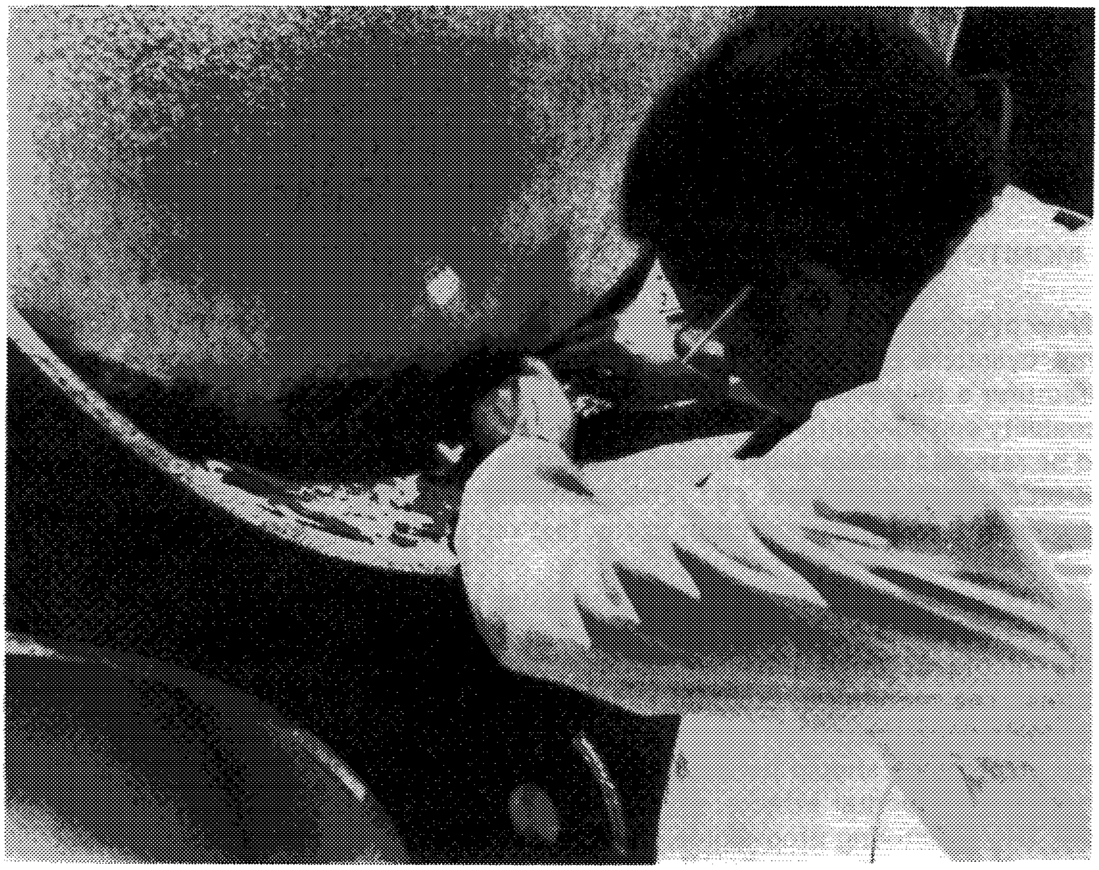


FIG. 5.6. Measuring corrosion attacks.

Aluminum-silicon-bronze and Monel valves are susceptible to stress-corrosion cracking in the presence of HF. Hydrolysis of small amounts of UF_6 leaking through the valve or left in the valve body after valve closure may produce HF if the valve cap is not tightly secured or if the valve packing allows moist air to leak in. Interior UF_6 corrosion of steel cylinder walls generally is of much less concern than exterior attack. Interior steel corrosion proceeds at rates of at least an order of magnitude less than external corrosion. However, the presence of impurities in either solid UF_6 or in the vapor phase can modify corrosion rates. For example, both pitting and stress-corrosion cracking of value components have been traced to the presence of arsenic in the UF_6 feed material. Any such observed attack mechanism should be evaluated in the context of long-term cylinder storage (see Figure 5.6).

Cracked packing nuts have been found; while this does not represent a serious problem, periodic inspections of stored cylinders should note such conditions since they may indicate seat and packing leakage. In addition to HF, atmospheric carbon dioxide (CO_2) may also be responsible for some of the observed cracking. Since long-term deterioration of the pressure vessel and corrosion damage to the valves and plugs from both internal and external influences are recognized as sources of potential problems, the progress of such influences should be monitored by establishing a formal programme of observation and record keeping. The data thus generated will serve as a basis for scheduling corrective actions in the most effective manner to assure continuing safety in long term storage of UF_6.

In practical application:

(a) Cylinders in long-term storage should be periodically inspected to record the status of atmospheric corrosion.

(b) Cylinder valves and plugs should be visually inspected on a periodic basis for evidence of leakage, cracking, or unusual surface deterioration. Leakage should be verified by use of radioactive detection instruments, chemical analysis, etc.
(c) Any pitting, corrosion, and general rusting should be monitored by periodically measuring wall-thickness ultrasonically. Cylinder contents should be transferred if the wall thickness approaches the minimum acceptable value given in Table 5.4.

5.15. MONITORING AND INSPECTION ACTIVITIES

New cylinders may be procured in advance of need. Changing schedules may result in some cylinders remaining in stock, unused for more than five years following the manufacturer's hydrostatic test. Because the purpose of the testing is to demonstrate serviceability and adequate wall thickness even after rusting, unused five-year-old cylinders should be retested before being placed in UF_6 service. Used cylinders intended for storage should be similarly inspected, and retested if necessary. By this procedure, all cylinders used for long-term storage conform to the test requirements when filled with UF_6.

A monitoring programme should be established at long-term storage facilities to determine the condition of the cylinders, including wall-thickness degradation, pitting, valve integrity, dents or other physical damage, and the physical condition of supporting structures. The monitoring program should verify cylinder records, specifically cylinder identification, location, manufacturing and use history, and certification records. Data from periodic inspections should be evaluated to track the condition of cylinders, to discover changing environmental effects, and to plan actions in a safe, economical, and timely fashion. The monitoring programme should also determine the heel mass in the cylinder (see Table 5.5).

TABLE 5.5. ALLOWABLE CYLINDER HEEL MASSES[a]

	Heel mass		
Cylinder Model No.	(kg)	(lb)	(Max. U-235, wt %)
5A or 5B	0.05	0.1	100.00
8A	0.25	0.5	12.50
12A or 12B	0.5	1.0	5.00
30B[b]	11.5	25.0	5.00
48A[c] or 48X	23.0	50.0	4.50
48F[c] or 48Y	23.0	50.0	4.50
48G or 48H	23.0	50.0	1.00
48O, 48OM, 48OM Allied or 48T	23.0	50.0	1.00

[a] ANSI N 14.1 [9].
[b] This cylinder replaces the 30A cylinder. The 30A cylinder has the same heel and maximum ^{235}U limit as the 30B.
[c] Cylinders 48A and 48F are identical to 48X and 48Y, respectively, except that the volumes are not certified.

5.15.1. Cylinders scheduled for storage

Cylinders scheduled for storage should be:

(a) subject to the same internal cleanliness and damage criteria as those scheduled for active service,
(b) inspected for external damage before filling,
(c) hydrostatically tested and inspected before filling.

5.15.2. Cylinders in storage status

Cylinders in storage status should be:

(a) periodically inventoried for accountability,
b) periodically inspected for surface valve and plug condition, and physical damage,
(c) periodically sampled for wall thickness determination,
(d) periodically inspected for leakage.

5.15.3. Cylinder storage areas

Cylinders storage areas should be checked for:

(a) stability or deterioration of supporting surfaces or structures,
(b) absence of flammable materials,
(c) conditions which might enhance corrosion such as accumulated moisture,
(d) security.

5.16. CLEANING AND MAINTENANCE

Cylinders intended for the storage of UF_6 should meet all applicable standards such as those given in ANSI N14.1 [9]. The standard should address external and internal surfaces of new and used cylinders and include a cleaning procedure for new cylinders and a decontamination method for removal of residuals. Cylinders to be used for storage of UF_6 should be within the 5-year period between hydrostatic tests when filled. However, cylinders already filled prior to the 5-year expiration date do not need a full test programme while remaining in storage. A UF_6 cylinder shall be removed from service (for repair or replacement) when it is found to have leaks, excessive corrosion, cracks, bulges, dents, gouges, defective valves, damaged stiffening rings or skirts, or other conditions that, in the judgment of the qualified inspector, render it unsafe or unserviceable in its existing condition. Cylinders shall no longer be used in UF_6 service when their shell and/or head thicknesses have decreased below minimum acceptable values. (See reference Table 5.4 for wall thickness of cylinders.)

Chapter 6

RADIOACTIVE WASTE MANAGEMENT

The management of radioactive waste refers to the handling, pre-treatment, treatment, conditioning, transportation, storage and disposal of radioactive waste materials generated from the production of UF_6. In general, UF_6 can be recycled. Table 6.1 provides a summary of radioactive waste management practices at some UF_6 conversion plants.

Sources and types of radioactive waste at conversion, enrichment and reconversion plants are considered in Sections 6.1–6.3. Section 6.4 describes, in a general manner, the principles and criteria for radioactive radioactive waste management as provided by the IAEA RADWASS Programme [24].

6.1. SOURCES AND TYPES OF RADIOACTIVE WASTE AT CONVERSION PLANTS

Radioactive waste arises mainly from two sources:

(a) waste products originating with the concentrates;
(b) waste products originating from the process reagents used as a result of contamination with radionuclides and toxic reagents.

Most radioactive waste which contains significant amounts of uranium is treated to recover the uranium, both because of its value and to decrease activity and volume of radioactive waste to be disposed of.

The following is radioactive waste that may be produced at UF_6 facilities:

Raffinate	The major waste produced in the refining of yellowcake to UO_3. It may contain metallic impurities, nitric or sulphuric acids, natural thorium and decay products of uranium which are present in the yellowcake.
Solvent extraction Treatment waste	Solvent extraction (SX) treatment waste which may be slightly radioactive and may contain silicate solids and degradation products of kerosene and TBP.
Calcium fluoride	Lime and KOH scrubber solution are reacted to convert potassium fluoride to KOH and to precipitate the fluoride as insoluble calcium fluoride containing very small quantities of uranium, i.e. less than 0.5%. Some scrubbers use water to scrub HF, and dilute HF is reacted with lime to form calcium fluoride. Calcium fluoride can also arise from fluidized bed reactors as a dry solid containing uranium.
Ammonium nitrate	It may occur in solvent extraction raffinates. It is normally contaminated with traces of uranium.
Fluorination ash	This is material from reactor filters. It normally contains short-lived uranium daughter nuclides.
Distillation waste	Impurities resulting from the distillation of crude UF_6.
Garbage and scrap metal	These materials may be contaminated with small quantities of uranium.

The management of these wastes differs significantly between facilities (see Table 6.1).

TABLE 6.1. SUMMARY OF RADIOACTIVE WASTE MANAGEMENT PRACTICES

Converter	Raffinate	SX Treatment Waste	Calcium Fluoride[a]	Amonium Nitrate	Reactor Ash/Fluospar	UF_6 Distillation	Sodium Removal Stage
Allied Signal	None	None	Goes to fluorspar recovery operation. Solutions go to settling pond for treatment prior to discharge.	None	Fluorspar treated for recycle. Effluent goes to pond for treatment before discharge.	Treated and residues disposed of in licensed disposal site.	Solid is sent to licensed disposal site. Solutions go to ponds.
British Nuclear Fuels Ltd	Neutralized with lime and discharged via pipeline to a local estuary.	None	Disposed in local radioactive waste disposal site.	None	CaF_2 treated and recycled. Residues disposed in licenced radioactive waste disposal site.	None	None
Comurhex (wet process)[b]	To raffinate pond	To radioactive waste treatment circuit for U recovery radioactive wastes disposed.	Drummed and stored. ADU reprocessed for U recovery.	Recycled as scrub solution in 5% circuit and in ADU circuit.	Recycled	None	None
(dry process)	None	None	Stored	None		Residue treated for U recovery.	

TABLE 6.1. (cont.)

Converter	Raffinate	SX Treatment waste	Calcium Fluoride[a]	Amonium Nitrate	Reactor Ash/Fluospar	UF_6 Distillation	Sodium Removal Stage
Canecoh	Evaporated to remove nitrates and nitrogen and shipped to uranium mills in northern Ontario.	Drummed and placed in licensed low-level radioactive waste management.	Sent to licensed storage[c]. KDU stored for future processing.	None	Recycled. Remainder stored in drums on-site.	None	None
Sequoyah Fuels	Pumped to raffinate pond for neutralization and treated for radium removal and then used as fertilizer.	Goes with raffinate to pond partially dried and recycled to mill.	Pumped to CsF_2 settling pond for treatment: solutions discharged.	In raffinate (used as fertilizer).	Recycled.	None	None
PNC	To radioactive waste treatment circuit	To radioactive waste treatment circuit	Drummed and stored	None	Recycled. Remainder stored in drums on-site.	None	None

[a] U absorption and F absorption resin are used for radioactive waste water treatment after CaF_2 precipitation at PNC test facility.
[b] Some radioactive wastes from the Pierrelatte operation are sent to the Narbonne facility for reprocessing and disposal.
[c] As experimental programme underway to recycle the CaF_2.

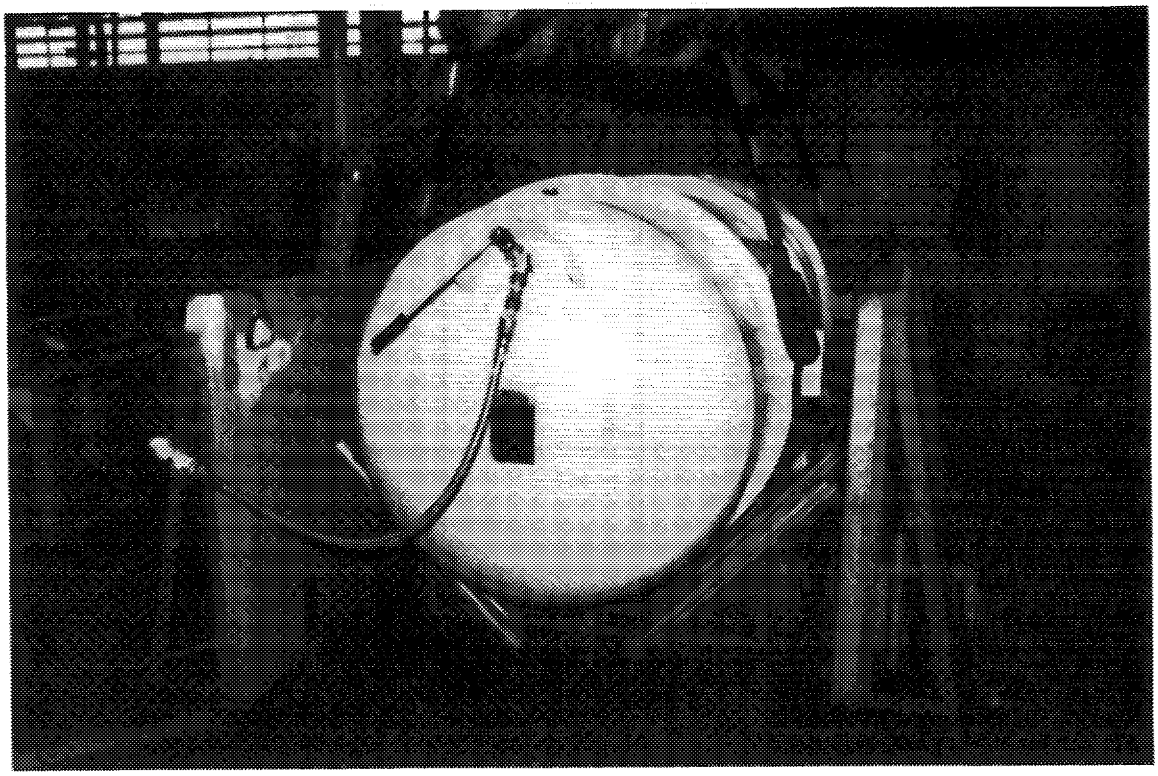


FIG. 6.1. Cylinder cleaning.

6.2. SOURCES AND TYPES OF RADIOACTIVE WASTE AT UF_6 ENRICHMENT PLANTS

The main source of radioactive waste at enrichment plants arises from UF_6 cylinder cleaning and plant component decontamination solutions (See Figure 6.1). These solutions are treated, filtered and in some cases the uranium is recovered. Other radioactive waste includes solid trap materials and scrubber solutions which are treated before discharge.

6.3. SOURCES AND TYPES OF RADIOACTIVE WASTE AT RECONVERSION PLANTS

The main sources of radioactive waste at UF_6 reconversion plants are filtrate from AUC (ammonium uranyl carbonate) and ADU (ammonium diuranate) process filtration stages for wet processing. Another ADU source is solutions from UF_6 cylinder cleaning. Hydrofluoric acid solution originates from hydrofluoric acid recovery systems for dry processes. Filtrate, normally comprised of ammonium fluoride, is neutralized by means of lime to give ammonia hydroxide and calcium fluoride. Recovered ammonia is recycled to the process precipitation stage for wet processes. Calcium fluoride with a small amount of uranium is directly stored or used for industrial purposes. After uranium removal, dilute HF solution is neutralized by lime to give calcium fluoride. Calcium fluoride is either stored or reused.

6.4. SAFETY PRINCIPLES AND REQUIREMENTS

Safe management of radioactive waste involves the application of technology and resources in an integrated and regulated manner so that occupational and public exposure to ionizing radiation is controlled and the environment protected in accordance with national regulations and international consensus documents. To meet this overall objective, the following internationally agreed upon safety principles, defined in the most recent draft RADWASS Safety Fundamentals, entitled The Principles of Radioactive Waste Management [25], need to be applied.

Principle 1. Protection of human health

Radioactive waste shall be managed in a way to secure an acceptable level of protection of human health.

Principle 2. Protection of the environment

Radioactive waste shall be managed in a way that provides protection of the environment.

Principle 3. Protection beyond national borders

Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will not be greater than what is acceptable within the country of origin.

Principle 4. Protection of future generations

Radioactive waste shall be managed in a way that predicted impacts on the health of future generations do not exceed relevant levels that are acceptable today.

Principle 5. Burden on future generations

Radioactive waste shall be managed in a way that will not impose undue burdens on future generations.

Principle 6. Legal framework

Radioactive waste shall be managed within an appropriate legal framework including clear allocation of responsibilities and provision for independent regularoty functions.

Principle 7. Control of radioactive waste generation

Generation of radioactive waste shall be kept to the minimum practicable.

Principle 8. Radioactive waste generation and management interdependencies

Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

Principle 9. Safety of facilities

Safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

In order to achieve the safety objective of these principles, a national radioactive waste management system must be established [26]. Such a system must specify the objectives and requirements of a national strategy for radioactive waste management and the responsibilities of the parties involved. It must also describe other essential features, e.g. licensing processes and safety and environmental assessments. The elements of such a national radioactive waste management system are summarized in the most recent draft Safety Standard, Establishing a National System for Radioactive Waste Management [26], which assigns the following ten responsibilities to the State, the regulatory body or the operators.

Responsibilities of the State:	1.	Establishment and implement of a legal framework.
	2.	Set up a regulatory body.
	3.	Define responsibilities of waste generators and operators.
	4.	Provide for adequate resources
Responsibilities of the Regulatory Body:	5.	Apply and enforce legal requirements.
	6.	Implement the licensing process.
	7.	Advise the government.
Responsibilities of the operators:	8.	Identify an acceptable destination for the radioactive waste.
	9.	Safely manage the radioactive waste.
	10.	Comply with legal requirements.

Achievement of the safety objectives as described in Ref. [25] also requires the definition of technical safety requirements for each individual subject area in radioactive waste management. These requirements are being formulated in the RADWASS Safety Standards for the respective subject areas [26–31].

Chapter 7

QUALITY ASSURANCE

7.1. INTRODUCTION

Quality assurance is defined as all those planned and systematic actions necessary to provide adequate confidence that an item, or service, will satisfy given requirements for quality. The total activities established and implemented to assure quality together constitute the quality assurance programme.

Each country normally requires those applicants who wish to construct nuclear facilities to establish and implement an effective overall quality assurance programme for the safety-related components, systems, structures and activities associated with the facility.

7.2. SCOPE

This chapter specifies requirements for an operator's quality assurance programme. The owner is responsible for planning and developing a programme which ensures that all his management, operations and technical responsibilities for quality are defined, integrated and executed effectively. The programme is aimed primarily at preventing non-conformance in quality and detecting and correcting it if it occurs. The programme requirements apply to all safety-related equipment, systems and activities. The owner-operator is required to identify all such equipment, systems and activities. The owner operator may apply the programme to other equipment, systems and activities at his option.

7.3. QUALITY ASSURANCE PROGRAMMES

The overall programme is made up of all quality assurance activities connected with the facility and is established and implemented by the combined effort of all those involved in the work related to it. This programme shall cover the procurement, design, manufacture, construction and installation, commissioning, operation, maintenance and decommissioning phases of the nuclear facility's life-cycle. A constituent quality assurance programme for each of the individual phases shall also be established and implemented. No safety-related activities shall be commenced in a phase prior to the approval of the quality assurance programme covering that phase by the competent authority.

Each operator is required to identify the scope of the overall quality assurance programme to the safety-related components, systems, structures and activities associated with the facility. A description of this programme to be applied to each UF_6 facility shall be included with the preliminary safety analysis report submitted in support of the application for the construction permit. Reference should be made to the relevant national and international standards, for example:

- IAEA Safety Series No. 37: Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, Third Edition (1990) [17].

- IAEA Safety Series No. 50-C-QA (Rev.1): Code on the Safety of Nuclear Power Plants: Quality Assurance (1988) [32].

Table 7.1 provides an outline for a quality assurance programme for radioactive material transport (from Safety Series No. 37) and an outline for a quality assurance programme for nuclear power plant safety (from Safety Series No. 50-C-QA). Note how similar in structure and content the QA programmes are for these different activities.

TABLE 7.1. COMPARISON OF QA REQUIREMENTS FOR TRANSPORTATION AND NUCLEAR POWER PLANTS

Quality assurance in the safe transport of radioactive material (Safety Series No. 37) [17]	Quality assurance for safety in nuclear power plants Safety Series No. 50-C-QA) [32]
1. INTRODUCTION	1. INTRODUCTION
1.1. General	General
1.2. Scope	Scope
1.3. Responsibility	Responsibility
2. QUALITY ASSURANCE PROGRAMMES	2. QUALITY ASSURANCE PROGRAMMES
2.1. Introduction	General
2.2. Graded approach to quality assurance	Procedures, instructions and drawings
2.3. Relationship of grading to package type	Management review
2.4. User's guide	
3. ORGANIZATION	3. ORGANIZATION
3.1. Responsibility, authority and communication	Responsibility, authority and communications
3.2. Organizational interfaces	Organizational interface
	Staffing and training
4. DOCUMENT CONTROL	4. DOCUMENT CONTROL
4.1. Document preparation, review and approval	Document preparation, review and approval
4.2. Document release and distribution	Document release and distribution
4.3. Document change control	Document change control
5. DESIGN CONTROL	5. DESIGN CONTROL
5.1. General	General
5.2. Design interface control	Design interface control
5.3. Design verification	Design verification
5.4. Design changes	Design changes
6. PROCUREMENT CONTROL	6. PROCUREMENT CONTROL
6.1. General	General
6.2. Supplier evaluation and selection	Supplier evaluation and selection
6.3. Control of purchased items and services	Control of purchased items and services
7. MATERIAL CONTROL	7. CONTROL OF ITEMS
7.1. Identification and control of materials, parts and components	Identification and control of materials, parts and components
7.2. Handling, storage and shipping of materials, parts and components	Handling, storage and shipping
	Maintenance

TABLE 7.1. (cont.)

Quality assurance in the safe transport of radioactive material (Safety Series No. 37) [17]	Quality assurance for safety in nuclear power plants (Safety Series No.50-C-QA) [32]
8. PROCESS CONTROL	8. PROCESS CONTROL
9. INSPECTION AND TEST CONTROL	9. INSPECTION AND TEST CONTROL
9.1. Programme of inspection	Programme of inspection
9.2. Test programme	Test programme
9.3. Calibration and control of measuring and test equipment	Calibration and control of measuring and test equipment
9.4. Indication of inspection, test and operating status	Indication of inspection, test and operating status
10. CONTROL OF USE AND CARE OF PACKAGES	
11. NON-CONFORMITY CONTROL	10. NON-CONFORMANCE CONTROL
	General
	Non-conformance review and disposition
12. CORRECTIVE ACTIONS	11. CORRECTIVE ACTIONS
13. RECORDS	12. RECORDS
13.1. Collection, storage and preservation of quality assurance	Preparation of quality assurance records
13.2. Package records and logbook	Collection, storage and preservation of quality assurance records
14. STAFF AND TRAINING	
15. AUDITS	13. AUDITS
	General
	Scheduling
DEFINITIONS	DEFINITIONS

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Chapter 8

SAFETY ANALYSIS

8.1. INTRODUCTION

Facilities that are involved in the production, handling, transportation, and storage of UF_6 should be sited, designed, constructed, modified, operated, maintained, and decommissioned according to a policy of providing for the safety and health of the employees, the safety and health of the public, and for the protection of the environment.

This policy should be implemented within a systematic and comprehensive safety programme. The safety programme should include:

(a) a safety analysis and review programme,
(b) measures to ensure that the risks associated with the activity are acceptable,
(c) a documented design basis,
(d) the use of appropriate standards, codes, and guides,
(e) operating, emergency, and maintenance procedures,
(f) training for operating and support personnel,
(g) administrative controls, operational safety requirements, etc.,
(h) a quality assurance programme,
(i) a configuration control programme.

Activities and facilities that are involved in the production, handling and transportation of UF_6 should be assessed periodically in a comprehensive safety analysis programme to ensure the protection of the environment and the safety and health of the employees and the public. The safety analysis and review programme should identify the hazards of an activity/facility; it should describe and analyse the adequacy of the measures taken to eliminate, control, or mitigate identified hazards; and it should analyse and evaluate potential accidents and their risks. The specific requirements for the safety analysis should be based on national and international requirements and on the facility operator's responsibility to operate the facility in a safe manner.

8.2. THE SAFETY ANALYSIS PROCESS

Environmental damage and health risk could result from accidental releases of radioactive and chemically noxious materials. Releases may be caused by the failure of equipment or safety-related systems [33]. Potential hazards and risks to the employees, to the public, and to the environment should be analysed to determine if the design criteria for the facility is adequate and what off-site emergency and contingency plans are required. Routine releases to the environment should be monitored to ensure that the limits set by regulatory agencies are met. Emissions should always be kept as low as reasonably achievable (ALARA).

The scope of an analysis should include both the radiological and non-radiological safety of an activity [34]. The safety analysis and review programme should address the production, handling, transportation, and storage of UF_6 including, siting, design, construction, modification, operation, maintenance, and decommissioning. Different types of safety analyses may be required for particular areas of concern, such as transportation. Safety analysis activities utilize various techniques. The methods used depend on factors such as the UF_6 operation involved, the location of the facility, and the requirements of the regulatory authority. Safety analyses may be prepared by facility staff or by independent consultants. Safety analysis techniques or methods may include: (1) safety assessments, (2) deterministic safety analyses, (3) probabilistic risk assessments, and (4) combinations of these methods.

(1) Safety assessments: Safety assessments identify the hazards of an activity, the worst accident that may develop performing the activity, the need to eliminate, control or mitigate the hazards, and the need for more detailed safety analysis [35].

(2) Deterministic safety analysis: In the deterministic safety analysis, "design basis events" are selected and evaluated to demonstrate the adequacy of the design of a facility. The deterministic safety analyses involve: (1) selection of design basis events — usually by frequency categories, (2) determination of the safety functions, (3) determination of the need for safety equipment or operator actions to limit the consequences, (4) determination of the design requirements for the operator actions, (5) demonstrating that the consequences are within the safety limits, (6) use of conservative analysis methods, models, and assumptions, (7) taking credit for only safety equipment, (8) making allowance for specific failures in equipment (single failure criteria). This method is often required for licensing by the regulatory authority.

(3) Probabilistic risk assessment (PRA): The PRA method is used to quantify the levels of "risk" associated with the activity or the facility. Risk may be used as an indicator of the level of safety. Risk is usually expressed in terms of the probabilities/frequencies of potential accidents and their consequences. If the results are unacceptable, actions should be taken to reduce the probability, the consequences, or both. The PRA methods involve: (1) identification of potential initiating events, (2) evaluation of the events to determine frequencies, failure rates, probabilities, etc., (3) determining the major contributors to risk, (4) consideration of multiple failures, (5) determining weakness in safety systems. PRA methods are often used to (1) supplement, complement, extend, focus, and refine the conservative deterministic safety analyses, (2) establish technical specifications, operational safety requirements, and maintenance intervals, (3) evaluate and improve plant availability and reliability, (4) and determine the best use of resources to be applied to safety.

Analyses of uranium hexafluoride processes have concluded that worst case accidents arise from UF_6 and/or anhydrous hydrogen fluoride leakage. Therefore, measures should be taken to prevent or mitigate those accidents. To prevent hazardous material leaking, equipment should be carefully designed. Consideration should be given to facility location, positioning of equipment to maximize access for maintenance, provision of internal negative pressure in work areas, and selection of proper materials. Redundant process containment and effluent treatment should be considered. Where an emergency system may fail to operate, redundant safety systems should also be considered. Additional examples can be found in Chapter 3.

8.3. TOPICS AND GUIDES FOR SAFETY ANALYSES FOR ACTIVITIES AND FACILITIES

This section provides an outline with subjects for many of the safety topics that should be addressed in safety analyses for UF_6 activities and facilities. Some topics may not be applicable to specific types of activity or facility. Topics for transportation, shipping, and packaging are provided in Section 8.4. Requirements and more detailed guidelines for several of the safety topics are provided in other chapters of this guidebook.

8.3.1. Site characteristics

- Geography and demography of the site
- Meteorology

- Short-term (accident) and long-term (routine) dispersion estimates for atmospheric dilution
- Surface and subsurface hydrology
- Floods from precipitation or dam failures
- Flood protection
- Low water considerations
- Dispersion of effluent in the surface water and groundwater
- Geology and seismology (earthquake history).

8.3.2. Facility and process/operation systems-description-design features

- Summary descriptions
  - Location, layout, arrangements
  - Process flow diagrams
- Support systems
- Safety design features and safety analysis considerations
  - Confinement features
  - Radiation and hazardous materials source terms
  - Nuclear criticality prevention
  - Chemical, radiological, and fire safety
  - Shielding
  - Ventilation
  - Effluent monitoring
  - Inspection and maintenance provisions and programmes
  - Instrumentation and control systems
- Material/product handling.

8.3.3. Principal design bases and criteria

- Purpose and functions of the facility, process systems, and safety systems
- Design basis accidents and features for their prevention and mitigation
- General design criteria
  - Wind, tornado, and seismic loadings
  - Flood, missile and blast protection
  - Confinement barriers and systems
  - Protection systems
  - Nuclear criticality safety
  - Radiological protection
  - Fire and explosion protection
  - Materials handling and storage
  - Industrial and chemical safety
  - Decommissioning
- Conformance with applicable national and international regulations, codes, standards, requirements, etc.

8.3.4. Safety structures, systems, and components (SSC)

- Criteria for selection of safety SSC
- Listing of safety SSC
- Safety functions and accident scenarios
- Safety and seismic classifications of SSC
- Specific design criteria for SSC.

8.3.5. Waste confinement and management

- Identification of wastes and pathways

- Waste handling – liquid and solid wastes
  - Methods and equipment
  - Packaging
- Storage
- Transport.

8.3.6. Facility safety programme

Radiation protection/health physics safety programme (ALARA Policies)

- Exposure and contamination control
  Description of the methods proposed for preventing the spread of contamination throughout the facility should be addressed. Areas of high contamination risk should be identified, and the system of dividing the facility into contamination control zones should be described. Access to contaminated zones should be controlled and occupancy times limited.

- Monitoring test, inspection, and calibration programmes
  Philosophy of the monitoring programme, reasons for monitoring, equipment, use of data collected should be described. Instruments, plans, and procedures for monitoring continually or periodically should be described.

- Radiation survey
  Radiation monitoring programmes should include evaluation of the adequacy of the containment and control provisions to ensure radiological safety of personnel.

- Personal dosimetry
  - Personal dosimeter type
  - Type of radiation detected
  - Frequency of dosimeter reading evaluation
  - Special dosimeter requirements

- Bioassay
  Methods for determining the extent of internal contamination (urinalysis, whole-body counting or other procedures).

- Air sampling programmes
  Areas to be sampled, sampling frequency, methods used to relate sample results to personnel exposure.

- First aid facilities

- Records and reporting
  Information relating to occupational safety and radiation safety, including radiation exposures, radiation survey results, effluent monitoring results and bioassay.

- Protective equipment
  - Respirators/gas masks
  - Chemical suits
  - Shielding and ventilation systems
  - Alarm systems
  - Safety and relief devices

- Nuclear criticality safety programmes
  - Nuclear criticality safety evaluations and safety limits

- Administrative and procedural nuclear criticality controls
- Training
- Audits
- Chemical safety

– Fire protection
  - Fire safety training, inspection, and drills
  - Policies for controlling flammable and combustible materials

– Environmental monitoring
  - Monitoring release points
  - Monitoring on-site and off-site environments
  - Emergency preparedness

– Safety analysis programme
  - Preparation and review
  - Updates for modifications to equipment and procedures

8.3.7. Analysis of normal operations

– Identification of hazards and mitigators associated with normal operation and anticipated operational transients.
– Design features, policies, and procedures for protection from hazardous materials and radiation exposure.
– Analysis of exposures of operators and of off-site public.
– Comparison of consequences with acceptance criteria.

8.3.8. Accident analysis

– Identify hazards and initiating events
  - Methods used to identify hazards and accident initiators
  - Internal and external hazards
  - Probabilities of initiating events

– Analysis of accident scenarios
  - Methods, models, source terms, assumptions, etc.
  - Selection of bounding scenarios
  - Mitigating effects of safety equipment and operator actions
  - Assumptions for failures in safety and other equipment and operator actions
  - Consequences
  - Effects on employees, public, and environment
  - Evacuation procedures and effects

– Probabilities for bounding accident scenarios, including equipment and operator failures

– Comparison of consequences with the safety limits

– Estimation of risk

– Operational limits resulting from the accident analysis

  Example: For a UF_6 handling operation, an analysis might include the following accident scenarios:
    UF_6 release due to equipment failure

HF or F_2 release due to equipment failure
Explosion due to hydrogen leaks or presence of impurities in a process system
Damage to facility due to the occurrence of incidents external to the plant site (e.g. train crash, natural disaster, adverse weather).

8.3.9. Conduct of operations

- Organizational structure and qualifications for engineering construction, operation, maintenance, and safety

- Testing, surveillance, and inspection programmes

- Training programmes
  Safety training with respect to plant operations should be provided with emphasis on UF_6 handling

- Normal operational programmes
  - Safety review programme
  - Operating maintenance, and testing procedures

- Emergency planning
  Procedures to handle a nuclear criticality accident when dealing with enriched U storage, transport, and processing should be detailed. Enriched U storage, and processing should be given special consideration.

- Configuration management and facility records.

8.3.10. Operational safety requirements

- Safety limits, limiting safety systems settings, and limiting conditions for operation
- Surveillance requirements (frequency and scope)
- Acceptance criteria
- Design features important to physical barriers and to maintaining safety margins
- Administrative controls for safety.

8.3.11. Quality assurance

- Quality assurance programme and organization:
  - Design,
  - Construction,
  - Operation.
- Conformance with national and international requirements.

8.4. TOPICS FOR SAFETY ANALYSES FOR TRANSPORTATION, SHIPPING AND PACKAGING

This section provides a description of some of the safety topics that should be addressed in safety analyses for the transportation, shipping, and packaging of UF_6 cylinders. Requirements and guidelines for transport and packaging are provided in Chapter 4.

8.4.1. General description

Provide a description of the package and contents, operating features of the package, and detailed drawings of the packaging.

8.4.2. Structural evaluation

Describe the structural design of the packaging; identify the weights and centers of gravity; include all mechanical properties of the materials; address general standards for all packages (chemical and galvanic reactions, positive closure, lifting and tiedown devices); provide standards for Type B and large quantity packaging (load resistance, external pressure); specify normal condition of transport (heat, cold, pressure, vibration, water spray, free drop, corner drop, penetration, compression); and define hypothetical accident conditions (free drop, puncture, thermal, water immersion), and summary of damage.

8.4.3. Thermal evaluation

Provide a summary of thermal properties of materials, technical specifications of components, thermal evaluation for normal and possible accident conditions of transport (maximum and minimum temperature, maximum internal pressure, maximum thermal stresses).

8.4.4. Containment

Identify the containment boundary (containment vessel, penetrations, seals, welds, closure) requirements for normal and possible accident conditions of transport (release of radioactive material, over-pressurization of the containment vessel, coolant contamination, coolant loss).

8.4.5. Shielding evaluation

Identify the radiation source (both gamma and neutron), describe the model specification (including radial and axial shielding configuration and shield densities), and present the results of the shielding evaluation.

8.4.6. Nuclear criticality evaluation

Describe the package fuel loading, present the criticality calculations (calculational or experimental method, fuel or other loading, criticality results), and present benchmark experiments (benchmark experiments applicability, results of benchmark calculations, and description of the model used).

8.4.7. Operating procedures

Describe the loading and unloading procedures for the package, and the procedures for preparation of an empty package for transport.

8.4.8. Acceptance tests and maintenance programme

Describe all acceptance tests for the package (visual inspection, structure and pressure tests, leak tests, component tests, shielding integrity tests, and thermal acceptance tests). Define the maintenance programme (structural and pressure tests; leak tests; subsystem maintenance; valves, and gaskets on containment vessel; shielding tests, and thermal tests).

8.4.9. Quality assurance

Describe the quality assurance programme to be applied to the design, fabrication, assembly, testing, maintenance, repair, modification, and use of the package.

Appendix A

SUGGESTED FORMAT AND CONTENT FOR EMERGENCY PLANS FOR FUEL CYCLE AND MATERIALS FACILITIES[1]

A.1. INTRODUCTION

An acceptable emergency plan should describe the licensed activities, the facility, and the types of accidents that might occur. It should provide information on classifying postulated accidents and the licensee's procedures for notifying and co-ordinating with offsite authorities. The plan should provide information on emergency response measures that might be necessary, the equipment and facilities available to respond to an emergency, and how the licensee will maintain emergency preparedness capability. It should describe the records and reports that will be maintained. There should also be a section on recovery after an accident, including plans for restoring the facility to a safe condition. Detailed information that would help response organizations assess accident consequences and estimate releases should be included in the plan.

An effective response to an emergency comprises WHAT is to be done (procedures), BY WHOM (response personnel), and WITH WHAT (equipment in designated locations). The emergency plan reflects, in general terms, the preplanning done in preparing to cope with an emergency, but the details of the actual response are contained in the emergency plan's implementing procedures.

The implementing procedures are the heart of the emergency response. They must be clear, precise, and easily understood. Each procedure should pertain to a narrow, specific response action.

A.2. FORMAT

A.2.1. Graphical presentations

Graphical presentations such as drawings, maps, diagrams, sketches, and tables should be employed if the information may be presented more accurately or conveniently by such means. Due concern should be taken to ensure that all information presented is legible, that symbols are defined, and that scales are not reduced to the extent that visual aids are necessary to interpret pertinent items of information. These graphical presentations should be located in the section where they are primarily discussed.

References used may appear as footnotes on the page where discussed or at the end of each chapter.

A.2.2. Physical specifications

Page numbering. Pages should be numbered with the digits corresponding to the chapter followed by a hyphen and a sequential number. e.g., the third page of Chapter 4 should be numbered 4-3. The chapter numbers should correspond to the chapters in this guide. Do not number the entire plan sequentially.

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[1] This appendix is derived from the US Nuclear Regulatory Commission's Regulatory Guide, January 1992, Office of Nuclear Regulatory Research. The example plan described is one which has been used successfully by operators in the USA. Other approaches could be satisfactory, but the basic components of the plan described should be part of any emergency response plan for fuel cycle and materials facilities.

List of effective pages. A list of every page in the plan and the effective revision number or revision date of each page should be provided as a means of verifying that the plan is complete and current. The list should include the pages of any enclosures that are part of the plan.

Table of contents. A table of contents and an index of key items should be included.

A.2.3. Procedures for updating or revising pages

Data and text should be updated or revised by replacing pages. The changed or revised portion on each page should be highlighted by a "change indicator" mark consisting of a bold vertical line drawn in the margin opposite the binding margin. The line should be of the same length as the portion changed.

All pages submitted to update, revise, or add pages to the plan should show the revision number or revision date. Each revision should include a new list of effective pages and an instruction sheet listing the pages to be inserted and the pages to be removed. Readers should be instructed to check the plan against the list of effective pages to verify that the revised plan is complete.

A.3. EXAMPLE EMERGENCY PLAN

1. FACILITY DESCRIPTION

The information is this section is to provide perspective about the facility and the licensed activity such that the adequacy and appropriateness of the licensee's emergency planning, emergency organization, and emergency equipment can be evaluated.

1.1. Description of licensed activity

Present briefly the principal aspects of the overall activities conducted at the facility, the location of the facility, and the type, form, and quantities of radioactive and other hazardous materials normally present should be included.

1.2. Description of facility and site

Provide a detailed drawing of the site for the emergency plan. An enlarged duplicate of the drawing suitable for use as a wall map should also be provided. The detailed drawing should be drawn to scale and show or indicate the following:

(1) Onsite and near-site structures with building numbers (if applicable) and descriptive labels.
(2) A bar scale in both meters and feet.
(3) A compass indicating north.
(4) Roads and parking lots onsite and main roads and highways near the site.
(5) Site boundaries, showing fences and gates.
(6) Exhaust stacks, storage areas, retention ponds, and other major site features.
(7) Rivers, lakes, streams, or other ground-water sources onsite and within approximately 1.5 kilometers.

Provide a concise description of all site features affecting emergency response, including communication and assessment centers, assembly and relocation areas, and process and storage areas. Identify any additional site features likely to be of interest because they are related to the safety of site operations. The emergency plan should include a list of all hazardous chemicals used at the site, typical quantities possessed, locations of use and storage, and the hazardous characteristics (radioactivity, pH, other) of material in sediment and retention ponds. The stack heights, typical stack flow rates, and the efficiencies of any emission control devices should be summarized in the emergency plan to help response organizations assess releases.

1.3. Description of area near the site

Include a description of the principal characteristics of the area near the site at which licensed activities are conducted. Indicate the site on a general area map (approximately 15 kilometers radius) and on a topographical map if available. Provide a map or aerial photograph indicating onsite structures and nearsite structures (about 1.5 kilometer radius). On this photograph or map, include the following:

(1) Locations of population centers (towns, cities, office buildings, factories, schools, arenas, stadiums, etc.);
(2) Locations of facilities that could present potential protective action problems (schools, arenas, stadiums, prisons, nursing homes, hospitals);
(3) Identification of primary routes for access of emergency equipment or for evacuation, as well as potential impediments to traffic flow (rivers, drawbridges, railroad grade crossings, etc.);
(4) Locations of fire stations, police stations, hospitals, and other offsite emergency support organizations (specify whether qualified to handle exposure to radioactive contamination or toxic chemicals);
(5) The sites of potential emergency significance (e.g. liquefied petroleum gas (LPG) terminals, chemical plants, pipelines, electrical transformers, and underground cables);
(6) Identification of the types of terrain and the land use patterns around the site.

2. TYPES OF ACCIDENTS

Emergency planning is concerned with individual and organizational responses to a range of potential accidents, including those accidents that have been hypothesized but that have a very low probability of occurrence.

2.1. Description of postulated accidents

Identify and describe each type of radioactive materials accident for which actions may be needed to prevent or minimize exposure of persons offsite to radiation or radioactive materials. Exposure levels at the site boundary should be treated as the levels potentially affecting persons offsite.

Describe the accidents in terms of the process and physical location where they could occur. Describe how the accidents could happen (equipment malfunction, instrument failure, human error, etc.), possible complicating factors, and possible onsite and offsite consequences. Accident descriptions should include nonradioactive hazardous material releases that could impact emergency response efforts. Facilities that can have criticality accidents should evaluate the direct radiation exposure from postulated criticality accidents in addition to the dose from released radioactive materials.

2.2. Detection of accidents

Describe the means provided to detect and to alert the operating staff of any abnormal operating condition or of any other danger to safe operations (e.g. a severe weather warning). For each type of accident identified in the emergency plan, describe the means of detecting the accident, the means of detecting any release of radioactive or other hazardous material, the means of alerting the operating staff, and the anticipated response of the operating staff. Examples are visual observation, radiation monitors, smoke detectors, process alarms, and criticality alarms. Indicate at what stage of the accident it would be detected. Also indicate if the area of the postulated accidents or remote readouts of alarms or detectors located in such areas are under continuous visual observation.

3. CLASSIFICATION AND NOTIFICATION OF ACCIDENTS

Accidents should be classified as an plant emergency or a site area emergency according to the definitions below. In its emergency plan and in co-ordination meetings with offsite authorities, the licensee should convey the concept that fuel cycle and materials facilities do not present the same degree of hazard (by orders of magnitude) as are presented by nuclear power plants. Thus, the classification scheme for these facilities is different. The licensee should explain to offsite authorities the definitions of accident severity and the expected response actions associated with plant emergency and site emergency conditions. The US Nuclear Regulatory Commission's "A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Materials Licensees" by S.A. McGuire [36] contains a description of past incidents in the USA involving radioactive materials.

3.1. Classification system

A *plant emergency* is defined as an incident that has led or could lead to a release to the environment of radioactive or other hazardous material, but the release is not expected to require a response by an offsite response organization to protect persons offsite. A plant emergency reflects mobilization of the licensee's emergency response organization,either in a standby mode that will activate some portions of the licensee's organization or full mobilization, but does not indicate an expectation of offsite consequences. However, a plant emergency may require offsite response organizations to respond to onsite conditions such as a fire.

A *site emergency* is defined as an incident that has led or could lead to a significant release to the environment of radioactive or other hazardous material and that could require a response by an offsite organization to protect persons offsite. A site emergency reflects full mobilization of the licensee's emergency response organization and may result in requests for offsite organizations to respond to the site.

In the emergency plan, identify the classification (plant emergency or site emergency) that is expected for each of the accidents postulated in Section 4.1 of this guide. Relate the classification to the accident description and detection means described in Section 4.2. Identify the emergency action levels (EALs) at which a plant emergency or site emergency will be declared. EALs are specific conditions that require emergency response measures to be performed. Licensees should establish specific initiating conditions relative to particular events or changes in instrument sensors. Appendix B provides a list of examples of initiating conditions for declaring a plant emergency or site emergency.

Although it is unlikely that a site emergency requiring offsite actions will occur at a fuel cycle or materials facility, the operator must be able to recognize potential offsite hazards and make the required notifications in such a manner that offsite response organizations can take appropriate actions, such as sheltering or evacuating persons in the affected area.

It is suggested that operators have a single emergency plan that can apply to all operator needs and regulatory requirements. To this end, it should be understood that an operator may wish to include in the emergency plan some incidents that are not radiological emergencies. For example, the operator may wish to include industrial actions to be implemented by offsite response organizations. The emergency plan should contain the preplanned protective action recommendations the operator will make to each appropriate offsite organization for each postulated accident. The operator should try to make protective action recommendations directly to regional or local officials responsible for implementing the specific protective actions. The recommendations should specify the size of the area where the actions are to be taken. The operator should obtain the input of offsite organizations to ensure that they recommend the most practical and efficient protective actions for each postulated accident. A standard reporting checklist should be developed to facilitate timely notification.

The standard reporting checklist should be developed in co-operation with offsite officials to ensure that it meets their information needs and that their personnel are trained to receive and relay such information. The operator should provide initial protective action recommendations at the same time it initially notifies offsite authorities of a site emergency declaration.

4. RESPONSIBILITIES

In this section, describe the emergency organization to be activated onsite for possible events, as well as its augmentation and support offsite. Delineate the authorities and responsibilities of key individuals and groups, and identify the communication chain for notifying and mobilizing the necessary personnel during normal and nonworking hours.

4.1. Normal facility organization

Provide a brief description of the normal (day to day) facility organization and identify by position those individuals who have the responsibility and authority to declare an emergency and to initiate the appropriate response.

4.2. Onsite emergency response organization

Describe the onsite emergency response organization for the facility, and include the organization for periods such as offshift, holidays, weekends, and extended outages when normal operations are not being conducted. Use organizations charts and tables when appropriate. If the organization is activated in phases, describe the basic organization and each additional component that may be activated to augment the organization.

4.2.1. Direction and co-ordination

Designate the position of the person and alternates who have the overall responsibility for implementing and directing the emergency response. Discuss this person's duties and authority, including control of the situation, termination of the emergency condition, co-ordination of the staff and offsite personnel who augment the staff, communication with parties requesting information about the event, authority to request support from offsite agencies, and authority to delegate responsibilities. Indicate the individuals who may be delegated certain emergency responsibilities.

4.2.2. Onsite staff emergency assignments

Specify the organizational group or groups assigned to the functional areas of emergency activity listed below. Indicate the basis for personnel assignment for both working and nonworking time periods. For each group, describe duties, authority, and interface with other groups and outside assistance.

accidents or fires unrelated to the operator's work with nuclear materials. The operator may include such incidents in the emergency plan.

The classification of emergencies involving potential or actual releases of nonradioactive hazardous materials should be co-ordinated with the local emergency planning committee.

3.2. Notification and co-ordination

3.2.1. Plant emergency

The purpose of declaring a plant emergency is to ensure that emergency personnel are alerted and at their emergency duty stations to mitigate the consequences of the accident, that the emergency is properly assessed, that offsite officials are notified, and that steps can be taken to escalate the response quickly if necessary. The operator should describe how and by whom the following actions will be taken:

- Decision to declare a plant emergency.
- Activation of onsite emergency response organization.
- Prompt notification of offsite response authorities that a plant emergency has been declared (normally within 15 minutes of declaring a plant emergency).
- Notification to the national regulatory authority immediately after notification of offsite authorities.
- Decisions to initiate any onsite protective actions.
- Decision to escalate to a site emergency, if appropriate.
- Decision to request support from offsite organizations.
- Decision to terminate the emergency or enter recovery mode.

3.2.2. Site emergency

The purpose of declaring a site emergency is to ensure that offsite officials are informed of potential or actual offsite consequences, that offsite officials are provided with recommended actions to protect persons offsite, and that the operator's response organization is augmented by additional personnel and equipment. The operator should describe how and by whom the following actions will be taken:

- Decision to declare a site emergency.
- Activation of onsite emergency response organization.
- Prompt notification of offsite response authorities that a site emergency has been declared, including the operator's initial recommendation for offsite protective actions (normally within 15 minutes of declaring a site emergency).
- Notification to the national regulatory authority immediately after notification of the appropriate offsite response organizations.
- Decision on what onsite protective actions to initiate.
- Decision on what offsite protective actions to recommend.
- Decision to request support from offsite organizations.
- Decision to terminate the emergency or enter recovery mode.

3.3. Information to be communicated

The operator should be prepared to provide clear, concise information to offsite response organizations. The communication should avoid technical terms and jargon and should be stated to prevent an under- or over- evaluation of the seriousness of the incident. Describe the types of information that will be communicated with respect to facility status, releases of radioactive or other hazardous materials, and recommendations for protective

The organizational groups should provide capability in the following areas:

- Facility system operations
- Fire control
- Personnel evacuation and accountability
- Search and rescue operations
- First aid
- Communications
- Radiological survey and assessment (onsite and offsite)
- Personnel decontamination
- Facility decontamination
- Facility security and access control
- Facility repair and damage control
- Post-event assessment
- Record-keeping
- Media contact
- Criticality safety assessment.

4.3. Local offsite assistance to facility

Describe provisions and arrangements for assistance to onsite personnel during and after an emergency. Indicate the location of local assistance with respect to the facility if not previously stated. Ensure that exposure guidelines are clearly communicated to offsite emergency response personnel. Identify the services to be performed, means of communication and notification, and type of agreements that are in place for the following:

- Medical treatment facilities
- First aid personnel
- Fire fighters
- Law enforcement assistance
- Ambulance service.

Describe the measures that will be taken to ensure that offsite agencies maintain an awareness of their respective roles in an emergency and have the necessary periodic training, equipment, and supplies to carry out their emergency response functions. Discuss any provisions to suspend security or safeguards measures for site access during an emergency.

4.4. Co-ordination with participating government agencies

Identify the principal government (local, regional and national) agencies or organizations having responsibilities for radiological or other hazardous material emergencies at the facility. For each organization, describe:

- Its authority and responsibility in a radiological or hazardous material emergency and its interface with others, if any;
- Its specific response capabilities in terms of personnel and resources available;
- Its location with respect to the facility;
- The rumor control arrangements that have been made with the organization. (The emergency plan should describe where the public and media can obtain information during an emergency.)

Typical agencies to be included are the local emergency planning committee; ministries of health, environmental protection, and emergency or disaster control; and local fire and police departments. Ensure that the operator will meet at least annually with each offsite response organization to review items of mutual interest, including relevant changes in the operator's emergency preparedness programme. The operator should discuss the emergency action level scheme, notification procedures, and overall response co-ordination process during these meetings.

5. EMERGENCY RESPONSE MEASURES

Specific emergency response measures should be identified for each class of emergency and related to action levels or criteria that specify when the measures are to be effected. Response measures include assessment actions, mitigative actions, onsite and offsite protective actions, exposure control, and aid to injured persons.

5.1. Activation of emergency response organizations

Describe the means used to activate the emergency response organization for each class of emergency during both regular and non-regular hours. Include a description of the method used to authenticate messages. Identify the activation levels for each class and relate them to the responsibilities identified in Section 4. In this and subsequent sections, describe the specific written procedures to be used.

5.2. Assessment actions

For each class of emergency, discuss the actions to be taken to determine the extent of the problem and to decide what corrective actions may be required. Describe the types and methods of onsite and offsite sampling and monitoring that will be done in case of a release of radioactive or other hazardous material. Describe provisions for projection of offsite radiation exposures.

5.3. Mitigating actions

For the events identified in Section 4, briefly describe the means and equipment provided for mitigating the consequences of each type of accident. Include the mitigation of consequences to workers onsite as well as to the public offsite. In the event of a warning of impending danger, describe the criteria that will be used to decide whether a single process or the entire facility will be shut down, the steps that will be taken to ensure a safe orderly shutdown of equipment, and approximate times required to accomplish a safe shutdown of processes. Mitigating actions could include steps to reduce or stop any releases and steps to protect personnel (e.g. evacuation, shelter, decontamination).

Means for limiting releases could include:

- Sprinkler systems and other fire-suppression systems
- Fire detection systems
- Fire-fighting capabilities
- Filtration or holdup systems
- Use of water sprays on airborne releases of radioactive material
- Automatic shutoff of process or ventilation flows
- Storage in fire-resistant containers
- Use of fire-resistant building materials
- Criticality controls.

5.4. Protective actions

The nature of onsite and offsite protective actions, the criteria for implementing those actions, the areas involved, and the procedures for notification to affected persons should be described in the plan. To prevent or minimize exposure to radiation, radioactive materials, and other hazardous materials, the plan should provide for timely relocation of onsite persons, timely recommendation of offsite actions, effective use of protective equipment and supplies, and use of appropriate contamination control measures.

5.4.1. Onsite protective actions

5.4.1.1. Personnel evacuation and accountability

This segment of the emergency plan should include:

- Criteria for ordering an evacuation
- The means and time required to notify persons involved
- Evacuation routes, transportation of personnel
- Locations of onsite and offsite assembly areas
- Search and rescue
- Monitoring of evacuees for contamination and control measures if contamination is found
- Criteria for command center and assembly area evacuation and re-establishment at alternate location
- Procedures for evacuating and treating injured personnel, including contaminated personnel
- Provisions for determining and maintaining the accountability of assembled and evacuated personnel.

5.4.1.2. Use of protective equipment and supplies

Effective use of protective equipment and supplies, including the proper onsite distribution or availability of special equipment,is an important measure for minimizing the effects of exposure to or contamination by radioactive materials. Measures that should be considered are:

- Individual respiratory protection
- Use of protective clothing
- Communications equipment associated with any self-contained breathing apparatus
- Use of potassium iodide to block uptake of radioactive iodine (if appropriate).

For each measure that might be used, describe:

- Criteria for issuance of emergency equipment, if appropriate
- Locations of emergency equipment and supplies
- Inventory lists indicating the emergency equipment and supplies at each specified location
- Means for distribution of these items.

5.4.1.3. Contamination control measures

Describe provisions for preventing further spread of radioactive materials and for minimizing radiation exposures from radioactive materials that are unshielded or released by abnormal conditions.

Onsite protective actions should be described and should include isolation, area access control, and application of criteria for permitting return to normal use. Action criteria for implementing the planned measures should be described.

5.4.2. *Offsite protective actions*

Describe the conditions that would require protective actions offsite and list postulated accidents that could meet any of the conditions. Discuss what protective action recommendations would be made to offsite authorities, when each recommendation would be made, and what area offsite would be affected. In developing guidance for recommendations for protective action, Ref. [36] and Ref. [37] may be helpful.

5.5. Exposure control in radiological emergencies

In this section, describe the means for controlling radiological exposures for emergency workers.

5.5.1. *Emergency radiation exposure control programme*

5.5.1.1. Radiation protection programme

Describe the onsite radiation protection programme to be implemented during emergencies, including methods to comply with exposure guidelines. Identify individuals, by position or title, who can authorize workers to receive emergency doses. Procedures should be provided in advance for permitting onsite volunteers to receive radiation doses in the course of carrying out lifesaving and other emergency activities. Procedures should provide for expeditious decision-making and a reasonable consideration of relative risks.

5.5.1.2. Exposure guidelines

Specify onsite exposure guidelines to be used in actions to control fires, stop releases, or protect facilities. Guidelines for exposure to uranium, plutonium, or other toxic materials should be based on the chemical toxicity when the toxicity hazard is greater than the radiation hazard. Exposure guidelines should be provided for:

- Removing injured persons
- Undertaking mitigating actions
- Performing assessment actions
- Providing onsite first aid
- Performing personnel decontamination
- Providing ambulance service
- Providing offsite medical treatment.

5.5.1.3. Monitoring

Describe provisions for determining the doses from external radiation exposure and committed dose from any internally deposited radioisotopes received by emergency personnel involved in any accidents, including volunteers and emergency workers from offsite support organizations who may receive radiation exposure while performing their duties at the operator's facility. Include provisions for distribution of dosimeters, both self-reading and permanent record devices, and means for assessing inhalation exposures.

Describe provisions for ensuring that dose and committed dose records are maintained for operator and offsite support organization's emergency workers involved in any nuclear accident.

5.5.2. *Decontamination of personnel*

Specify action levels for decontaminating personnel. Describe the means for decontaminating emergency personnel, supplies, instruments, and equipment; and describe the means for collecting and handling radioactive wastes. Describe provisions for surveying and decontaminating relocated onsite personnel, including providing extra clothing and decontaminates suitable for the type of contamination expected.

5.6. Medical transportation

Specify how injured personnel, who may also be radiologically contaminated, will be transported to medical treatment facilities. Describe how chemicals or hazardous materials used in conjunction with radioactive materials may impact transportation.

5.7. Medical treatment

Describe arrangements made for hospital and medical services, both local and backup, and their capabilities to evaluate and treat injuries from radiation, radioactive materials, and other hazardous materials used in conjunction with radioactive materials. The description should include the capabilities to control any contamination that may be associated with physical injuries. The operator should be prepared to provide ambulance and hospital personnel with health physics support if needed.

6. EMERGENCY RESPONSE EQUIPMENT AND FACILITIES

In this chapter, describe in detail the onsite equipment and facilities designated for use during emergencies.

6.1. Command center

Describe the principal and alternative locations from which control and assessment for the emergency will be exercised. Identify the criteria used to predetermine the number and location of command centers in order to ensure that at lease one will be habitable during any emergency. Indicate the means for identifying which command center will be used in a given emergency. Specify the criteria for evacuating a command center and re-establishing control from an alternative location. Provide a description of the primary and alternative locations from which operator emergency workers would be dispatched for radiation survey, damage assessment, emergency repair, or other mitigating tasks if these persons would not be dispatched from the command center.

6.2. Communications equipment

6.2.1. Onsite communications

Describe the primary and any alternative onsite communication systems that would be used to transmit and receive information throughout the course of an emergency and the subsequent recovery. Discuss the frequency of operational tests.

6.2.2. Offsite communications

A backup means of offsite communication, other than commercial telephone, should be provided for notification of emergencies and requests for assistance. Operational tests of backup communications systems should be conducted periodically.

6.3. Onsite medical facilities

Describe the facilities and medical supplies at the site designated for emergency first aid treatment and contamination control of injured individuals.

6.4. Emergency monitoring equipment

List and describe the dedicated emergency equipment that will be available for personnel and area monitoring, as well as that for assessing the release of radioactive materials to the environment. The description should include the purpose of the equipment. The location of all monitoring equipment should be described. The emergency plan should discuss how the storage locations will ensure that sufficient emergency monitoring equipment will be accessible in a nonhazardous location for each type of postulated accident. Include similar descriptions of routine effluent monitors and meteorological measurement systems, if present. Describe how these are to be used to assess the magnitude and dispersion of releases. In addition to the radiological monitoring equipment, indicate, if applicable, the instrumentation to be used for monitoring chemically toxic materials. Describe available meteorological monitoring equipment, including locations of monitors, elevations of sensors, and location of readout.

7. MAINTAINING EMERGENCY PREPAREDNESS CAPABILITY

7.1. Written emergency plan procedures

Identify the means for ensuring that written emergency plan procedures will be prepared, kept up to date, and distributed to all affected parties. Describe the review process that will ensure these procedures clearly state the duties, responsibilities, action levels, and actions to be taken by each group or individual in response to an emergency condition. Describe provisions for approval of the procedures, and ensuring that each person responsible for an emergency response function has easy access to a current copy of each procedure that pertains to his or her functions.

7.2. Training

Describe the topics and general content of training programmes used for training the onsite emergency response staff. Specify the training afforded to those personnel who prepare, maintain, and implement the emergency plan. Ensure that the procedures include schedules and lesson plans for the training, frequency of retraining, and the estimated number of hours of initial training and retraining that will be provided. Include the training requirements for each position in the emergency organization. Describe training to be provided on the use of protective equipment such as respirators. Describe the training programme for onsite personnel who are not members of the emergency response staff so that they are aware of what actions they may have to take following the declaration of an emergency. Discuss what special instructions and orientation tours the operator will offer periodically to fire, police, medical, and other offsite emergency response personnel. Topics to be addressed during training for offsite emergency response personnel should include exposure guidelines, personnel monitoring devices, and basic contamination control principles.

7.3. Drills and exercises

Describe provisions for periodic drills and exercises to test the adequacy of implementing procedures, to test emergency equipment and instrumentation, and to ensure that the emergency personnel are familiar with their duties. Typically, drills are internal tests of specific operator emergency response functions, related functions are often simulated, and offsite organizations are not invited to participate. Exercises are typically full-scale tests of the operator's entire emergency response organization, and offsite organizations are invited to participate. Preplanned descriptions of accidents should be used to prepare scenarios appropriate to the objective of each drill and exercise. The procedures should include a requirement for one or more non-participating observers to evaluate the effectiveness of the personnel, the procedures, the readiness of equipment and instrumentation, and to recommend needed changes. For those drills and exercises that involve simultaneous activities at more than one location, observers should be provided at each location. Describe how criteria for acceptable performance will be prepared and provided to observers for evaluating the performance of participants.

7.3.1. Biennial exercises

Ensure that an exercise will be held once every two years and that offsite response organizations will be invited to participate in the biennial exercise in order to exercise co-ordination with offsite assistance organizations, including testing procedures and equipment for notifying and communicating with local and regional agencies. Ensure that the nuclear licensing authority will be invited to participate or observe if they wish. Ensure that exercise scenarios are not known by exercise participants and are plausible for the specific site. Discuss any provisions to suspend security or safeguards measures for site access during an exercise. These exercises should be planned so that all emergency response activities are adequately demonstrated.

7.3.2. Quarterly communications checks

Ensure that checks are conducted with offsite response organizations each quarter to verify and update all necessary telephone numbers.

7.4. Critiques

Ensure that a critique will be prepared for each drill and exercise by one or more of the non-participating observers and that it will evaluate the appropriateness of the emergency plan, procedures, facilities, equipment, personnel training, and overall effectiveness. The emergency plan and implementing procedures should be reviewed after each exercise, based on the evaluation of the exercise. The emergency plan should be reviewed and revised, if necessary, whenever changes occur in processes, kinds of material at risk, or plant organization. Describe how deficiencies identified by the critique will be corrected in a timely manner. (See Section 8 for records of exercises and exercise critiques).

7.5. Independent audit

Discuss the programme to be used annually to review and audit the operator's emergency preparedness programme, including the emergency plan and its procedures; training activities; emergency facilities, equipment, and supplies; and records associated with offsite support agency interface to ensure that the overall emergency preparedness programme is being adequately maintained. Describe the minimum qualifications of the persons who will perform the annual audit and ensure that the audits will be made by persons not having direct responsibilities for implementing the emergency response programme. Changes in plant layout should be included in the changes that would warrant revision of the emergency plan. Describe the provisions for initiating corrective actions based on audit findings and for ensuring completion of these actions.

7.6. Maintenance and inventory of emergency equipment, instrumentation and supplies

Describe the plans for ensuring that the equipment and instrumentation are in good working condition and that an adequate stock of supplies is maintained. A quarterly inventory should be made to ensure all emergency equipment and supplies are intact and in good operating condition, including instrumentation for operation and calibration, demand respirators, self-contained breathing apparatus, fire-fighting equipment and gear, supplemental lighting, and communications equipment. The procedures should include timely corrective actions to be taken when deficiencies are found during these checks.

7.7. Letters of agreement

Changes to the emergency plan should be communicated to the appropriate offsite response organizations; ensure that letters of agreement with offsite agencies are reviewed annually and renewed at least every four years or more frequently if needed. Letters of agreement may be included in the emergency plan or maintained separately.

8. RECORDS AND REPORTS

8.1. Records of incidents

Describe the assignment of responsibility for reporting and recording incidents of abnormal operation, equipment failure, and accidents that led to a plant emergency, including permanent retention with the operator's decommissioning records. Provide a detailed description of the records that will be kept. The records should include the cause of the incident, personnel and equipment involved, extent of injury and damage (onsite and offsite) resulting from the incident, all locations of contamination with the final decontamination survey results, corrective action taken to terminate the emergency, and the action taken or planned to prevent a recurrence of the incident. The records should also include the onsite and offsite support assistance requested and received, as well as any programme changes resulting from the lessons learned from a critique of emergency response activities. The titles of the personnel responsible for maintaining the records should be specified. Those records unique to a radiological emergency, not covered by existing national regulatory authority regulations or license conditions, should be retained until the operations are terminated.

8.2. Records of preparedness assurance

Provide a description of the records that will be kept. These should include records of:

- Training and retraining (including lesson plans and test questions)
- Drills, exercises, and related critiques
- Inventory and locations of emergency equipment and supplies
- Maintenance, surveillance, calibration, and testing of emergency equipment and supplies
- Agreements with offsite support organizations
- Reviews and updates of the emergency plan
- Notification of all personnel and offsite agencies affected by an update of the plan or its implementing procedures.

9. RECOVERY AND PLANT RESTORATION

Describe plans for restoring the facility to a safe status. Although it is not possible to detail specific plans for every type of incident, the plans should include the general requirements for (1) assessing the damage to and the status of the facility's capabilities to control radioactive materials, (2) determining the actions necessary to reduce any ongoing releases of radioactive or other hazardous material and to prevent further incidents, (3) accomplishing the tasks to meet any required restoration action, and (4) describing in general the key positions in the recovery organization.

Specifically, recovery plans should include requirements for checking and restoring to normal operations all safety-related equipment involved in the incident (e.g., criticality alarms, radiation monitoring instruments, respiratory protection equipment, fire-suppression and fire-fighting equipment, containments, and air filters) and assignment of responsibility for compiling, evaluating, and ensuring retention of all records associated with the incident.

During any planned restoration operations, personnel exposures to radiation must be maintained within allowable limits and maintained as low as reasonably achievable.

Appendix B

EXAMPLES OF INITIATING CONDITIONS

Conditions that initiate a plant emergency

1. Fire onsite that might affect radioactive material or safety systems.
2. Severe natural phenomenon that might affect radioactive material or safety systems (e.g., earthquake, flood, tsunami, hurricane, tidal surge, hurricane force winds, tornado striking facility).
3. Other severe incidents that might affect radioactive material or safety systems - aircraft crash into the facility, damage to the facility from explosives, uncontrolled release of toxic or flammable gas in the facility.
4. Elevated radiation levels or airborne contamination levels within the facility that indicate severe loss of control (factor of 100 over normal levels).
5. Ongoing security compromise (greater than 15 minutes).
6. Spent reactor fuel accident with release of radioactivity to containment or fuel-handling building.
7. Discovery of a critical mass quantity of special nuclear material in an unsafe geometry container or other condition that creates a criticality hazard.
8. Other conditions that warrant precautionary activation of the operator's emergency response organization.

Conditions that initiate a site emergency

1. Fire onsite that involves radioactive material or compromises safety systems.
2. Severe natural phenomenon that actually compromises safety systems or the integrity of radioactive material (e.g., earthquake, flood, tsunami, hurricane, tidal surge, hurricane force winds, tornado striking facility).
3. Other severe incidents that actually compromise safety systems or the integrity of radioactive material - aircraft crash into the facility, damage to the facility from explosives, uncontrolled release of toxic or flammable gas in the facility.
4. Elevated radiation levels or airborne contamination levels outside the facility that indicate a significant release to the environment (factor 100 over normal levels).
5. Imminent or actual loss of physical control of the facility.
6. Major damage to spent reactor fuel with release of radioactivity outside of containment of fuel-handling building.
7. Imminent or actual occurrence of an uncontrolled criticality.
8. Other conditions that warrant activation of offsite emergency response organizations or precautionary notification of the public near the site.

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GLOSSARY

Bird cage
An outer container or framework surrounding and rigidly centering a vessel containing fissile material; its principal function is to maintain the specified spacing among the individual vessels in order to assure nuclear criticality safety.

Certified volume
The capacity of the cylinder established by means of a water mass measurement at a given specified temperature.

Cleaned cylinder
A previously used cylinder that has been decontaminated to reduce residual quantities of uranium and other contaminants to a specified level.

Cylinder
The cylindrical shell with heads, penetrations, and permanently attached structural equipment.

Heel
The non-volatile residues and residual UF_6 remaining in the cylinder after routine operational emptying. For nuclear criticality safety during storage and transport, the heel is considered to be UF_6.

Emptied cylinder
A cylinder containing a residual amount of UF_6 and nonvolatile reaction products (heel). For criticality calculations, the heel (for example in Table 5.5) is considered to be UF_6.

Fissile UF_6
UF_6 where the uranium is enriched in ^{235}U to $\geq 0.72\%$.

Note: (a) For UF_6 transport, if the ^{235}U enrichment is in the range of $\geq 0.72\%$ to 1.0%, it is packaged as "fissile exempt" (see Safety Series No. 6 for other specific packaging, classification, and labelling requirements). (b) For storage, only UF_6 where the uranium is enriched to $> 1\%$ ^{235}U requires special consideration for nuclear criticality safety.

Maximum allowable working temperature
The maximum temperature of the cylinder and service equipment as specified for the plant processes to which the cylinder will be subjected.

Package
The cylinder and any protective packaging when used and the UF_6 contents as presented for transport.

Qualified inspector
An inspector so designated by the prevailing authority.

Service equipment
The closures of penetrations in the cylinder (valves and plugs).

Staging area
The area for temporary storage of cylinders received from off-site or on-site facilities or from storage areas for subsequent handling and preparation.

Storage array

A regular arrangement of stored UF_6 cylinders.

Tamper indicating device

A device that covers or engages the UF_6 cylinder valve and, when equipped with a numbered seal, indicates whether unauthorized manipulation of the valve has occurred.

Tare mass

The mass of the cylinder including its service equipment and its permanently attached structural equipment.

Validated computational technique

A calculational method that has been tested by comparison with critical experiments to establish the reliability of results as applied to the conditions of interest.

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