IAEA-TECDOC-608

Interim guidance on the safe transport of uranium hexafluoride

INTERNATIONAL ATOMIC ENERGY AGENCY

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FOREWORD

Since the early 1940s, millions of tonnes of uranium hexafluoride (UF_6) have been transported throughout the world. During this time there has been no significant transport accident involving UF_6 which has resulted in serious injury or the loss of life from either the radiological or the chemical nature of UF_6.

Despite this safety record, recent events have caused the packaging and transport requirements for UF_6 to be re-evaluated by experts advising the International Atomic Energy Agency (IAEA).

In 1984 a ship, the Mont-Louis, carrying 30 large packages of UF_6 sunk in the North Sea. Although all of the packages were recovered with no release of contents -- and therefore no chemical or radiological contamination of the environment -- significant attention was drawn to the transport of UF_6 by the proximity of this incident to large population centres and important commercial sea-lanes.

In 1986, at a production plant in Oklahoma, USA, a cylinder containing UF_6 ruptured due to an unauthorized heating in an attempt to remove excess contents. The consequent expansion of the UF_6 in the phase change from solid to liquid overpressurized the packaging, which ruptured releasing large quantities of liquid and gaseous UF_6 into the plant area resulting in the death of one person. This death was caused by the chemical, and not the radiological, hazards of UF_6. Although this accident did not occur during transport and the scenario is conceivably too improbable to take account of in transport operations, it illustrates that, should the contents of a large package of depleted, natural or low-enriched UF_6 be released in a transport accident involving a fire, the radiological consequences would be small, whereas the chemical consequences could be significant.

In 1985, the IAEA issued a new edition of the Regulations for the Safe Transport of Radioactive Materials, Safety Series No. 6, 1985 Edition, in which it is required that:

(a) for radioactive material having other dangerous properties, the transport regulations for dangerous goods of each country through or into which the material is to be transported, and the regulations of the cognizant transport organizations must be complied with; and

(b) the possible formation of products having dangerous properties by the interaction of contents with the atmosphere or with water (e.g., the case of UF_6) must be taken into account.

The fifth meeting of the Standing Advisory Group on the Safe Transport of Radioactive Material (SAGSTRAM), convened in Vienna, Austria in March 1986, recommended that the IAEA take the lead, on a high priority basis, to assess the adequacy of the regulations for the transport of UF_6, considering both the radiological and chemical hazards posed by this material, and prepare appropriate documentation to guide the further development of regulations in this area. In making this recommendation SAGSTRAM recognized that safety provisions for the transport of dangerous goods having other than radiological hazards are generally and historically established by other cognizant international organizations. However, it was felt that guidance from the Agency on transport of UF_6 would be beneficial to the dangerous goods transport community

In July 1986, a group of consultants was convened by the IAEA to provide initial guidance on this topic, and a Technical Committee meeting was held in November 1986 to finalize the development of these recommendations.

IAEA-TECDOC-423, "Recommendations for Providing Protection During the Transport of Uranium Hexafluoride", was published in 1987 and distributed for comments. The sixth meeting of SAGSTRAM, convened in Vienna in November 1987, reviewed the comments and recommended that the Agency should publish a Safety Series document to provide the necessary guidance which takes account of the comments received. In order to achieve this goal a consultants meeting was convened in April 1988 followed by a Technical Committee meeting in May 1988, whose work was the basis of a new draft text.

The seventh meeting of SAGSTRAM then endorsed the new draft text, subject to some editorial amendments, which was then circulated for comments to the Member States involved in its development. The nature of the comments, however, revealed essentially a lack of agreement on a few but rather fundamental provisions in the draft text, and the IAEA decided to defer publication. In October 1990 another consultants meeting was convened by the Agency to resolve the outstanding issues. The text of the draft was amended according to the consultants' advice. An extract of the Consultants' Report comprising the contentious issues is appended to the Foreword to highlight the problem area and the uncertainties that still exist.

The present document, which supersedes IAEA-TECDOC-423, is the outcome of two Technical Committee Meetings, three Consultants Service Meetings and three rounds of comments by Member States. The eighth meeting of SAGSTRAM convened in Vienna in December 1990 recommended, contrary to earlier recommendations, the publication of the document again as a TECDOC, representing a statement of the work done in this area. SAGSTRAM considered that the prevailing uncertainties, in particular those concerning the release criteria during the projected fire test, preclude publication as a Safety Guide, and that a Co-ordinated Research Programme under the auspices of the Agency should provide the necessary input to resolve the remaining problems. Since the intention to incorporate the provisions on UF_6 in the next major revision (1996) of the IAEA Regulations and the supporting documents still stands, the text in this document has been split into regulatory, advisory and explanatory material. Any additional information arising from experience gained in the use of this TECDOC should then be taken into account.

Extract from the Report of the Consultants Service Meeting (CSM) on the Development of a Safety Guide on Guidance for Providing Protection during the Transport of Uranium Hexafluoride (UF_6), Vienna, 1-3 October 1990.

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1. Required Test Pressure

Comments by the USA and the UK on the structural test requirements were discussed. The latest draft of the proposed regulations "Guidance on the Safe Transport of Uranium Hexafluoride", dated January 1990, contained two versions of paragraph 217 on the structural test for consideration by the CSM. One version required a minimum test pressure of 2.8 MPa. The second version required a test pressure which is a minimum of 1.5 times the maximum allowable working pressure but not lower than 1.4 MPa. The version involving the 2.8 MPa requirement was based on cylinders currently in use with this requirement. The version requiring 1.5 times the maximum allowable working pressure is based on national and international pressure vessel code requirements. The lower limit of 1.4 MPa used with this requirement was specified to give assurance for the required resistance to impact damage and to be consistent with plant operation conditions.

The version requiring a minimum of 1.5 times the maximum pressure but not lower than 1.4 MPa was adopted by the CSM. The 1.5 minimum is a universally accepted code requirement. The 1.4 MPa allows the use of all UF_6 cylinders currently in use. The ability of cylinders designed to the 1.4 MPa pressure to meet drop test and other transportation requirements is documented and presented as Working Paper No. 2 in the May 1988 Technical Committee Meeting on "Guidance on the Safe Transport of Uranium Hexafluoride", (TC-587.2). This is documented in the Chairman's Report of that meeting.

For the above reasons the 2.8 MPa approval requirement was also removed from para 2.28 on "Transition Arrangements and Approval of Shipments".

2. Allowed Release during the Fire Test and Test Duration

The CSM considered that the fire test specification and duration to be applied to UF_6 packages should correspond in all respects to the thermal test currently applicable to Type B packages - viz. para 628 of Safety Series No. 6.

Concerning the allowable release during the fire test, the CSM considered that a necessary pass criterion would be to demonstrate "no rupture" of the cylinder. The consultants could not be certain, however, whether this could also be considered a sufficient condition.

Consideration was given to placing a specific leakage figure (e.g. an "equivalent A_2" figure of the order 10 to 40 kg, based on the work of C. Ringot and J. Hamard and A. Biaggio and J. Lopez-Vietri) during one week following the fire test. However, there was insufficient data available to judge the relative importance of preventing rupture/ preventing excessive leakage, given that these phenomena are interrelated. It is therefore suggested that further consideration of the need for the magnitude of permitted release criterion be undertaken within the framework of the mentioned Co-ordinated Research Project.

3. Exemption Levels

The CSM adopted an exemption level of 0.1 kg for packages designed to contain UF_6. Although UF_6 itself does not explode, due to the buildup of internal pressure caused by the hydraulic expansion or gas formation of the UF_6 during a fire, there is a great risk of explosion of small, bare cylinders. This was documented in a 1966 report by A.J. Mallet, titled "ORGDP Container Test and Development Programme, Fire Tests of UF_6-filled Cylinders". The 0.1 kg is well below the toxic limit of 10 to 40 kg (based on the work of C. Ringot and J. Hamard and of A. Biaggio and J. Lopez-Vietri), and will permit the shipment of sample tubes containing UF_6. These sample tubes are constructed of plastic or other non-pressure containing material, and thus, cannot explode. The sample tubes contain less than 0.065 kg UF_6.

EDITORIAL NOTE

CONTENTS

Section I

INTRODUCTION

Uranium hexafluoride (UF_6) is a radioactive material that has significant non-radiological hazardous properties. In conformity with international regulatory practice for dangerous goods transport, these properties are classed as "subsidiary risks", although they predominate in the cases of depleted and natural UF_6. UF_6 is transported as a solid material below atmospheric pressure. An accidental release of UF_6 would result in an immediate chemical reaction with air moisture. One of the reaction products is HF, which constitutes basically the major subsidiary risk of UF_6, when packaged in large cylinders. Small bare cylinders of UF_6 constitute an additional subsidiary risk by the reported explosive rupture in a fire [1]. In addition to its radioactive properties, enriched UF_6 is a fissile material capable of initiating an uncontrolled self-sustaining neutron reaction, i.e., a critical system, under certain conditions.

The IAEA Regulations for the Safe Transport of Radioactive Material, 1985 Edition, Safety Series No. 6, [2] (hereinafter referred to as "the Regulations") make recommendations that aimed to provide an adequate level of safety against radiological and criticality hazards. The basis for these is that the stringency of package performance requirements, operational procedures and approval and administrative procedures is graded relative to the severity of the hazard. For example, where the radiological hazard posed by the contents of a package is small, sufficient but minimal requirements and procedures are specified. As the radiological hazard increases additional requirements and procedures are imposed.

The non-radiological hazards of the contents are not specifically addressed in the Regulations but para. 105 therein states:

> 105 "For radioactive material having other dangerous properties, and for transport or storage of radioactive material with other dangerous goods, the relevant transport regulations for dangerous goods of each of the countries through or into which the material is to be transported, and the regulations of the cognizant transport organizations, shall apply, in addition to these Regulations. It is also necessary to take into account the possible formation of products having dangerous

properties by interaction of contents with the atmosphere or with water (e.g., the case of UF_6)."

The United Nations Recommendations on the Transport of Dangerous Goods [3] is the key document in this respect as the basis for relevant international and national mode-dependent regulations. It provides guidance on the packaging and transport of a multitude of specified dangerous goods classified into 9 classes. In addition to general provisions, specific recommendations are included for most of these classes on packing, on intermediate bulk containers and on multimodal tank containers, with performance test and design standards graded in relation to the potential hazard.

For radioactive material - known as Class 7 - the UN Recommendations make a general citation of the IAEA Regulations. With respect to subsidiary risks of radioactive material, the information in paragraphs 105, 406 and 407 of the Regulations is effectively quoted by including the following clause:

> "it is necessary, however, for consignments of radioactive material to comply with transport regulations applicable to other hazardous properties which such material may possess."

For materials with toxic and corrosive properties similar to those of UF_6, the UN Recommendations provide guidance on packing and shipment in packages (maximum mass 400 kg, maximum volume 450 L), intermediate bulk containers (maximum volume 3000 L) and multimodal tank containers (minimum volume 450 L). However, the application of these requirements to the transport of UF_6 proves to be extremely difficult because of the following factors:

- the unique physical and chemical properties of UF_6 (see Appendix II);
- the high chemical toxicity of UF_6 and its hydrolysis products (see Appendix III);
- the restrictions on some safety related items (e.g. pressure release valves); and
- the absence of provisions for cylinders and other receptacles in the UN Recommendations.

Other difficulties arise from the fact that the cylinders used for transporting UF_6 are also used in the production, storage and use of the material and that the fraction of their life cycle in which transport is involved is small. Consideration must also be given to the large number of existing cylinders (estimated to be between 60,000 and 70,000).

In view of these facts, and taking into account that UF_6 has been transported safely by the nuclear industry for many years, it was felt that specific recommendations should be provided for its transport. These recommendations, listed in Section II, are additional to the requirements of the Regulations.

The intent of these additional recommendations is to restrict contamination and to provide protection to workers and to the general public against the chemical hazard possibly resulting from a severe accident involving the transport of UF_6, and in addition against the consequences of explosive rupture of small bare cylinders of UF_6.

Following the basic format of the Regulations, the additional recommendations are generic in form and are performance oriented, the burden of providing protection being imposed upon the package as a whole, that is the cylinder, the service equipment and the outer protective structure, and not only upon the cylinder itself.

It is, therefore, recommended that UF_6 packagings and packages should, in addition to the relevant requirements of the Regulations, a summary of which is given in Appendix I, be designed, manufactured and used to conform at least with the requirements given in Section II. In particular, because of the nonradiological hazards associated with UF_6, the use of the package types specified in the Regulations as permissible for this material (e.g., IP-1, IP-2, Type A) is acceptable only in so far as the recommendations specified herein are also observed. Some advisory material for the design, manufacturing, testing and use of UF_6 packagings is summarized in Refs. [4-6].

The Agency has prepared these recommendations with the assistance of Member States and in conformity with the recommendations of the Standing Advisory Group on the Safe Transport of Radioactive Material (SAGSTRAM). Their purpose is to give guidance on the safe transport of UF_6, and to assist of other international organizations and Member States in providing adequate and harmonized requirements throughout the world. It should be noted that additional requirements may arise from national regulations, e.g. pressure vessel regulations.

Section II

RECOMMENDED REQUIREMENTS FOR THE SAFE TRANSPORT OF URANIUM HEXAFLUORIDE ADDITIONAL TO THOSE OF THE IAEA REGULATIONS FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIAL, 1985 EDITION (AS AMENDED 1990), SAFETY SERIES No. 6 ("The Regulations")

Scope

2.01 **Packages** containing more than 0.1 kg for the transport of uranium hexafluoride, shall, in addition to the applicable recommendations of the Regulations, be designed, manufactured, tested and used in accordance with the following recommendations.

Definitions

2.02 For the purpose of these recommendations:

(1) "**Certified volume**" shall mean the water capacity of the **cylinder** at a tolerance of $\pm$ 0.1% with $20^{\circ}C$ as the reference temperature;

(2) "**Cylinder**" shall mean the cylindrical shell with heads, penetrations and permanently attached structural equipment;

(3) "**Heel**" shall mean the nonvolatile residues and the residual amount of UF_6 remaining in the **cylinder** after routine operational emptying;

(4) "**Maximum allowable working pressure**" shall mean the maximum gauge pressure actually built up in the **cylinder** and **service equipment** when it is subjected to the **maximum allowable working temperature.** Its determination shall take into account the effect of impurities on the total gas pressure;

(5) "**Maximum allowable working temperature**" shall mean the maximum temperature of the **cylinder** and **service equipment** as specified for the plant systems where the **cylinder** shall be operated;

(6) "**Package**" shall mean the **packaging** with its specified contents as presented for transport;

(7) "**Packaging**" shall mean the assembly of the **cylinder, service** and **structural equipment;**

(8) "**Service equipment**" shall mean the closures of penetrations (valves and plugs);

(9) "**Structural equipment**" shall mean any item either permanently attached, or assembled to the **cylinder** as presented for transport;

(10) "**Tare mass**" shall mean the mass of the cleaned **cylinder** including its **service equipment** and its permanently attached **structural equipment** measured at a tolerance of $\pm$0.1%.

Design and Manufacture

2.03 The **packaging** shall be designed and manufactured in accordance with the provisions of technical codes acceptable to the Competent Authority.

2.04 For transport the design of the **package** shall take into account an ambient temperature range of -40°C to 38°C. For components of the **packaging** a temperature range of -40°C to 70°C shall be taken into account.

2.05 The **cylinder** including its **service equipment**, shall be designed to the **maximum allowable working temperature**, and to a **maximum allowable working pressure** which corresponds to the total pressure of the specified contents at the **maximum allowable working temperature**.

2.06 The **package** shall be designed and manufactured to withstand the static and dynamic stresses that occur in normal handling and transport. In addition, the **cylinder** and its **service equipment** shall be designed to withstand the structural test as specified in para 2.17. Under each of these conditions there shall be no leakage and there shall be no unacceptable stress, in excess of the levels permissible for the materials as specified in the technical codes acceptable to the Competent Authority, at the most severely stressed part of the **packaging**.

2.07 The **cylinder** including its permanently attached **structural equipment** shall be designed so as to prevent permanent deformation and leakage at an external pressure of 0.15 MPa (gauge pressure).

2.08 The package shall be so designed that, if it were subjected to the leak test as specified in para 2.18 no leakage in excess of the specified value for the test would occur.

2.09 The **package** shall be designed so as to prevent loss or dispersal of the contents when it is subjected to a free drop test on a flat, horizontal and unyielding surface. The **package** attitude shall be such that it suffers maximum damage. The height of the drop, measured from the lowest point of the specimen to the upper surface of the target, shall be not less than the distance specified in Table I.

TABLE I. FREE DROP DISTANCES FOR TESTING PACKAGES

Package mass (kg)	Free drop distance (m)
0 < package mass < 500	1.8
500 ≤ package mass < 5 000	1.2
5 000 ≤ package mass < 10 000	0.9
10 000 ≤ package mass < 15 000	0.6
15 000 ≤ package mass	0.3

2.10 **Packages** designed to contain more than 0.1 kg of uranium hexafluoride shall be capable of withstanding the thermal test as specified in para. 628 of the Regulations without rupture of the cylinder. Compliance shall be demonstrated according to para. 601 of the Regulations.

2.11 **Cylinders** shall not be provided with pressure-relief valves. The number of penetrations in cylinders shall be minimized.

2.12 After fabrication and testing and before filling the inside of the **cylinder** shall be thoroughly cleaned of grease, oil, scale, slag, and other foreign matter using an appropriate procedure. The **cylinder** interior shall also be dried.

Inspection and Testing

2.13 Every manufactured **packaging** and its components, either together or separately, shall be subjected to initial inspection and testing prior to first use and reinspection and retesting periodically thereafter. These inspections and tests, which may be carried out in a country other than the country of origin or ownership, shall be performed as approved by the Competent Authority of the country of origin or use, and they shall be certified in accordance with a Quality Assurance programme acceptable to that Competent Authority.

2.14 The initial inspection and testing shall consist of the conformity inspection and visual inspection, the establishment of the **certified volume**, the structural test, the leak test and functional test of the **service equipment**.

2.15 The conformity inspection shall demonstrate compliance with the design specifications and the manufacturing programme.

2.16 Reinspection and retesting shall consist of a visual inspection, the structural test, the leak test and a functional test of the **service equipment**. The interval for reinspection and retesting shall not be longer than 5 years. **Packages** containing material and which have not been inspected and tested within a 5 year period prior to transport, shall be inspected according to a programme acceptable to the Competent Authority. Once such **packages** have been emptied they shall not be refilled prior to the execution of the full reinspection programme.

2.17 The structural test for the cylinder shall be a hydraulic test to an internal pressure of at least 1.5 times the **maximum allowable working pressure**. The test pressure shall not be lower than 1.4 MPa. For retesting any other equivalent non-destructive examination acceptable to the Competent Authority may be applied.

2.17a The structural test for the valve shall be a pressure test to an internal pressure of at least 2.8 MPa.

2.18 The leak test shall be performed by means of a procedure capable of indicating leak rates from the **cylinder** and its **service equipment** with a sensitivity of 0.1 Pa L/s. The pressure to be used in this test shall be at least 0.689 MPa.

Marking

2.19 A plate made from a non-corroding metal shall be durably attached to the **cylinder** of every **packaging** for uranium hexafluoride. The method of attaching the plate shall not reduce the strength of the **cylinder.** At least the following particulars including units as applicable shall be legibly and durably marked on this plate:

- Approval number
- Manufacturer's name
- Manufacturer's serial number
- Owner's name
- Model type
- **Maximum allowable working pressure**
- **Maximum allowable working temperature**
- **Certified volume**
- Permissible filling mass of uranium hexafluoride
- **Tare mass**
- Date of initial test and most recent periodic test.

Use of Packaging

2.20 The uranium hexafluoride shall be in solid form, and the internal pressure of the **cylinder** shall be below atmospheric pressure, when the **package** is offered for transport.

2.20.1 Except as provided in 2.20.2, the total mass of contents shall not exceed a value which would lead to ullage smaller than 5% at 121°C.

2.20.2 In applying the requirement of 2.20.1 a density of 3.26 g/cm^3 shall be assumed for calculating the ullage provided that the purity of uranium hexafluoride is at least 99.5%. More restrictive limitations shall be applied as appropriate where the purity of uranium hexafluoride is less than 99.5%.

2.20.3 The maximum mass of contents of certain **cylinders** designed for long term storage of high purity depleted UF_6 may be increased so as to provide 5% ullage at a maximum working temperature of 113°C based on a UF_6 density of 3.33 g/cm^3 and the actual **certified volume** of the **cylinder.**

2.20.4 The calculated filling mass of UF_6, except for depleted UF_6, in the solid state shall not exceed 61% of the minimum specified volume of the **cylinder** at 20°C using a UF_6 density of 5.1 g/cm^3. The volume of solid depleted UF_6 at 20°C shall not exceed 62% of the **certified volume** of the **cylinder.**

2.21 Empty **cylinders** shall be closed and made leak tight to the same degree as filled **cylinders.**

2.22 Empty, uncleaned **cylinders** shall be radiologically monitored to assure that the radiation levels are within specified limits.

2.23 During transport a secure base shall be provided as a support structure for the **package.** This support structure may be permanently attached either to the **packaging** or to the vehicle or temporarily attached to both of them. Skids, frameworks, cradles or other similar devices are acceptable.

Quality Assurance and Maintenance

2.24 A quality assurance programme or programmes shall be established for the design, manufacture, use, servicing and maintenance of **packages** of uranium hexafluoride. The level of quality assurance assigned shall also take into account the chemical hazards of uranium hexafluoride.

Specific Maintenance Requirements

2.25 (a) **Packagings** shall be maintained to the designed criteria and verified by appropriate inspection and/or tests. These shall be carried out in accordance with prescribed procedures which must cover, as a minimum, all relevant tests and features described elsewhere in this document.

(b) Cleaning of the **cylinders** shall be performed by using an appropriate procedure only.

(c) All repairs shall be performed in accordance with the specified design and manufacturing programme of the **packaging.** If this is not possible, the proposed repairs and repair programmes shall be subject to approval by the Competent Authority in advance.

Design Approval

2.26 Except for **packages** designed to contain less than 0.1 kg of uranium hexafluoride, each design of **package** for uranium hexafluoride shall require unilateral approval from the Competent Authority of the country of origin that the design meets the provisions of these recommendations. The approval procedure may be part of the approval procedure for Type B package design and/or the approval procedure for a **package** design for fissile material, as appropriate, required by the Regulations.

2.27 Upon approval the Competent Authority shall issue an approval certificate and allocate an approval number. This approval number shall be of the type described in para 724 of the Regulations with "UF_6" in place of the Type Code, e.g. CDN/XXX/UF_6 - a package design for uranium hexafluoride approved by the competent authority of Canada.

Transitional Arrangements and Approval of Shipment

2.28 **Packagings,** with their components, already constructed in accordance with the requirements of an existing national or international standard, may be allowed to continue to be used for a transition period of at least 2 years after the entry into force of these provisions, provided they are re-tested and re-inspected in accordance with para. 2.15. After the transition period all such packagings shall require multilateral approval of shipment unless the design has been approved in accordance with the provisions of this document.

2.29 The shipment of packages not complying with the requirements of 2.20.1 as provided in 2.20.2, or not complying with 2.20.3, shall require multilateral approval by the Competent Authority of the country of origin and of each country through or into which the consignment is to be transported.

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Section III

ADVISORY MATERIAL

A 2.10 No actual fire test is required in order to demonstrate compliance. The use of a mathematical model and an appropriate calculation is acceptable as specified in para. 601 of the Regulations.

A 2.17 The procedure for this test should follow the recommendations of ISO/DIS 4706.2- Refillable Welded Steel Cylinders [7], namely:

- All cylinders of each batch shall be subjected to pressure test.
- It shall be observed that the pressure in the **cylinder** increases gradually and regularly until the test pressure is reached. The **cylinder** shall be held long enough under test pressure to ascertain that there is no tendency to decrease in pressure and that tightness is achieved.

A 2.19 It is recognised that in some cases **cylinders** are sold with the contents. Provisions for marking changes of ownership should be made in the preparation of the plate.

A 2.20.1 Consideration should be given to the volume and mass of **heels** that are present in the **cylinder** prior to its filling.

A 2.23 In considering the requirements of this section it is recommended [3] that the minimum dynamic loadings, in addition to static loadings, to be withstood, should be based on the loadings of 2 g in the vertical down direction, 1 g in the vertical up direction, 2 g in the longitudinal direction and 1 g in the transverse direction, applied through the centre of gravity of the **package**.

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Section IV

EXPLANATORY MATERIAL

E 2.02(10) It is important to note that the tare mass is defined for cleaned **cylinders.** In the process of refilling a **cylinder** its actual initial mass is usually slightly larger, resulting from the presence of a certain quantity of **heel(s).**

E 2.05 The **maximum allowable working temperature** of the cylinder is specified for design and plant conditions. The requirement for the **package**, however, relates to ambient conditions envisioned during routine transport activities.

E 2.06 The requirement in this paragraph is part of all national and international pressure vessel codes. Its purpose is to ensure the structural adequacy of the **cylinder.**

E 2.09 The free drop test requirements in this paragraph are similar to those prescribed in the Regulations for testing packages for ability to withstand normal conditions of transport. The heat resistance test prescribed in para 2.10, however, is similar to the thermal test in the Regulations, which is one of the tests for demonstrating ability to withstand accident conditions in transport. This is based on the understanding that the requirement for resistance to hydraulic rupture (para 2.17) compensates for the less severe free drop test. If, however, the contents of a package exceed the appropriate limit for a Type A package or constitute fissile material, the normally-applicable requirements for Type B or fissile package design should be met.

E 2.10 Paragraph 2.10 cites paragraph 628 of the Regulations, which specifies the thermal test parameters of 800°C temperature and 30 minutes duration.

The 0.1 kg exemption level provides assurance against the explosion of small, bare cylinders of UF_6 [1]. The 0.1 kg level is well below the toxic risk limit of 10 kg, based on the work of C. Ringot and J. Hamard [8] and of A. Biaggio and J. Lopez-Vietri [9].

E 2.21 In many cases the filled **cylinder** can be classified as LSA material based on its specific activity (in terms of Bq/g). The evacuated **cylinder**, containing only the heels, might require another classification, considering both the concentration of radioactive nuclides and the external radiation levels.

Appendix I

EXISTING IAEA REGULATIONS FOR THE TRANSPORT OF UF_6

AI.1 INTRODUCTION

This Appendix provides a summary of those recommendations in Safety Series No. 6 which relate specifically to the safe transport of UF_6.

AI.2 REGULATORY REQUIREMENTS

The IAEA periodically publishes the Regulations for the Safe Transport of Radioactive Material (Safety Series No. 6). These Regulations serve as a model for regulations implemented by Member States, and for the regulatory documents promulgated by transport-related international organizations. The latest edition of the Regulations was issued in 1985 and an As Amended version was published in 1990 [2]. The following summarizes these requirements relating to solid unirradiated UF_6 which lead to six general combinations of material classifications and packaging requirements* as follows:

1) Packaged UF_6, of any enrichment, or empty packagings, shall comply with the requirements of excepted packages subject to the constraints of para. 415 of the Regulations, which include:

   (i) The requirements of other regulations for non-radiological hazards must also be satisfied (para. 407);

   (ii) The package must retain its contents under conditions likely to be encountered in routine transport (para. 419(a));

   (iii) The package must bear on an internal surface a marking "Radioactive" visible on opening the package -- but need not be marked with radioactive labels externally (para. 419(b));

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* If UF_6 can be classified as LSA-I, the Regulations also would appear to allow the transport of UF_6 as unpackaged (para. 425(a)); however, due to the chemical reactions which will occur between unpackaged UF_6 and air and water, such transport is not possible.

(iv) The package must satisfy the general design requirements (paras 505-514);

(v) The radiation level on the package surface must not exceed 5μSv/h (0.5 mrem/h) (para. 416);

(vi) The contamination levels for excepted packages must be satisfied (para. 408);

(vii) The uranium-235 enrichment must not be greater than 1%, except in the cases of items (viii) and (ix) below (para. 560(c));

(viii) If the uranium-235 enrichment is greater than 1% but not greater than 5%, the package must contain not more than 15 g of fissile material, and all its external dimensions must be greater than 10 cm (para. 560(a)); and

(ix) If the uranium-235 enrichment is greater than 5%, the package must not contain more than 10^{-6} TBq of activity (Table IV of the Regulations), the package must not contain more than 15 g of fissile material, and all its external dimensions must be greater than 10 cm (para. 560(a)).

(x) In addition, for shipment as an empty packaging, the following are required (see para. 421 of the Regulations):

(a) It is in a well-maintained condition and securely closed;
(b) The level of internal non-fixed contamination does not exceed 400 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, and 40 Bq/cm^2 for all other alpha emitters; and
(c) Any labels which may have been displayed on it to conform with requirements as a filled package are no longer visible.

2) Uranium-235 enrichment not greater than 0.72%

- Classified as non-fissile, LSA-I; and
- Shall comply with the requirements of IP-1.

3) Uranium-235 enrichment greater than 0.72% but not exceeding 1.0%

- Classified as fissile, LSA-II;
- Regulated as non-fissile radioactive material (excepted from packaging requirements for fissile materials); and therefore
- Shall comply with the requirements of IP-2; and
- Shipped as a package containing non-fissile material.

4) Uranium-235 enrichment greater than 0.72% and maximum contents of package less than 15 g of uranium-235

(a) Enrichment 5% or less

- Classified as fissile, LSA-II;
- Regulated as non-fissile radioactive material (excepted from packaging requirements for fissile materials); and therefore
- Shall comply with the requirements of IP-2; and
- Shipped as a package containing non-fissile material.

(b) Enrichment more than 5%

- Classified as fissile radioactive material, LSA-II if specific activity not greater than 10^5 Bq/g;
- Regulated as non-fissile radioactive material (excepted from packaging requirements for fissile materials); and therefore
- Shall comply with the requirements of either IP-2 (if LSA-II), otherwise Type A; and
- Shipped as a package containing non-fissile material.

5) Uranium-235 enrichment greater than 1.0% but not greater than 5.0% and maximum contents of package greater than 15 g of uranium-235

- Classified as fissile radioactive material, LSA-II;
- May be shipped in a packaging satisfying IP-2 containment and shielding requirements and satisfying criticality safety requirements; and
- Shipped as a package containing fissile material.

TABLE AI.1. REQUIREMENTS IMPOSED ON UF_6 TRANSPORT PACKAGES BY IAEA SAFETY SERIES No. 6
(number in parentheses indicate relevant paragraph numbers from Safety Series No. 6)

Uranium Enrichment (% of U-235)	Maximum Contents (g of U-235)	Material Classification	Maximum Radiation Level	Fissile Material Classification	Fissile Packaging Requirements	UN Number [a]	Packaging Requirements	Labelling & Documentation Requirements	Approval Require-ments
EXCEPTED PACKAGES -- SEE TEXT, SECTION II.1									
≤ 0.72%	(b)	LSA-I [c]	10 mSv/h 3 m from unshielded if LSA-I or LSA-II (422) & 2 mSv/h at package surface if not under Exclusive Use (433), or 10 mSv/h at package surface if under Excluse Use (434)	Non-fissile	None	2978	IP-1 (426, 518)	(436-453)	None
> 0.72% to 1.0%	(b)	LSA-II [d]		Fissile	Fissile Excepted (560)	2978	IP-2 (426, 519)	(436,453)	None
> 0.72%	15 g (560 (a))	LSA-II [e] if enrichment ≤ 5% if enrichment > 5%, LSA-II [e] if specific activity ≤ 10^5 bq/g, otherwise not LSA		Fissile	Fissile Excepted (560)	2978	IP-2 if LSA (426,519,560), or Type A if not LSA (524-538)	(436-453)	None
> 1.0% to 5.0%	(b) (f)	LSA-II [e]		Fissile	Fissile (559, 561, 568) (g)	2977	IP-2 (426, 519); and Fissile (559)	(436-459)	Multilateral (710)
> 5.0%	(f)	LSA-II [e] if specific activity ≤ 10^5 Bq/g, otherwise not LSA		Fissile	Fissile (559,561,568) (g)	2977	(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)	(436-459)	Multilateral (710)

*

(a) UN number is used internationally to assist hazard identification in emergency response.

(b) Controlled by unshielded material radiation level at 3 m (422).

(c) Natural and depleted solid unirradiated uranium is classified as LSA-I (131(a)(ii) and (iii).

(d) LSA-I cannot be fissile material (131)(a)(iii)). 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 (131(b)(ii)):

$$10^{-4}\ A_2/g$$

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.

According to Table AII.1 (Appendix II), specific activity up to 5% enrichment level is 6.7×10^4 Bq/g or less. Above this enrichment level UF_6 cannot be classified as LSA-II, unless specific activity remains below 10^5 Bq/g also taking into account daughter products of uranium isotopes.

UF_6 enriched to levels were the specific activity exceeds 10^5 Bq/g cannot be classified as LSA-III because the requirement of para.131(c)(ii) 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).

6) Uranium-235 enrichment greater than 5.0% and maximum contents of package greater than 15 g of uranium-235

(a) Specific activity not greater than 10^5 Bq/g (see Table AII.1)

- Classified as fissile radioactive material, LSA-II;
- Shall comply with IP-2 containment and shielding requirements and satisfying criticality safety requirements; and
- Shipped as a package containing fissile material.

(b) Specific activity greater than 10^5 Bq/g (see Table AII.1)

- Classified as fissile radioactive material;
- Shall comply with Type A containment and shielding requirements if activity does not exceed 0.001 TBq, otherwise shipped in a package satisfying Type B containment and shielding requirements, and in both cases satisfying criticality safety requirements; and
- Shipped as a package containing fissile material.

Key requirements imposed for each of the last five of these six material classification/packaging combinations are summarized in Table AI.1. Shipment of packaged UF_6 as excepted packages is not generally practical because of the small quantities of UF_6 per package involved. Requirements imposed by the Regulations for the shipment of empty packagings were outlined above.

Protection of the valves of UF_6 packages is a very important issue. The extent to which the Regulations requires protection (inherently or directly) depends upon the material classification/package which applies.

If the UF_6 package is a Type B (it will also be a package containing fissile material), the valve must be protected for the accident condition tests (paras 627-629). Similarly, for other fissile material shipments (where the package may be either IP-2 or Type A), the mechanical and thermal tests (paras 627 and 628) required to assure prevention of criticality (para. 564) may also inherently require valve protection. An IP-2 package will inherently have the valve protected from normal transport condition drops (para. 622), whereas an IP-1 or excepted package will have the valve protected from accelerations and vibrations which may arise during transport (para. 511).

Appendix II

PROPERTIES OF UF_6 AND ITS REACTION PRODUCTS

INTRODUCTION

A.II.1. This Appendix gives a short summary of the relevant properties of the materials involved. Hazards associated with these materials, both from the radiological and chemical point of view, are discussed as well. A brief description of possible consequences of accidents is given.

PROPERTIES OF URANIUM HEXAFLUORIDE

A.II.2. Uranium hexafluoride, UF_6, is a white solid at room temperature. It is the only compound of uranium which is a gas at low temperature. At atmospheric pressure (0.101 MPa, 760 mmHg) the partial vapour pressure above the solid at 56.4°C equals atmospheric pressure. It liquefies at 64.0°C at a pressure of 0.151 MPa (1137 mmHg).

Physical properties

A.II.3. The most important physical properties of UF_6 are given below [10,11]:

Heat of sublimation (64°C)	137,500 J/kg
Heat of fusion (64°C)	54,167 J/kg
Heat of vaporization (64°C)	83,333 J/kg
Critical pressure	4.61 MPa
Critical temperature	230.2°C
Triple point	64.0°C

Vapour pressure - temperature relations:

For temperatures $64^\circ C \leq t \leq 120^\circ C$:

$$\lg_{10} P \text{ (MPa)} = 3.11964 - 1126.288/(t + 221.963), \text{ and for}$$

$0^\circ C \leq t \leq 64^\circ C$:

$$\lg_{10} P \text{ (MPa)} = 2.50853 + 0.0075377\, t - 942.76/(t + 183.416)$$

The diagrams for UF_6 phases, densities and heat capacities of UF_6 (liquid, solid and vapour), UF_6 sublimation and vaporization heat and thermal conductivity of UF_6 vapour are given in Figures AII.1-9.

Usually UF_6 contains small quantities of HF. The vapour pressure inside a UF_6 packaging is therefore somewhat higher. The phase diagram of UF_6-HF mixtures is given in [10].

Practical grade UF_6 is defined in [12]. This specification gives the limits to impurities and the upper values of vapour pressure designated in Fig. AII.1 a "ASTM LIMIT".

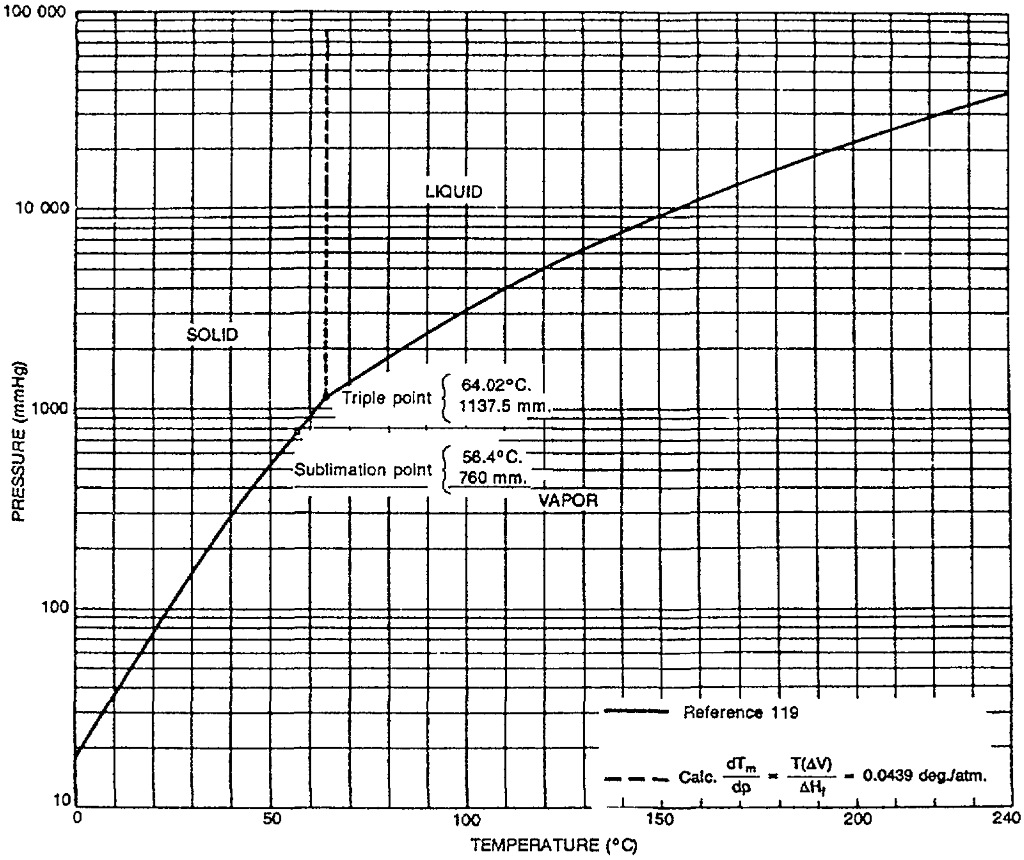


FIG. AII.1. Phase diagram of UF_6 [10].

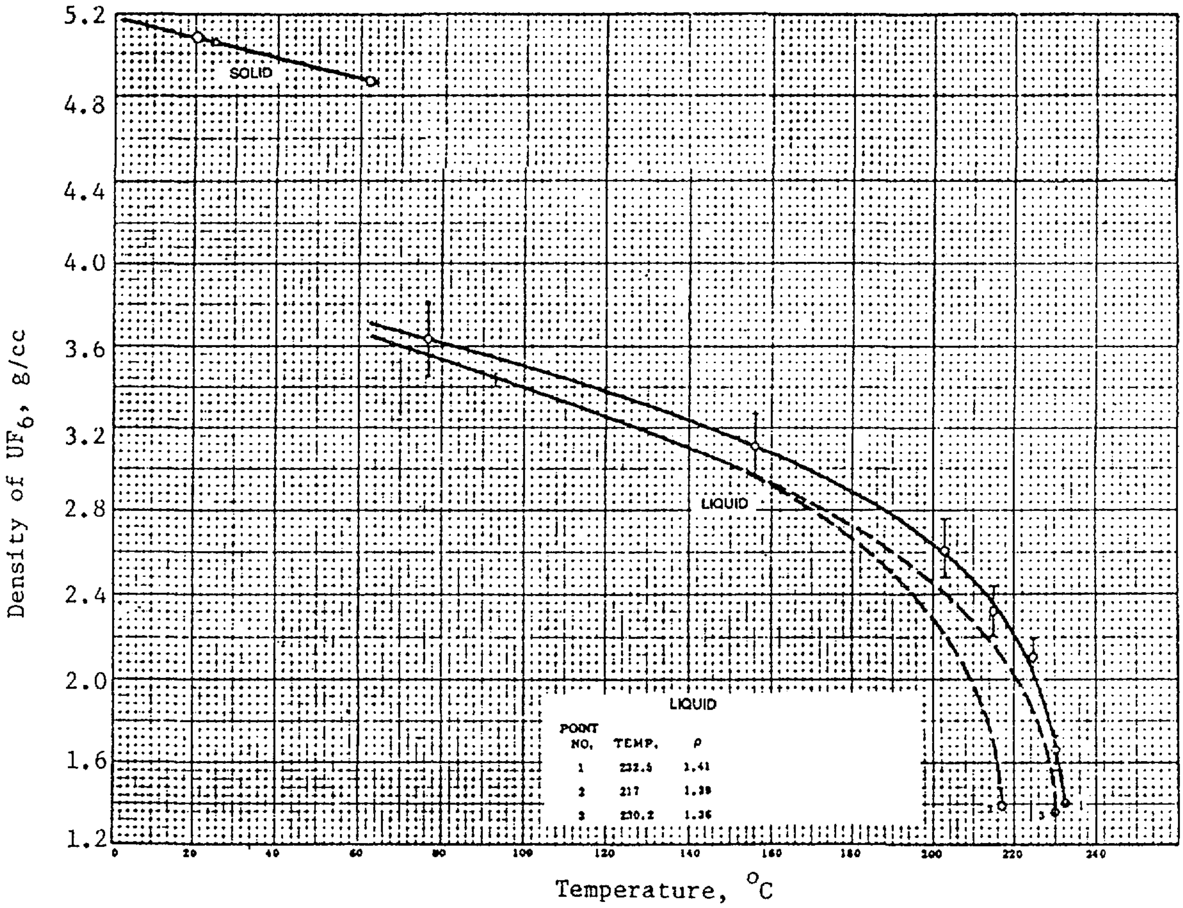
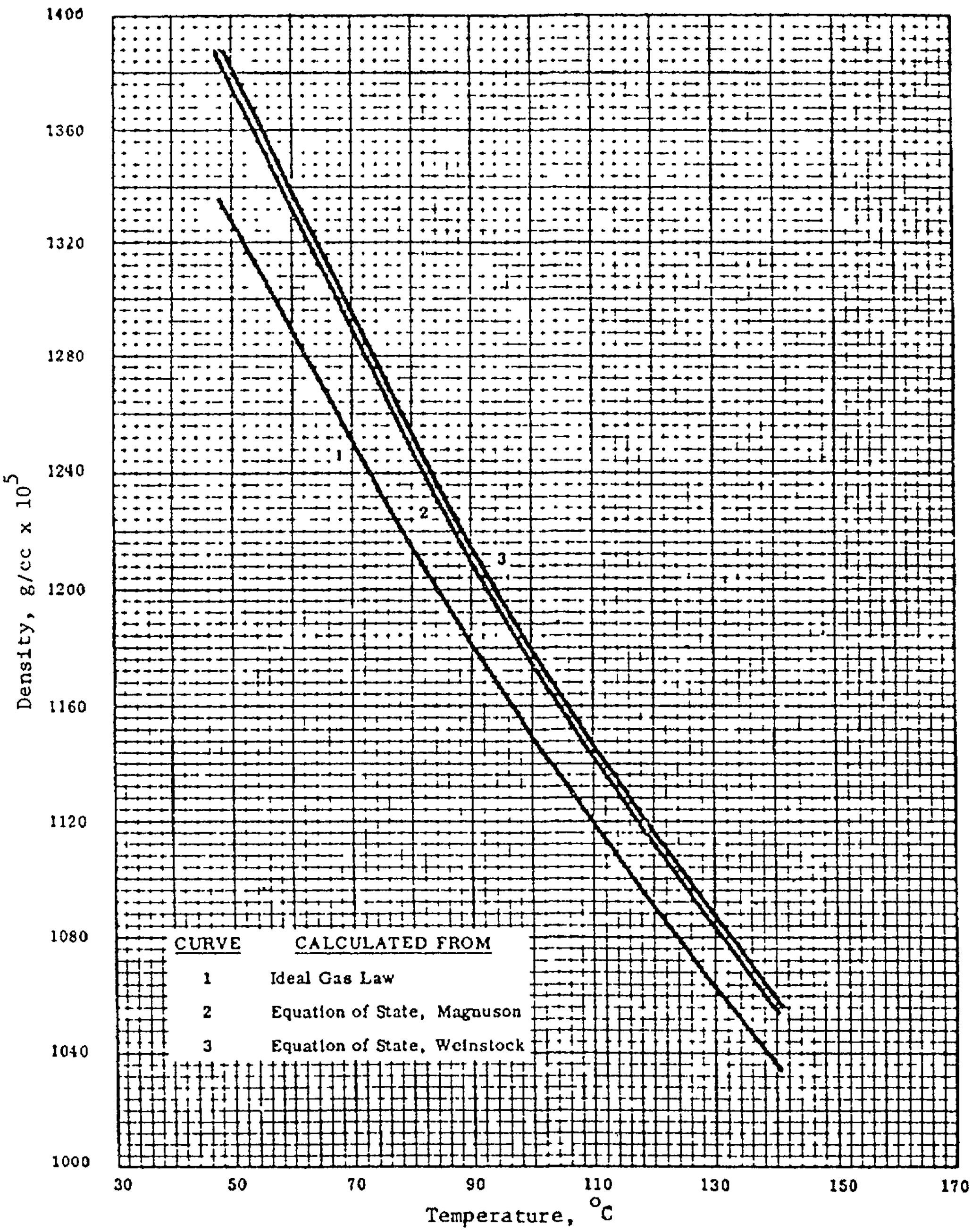


FIG. AII.2. Density of solid and liquid UF_6 [10].



The vapour density of UF_6 is given by the expression:

$$\rho = 4.291 \times 10^{-2} (P/T) (1 + 1.2328 \times 10^{4} P/T^{3}) \text{ kg/L}$$

ρ is the pressure in KPa and T the temperature in degrees Kelvin.

FIG. AII.3. Vapour density of UF_6 (calculated at atmospheric pressure) [10].

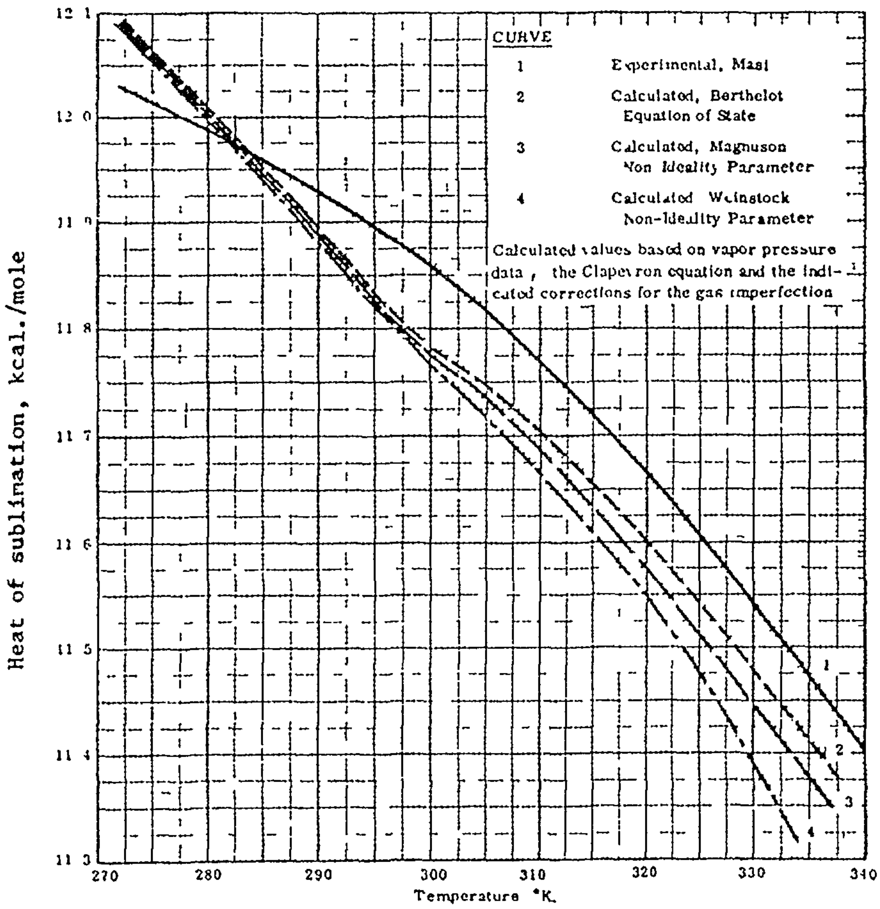


FIG. AII 4. Heat of sublimation of UF_6 [10]

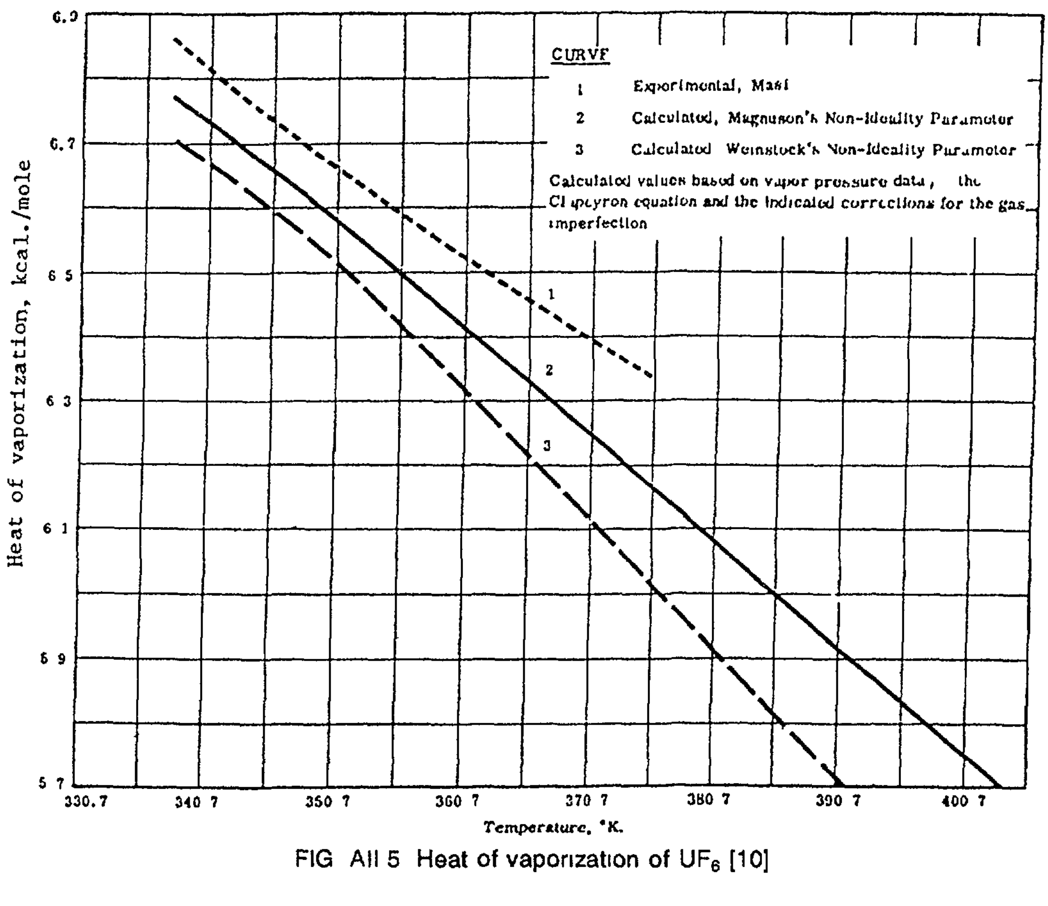


FIG AII 5 Heat of vaporization of UF_6 [10]

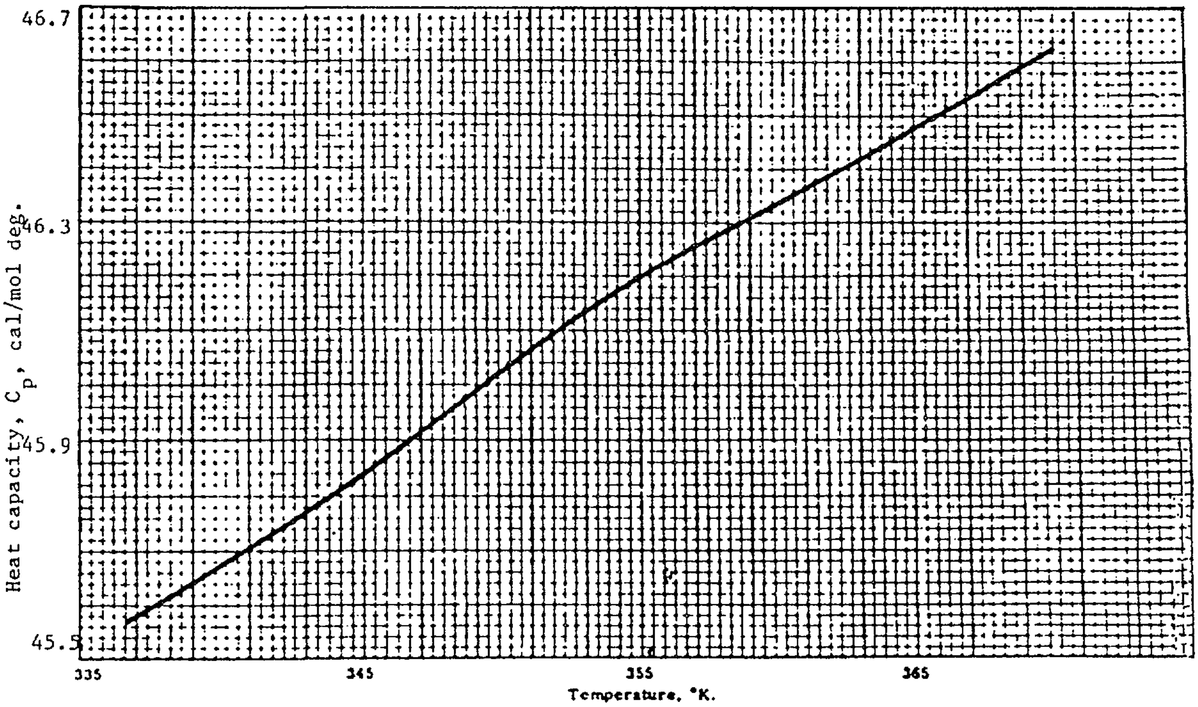


FIG. AII.6. Heat capacity of the liquid UF_6 [10].

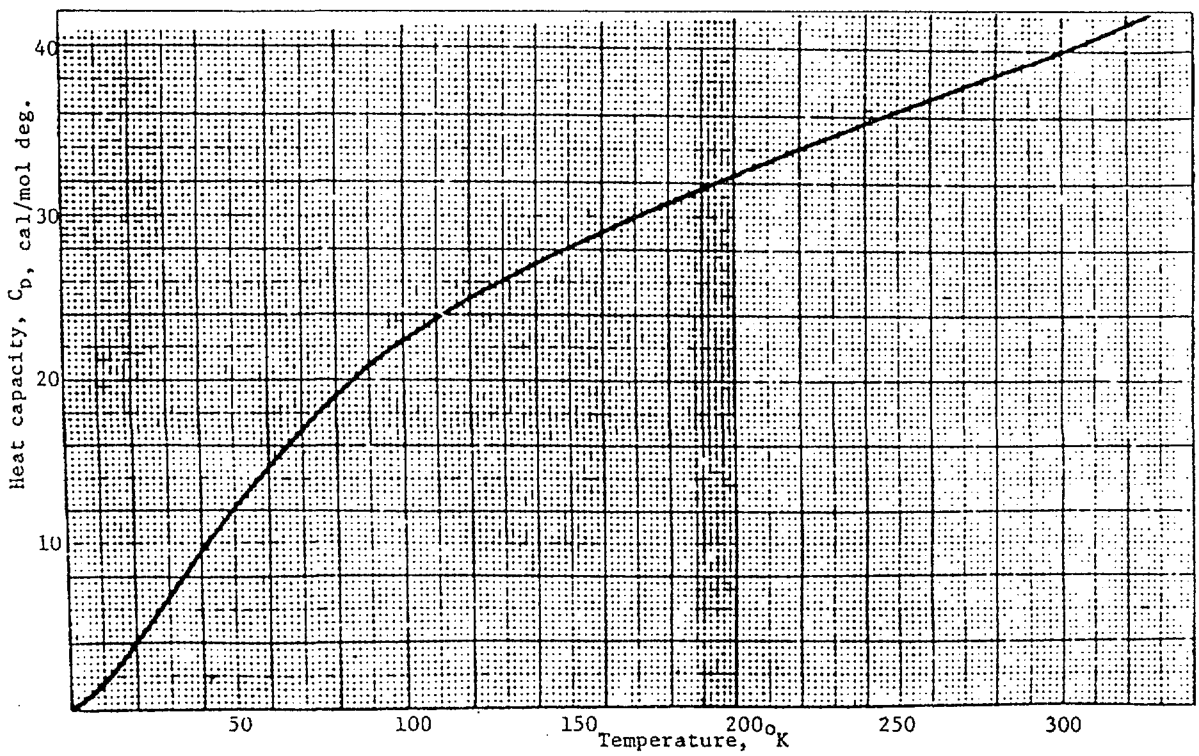


FIG. AII.7. Heat capacity of the solid UF_6 [10].

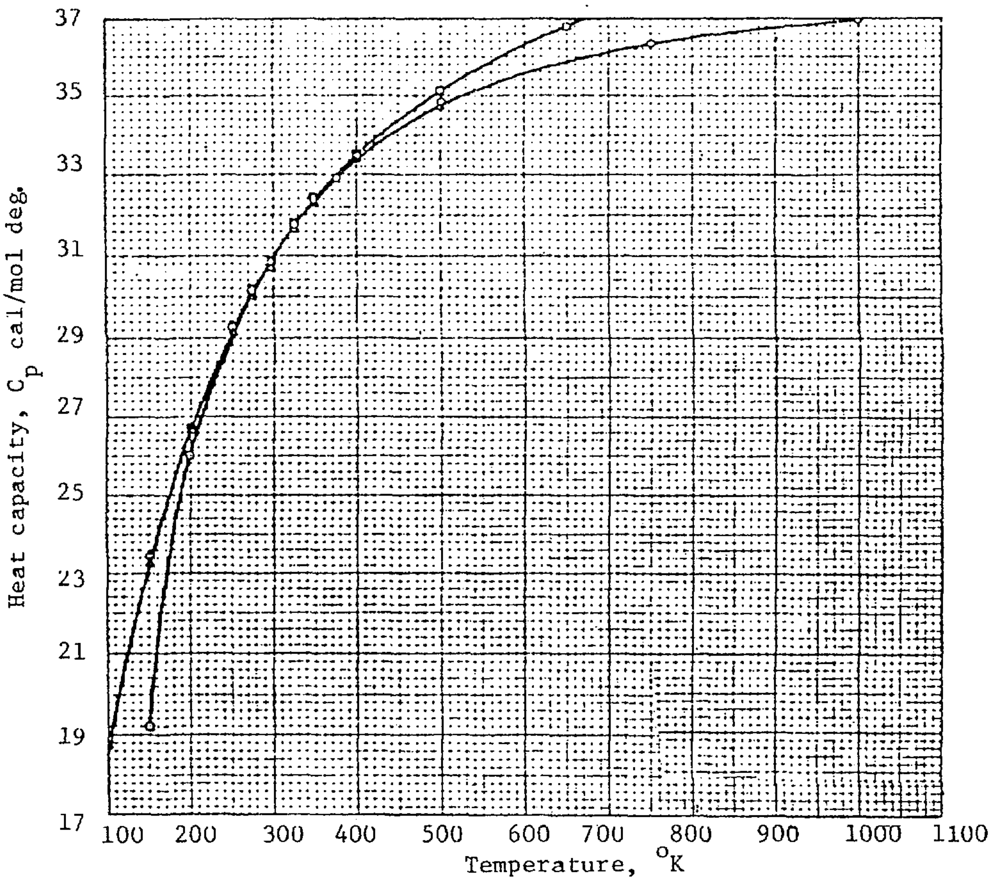


FIG. AII.8. Heat capacity of UF_6 vapour [10].

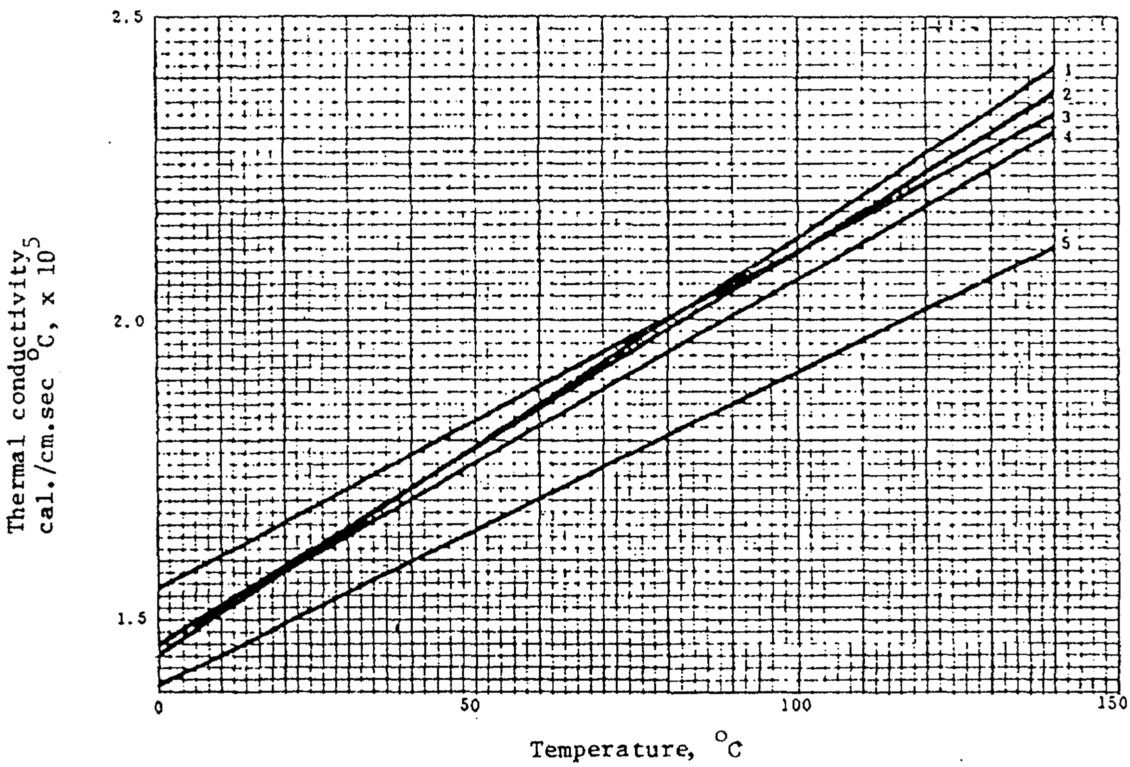


FIG. AII.9. Thermal conductivity of UF_6 vapour [10].

Chemical properties

AII.4. Uranium hexafluoride is a highly reactive material which reacts chemically with water, ether and alcohol to form soluble reaction products. These reactions are very exothermic. Water reacts with UF_6 to produce uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF) both of which are very hygroscopic. Two reactions could be mentioned:

(a) In gaseous phase:

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

where $\Delta H = -156.8$ KJ/mole

(b) In a condensed state:

$$UF_6(s) + 2H_2O(l) \rightarrow UO_2^{++} + 2F^- + 4HF(g)$$

where $\Delta H = -211.6$ KJ/mole

In the condensed state the reaction of a solid mass UF_6 with water may be slow due to the formation of UO_2F_2 hydrate which covers the UF_6 minimizing further reaction with the environment.

Due to the oxidizing properties of UF_6, the reaction of liquid UF_6 with some organic materials is unpredictable and may be explosive [13]. Small quantities of hydrocarbon oil may react vigorously resulting in a serious explosion. As a result extreme caution should be used to ensure that cylinders are clean and free of organics.

The reactivity with fully fluorinated hydrocarbons is low. UF_6 does not react with oxygen, nitrogen or dry air and it is sufficiently inert to dry aluminium, copper, monel, nickel and aluminium bronze that they can be exposed to UF_6 without excessive corrosion.

AII.5. When released to the atmosphere, gaseous UF_6 reacts with humidity to form HF and UO_2F_2. Because the rate constant of the reaction is high the reaction rate is dependent on the availability of water. The minimum amount of water necessary to hydrolize 1000 kg of UF_6 is 100 kg. At 25°C and 50% humidity this amount of water represents ~ 6000 m^3 of air. It is obvious, therefore, that in case of a large scale release of UF_6 the hydrolysis might take a considerable time. If such a release occurs in an open area, in which case the dispersion is going to be governed by meteorological conditions, the plume might still have a considerable concentration of unhydrolysed UF_6 even at a distance of several hundred metres.

Activity of UF_6

AII.6. The total activity in a mass of UF_6 is controlled by several factors including the nature of the feed material, the degree and method of enrichment, the length of time since the UF_6 has been processed, and its impurity contents.

AII.7. The specific activity of UF_6 at various levels of enrichment is given as an example in Table AII.1.

TABLE AII.1 SPECIFIC ACTIVITY VALUES FOR URANIUM HEXAFLUORIDE AT VARIOUS LEVELS OF ENRICHMENT [6]

Mass percent U-235 present in uranium mixture	Specific activity[(a)]	
	Bq/g (UF_6)	Ci/g (UF_6)
0.45	1.2×10^{4}	3.3×10^{-7}
0.72 (natural)	1.7×10^{4}	4.8×10^{-7}
1.0	1.9×10^{4}	5.1×10^{-7}
1.5	2.5×10^{4}	6.7×10^{-7}
5.0	6.7×10^{4}	1.8×10^{-6}
10.0	1.2×10^{5}	3.2×10^{-6}
20.0	2.5×10^{5}	6.8×10^{-6}
35.0	5.0×10^{5}	1.3×10^{-5}
50.0	6.2×10^{5}	1.7×10^{-5}
90.0	1.5×10^{6}	3.9×10^{-5}
93.0	1.8×10^{6}	4.7×10^{-5}
95.0	2.3×10^{6}	6.1×10^{-5}

(a) The values of the specific activity include the activity of uranium-234 which is concentrated during the enrichment process, and do not include any daughter product contribution. The values are for the material originating from natural uranium enriched by gaseous diffusion method. If the origin of the material is not known the specific activity should be either measured or calculated using isotopic ratio data.

AII.8. As UF_6 is produced by a chemical process its equilibrium with its daughter compounds is disturbed during the process. As all uranium isotopes have very long half lives while the daughters of uranium-238 and uranium-235 (thorium-234 and thorium-231, respectively) have short half lives, a secular equilibrium is going to be attained after a period of approximately 150 days. After that period the specific activity is going to be e.g. 3.6×10^4 Bq/g UF_6 for enrichment of 0.45% and 4.0×10^4 Bq/g UF_6 for natural uranium. The specific activity of highly enriched UF_6 changes only slightly, e.g. at an enrichment of 90% it will be 1.55×10^6 Bq/g UF_6.

AII.9. UF_6 produced from non-irradiated uranium, e.g., uranium ore concentrate, contains no sources of radioactivity other than naturally occurring isotopes of uranium, i.e., U-233, U-235 and U-234 and their daughter products.

UF_6 produced from irradiated and reprocessed uranium can additionally contain significant concentrations of:

a) other uranium isotopes, e.g., U-232, U-233, U-236, U-237
b) transuranic elements, e.g., Np-237, Pu-239
c) fission products, e.g., Ru-106, Zr-95/Nb-95, Tc-99
d) daughter products of these species, e.g., Th-228, Tl-208.

The overall composition of this type of UF_6 will depend upon the reactor type in which the source uranium was irradiated, the burn-up and subsequent cooling history, the efficiency of decontamination for impurities obtained in reprocessing and reconversion and the time elapsed since these processes were carried on. In these circumstances calculation of transport indexes must be made for each package based upon specific analytical data.

During its commercial production and enrichment, UF_6 might be slightly contaminated with reprocessed uranium. In such cases the material may be treated as being of non-irradiated origin, provided it meets the specifications for commercial UF_6 [12], which are based on U-236 limitations.

AII.10. While UF_6 packagings often are filled by a liquid transfer they are emptied by evaporation. The result is that radioactive impurities (or heels) which are not volatile tend to remain in the packaging. Periodic removal of these heels may be necessary.

AII.11. Depleted and natural UF_6 are not classified as fissile materials, and accordingly there is no possibility for nuclear criticality during transport. Although uranium enriched up to 1% U-235 is classified as fissile, uranium as UF_6 in this enrichment range will not sustain a nuclear reaction. UF_6 enriched to greater than 1% U-235 is fissile material requiring additional controls to prevent accidental nuclear criticality. These additional controls are found in the Regulations.

Appendix III

POTENTIAL ACCIDENT CONSEQUENCES AND EMERGENCY RESPONSE PLANNING AND PREPAREDNESS FOR ACCIDENTS INVOLVING THE RELEASE OF UF_6

Hazards associated with a release of UF_6

AIII.1. The hazards associated with released UF_6 are mainly due to the exposure to HF and UO_2F_2 and they are dealt with in the following sections. The hazards of exposure to unhydrolysed UF_6 are higher than those involved in the combined exposure to UO_2F_2 and HF. Although exposure to UF_6 may result in a hydrolysis reaction occurring within the body, there is currently no human data available that demonstrates the extent of damage caused by this raeaction. Health effects mentioned in the following sections apply to adults, care should be taken in the use of these values when applied to infants or children.

HAZARDS OF URANYL FLUORIDE

AIII.2. Uranyl fluoride, UO_2F_2, is produced by hydrolysis of UF_6. It is a yellow hygroscopic solid which is very soluble in water. The hazards which are associated with UO_2F_2 relate to fissile, radiological and toxic properties of UO_2F_2.

AIII.3. Fissile properties of UO_2F_2 are comparable to 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 which will be dissipated over large areas. The fissile properties of UF_6 are discussed in more detail in AII.11.

AIII.4. The radiological effect of UO_2F_2 can take two pathways. One is the inhalation of aerosols of UO_2F_2 and the other is the potential intake associated with environmental contamination from depostion of UO_2F_2.

AIII.5. As UO_2F_2 is very soluble in both water and in lung fluid , it should be classified as Lung Class D [14] for which the Annual Limit for Intake (ALI) of all the important isotopes of uranium is 5×10^4 Bq. According to the basic dosimetric considerations upon which the Regulations are based, an intake of 1 ALI within a time period of 30 minutes is considered to be the limiting dose for radiological effects. By comparison an intake of 25 mg of soluble uranium within the same time period is considered as the threshold of renal damage (see para. AIII.7). Thus, by consulting Table AII.1, it can be seen that it is equivalent to one ALI if the enrichment is approximately 80%. It is estimated that in all circumstances the toxicological effects of acute exposures will exceed the radiological consequences. Table AIII.1 [15] demonstrates this.

TABLE AIII.1 COMPARISON OF CHEMICAL TOXICITY OF SOLUBLE URANIUM*

Absorbed Quantity of Soluble Uranium (mg-U/kg)	Equivalent Radiation Dose (μCi)	Acute Health Effects Chemical Toxicity	Acute Health Effects Radiotoxicity
0.03	0.16	No effect	No effect
0.058	0.30	Renal injury	No effect
1.63	8.45	50% lethality	No effect
19.29	100	Lethal	Onset of radiological effects

* At 97.5% U-235 and 1.14% U-234 enrichment.

AIII.6. UO_2F_2 as a solid particulate compound may deposit on the ground over a large area. There are no internationally accepted values for uranium contamination levels for uncontrolled occupancy. However the value of 0.3 Bq/cm^2 (10^{-5} μCi/cm^2) is accepted in many countries [16] for unlimited occupancy of uncontrolled areas. This is equivalent to ground concentration of approx. 0.1 g/m^2 for natural uranium and to 0.003 g/m^3 for 50% enriched uranium.

AIII.7. The toxicological effects of soluble uranium compounds are discussed, e.g., by Just et al [15, 17, 18]. Their findings are summarized in Fig. AIII.1. In order to get the amounts of material inhaled one has to multiply the integrated exposure by the breathing rate (0.02 m^3/min) and by the fraction of inhaled uranium absorbed by the body (0.43). For example, the Renal Injury Level for exposures shorter or equal to 30 minutes is 1250 x 0.02 x 0.43 = 10.75 mg.

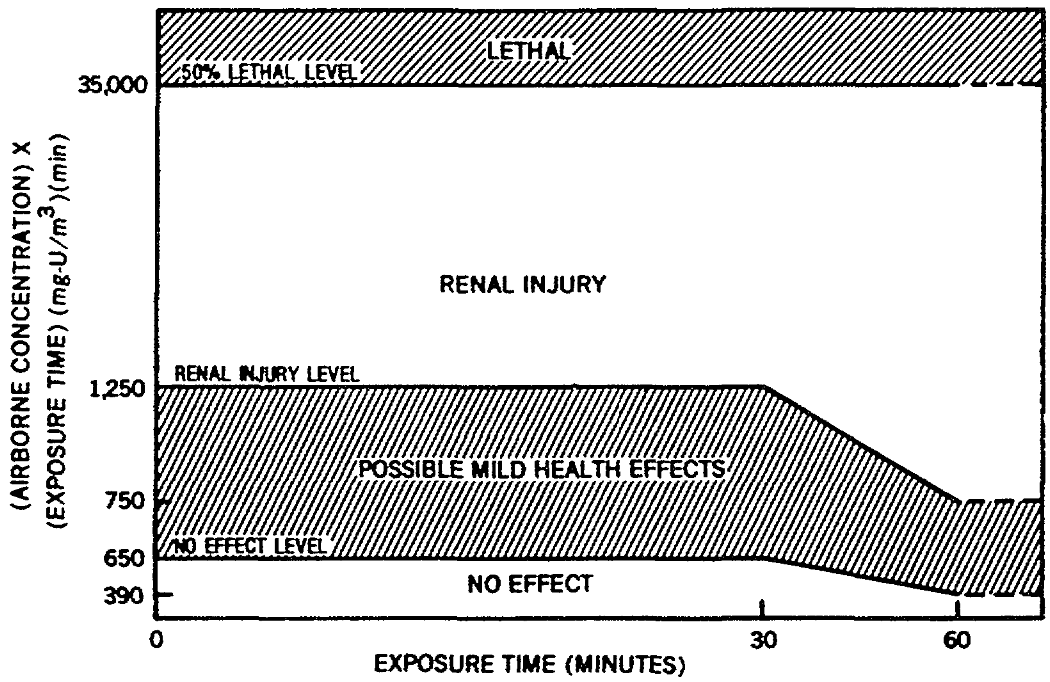


FIG. AIII.1. Toxicity of acute exposures to soluble uranium [15].

HAZARDS OF HYDROGEN FLUORIDE

AIII.8. Hydrogen fluoride is a colourless fuming corrosive liquid which boils at 20°C. It is one of the strongest corrosive agents, and it is considered to be one of the most destructive inorganic agents known to human tissues. A distinction is made between anhydrous hydrogen fluoride (UN Number 1052) and an aqueous solution of hydrofluoric acid (UN Number 1790), which is less dangerous.

AIII.9. The toxicology of hydrogen fluoride is discussed, e.g. by Just et al. [15, 17, 18]. The findings are summarized in Fig. AIII.2 and Table AIII.2 and by C. Ringot [8].

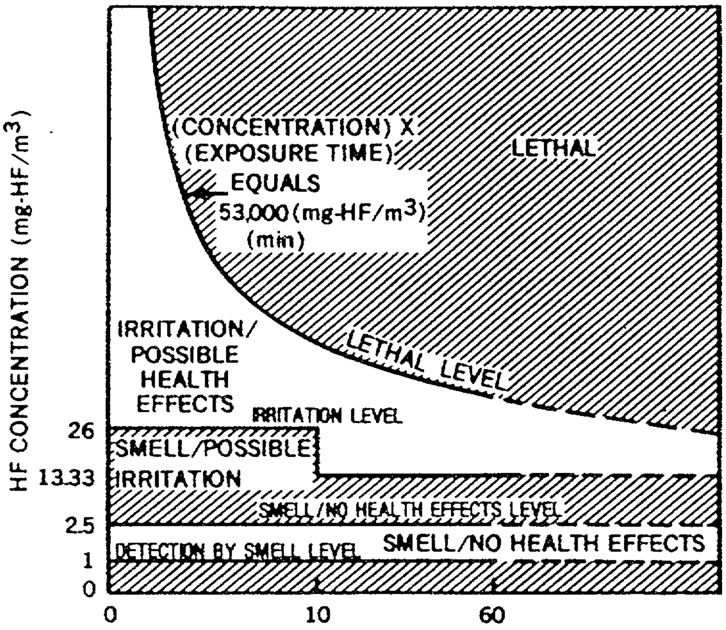


FIG. AIII.2. Toxicity of acute exposures to hydrogen fluoride [17].

TABLE AIII.2 SUMMARY OF ESTIMATES OF HYDROGEN FLUORIDE TOXICITY [18]

Source	Effect	Concentration (mg–HF/m^3)	Exposure Time (min)
	Threshold of detection by smell	0.02 to 1	-
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 & Health Administration (OSHA)	Permissible Exposure Limit (PEL)	2	480
National Research Council	Emergency Exposure Limit	13.3	10
NIOSH/OSHA	Immediately Dangerous to Life or Health (IDLH)	25.4	30

POTENTIAL CONSEQUENCES OF ACCIDENTS

AIII.10. The chemical hazard may dominate the consequences of transport accidents involving depleted, natural and low enriched UF_6. However the radiological and especially criticality hazards may become more important in accidents of high enriched UF_6.

AIII.11. A criticality accident that results from the transport of enriched UF_6 (see AII.11) could temporarily result in a large pulse of radiation levels in the vicinity of the package. Radiation levels could be significant up to some hundred metres away from the package. Following nuclear criticality there would also be residual high radiation in the vicinity of the package. Specific consequences of criticality accidents depend on the uranium enrichment level and on accident conditions.

AIII.12. Transport accidents in which UF_6 is involved may be followed by content release. The amount of UF_6 released and release rate depends upon the size of the opening in the package, the availability of heat and emergency measures taken.

AIII.13. As long as fire is not involved, a break of the cylinders valve seems to be the most probable mechanical consequence of a road accident. If such a break occurs the material will escape slowly by sublimation unless brought into contact with water. The rate of release depends strongly on the ambient temperature. In those cases involving small openings the UO_2F_2 formed by the hydrolysis of UF_6 will deposit in the openings and will probably reseal the openings. Properly trained and equipped personnel can overcome the negative effects of such an accident by using mechanical plugging devices or taking some similar action. If, however, untrained people try to cope with such an accident they might aggravate the consequences of the situation by the use of improper procedures. For this reason shippers of UF_6 have issued detailed instruction for such emergencies [19]. When appropriate response procedures are followed the consequences of this type of accident cannot be significant.

AIII.14. Transport accidents involving large fires are considered to have the potential for serious effects. Such accidents may give rise to the release of large quantities of UF_6 - in a relatively short period of time.

A massive UF_6 release may result in dangerous concentrations of both uranium and HF and may also cause area contamination of several square kilometres. A discussion of such a hypothetical accident is given in Ref. [10]. In that document some emergency procedures are recommended.

AIII.15. In considering possible accidents involving the transport of UF_6 by sea, scenarios describing the sinking of a ship followed by a breech of the valve with water in leakage have been studied [11,20] The conclusion was that any water inleakage would not result in a chemical explosion.

AIII.16. Additionally, fires on ships are known to have long duration and high temperatures that might result in releases with consequent serious exposures to the ship's crew, and if the ship is in port, to other individuals within the vicinity of the vessel.

AIII.17. No assessment is known to have been made concerning the risk involved in air transport of UF_6. However, only small quantities of UF_6 are expected to be shipped by air.

REFERENCES

[1] MALLET, A.J., ORGDP Container Test and Development Programme: Fire Tests of UF_6-filled Cylinders, K-D-1984, Union Carbide Corp., Oak Ridge, Tennessee (1966).

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