USEC-651 (Revision 7)

Uranium Hexafluoride: A Manual of Good Handling Practices

JANUARY 1995

United States Enrichment Corporation

FORWARD

On July 1, 1993, the United States Enrichment Corporation (USEC) assumed responsibility for operating the gaseous diffusion plants at Paducah, Kentucky and Portsmouth, Ohio.

Over the last 28 years, guidelines for packaging, measuring and transferring uranium hexafluoride (UF_6) have been revised and issued by the U.S. Department of Energy (DOE) in its ORO-651 series. The USEC is now responsible for updating and maintaining this information.

History of the Document

In 1957, K-1323, *A Brief Guide to Handling UF_6* was published. This was superseded in 1966 by the first issue of ORO-651. ORO-651 was reissued in 1967 to make editorial changes and to provide minor revisions in procedural information. In 1968 and 1972, Revisions 2 and 3 respectively were published to reflect current conditions and information. Revision 4, issued in 1977, included updates to information on cylinders, valves and methods of use. In 1987, Revision 5 added material dealing with pigtails, overfilling cylinders, handling precautions, cylinder heel reduction procedures, and definitions. Weighing standards previously presented in ORO-671, Volume 1, *Procedures for Handling and Analysis of UF_6* were also included; thus Revision 5 superseded ORO-671-1. Revision 6 of ORO-651, which was issued in 1991, added sections on quality assurance and storage of UF_6 as well as an expanded discussion of UF_6 physical and chemical properties.

Revision 7

This edition of *Uranium Hexafluoride: A Manual of Good Handling Practices,* USEC-651, is the seventh revision in a continuing effort to keep the information current with developing technologies and agreements for the supply of enriched uranium. USEC-651 supersedes all prior issues. The guidelines set forth in this document will normally apply in all transactions involving receipt or shipment of UF_6 by USEC unless stipulated otherwise by contracts or agreements with USEC or by notices published in the Federal Register.

Any questions or requests for additional information on the subject matter covered herein should be directed to the United States Enrichment Corporation, Two Democracy Center, 6903 Rockledge Drive, Bethesda, Maryland, 20817, Attention: Vice President of Production.

CONTENTS

FIGURES

TABLES

APPENDIX

ACRONYMS

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BTU	British Thermal Unit
BTU/lb/°F	British Thermal Units per pound per degree Fahrenheit
Bq/μg	Becquerels per microgram
μCi/g	Microcuries per gram
DOE	U. S. Department of Energy
DOT	U. S. Department of Transportation
g/cc	Grams per cubic centimeter
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aeronautics Organization
ISO	International Standards Organization
J/kg	Joules per kilogram
J/kg/K	Joules per kilogram per degree Kelvin
kPa	Kilopascal
lb/ft^3	Pounds per cubic foot
in. Hg	Inches of mercury
mm Hg	Millimeters of mercury
NIST	National Institute of Standards and Technology

NRC	U. S. Nuclear Regulatory Commission
OSTI	Office of Scientific and Technical Information
psia	Pounds per square inch absolute
psig	Pounds per square inch gage
PSP	Protective structural package
SA	Specific activity
QA	Quality Assurance
UF_6	Uranium Hexafluoride
USEC	United States Enrichment Corporation

DEFINITIONS

BTU	British Thermal Unit; the amount of heat required to raise the temperature of 1 pound of water 1°F.
Cold Burp	Evacuating low-molecular-weight gases from a cylinder without application of heat to the cylinder.
Cold Pressure Check	Vacuum check at ambient temperature.
Flashing	Rapid change from liquid to gas.
Heel	The residual quantity of uranium material that remains in a cylinder after routine evacuation procedures.
Manifold	A permanent valving and piping system used in association with UF_6 transfers into or out of cylinders.
Pigtail	The flexible tubing that connects the cylinder valve to the piping manifold of the process system.
Specific activity	The activity per unit weight of a sample of radioactive material.
Triple point	The conditions (22 psia and 147.3°F) at which UF_6 can exist as a solid, liquid and gas at the same time.
Ullage	The gas volume above the liquid in a container.
Uranium	
Natural uranium	Uranium with an assay of 0.711% U-235 which occurs naturally.
Low enriched uranium	Uranium with an assay greater than 0.711% U-235 and less than 20% U-235. Typical assays used in commercial light water moderated reactors range from 3% to 5% U-235.
Depleted uranium	Uranium with an assay less than 0.711% U-235.

1. INTRODUCTION

The United States Enrichment Corporation (USEC) is continuing the policy of the U.S. Department of Energy (DOE) and its predecessor agencies in sharing with the nuclear industry their experience in the area of uranium hexafluoride (UF_6) shipping containers and handling procedures. The USEC has reviewed Revision 6 of ORO-651 and is issuing this new edition to assure that the document includes the most recent information on UF_6 handling procedures and reflects the policies of the USEC. The document number, USEC-651, continues the numerical title to which it is customarily referred.

This manual updates the material contained in earlier issues. It covers the essential aspects of UF_6 handling, cylinder filling and emptying, general principles of weighing and sampling, shipping, and the use of protective overpacks. The physical and chemical properties of UF_6 are also described.

The nuclear industry is responsible for furnishing its own shipping cylinders and suitable protective overpacks. A substantial effort has been made by the industry to standardize UF_6 cylinders, samples, and overpacks. The American National Standards Institute (ANSI) has played a major role in the effort, with current packaging information being published in the latest revision of ANSI N14.1, *Packaging of Uranium Hexafluoride for Transport*. It is standard practice to meet the requirements of the latest revision of ANSI N14.1.[1]

The quality of feed materials is important to the safe and efficient operation of the enriching facilities, and the UF_6 product purity from the enriching facilities is equally important to the fuel fabricator, the utilities, the operators of research reactors, and other users. These requirements have been the impetus for an aggressive effort by USEC and its contractors to develop accurate techniques for sampling and for chemical and isotopic analysis. A quality control program is maintained within USEC enriching facilities to ensure that the proper degree of accuracy and precision is obtained for all the required measurements.

The procedures and systems described for safe handling of UF_6 presented in this document have been developed and evaluated during more than 40 years of handling vast quantities of UF_6. With proper consideration for its nuclear properties, UF_6 may be safely handled in essentially the same manner as any other corrosive and/or toxic chemical.

[1] A copy can be obtained from the American National Standards Institute, 11 West 42nd St., New York, NY 10036. Telephone (212) 642-4900. Sales FAX (212) 302-1286.

2. QUALITY ASSURANCE

Federal regulations, industry standards, and good management practices require documented quality assurance (QA) programs covering all aspects of uranium hexafluoride handling. These programs help to assure the safe handling of UF_6 through each phase of operations. Within the United States, work is performed under the jurisdiction of several organizations that mandate specific QA program requirements (Table 1). Uranium hexafluoride operations outside the United States are performed under regulations and guidance from other organizations, such as the International Atomic Energy Agency (IAEA) and the International Standards Organization (ISO).

QA programs are applicable to handling operations and component items, such as cylinders, pigtails, and valves. Operations, such as cylinder weighing and transport, are performed using formal procedures, which include QA criteria to assure they are performed in accordance with current instructions and regulations. Components are designed, procured, fabricated, and inspected using QA plans developed specifically for each item.

Table 1 summarizes the organizations, their QA regulations and guidelines applicable to UF_6 operations, and the items and materials used during those operations. Since the requirements are periodically changed, the latest revisions of the applicable regulations and standards should be used.

Table 1. Quality Assurance Requirements

ORGANIZATION	REQUIREMENT
Nuclear Regulatory Commission	Section 10 of the *Code of Federal Regulations*, Part 71, Subpart H; Part 50.34; Appendix B to Part 50; and Part 830
Department of Transportation	Section 49 of the *Code of Federal Regulations*, Parts 173.474 and 173.475
American National Standards Institute	ANSI N14.1 (latest revision), *American National Standard for Nuclear Materials - Uranium Hexafluoride - Packaging for Transport*
American Society of Mechanical Engineers	ASME NQA-1, *Quality Assurance Program Requirements for Nuclear Facilities*
Department of Energy	*Regulatory Oversight Agreement Between the U.S. Department of Energy and the United States Enrichment Corporation*, Appendix A: Safety Basis and Framework for DOE Oversight of the Gaseous Diffusion Plants, Section 3.6, Quality Assurance. (These DOE requirements will be in effect until the Nuclear Regulatory Commission assumes regulatory control over the gaseous diffusion plants.)

3. TOLL ENRICHMENT INFORMATION

3.1 General

USEC provides Toll Enrichment service to nuclear power plants by increasing the concentration of the uranium-235 isotope from its naturally occurring concentration of 0.71% to the concentration used in nuclear reactors. The Oak Ridge Gaseous Diffusion Plant began operations in the mid-1940's. The Paducah, Kentucky and Portsmouth, Ohio gaseous diffusion plants were built in the early 1950's to increase the United States' capacity to enrich uranium. Shipments of enriched material to private industry for reactor use were started in 1957 on a rental basis and continued until the Toll Enrichment program was started in 1969.

The Portsmouth and Paducah plants continue to enrich uranium for the nuclear power industry; the Oak Ridge plant was shut down in 1985 for economic reasons. USEC supplies about one-half of the worldwide uranium enrichment requirements.

A Toll Enrichment charge is assessed by USEC for enriching and packaging of UF_6 from the diffusion facilities. A list of fees for enriching services can be obtained from the United States Enrichment Corporation, Two Democracy Center, 6903 Rockledge Drive, Bethesda, Maryland, 20817.

3.2 Cylinder Packaging Limits

The UF_6 supplied by USEC is packaged in cylinders of different sizes, depending on the total quantity and/or the uranium-235 assay (weight percent of uranium-235) involved. The shipping limits for standard cylinders are shown in Table 2. For ease of reference, this table is reproduced at the end of this document in the Appendix. The UF_6 shipped to USEC facilities in the standard cylinders shall conform to the shipping limits and the maximum uranium-235 assay listed in this table.

3.3 Inspection, Cleaning, Testing and Repairing of Privately Owned Cylinders

Companies providing cylinders for use at USEC facilities shall comply with USEC policy on inspection, cleaning, testing, and repairing of cylinders.

Table 2. UF_6 Cylinder Data Summary

Cylinder Model	Nominal Diameter inches	Material of Construction	Minimum Volume ft³	Minimum Volume liters	Approximate Tare Weight Without Valve Protector lb	Approximate Tare Weight Without Valve Protector kg	Maximum Enrichment U^{235} wt%	Shipping Limit Maximum,[a] UF_6 lb	Shipping Limit Maximum,[a] UF_6 kg
1S	1.5	Nickel	0.0053	0.15	1.75	0.79	100.00	1.0	0.45
2S	3.5	Nickel	0.026	0.74	4.2	1.91	100.00	4.9	2.22
5A	5	Monel	0.284	8.04	55	25	100.00	55	24.95
5B	5	Nickel	0.284	8.04	55	25	100.00	55	24.95
8A	8	Monel	1.319	37.35	120	54	12.5	255	115.67
12A	12	Nickel	2.38	67.4	185	84	5.0	460	208.7
12B	12	Monel	2.38	67.4	185	84	5.0	460	208.7
30B[c]	30	Steel	26.0	736.0	1,400	635	5.0[b]	5,020	2,277
48A	48	Steel	108.9	3,084	4,500	2,041	4.5[b]	21,030	9,539
48X[d]	48	Steel	108.9	3,084	4,500	2,041	4.5[b,g]	21,030	9,539
48F	48	Steel	140.0	3,964	5,200	2,359	4.5[b]	27,030	12,261
48G	48	Steel	139.0	3,936	2,600	1,179	1.0[f]	26,840[e]	12,174[e]
48Y[d]	48	Steel	142.7	4,041	5,200	2,359	4.5[b]	27,560	12,501
48H	48	Steel	140.0	3,964	3,170	1,438	1.0[f]	27,030	12,261
48HX	48	Steel	140.0	3,964	3,170	1,438	1.0[f]	27,030	12,261
48OM	48	Steel	140.0	3,964	3,050	1,386	1.0	27,030	12,261

[a] Shipping limits are based on 250°F (121°C) maximum UF_6 temperature (203.3 lb UF_6/ft³), certified minimum internal volumes for all cylinders, which provides a 5 percent ullage for safety. The operating limits apply to UF_6 with a minimum purity of 99.5 percent. More restrictive measures are required if additional impurities are present. The maximum UF_6 temperature must not be exceeded.

[b] Maximum enrichments indicated require moderation control equivalent to a UF_6 purity of 99.5 percent. Without moderation control, the maximum permissible enrichment is 1.0 wt percent uranium-235.

[c] The 30B cylinder replaces the Model 30A cylinder which is no longer in use.

[d] Models 48X and 48Y replace Models 48A and 48F whose volumes have not been certified.

[e] For USEC gaseous diffusion plant depleted uranium with UF_6 purity in excess of 99.5 percent, the shipping limit is 28,000 lb for cylinders with 8,800-lb water capacity or greater.

[f] Enrichment to 4.5 wt percent is safe with moderation control equivalent to a UF_6 purity of 99.5 percent, but limited to 1.0 wt percent uranium-235 for shipment.

[g] Enrichment to 5.0 wt percent is safe with moderation control equivalent to a UF_6 purity of 99.5 percent, but limited to 4.5 wt percent for shipment.

3.3.1 General

It is USEC policy to inspect visually and document findings for all UF_6 cylinders when they arrive at USEC facilities. These inspections provide added assurance that the cylinders meet specifications and are safe for use. Both the shippers and the receivers should inspect the cylinders at their facilities and record the necessary data. Examples of acceptable and unacceptable cylinder damage are described and shown in Figure 1. A typical cylinder inspection data sheet is shown in Figure 2.

Occasionally, UF_6 cylinders require cleaning to remove excessive buildup of impurities. It may also be desirable to remove the heel[2] when UF_6 of a different isotopic assay is to be added to the cylinder. Cleaning services are normally procured or furnished by the cylinder owners since USEC does not normally clean privately owned cylinders.

A standard for UF_6 cylinders has been established by ANSI. This standard, ANSI N14.1, latest revision, includes only those cylinders that meet all of the acceptance criteria for UF_6 handling. Cylinders not meeting the requirements of this standard, but now in use and having necessary regulatory approval, are considered to be acceptable for continued use provided they are inspected, tested, and maintained within the intent of the ANSI standard.

Cylinders and/or valves not covered by the standard shall be approved by USEC and the U. S. Department of Transportation (DOT) before the cylinders are accepted for shipments to or from USEC facilities.

3.3.2 Feed Cylinders

Upon receipt, cylinders of feed material are inspected externally and the findings are documented. If there is evidence of leakage, leak-control measures are taken, and the shipper is notified immediately. If the leakage is caused by a structural defect, the shipper is requested to provide instructions for the disposition of the cylinder. If the leakage is caused by a faulty valve, the shipper shall provide authorization, by facsimile or letter, for valve replacement. The internal pressure may be measured, and if the internal pressure is greater than 10 pounds per square inch (psia), the shipper is requested to provide instructions for the USEC facility to either return the cylinder to the shipper or to cold burp the cylinder at the receiving site. The costs incurred for valve replacement and/or cold burping are billed to the shipper. USEC reserves the right to reject nonconforming cylinders. Cylinders containing UF_6 with pressure greater than 14.7 psia shall not be transported.

The net weight of UF_6 feed accepted by USEC is the difference between the weights of the cylinder before and after emptying (gross full weight minus gross empty weight). A reasonable

[2]The residual quantity of uranium material that remains in a cylinder after routine evacuation procedures.

Examples of Acceptable and Unacceptable Damage to UF_6 Cylinders

DWG. NO. K/G-94-2209/AH

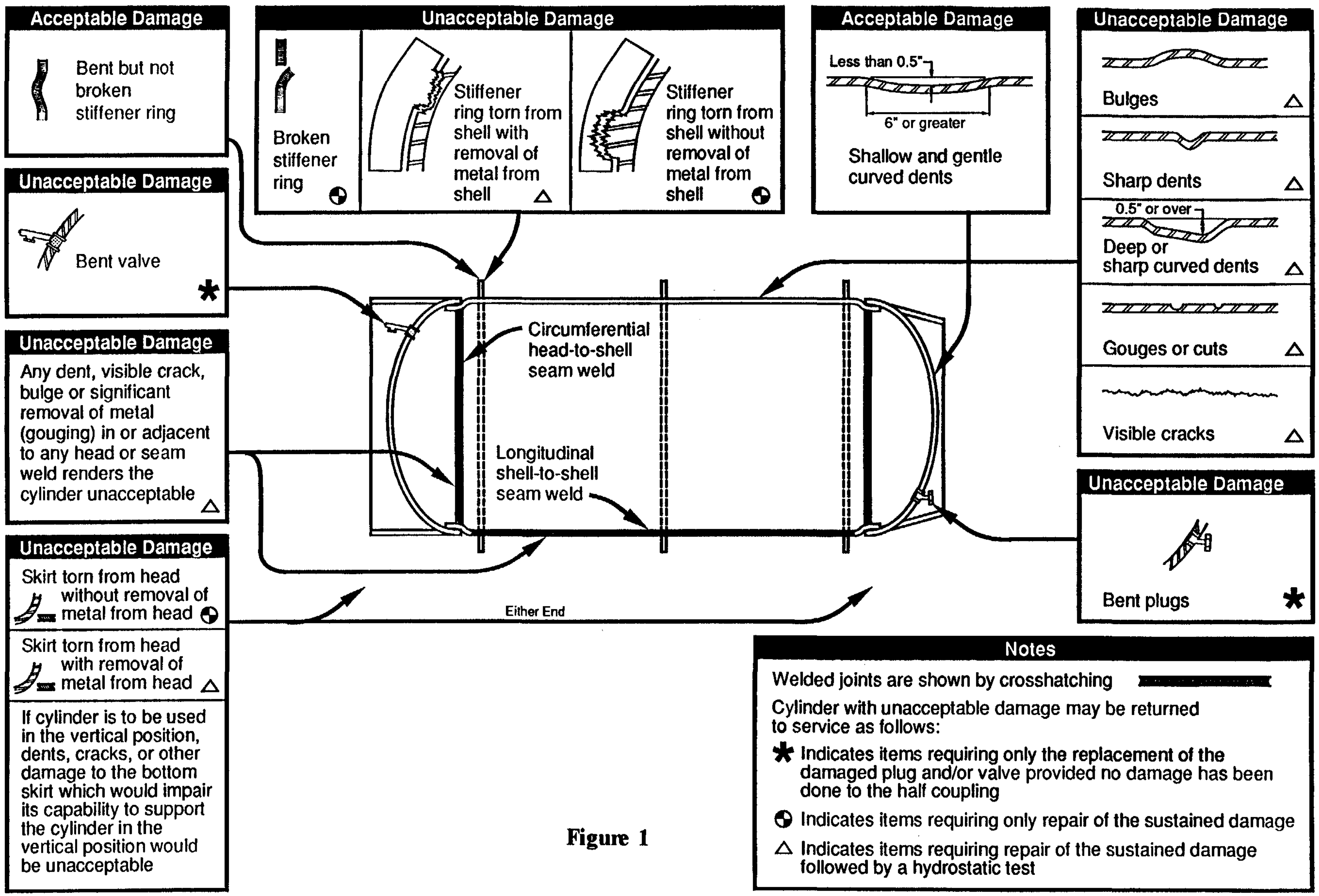


Figure 1

UF_6 CYLINDER INSPECTION DATA SHEET

CN-45

CYLINDER NUMBER	CYLINDER MODEL		☐ DATE SHIPPED ☐ DATE RECEIVED	
	☐ 30A (2½-ton) ☐ 48F (14-ton HW) ☐ ______		WATER CAPACITY ______	CYLINDER BEING INSPECT.
Cylinder is Code Stamped ☐ YES ☐ NO	☐ 30B (2½-ton) ☐ 48Y (14-ton HW) ☐ ______		HYDROSTATIC PRESSURE TEST DATE OF ______	☐ PRIOR TO BEING SHIPPED
	☐ 48A (10-ton) ☐ 48G (14-ton LW) ☐ ______			☐ AFTER BEING RECEIVED
	☐ 48X (10-ton) ☐ 48H (14-ton LW) ☐ ______		☐ IS ACCEPTABLE ☐ IS NOT ACCEPTABLE	☐ PRIOR TO BEING FILLED
INCHES Hg ______	CYLINDER STATUS	☐ FULL ☐ EMPTY	CYLINDER'S CONTENTS ARE SOLIDIFIED ☐ YES ☐ NO	☐ PRIOR TO BEING TESTED

CYLINDER IS OVERFILLED:
☐ YES ☐ NO. Net weight is ______ pounds; Maximum Allowable Fill Limit is ______ pounds.

		CONDITION		
		Acceptable	Un-Acceptable	Not Applicable
I. CYLINDER VALVE, VALVE PORT AND PLUGS	A. VALVE			
	1. Valve Type ______			
	2. Physical Damage ______			
	3. Thread Engagement ______ (Threads showing ______)			
	4. Valve Cap - Present and in Place ______			
	B. VALVE PORT			
	1. Plugged with UF_6 ______			
	2. Contaminated with Other U-Salts or Foreign Material ______			
	C. PLUGS			
	1. Physical Damage ______			
	2. Thread Engagement ______ (Threads showing ______)			
	3. Sealed ______			
	D. VALVE PROTECTOR:			
	1. Present and Properly Positioned ______			
	2. Sealed ______			
	Description of Damage (if any): ______			
II. CYLINDER WELDS	A. CIRCUMFERENTIAL HEAD SEAM WELD - VALVE END ______			
	B. CIRCUMFERENTIAL HEAD SEAM WELD - PLUG END ______			
	C. LONGITUDINAL SEAM WELD ______			
	D. LIFTING LUGS - WELD ______			
	Description of Damage (if any): ______			
III. CYLINDER SHELL AND HEADS	A. SHELL ______			
	B. HEAD-VALVE END ______			
	C. HEAD-PLUG END ______			
	Description of Damage (if any) ______			
IV. STIFFENING RINGS	A. VALVE END ______			
	B. CENTER ______			
	C. PLUG END ______			
	Description of Damage (if any) ______			
V. SKIRTS	A. VALVE END ______			
	B. PLUG END ______			
	Description of Damage (if any): ______			

DATE AND TIME INSPECTED	INSPECTED BY

SECTION A

THIS SECTION TO BE COMPLETED BY QUALITY EVALUATION.

REMARKS

	DATE	QUALIFIED INSPECTOR
The above item(s) is ☐ Acceptable ☐ Unacceptable		

SECTION B

THIS SECTION TO BE COMPLETED WHEN THE DAMAGE INDICATED ABOVE IS EVALUATED BY OTHER THAN QUALITY EVALUATION PERSONNEL.

The following damage has been evaluated and disposition is:

APPROVED BY	TITLE	DATE

UCN-9009
(5 2-92)

DISTRIBUTION: *White - Uranium Control (KYRC)*
Blue - Quality Evaluation (When Section A is completed)
Buff - Originator

CONDITION LEGEND: A - Acceptable
B - Unacceptable
NA - Not Applicable

Figure 2
Typical Cylinder Inspection Data Sheet

Table 3. Maximum Cylinder Heel Weights for Shipping			
Cylinder Model No.	Heel		Maximum Uranium-235 %
	lb UF_6	kg UF_6	
5B*	0.1	0.045	100.00
5B**	0.5	0.227	100.00
8A*	0.5	0.227	12.50
12A or 12B*	1.0	0.454	5.00
30B*	25.0	11.34	5.00
48X, 48G, 48Y, 48H, 48HX or 48OM*	50.0	22.68	4.50

*49 CFR 173.417(a)(7) authorizes shipment of these cylinders without a protective overpack if heels are at or below the limits of Table 3.

**In protective overpacks.

NOTE: Heels weighing in excess of values in Table 3 may require removal by cylinder cleaning. Systems should be configured and inspected to assure that contaminants or impurities are not injected into the cylinders during evacuations.

effort is made to evacuate the feed cylinders so that the heel weight is minimized. After routine evacuation, the heel should not exceed the weight as shown in Table 3.

3.3.3 UF_6 Cylinders

Empty, clean cylinders received for filling with product or depleted uranium material are inspected, weighed and documented. Inspection may include a borescopic[3] examination of the interior of the cylinder. The empty cylinders must be free of impurities, particularly hydrogenous materials, which could contaminate or react with UF_6 added to the cylinder. After valve installation, the empty cylinders are pressurized with dry oil-free inert gas (such as air, nitrogen or carbon dioxide) to a minimum of 100 pounds per square inch gage (psig) and soap tested. Acceptable cylinders are then evacuated to 5 psia or less.

Cylinders failing to meet these criteria are rejected until proper repair and/or cleaning is completed. If a cylinder is rejected because of a faulty valve or plug, the shipper may verbally authorize replacement and payment of incurred cost, and confirm this authorization by letter or

[3]A borescope is a device similar to a periscope inserted into the cylinder through the valve to view the interior.

facsimile. Rejection for any reason other than a faulty valve or plug may be cause for returning the cylinder to the shipper without further processing.

3.3.4 Cylinder Heel Recycle

Before a cylinder is filled with liquid UF_6, USEC requires that the cylinder be clean and dry. However, frequent and routine movement of UF_6 from the uranium enriching plants to a fuel fabricator, from feed manufacturer to enrichment plant or UF_6 reduction facility, makes recycling of cylinders containing heels a technically and economically attractive alternative.

The only safety check for cylinder contents that is routinely available to plant personnel is a cold pressure check that is made before filling the recycled cylinders. Therefore, it is necessary to have a high degree of confidence in the integrity of the UF_6 processor's procedures and equipment. Hence, recycle with a UF_6 processor shall be mutually agreed upon and is not only contingent upon adequate procedures, but also upon continued implementation of these procedures.

Approval to recycle cylinders at USEC facilities shall be requested by the UF_6 processor. There are three basic criteria for such approval. The first is positive assurance that the cylinder does not contain extraneous contaminants and noncondensable gases (a guarantee, in essence, that the heel is composed of nothing but UF_6 and non-volatile uranium products). The second is that an as-received cylinder shall be at a pressure less than 5 psia, and the third is that the heel shall not exceed the weight specified in Table 3. Further, cylinders received for recycle shall meet all specifications as shown in Section 5 and have a current hydrostatic test and inspection date. Failure to meet any of these criteria will require the cylinder to be cleaned, tested, and inspected before it can be filled with liquid UF_6.

Under a recycle program for Model 30B product cylinders, it should be noted that:

1. Recycle cylinders containing heels are filled from a parent cylinder previously filled and not directly from a withdrawal position in the enriching plant.

2. No warranty is made for the UF_6 after it has been transferred from the parent cylinder into a cylinder containing a heel. Any questions relating to the properties or specifications of USEC-furnished material are resolved by recourse to the official USEC sample taken from the parent cylinder.

3. Billing for enriching services is based on the quantity of UF_6 transferred to the cylinder containing the heel.

4. UF_6 PHYSICAL AND CHEMICAL PROPERTIES

4.1 General

Uranium hexafluoride is a compound of hexavalent uranium and fluorine. It is the process gas used by the gaseous diffusion plants to increase the concentration of the fissionable isotope uranium-235 in the mixture of uranium-238, uranium-235, and uranium-234 found in naturally occurring uranium ore. UF_6 is used for two reasons. First, it can conveniently be used as a gas for processing, as a liquid for feeding and withdrawing, and as a solid for storage. Each of these states is achievable at relatively low temperatures and pressures. Second, because fluorine has only one natural isotope, all the isotopic separative capacity of the diffusion plant is used to enrich the concentration of the lighter uranium isotopes.

4.2 Chemical Characteristics

In the solid state, UF_6 is a nearly white, dense crystalline solid. The appearance of the solid is a function of whether it was formed by freezing from the liquid phase or desubliming from the vapor phase. In the first case, the solid particles will be irregularly shaped grains somewhat like rock salt, and in the second case, the solid will be a formless mass. The liquid is colorless and, even though it is very heavy, has a low viscosity so it flows freely and completely wets the surface of its container. The liquid phase is not stable at atmospheric pressure. The gas is colorless.

Uranium hexafluoride does not react with oxygen, nitrogen, carbon dioxide, or dry air; however, each of these gases is soluble in the UF_6 liquid phase, and very much less soluble in the solid phase. Gaseous UF_6 does react rapidly with water vapor as does the exposed surface of solid UF_6. Because of this, UF_6 is always handled in leak-tight containers and processing equipment to prevent it from reacting with water vapor in the air. The reaction of gaseous UF_6 with water vapor at elevated temperatures is shown in Equation 1.

$$\underset{\text{(gas)}}{UF_6} + \underset{\text{(vapor)}}{2H_2O} \rightarrow \underset{\text{(solid)}}{UO_2F_2} + \underset{\text{(gas)}}{4HF} + \text{heat} \qquad (1)$$

At room temperature, depending upon the relative humidity of the air, the products of this reaction are UO_2F_2 hydrates and $HF\text{-}H_2O$ fog, which are seen as a white cloud. A typical reaction with excess water is given in Equation 2.

$$\underset{\text{(gas)}}{UF_6} + \underset{\text{(vapor)}}{(2 + 4x)H_2O} \rightarrow \underset{\text{(solid)}}{UO_2F_2{*}2H_2O} + \underset{\text{(fog)}}{4HF{*}xH_2O} + \text{heat} \qquad (2)$$

If, because of extremely low humidity, the HF-H_2O fog is not formed, the finely divided UO_2F_2 causes only a faint haze. The UO_2F_2 is a water soluble, yellow solid whose exact coloring depends on the degree of hydration, as well as the particle size.

The heat release for this reaction, as written in Equation 1, is 124 BTUs per pound of UF_6 gas reacted. The heat release is much larger if the UO_2F_2 is hydrated and HF-H_2O fog is formed. Thus, the heat release for Equation 2 is 1057 BTUs per pound of UF_6 vapor, due mostly to the condensation of water vapor as it is incorporated into the UO_2F_2 hydrate and the HF-H_2O fog, and to the interaction of the HF and the water. For the reaction of solid UF_6 and liquid water to form a solution as shown in Equation 3, the heat release is 258 BTUs per pound of solid UF_6 reacted.

$$\underset{\text{(solid)}}{UF_6} + \underset{\text{(liquid)}}{1602H_2O} \rightarrow \underset{\text{(liquid)}}{UO_2F_2(aq,4HF/1600H_2O)} + \text{heat} \quad (3)$$

Most of the additional heat released by the reaction in Equation 3, over that of reaction in Equation 1, is from the interaction of HF and water; however, the rate of heat release is usually considerably slower because the complex uranium oxyfluoride layer formed on the surface of the solid UF_6 constitutes a diffusion barrier that limits the access of water to the UF_6 surface. This also explains the slow hydrolysis rate of solid UF_6 by water vapor, while the reaction in the gas phase is almost instantaneous.

When there is a release of UF_6 as a gas to the atmosphere, reactions similar to that shown in Equation 2 normally occur, and the visible white cloud rises rapidly because of the heat generated by the reaction.

Uranium hexafluoride reacts with most metals to form a fluoride of the metal and a poorly volatile or non-volatile lower-valence uranium fluoride. Nickel and nickel-plated steel, Monel, copper, and some aluminum alloys are generally used for processing equipment. Mild steel is corroded by UF_6 and the resulting film greatly reduces, but does not prevent, further attack. Steel is used for shipping and storage cylinders, since the small amount of corrosion that occurs does not warrant the cost of more expensive metals.

Uranium hexafluoride reacts rapidly with hydrocarbons. If the UF_6 is in the gas phase, the reaction forms a black residue of uranium-carbon compounds. In the liquid phase, the reaction proceeds at an accelerated rate and has been known to cause explosions in cylinders. Great care must be taken to avoid introducing hydrocarbon oil into processing equipment or cylinders.

Uranium hexafluoride is a chemically stable compound. However, in a field of intense alpha radiation, it slowly decomposes to solid UF_5 and fluorine gas.

4.3 Physical Properties

4.3.1 Phase Diagram

Safe handling of UF_6 requires a detailed knowledge of its physical characteristics. Because UF_6 is always processed in leak-tight piping, equipment, and containers, it is not visible to the operator. The operator must follow its presence by observing changes in pressures or weights. Such changes are conveniently illustrated by means of a phase diagram that shows the physical state, i.e., solid, liquid, or gas, of UF_6 as a function of its pressure and temperature. It should be noted that these data are for UF_6 alone, as a single-component system. If air, nitrogen, HF, or other gases are present, the total pressure condition for a given temperature will be higher, i.e., the sum of the partial pressures of the system components.

Figure 3 is the phase diagram covering the range of conditions usually encountered in working with UF_6. It shows the correlation of pressure and temperature with the physical state of the UF_6. The triple point occurs at 22 psia and 147.3°F. These are the only conditions at which all three states--solid, liquid, and gas--can exist together in equilibrium. If the temperature or pressure is greater than at the triple point, there will be only gas or liquid. If the temperature or pressure is lower, there will be only solid or gas. For instance, at atmospheric pressure, 14.7 psia, there can only be gas or solid regardless of the temperature. At 100°F, for example, the pressure of gas over solid is 5 psia. This is a typical condition in a UF_6 cylinder in storage.

The curve in Figure 3 also shows the terms used to describe the changes of phase that occur as temperature and/or pressure are altered. Below the triple point, solid UF_6 sublimes to gas, and gaseous UF_6 desublimes to solid. Above the triple point, liquid UF_6 vaporizes to gas, and gaseous UF_6 condenses to liquid. At 147.3°F and pressures above 22 psia, liquid UF_6 and solid UF_6 exist in equilibrium with no driving force for phase alteration.

As heat is added to solid UF_6 in a closed system, the solid mass absorbs heat and some of it sublimes to gas. Sublimation continues until the pressure of 22 psia and the temperature of 147.3°F are reached, at which point solid, gas, and liquid coexist. Additional heat incrementally melts the remaining solid, and when all of the solid UF_6 has melted, further addition of heat increases the temperature of the liquid and causes a portion of the liquid to vaporize to gas. These are the same kinds of phase changes that take place when ice melts to water and when water boils, but the amount of heat required for UF_6 to change states is smaller than for water. Table 4 compares these values in BTUs. Table 5 summarizes the physical properties of UF_6.

4.3.2 Density

Most materials, unlike water, undergo a volume expansion, and thus a decrease in density upon transformation from solid to liquid. This volume expansion for UF_6 is among the largest known, with the density decreasing as much as 40% when heated to a maximum temperature (250°F). The large increase in volume places certain restrictions on handling systems and procedures.

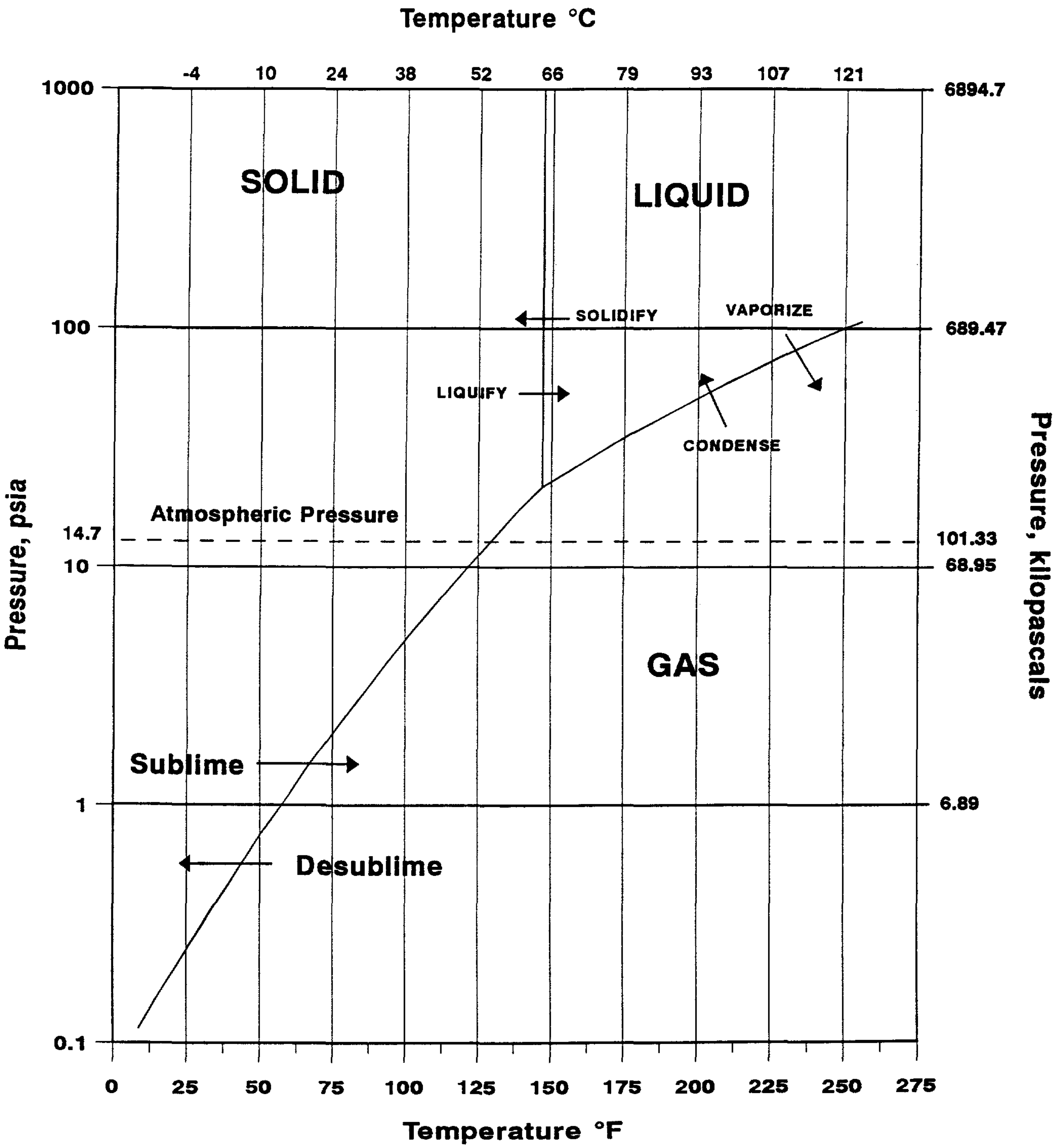


Figure 3
UF_6 Phase Diagram

Table 4. Comparison of Phase Changes for UF_6 and Water

Description	UF_6	Water
Heat of Sublimation	58.2 BTU/lb (135,373 J/kg)	1116 BTU/lb (2,595,816 J/kg)
Heat of Fusion	23.5 BTU/lb (54,661 J/kg)	143 BTU/lb (332,618 J/kg)
Heat of Vaporization	35.1 BTU/lb (81,643 J/kg)	973 BTU/lb (2,263,198 J/kg)
Specific Heat of Solid	0.114 BTU/lb/°F (477 J/kg/K)	0.5 BTU/lb/°F (2,093 J/kg/K)
Specific Heat of Liquid	0.130 BTU/lb/°F (544 J/kg/K)	1.0 BTU/lb/°F (4,186 J/kg/K)

Table 5. Physical Properties of UF_6

Sublimation Point	14.7 psia (760 mm Hg) (101 kPa) 133.8°F (56.6°C)
Triple Point	22 psia (1140 mm Hg) (152 kPa) 147.3°F (64.1°C)
Density, Solid, 68°F (20°C) Liquid, 147.3°F (64.1°C) Liquid, 200°F (93°C) Liquid, 235°F (113°C) Liquid, 250°F (121°C)	317.8 lb/ft^3 (5.1 g/cc) 227.7 lb/ft^3 (3.6 g/cc) 215.6 lb/ft^3 (3.5 g/cc) 207.1 lb/ft^3 (3.3 g/cc) 203.3 lb/ft^3 (3.3 g/cc)
Heat of Sublimation, 147.3°F (64.1°C)	58.2 BTU/lb (135,373 J/kg)
Heat of Fusion, 147.3°F (64.1°C)	23.5 BTU/lb (54,661 J/kg)
Heat of Vaporization, 147.3°F (64.1°C)	35.1 BTU/lb (81,643 J/kg)
Critical Pressure	668.8 psia (34,577 mm Hg) (4610 kPa)
Critical Temperature	446.4°F (230.2°C)
Specific Heat, Solid, 81°F (27°C)	0.114 BTU/lb/°F (477 J/kg/K)
Specific Heat, Liquid, 162°F (72°C)	0.130 BTU/lb/°F (544 J/kg/K)

Figure 4 shows the density change of the solid as it is heated from 70°F to the triple point of 147.3°F. Figure 5 shows the density of the liquid from 147.3°F to 320°F. Comparing the two curves shows that at the melting point, the density changes from 303 lb/ft^3 for the solid to 227 lb/ft^3 for the liquid. To put this in more familiar terms, a gallon of solid UF_6, when melted, would fill a 1.33-gallon container. Figure 5 also shows that the liquid continues to expand as it is heated. These facts are important for determining the weight of UF_6 that can be safely contained in a cylinder. If a cylinder were filled with solid UF_6 as, for instance, by desubliming in a cold trapping facility, it is possible to put more solid UF_6 in the cylinder than the cylinder can hold as liquid UF_6. If such a cylinder were heated, the melting of the solid and the expansion of the liquid UF_6 would completely fill it. Continued heating would cause the cylinder to rupture, resulting in a release of the UF_6.

The same rupture potential exists if UF_6 freezes and plugs a process line. Application of external heat to the middle portion of the plug can melt the solid and develop large hydraulic forces on the pipe and the ends of the plug, creating the potential for a UF_6 release due to pipe rupture. To remove a pipe plug, the best practice is to evacuate the pipe to a low enough pressure that the UF_6 will be removed by sublimation without entering the liquid phase.

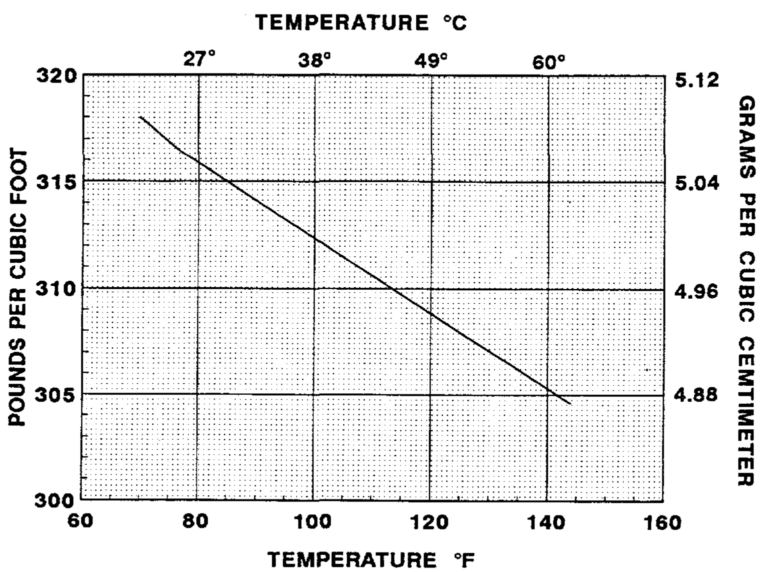


Figure 4
Density of Solid UF_6

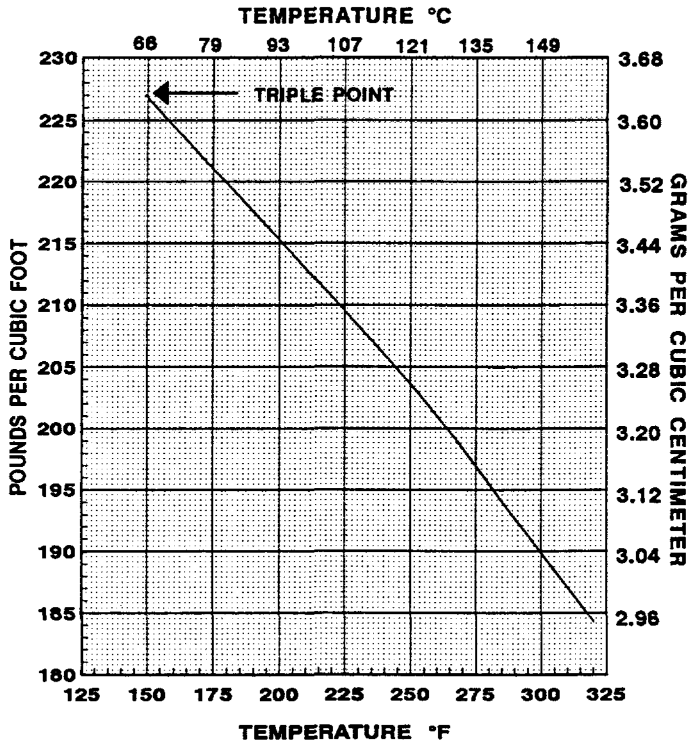


Figure 5
Density of Liquid UF_6

4.3.3 Pressure Units

Depending on the temperature, the pressure in a UF_6 cylinder is either positive or negative with respect to atmospheric pressure. Several scales are used to express the measurement of the pressure in a container. Two pressure scales based on English units (pounds per square inch or psi) are in common use in American industrial practice. One of these is an absolute scale (psia), while the other measures incremental pressure above atmospheric pressure (psig, also known as gage pressure). For pressure below atmospheric, units are given in inches of mercury (in. Hg) with an absolute vacuum being indicated as -30 in. Hg and atmospheric pressure as 0 in. Hg. The inches-of-mercury scale is commonly used on compound gages to give a scale that is continuous with gage pressure units.

The pressure scale, commonly used in laboratory work, is based on the barometric scale, where atmospheric pressure will support a mercury column 30 in. high. This scale is used extensively in measurement of subatmospheric pressures. Subatmospheric pressure can be expressed in inches of mercury (in. Hg) which is an inversion of the absolute pressure scale. Barometric pressure is also measured in millimeters of mercury (mm Hg), where atmospheric pressure will support a mercury column 760 mm high.

In the International System of Units, pressure is measured in pascals (Pa), with 101,330 pascals or 101.33 kilopascals (101.33 kPa) equal to atmospheric pressure.

These pressure and vacuum scales are compared in Figure 6. The scales can be used to convert any of the pressure or vacuum values in this document to other units that may be more useful or more familiar to the reader.

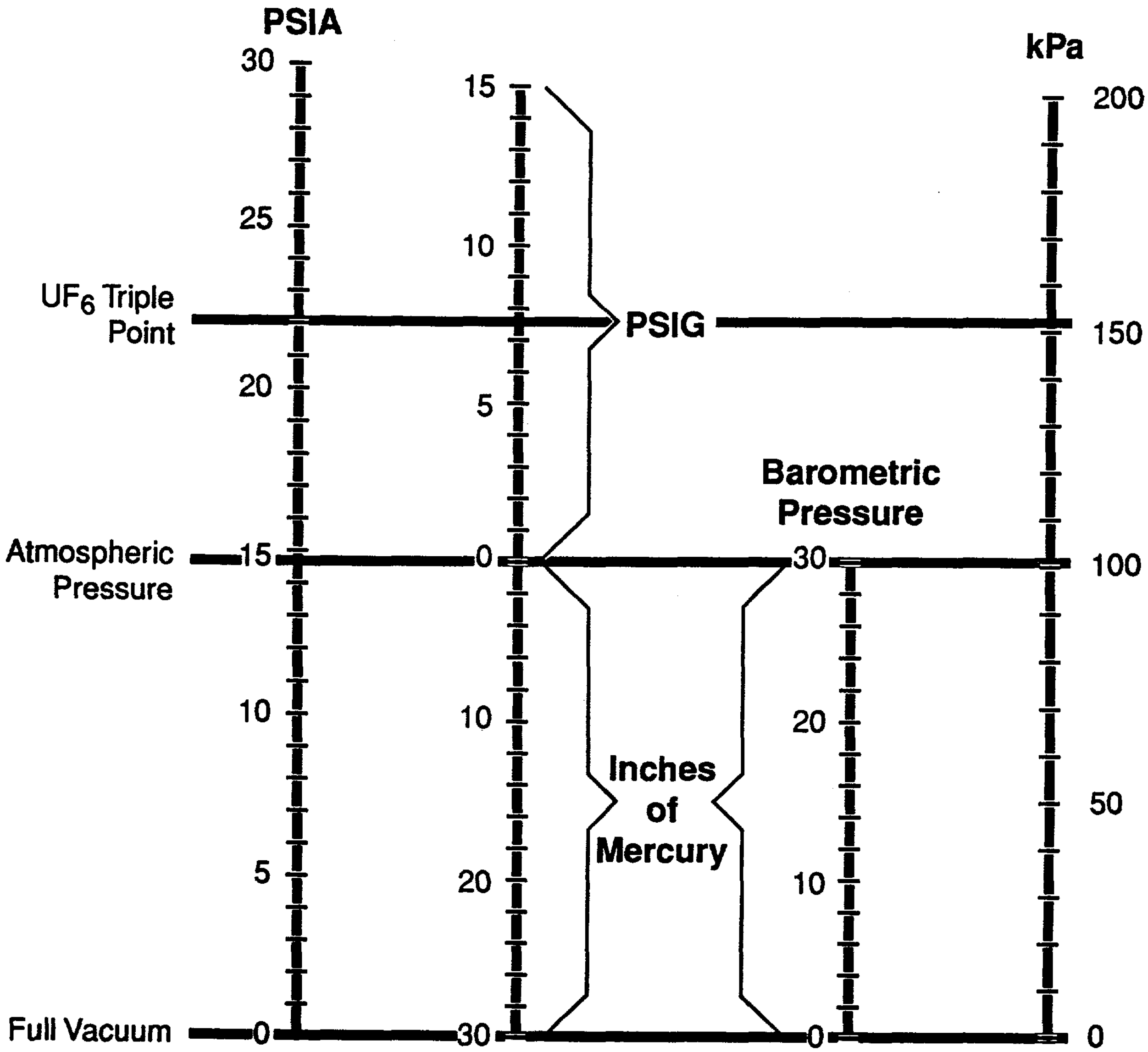


Figure 6
Comparison of Pressure Scales

Conversion factors, or stoichiometric equivalents, for seven chemical forms of uranium are listed in Table 6. To compute the quantity of the compound named at the top of the column, a given quantity of the compound named in the left column is multiplied by the factor in the column and line indicated. Example: 1.4790 kg of UF_6 contains 1 kg of uranium; the uranium in 1.3037 kg of UF_6 will produce 1 kg UO_2.

Table 6. Conversion Factors

	U	UF_4	UF_6	UO_2	U_3O_3	UO_3	UO_2F_2
U	1.0000	1.3194	1.4790	1.1345	1.1793	1.2017	1.2941
UF_4	0.75794	1.0000	1.1210	0.8599	0.8938	0.9108	0.9809
UF_6	0.67612	0.8920	1.0000	0.7670	0.7973	1.0593	0.8750
UO_2	0.88147	1.1630	1.3037	1.0000	1.0395	1.0593	1.1408
U_3O_3	0.84796	1.1188	1.2542	0.9620	1.0000	1.0190	1.0974
UO_3	0.83215	1.0979	1.2308	0.9440	0.9814	1.0000	1.0769
UO_2F_2	0.77271	1.0195	1.1429	0.8766	0.9113	0.9286	1.0000

5. STANDARD CYLINDER INFORMATION

5.1 Cylinder Valves

Valves are a critical component of UF_6 packaging and containment systems, and only cylinders with valves of approved design and manufacture will be accepted for processing at USEC facilities. The valves described in this section have provided satisfactory service and are approved for use with UF_6. Other valves shall receive USEC approval prior to cylinder shipment to a USEC facility.

5.1.1 Hoke Nos. 4618N4M and 4628N4M (or approved equal)

These valves, or an approved equal, may be used on the Models 1S and 2S sample cylinders. Both the straight-through type, 4618N4M, and the angle type, 4628N4M, are of Monel construction. The composition and low internal volume make these valves suitable for critical gas analysis applications. Each type has a screw handle, an Inconel diaphragm welded to the body, 1/4-inch outside diameter tube connectors, and a 1/8-inch orifice.

5.1.2 Hoke No. 2422L64M3 (or approved equal)

This valve, or an approved equal, may be used on the Model 2S sample cylinder. It is an angle type valve of Monel construction. The metal plug stem is also of Monel construction and is packed with Teflon. The inlet port is 3/8-inch male pipe and the outlet port is 1/4-inch female pipe.

5.1.3 Three-quarter-inch Valve (Superior or approved equal)

Two of these valves are used on Models 5B, 8A, and 12B cylinders. The body, packing nut, packing ring, packing follower, and cap collar are of aluminum-silicon bronze. The stem is Monel and the packing and cap gasket are Teflon. The ports are 3/8-inch diameter.

5.1.4 One-inch Valve (Superior or approved equal)

The 1-inch valve is used on the Model 30B and on all Model 48 cylinders. The body, packing nut, packing ring, packing follower and cap are aluminum-silicon bronze, while the stem is Monel. The packing and cap gasket are Teflon.

5.2 Requirements For UF_6 Cylinders

Uranium hexafluoride cylinders shall adhere to rigid standards for design, fabrication and certification. Cylinders, including those fabricated outside the United States, shall comply with the standards specified in the latest revision of ANSI N14.1.

5.2.1 Approval for Cylinder Modification

The cylinder designs in ANSI N14.1 (latest revision) have been proven to satisfy the requirements for UF_6 service. To minimize points of leakage, only one valve and one plug are specified. If additional valves and/or plugs are deemed necessary by the purchaser, they may be used, if installed and tested in the manner specified in the latest revision of ANSI N14.1.

5.2.2 Reports, Certification and Records

For each cylinder fabricated, the manufacturer shall furnish to the purchaser and to the National Board of Boiler and Pressure Vessel Inspectors, copies of the Manufacturer's Data Report, American Society of Mechanical Engineers (ASME) Code Form U-1 or U-1A.

The manufacturer shall provide, if required by the purchaser, a copy of the as-built drawing for the cylinder. The manufacturer shall also provide to the purchaser one copy of each radiograph, properly identified with the cylinder and the location to which it applies.

The manufacturer shall measure the actual water capacity of each cylinder and certify to the purchaser the water weight at a temperature of 60°F (16°C). This weight shall be accurate to ±0.10%. For a cylinder to be acceptable, the quotient of the certified water weight divided by 62.37 [pounds of water in 1 ft^3 at 60°F (16°C)] shall not be less than the minimum cubic foot capacity specified in the design conditions stated in the applicable specification. The certified water capacity and hydrotest date shall also be stamped on the cylinder nameplate.

The manufacturer shall retain fabrication and inspection records in accordance with ASME Code requirements. The purchaser shall retain copies of the Manufacturer's Data Report, drawings, certifications, and other related papers on file throughout use or ownership of the cylinder. Radiographs shall be retained for a minimum of 5 years. The documents shall be transferred with the cylinder upon change of ownership.

5.2.3 Certification of Cylinders and Valves of Non-U.S. Origin

Users of cylinders made outside the United States shall certify that the design, fabrication, tests, cleanliness, and volume of their cylinders are in compliance with requirements specified in ANSI N14.1 (latest revision) before they are accepted for sampling, filling, or material transfer at USEC facilities. This certification should be submitted in English. The nameplate markings on such cylinders shall be clearly identifiable either in metric units or in English units. Translations of the descriptive non-English markings for each cylinder are required. In all instances where the certification data were not generated by the originator of the certification, a copy of the manufacturer's or vendor's data shall accompany the certification.

Users of valves of non-U.S. origin shall certify that the design, fabrication, materials and testing meet the requirements specified in Section 5 and as described in ANSI N14.1 (latest revision).

Allowable deviations from established standards for valves and/or cylinders require written USEC approval with concurrence from USEC operating facilities before operation.

5.3 Cleanliness

Cleanliness is of primary importance whether the UF_6 cylinder is new or already in service. For safety, extreme care must be taken to avoid introducing hydrocarbon oils into the cylinders.

WARNING

The cleanliness of UF_6 cylinders is of serious concern to the nuclear industry, since the reaction of UF_6 with hydrocarbon oils, even in small quantities, and some other impurities is quite vigorous and can result in serious explosions. The purity of the UF_6 contained can also be adversely affected.

Evacuation of air from cylinders should not be attempted with an oil-containing vacuum pump that is not equipped with an oil backflow reservoir of sufficient volume to prevent backflow of oil into the cylinder in the event of pump stoppage. Air ejectors or similar equipment are preferred and recommended to preclude introduction of reactive contaminants into cylinders.

5.3.1 New Cylinders

The inside of the cylinder shall be thoroughly cleaned of all grease, oil, scale, slag, oxides, dirt, moisture and other foreign matter. The interior surfaces shall be left clean, dry and free of all contamination.

5.3.2 In-Service Cylinders

To assure product purity, cylinders containing residual or heel quantities of uranium may require cleaning prior to refilling, and when maintenance or hydrostatic testing is to be performed.

5.3.3 Cylinder Outer Surfaces

Cylinder surfaces shall be monitored and cleaned of surface contamination as necessary to meet applicable requirements.

5.3.4 Cylinder Cleaning and Decontamination

A typical cleaning procedure for new cylinders and a method for large cylinder decontamination are included in the appendices of ANSI N14.1 (latest revision).

5.4 Service Inspections, Tests and Maintenance

To maintain safe, usable UF_6 cylinders, routine and periodic cylinder tests must be performed. Cylinder repairs and valve and plug replacement shall follow the standards as set forth in Sections 5.4.3 through 5.4.6 of this manual.

5.4.1 Routine Inspections

All UF_6 cylinders shall be routinely inspected as they are received and prior to sampling, emptying, filling, or shipping to assure that they remain in a safe, usable condition. A careful inspection of cylinders and valves is an important prerequisite to any operation. Filled cylinders are easily dented or otherwise damaged; therefore, cylinders shall be moved with care.

5.4.2 Periodic Inspections and Tests

All cylinders shall be periodically inspected and tested throughout their service lives at intervals not to exceed five years. Full cylinders need not be emptied simply to comply with the five-year test cycle. However, cylinders that have not been inspected and tested within the required five-year period, once emptied, shall not be refilled until properly reinspected, retested, and restamped on the nameplate. Cylinders containing UF_6 that have not been recertified within the five-year requirement period shall be visually inspected for degradation of the cylinder wall before shipment. Any questionable conditions should be investigated further, including the use of ultrasonic wall thickness measurements, if appropriate.

The periodic inspection shall consist of internal and external examination of the cylinder by a qualified inspector (one who has passed the written examination sponsored by the National Board of Boiler and Pressure Vessel Inspectors or other competent inspector designated by the owner's inspection authority), an ASME Code-type hydrostatic strength test, and an air-leak test. This periodic inspection and test shall be in accordance with ANSI N14.1 (latest revision). Cylinders that pass the periodic inspection and tests shall be restamped on the nameplate with the month and year that the inspection and tests were performed. This restamping shall be placed close to the previous or original stamping. Records of periodic inspections and tests shall be retained by the cylinder owner for five years or until a subsequent periodic inspection and test has been performed and recorded.

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 which, in the judgment of the qualified inspector, render it unsafe or unserviceable. Cylinders shall no longer be used in UF_6 service when their shell and/or head thicknesses have decreased below the values specified in ANSI N14.1 (latest revision). These minimum wall thickness values are given in Table 7.

Table 7. Minimum Cylinder Thickness

Cylinder Model	Minimum Thickness	
	Inches	Centimeters
1S, 2S	1/16	.16
5B	7/64	.28
8A	1/8	.32
12A, 12B	3/16	.48
30B	5/16	.80
48X, 48Y	1/2	1.27
48H*, 48HX*, 48G*, 480M*	1/4	.64

* Low-specific-activity UF_6 cylinders

A UF_6 cylinder shall be removed from service if inspections show that any unauthorized repair or modification has been made to the cylinder. The cylinder should not be used until the repair or modification has been evaluated by the owner and shown to meet design and regulatory requirements. One example is a cylinder which has had a hole added to the lifting lug. In several instances, 48 inch cylinders have been identified which have second holes in the lifting lugs just below the original holes. Such a cylinder should not be used until an evaluation is made to assure the added hole does not compromise the requirements for lifting and tie downs.

A tagging system will identify defective cylinders or valves. Presence of such a tag is intended to prevent use of cylinders with defective components until satisfactory repairs are made. Additionally, a Hydro Date Expired tag should be used to identify cylinders exceeding the five-year test date limit.

5.4.3 Cylinder Maintenance

Cylinder repairs and alterations are authorized provided 1) they meet the approval of a qualified inspector, 2) they comply with the design, material, fabrication, and welding qualification requirements of the ASME Code for Unfired Pressure Vessels (or equivalent regulatory system), and 3) they are performed by an authorized ASME Code shop or a shop possessing a National Board Inspection Code Repair Stamp.

Welded repairs or alterations to pressure parts require the use of ASME code-qualified welding procedures, welders, and inspectors. Repairs must be followed by the hydrostatic strength test. Plug or valve replacements should be checked for proper insertion and tightness, and should be followed by air-leak tests, when possible. Repairs to structural attachments will not require pressure or leak tests of the cylinder unless repairs of torn or deformed areas of pressure-containing materials are involved.

5.4.4 Cylinder Valve and Plug Replacement

Replacement of brazed 3/4-inch valves in 5-, 8-, and 12-inch cylinders can only be accomplished by following the brazing specifications referenced with each type of cylinder. Field replacement should not be attempted, since the valve coupling may crack due to the presence of metal contaminants.

Replacement of tinned valves in cylinders containing UF_6 is accomplished by first assuring that the cylinder has cooled the required number of days, and, if possible, by obtaining a cold pressure measurement to determine that the pressure is subatmospheric. The operator should use the appropriate safety equipment and tools to perform the exchange. When the valve is slowly loosened, no outgassing should occur, and inleakage should be audible. A newly tinned valve, previously inspected, should be positioned for insertion as soon as the defective valve is removed. The replacement valve is then torqued into the cylinder to not less than 200 ft-lb or more than 400 ft-lb. After insertion, the number of threads inserted should not be less than 7 or more than 12 for either valve size. These valves have 13 to 14 threads as manufactured. If possible, the threads at the valve coupling should be soap tested at 5 psig to assure that a seal was successfully made. An alternate test is to record the vacuum after valve change. If the pressure is unchanged after five days, the seal was successfully made. Removal of air at room temperature by evacuation (cold burping) may be required after a valve change to preclude high pressures during subsequent heating of the repaired cylinder.

Components that meet all dimensional specifications are required to obtain proper thread engagement for both valves and plugs.

The inspection procedure for the cylinder plug(s) is as follows:

Inspect the plug to determine the number of threads engaged. If the plug has the number of total threads stamped on the head of the plug, this number shall be used to determine the actual thread engagement by subtracting the threads showing from the total threads. A minimum engagement of five threads is required. If a seal welded plug has the number of threads stamped on the end of the plug, it has been previously inspected ultrasonically and is acceptable.

If the total number of threads is not stamped on the head of the plug, verify that each square head or thin hex head plug* has at least one but not more than two threads showing. Verify that each hex head plug has at least one but not more than four threads showing. This inspection ensures that the minimum requirement for at least five threads engaged into the cylinder coupling is met. Plugs that have been seal welded are acceptable providing a minimum of five threads are engaged. When the seal weld prevents an accurate determination of the number of threads showing, the actual threads engaged can be determined ultrasonically. If the plug meets the five-thread minimum engagement criterion, the total number of plug threads should be stamped on the end of the plug.

Where cylinder plugs do not pass the criteria for thread engagement, or where damage is evident, the cylinder shall not be shipped or used until the defect is corrected or has been determined to be acceptable. For cylinder plugs that do not appear to be properly engaged, the actual number of threads engaged should be determined ultrasonically.

*NOTE: Thin hex head plugs have hex heads less than 3/8 inches in height.

5.4.5 Three-quarter-inch Valve Wear Inspections

Because a brazed joint is required on the 3/4-inch valves in 5-, 8-, and 12-inch cylinders, these valves cannot be easily replaced. If possible, the 3/4-inch valve should be rebuilt in-place following decontamination and inspection. In addition to the inspection of the internal and external cylinder surfaces, the valve body is visually inspected for corrosion, erosion, distortion, or other damage that would make it unserviceable. This inspection is followed by a helium leak test. Other tests, such as radiographic examination, may be conducted prior to use.

5.4.6 One-inch Valves - Defects

Valves are one of the most critical items in containing UF_6 and their safe use cannot be compromised. When valves are found to have defects that may be generic, it is often prudent to suspend use of the entire lot or heat of valves that may also contain those defects.

Over the years, several one-inch valves or valve components have been found to be unsatisfactory for service in USEC enrichment facilities. Although most unacceptable valves exhibited material defects that contributed to cracking and breaking, some defects were attributable to dimensioning, processing, or testing of the valves prior to use in UF_6 service.

Valve packing nuts that have been inspected and found satisfactory have been marked as follows: A, A6, 6A, 636A, 51-1, or PGDP. Some valve packing nuts without these markings have split during service and could allow stem packing rings to be forcefully ejected from the valve, resulting in a UF_6 release. Descote valve packing nuts with heat number R-91 are prone to cracking and should not be used.

Valves considered unacceptable for use include, but are not limited to, the following:

> Superior Model 11246 valves showing a small raised "8" on the side and Rego Model 11246 valves showing an "LH" have broken at the thread while opening or closing the stem. The Superior raised "8" valve should not be used for UF_6 service and should be replaced with a valve of known quality. Some of the Rego "LH" valves have been made with the proper materials; these have been stamped with a "3." Rego "LH" without the "3" should be replaced before cylinder use. Superior valves marked with heat numbers 17 through 22 have failed during installation and should not be used.

5.5 Safety Considerations

5.5.1 General

The variations of density, vapor pressure, and physical state with temperature and the chemical and nuclear properties of UF_6 require the development and use of safe handling procedures. Procedures incorporating the safety considerations presented in this section have been developed and evaluated in USEC facilities during more than 40 years of handling vast quantities of UF_6. These procedures should be used as guidelines. Other procedures that assure equivalent safety may be used or required because of site-specific equipment, regulations, or needs. Aside from nuclear considerations, UF_6 can be safely handled in essentially the same manner as any other corrosive and/or toxic chemical.

Gaseous UF_6, when released to the atmosphere, reacts with atmospheric moisture to form HF gas and particulate UO_2F_2 that tends to settle on surfaces. The corrosive properties of UF_6 and HF are such that exposure can result in skin burns and lung impairment. The inhalation of fumes for more than a few breaths may result in lung impairment soon after the exposure and in some instances, mild but repairable kidney damage within a few days. Water-soluble uranium compounds such as UO_2F_2, like most heavy metal compounds, are toxic to the kidneys when inhaled or ingested in large quantities. For UF_6 the chemical toxicity is more significant than the radiotoxicity.

The UO_2F_2 and HF that form during a release to the atmosphere are normally readily visible because they react with additional water vapor to nucleate a white cloud. A concentration of 1 milligram of UO_2F_2 and the associated HF per cubic meter of air at normal humidities is sufficient to produce the cloud and be visible. The cloud from large releases may be so dense that it obscures vision.

5.5.2 Hazards and Precautions

Some of the hazards of UF_6 handling and the precautions used to control or eliminate the hazards are listed below:

Handling Cylinders of Liquid UF_6

Movement of large cylinders containing liquid UF_6 should be minimized, especially with respect to lift height, and performed only with the valve protector correctly installed. Liquid UF_6 under pressure is hot, very dense, and mobile. Movements of partially filled cylinders result in surges of the dense liquid that can upset handling equipment and cause loss of control. At ambient air temperatures, a 3-day cool-down period should be observed for the Model 30B cylinder and a 5-day period for Model 48 cylinders before transporting.

Leaks in a cylinder containing liquid UF_6 are difficult to control. Caution should be exercised in handling cylinders until the contents have solidified. A cylinder shall not be shipped until its contents have completely solidified and the pressure in the cylinder is below atmospheric pressure.

Damaged Cylinder Valves

Valves that are damaged while handling full cylinders of UF_6 require immediate action. If the valve has been broken off, the release can usually be stopped by driving a tapered wood plug into the opening. It is recommended that any site handling significant quantities of liquid UF_6 have emergency equipment available similar to that shown in Figure 7.

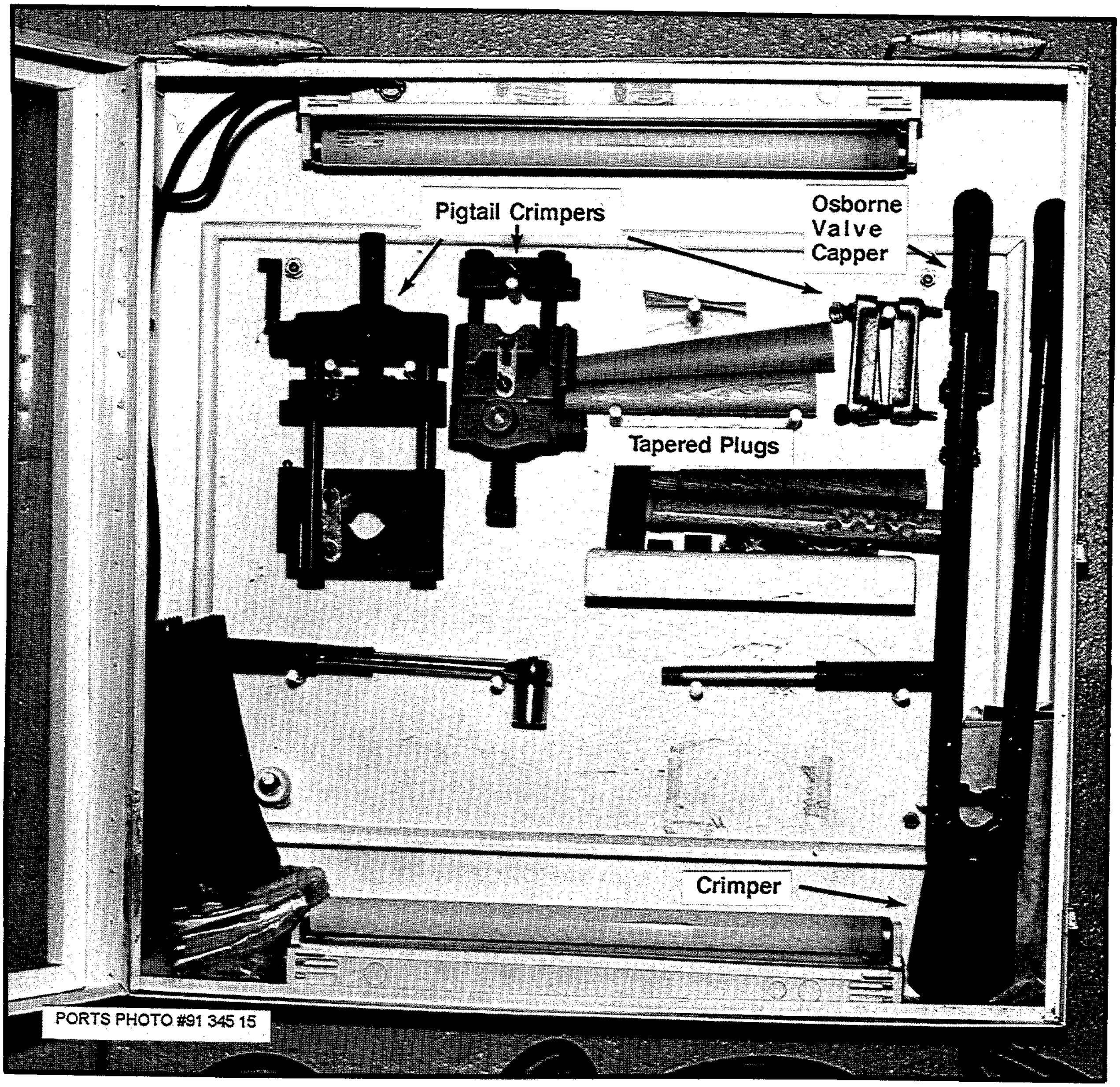


Figure 7
Emergency Equipment

Manifold Connection Leaks

Leaking connections can result in significant UF_6 releases. All connections, especially flexible connectors, should be checked for tightness, kinking, abrasion, and other damage before use. After cylinder hookup, all connections should be pressure tested and vacuum leak rated before use.

Release of UF_6

The control of UF_6 releases requires pre-planning with respect to emergency procedures and equipment. Protective respiratory equipment, wooden plugs, patches, a release detection and alarm system, and some type of cooling mechanism should be readily available in areas where UF_6 is processed. Entry into the dense clouds generated by UF_6 releases requires the use of breathing apparatus capable of preventing HF and particulate inhalation. Skin protection is necessary to prevent burns. It is essential that all persons not properly trained or protected be evacuated from areas affected by the release. The wooden plugs used for controlling releases should be designed to be inserted into holes that 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.

A UF_6 release may be controlled by freezing the opening in the system with appropriate cooling. This cooling is usually provided by a water stream for cylinders not requiring moderation control. In no case should water be streamed directly into a cylinder opening. A wet towel or rag wrapped around the release area can be very effective in stopping leaks. Dry ice or pressurized CO_2 from large-capacity fire extinguishers may be used safely with any enrichment to stop leaks. If the cylinder content is liquid, extended cooling periods will be required.

Radiation

The radioactivity of UF_6 produced from unirradiated uranium varies with the uranium-235 enrichment. Naturally occurring uranium has a specific activity (SA) of 1.5 disintegrations per minute per microgram (d/m/μg) (0.67 μCi/g or 0.03 Bq/μg). The isotopes of uranium-238 and uranium-234 each contribute about half of this activity. As the enrichment in uranium-235 is increased, the activity from uranium-234, which enriches faster than uranium-235, increases rapidly. While the exact SA of slightly enriched uranium depends on the material flows at an enrichment plant, for enrichment assays up to 5% uranium-235, the SA may be approximated using Equation 4.

$$SA = (0.2 + 0.64E)\ \mu Ci/g \tag{4}$$

where: E = weight percent of uranium-235

Alpha particles, resulting from the primary disintegration of uranium, present no external radiation problem, since they do not penetrate the dead layer of skin. The decay products of uranium, however, include isotopes that emit mildly penetrating beta rays and highly penetrating gamma rays. Beta radiation levels as high as 200 mrad/hr may be found at the surface of UF_6 cylinders. When UF_6 is vaporized from a cylinder, the decay products usually remain behind. Thus, the internal surfaces of an empty cylinder may have beta radiation levels up to several rad/hr. Similarly, the gamma radiation from an empty cylinder will be much higher than from a filled cylinder and may range up to 200 mrad/hr.

Radiation exposures of employees working around UF_6 cylinders are easily controlled at very low levels through conventional distance-time limitations. Note: Contribution of the radioactivity from fission products and transuranic elements that may be present in UF_6 produced from irradiated uranium is not considered in this report.

Mechanical Hazards

The mechanical hazards of handling UF_6 cylinders are not unique. The surging of liquid in partially filled cylinders and the eccentric center of gravity of cooled cylinders add to the normal hazards of handling heavy loads.

Criticality Control

A consideration of foremost importance in the handling and shipping of cylinders of UF_6 is the application of stringent controls to prevent an inadvertent criticality. This goal is accomplished by employing, individually or collectively, specific limits on uranium-235 enrichment, mass, volume, geometry, moderation and spacing, and in some instances, utilizing the neutron absorption characteristics of the steel cylinder walls. Most of the above limitations, including temperature control to prevent cylinder rupture in process operations, are specified throughout this report. The amount of UF_6 that may be contained in an individual cylinder and the total number of cylinders that may be transported concurrently are determined by the nuclear properties of enriched UF_6. Spacing of cylinders of enriched UF_6 in transit is assured by use of DOT specification packages or DOE and/or NRC approved packages, which also provide protection against impact and fire.

Use of 30-inch and 48-inch cylinders at uranium-235 enrichments of 5.0% and 4.5%, respectively, is dependent upon moderation control, i.e., a hydrogen-to-uranium atomic ratio of less than 0.088, which is equivalent to the purity specification of 99.5% for UF_6. For shipment of UF_6 above 5.0% uranium-235 enrichment, geometry or mass limits are employed. Shipment of UF_6 in Models 48G, H, and HX cylinders without overpacks is limited to a maximum of 1 weight percent of uranium-235.

Note: The specific details governing criticality control are not covered in this document since such information is generally available in other publications.

6. STANDARD USEC UF_6 CYLINDER AND VALVE DATA

6.1 General

The information included for each standard USEC UF_6 cylinder includes a structural diagram, a photograph of the cylinder and valve, and general descriptive data on weight, dimensions, pressure ratings, and isotopic limits. All diagram measurements are in inches.

All privately owned cylinders used in shipments to and from USEC facilities shall meet the specifications of ANSI N14.1 (latest revision) unless deviations have been approved by USEC and DOT prior to use. All cylinders shall be certified for structural integrity, as described in Section 3.3 of this manual.

All cylinders and valves not meeting the described standard shall be rejected for use at the USEC facilities unless approved by USEC in writing.

6.2 UF_6 Cylinder Model 1S

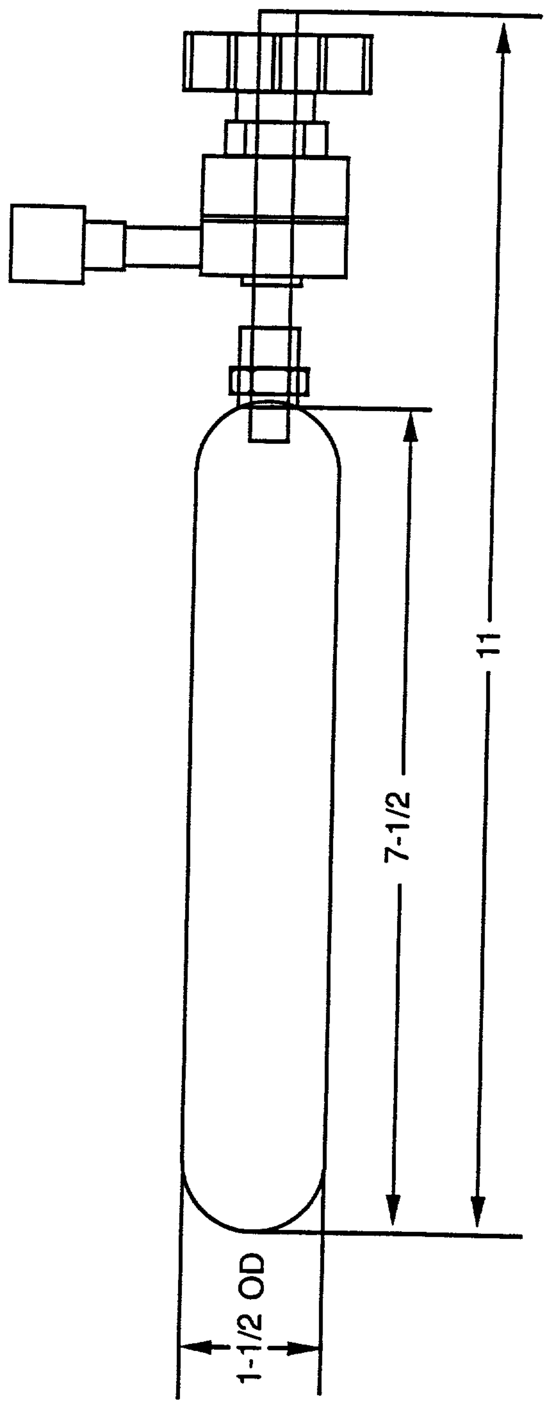


Figure 8
Schematic of Cylinder Model 1S

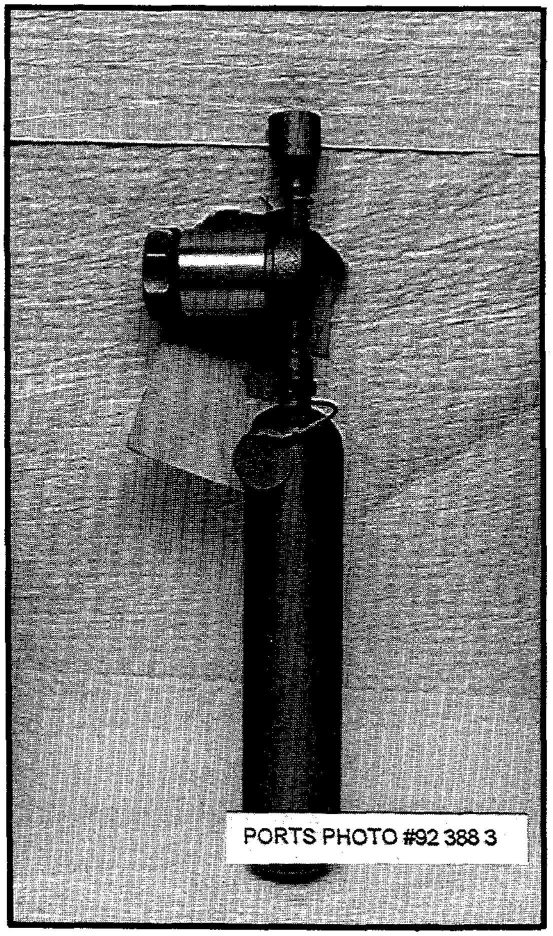


Figure 9
Cylinder Model 1S

Nominal Diameter	1-1/2 in. (38 mm)
Nominal Length	11 in. (280 mm)
Wall Thickness	1/16 in. (1.6 mm)
Nominal Tare Weight	1-3/4 lb (0.79 kg)
Maximum Net Weight	1 lb (0.45 kg)
Nominal Gross Weight	2-3/4 lb (1.25 kg)
Minimum Volume	0.0053 ft^3 (150 cm^3)
Basic Material of Construction	Nickel
Service Pressure Limit	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	100% ^{235}U
Valve Used - Hoke No. 4618N4M, 4628N4M, or equal.	

6.3 UF_6 Cylinder Model 2S

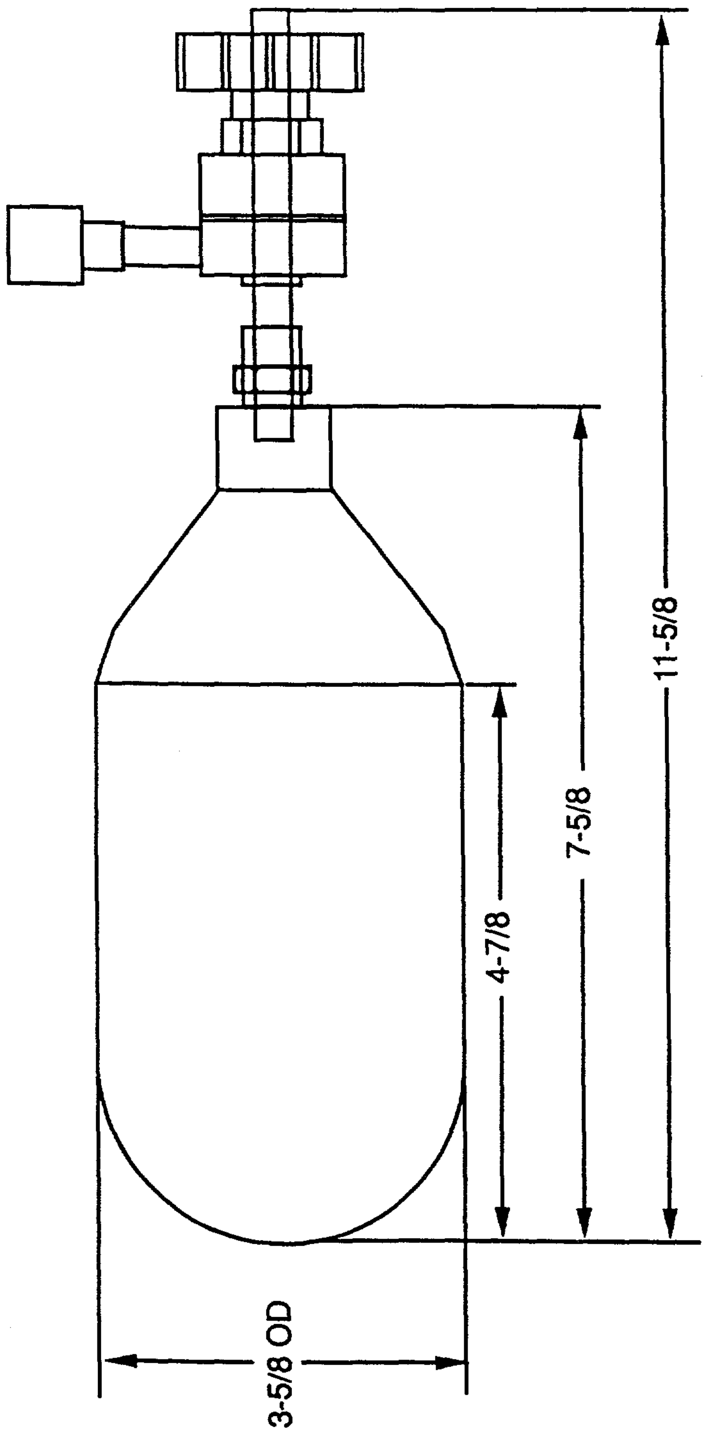


Figure 10
Schematic of Cylinder Model 2S

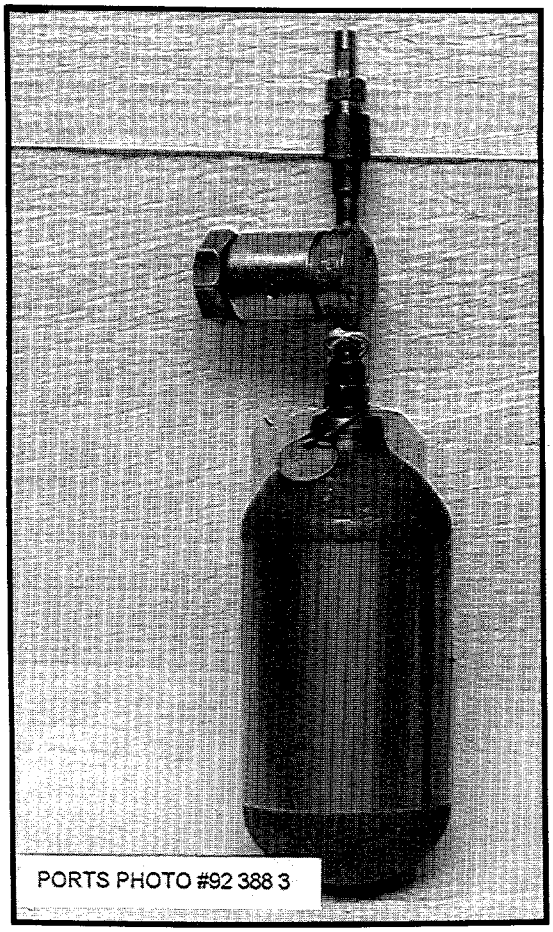


Figure 11
Cylinder Model 2S

Nominal Diameter	3-5/8 in. (90 mm)
Nominal Length	11-1/2 in. (290 mm)
Wall Thickness	0.112 in. (2.8 mm) minimum
Nominal Tare Weight	4.2 lb (1.91 kg)
Maximum Net Weight	4.9 lb (2.22 kg)
Nominal Gross Weight	9.1 lb (4.13 kg)
Minimum Volume	0.026 ft^3 (736 cm^3)
Basic Material of Construction	Nickel
Service Pressure	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	100% ^{235}U

Valve Used - Hoke No. 2422L64M2, or equal
PORTS Hoke No. 4618N4M, 4628N4M

6.4 UF_6 Cylinder Models 5A and 5B

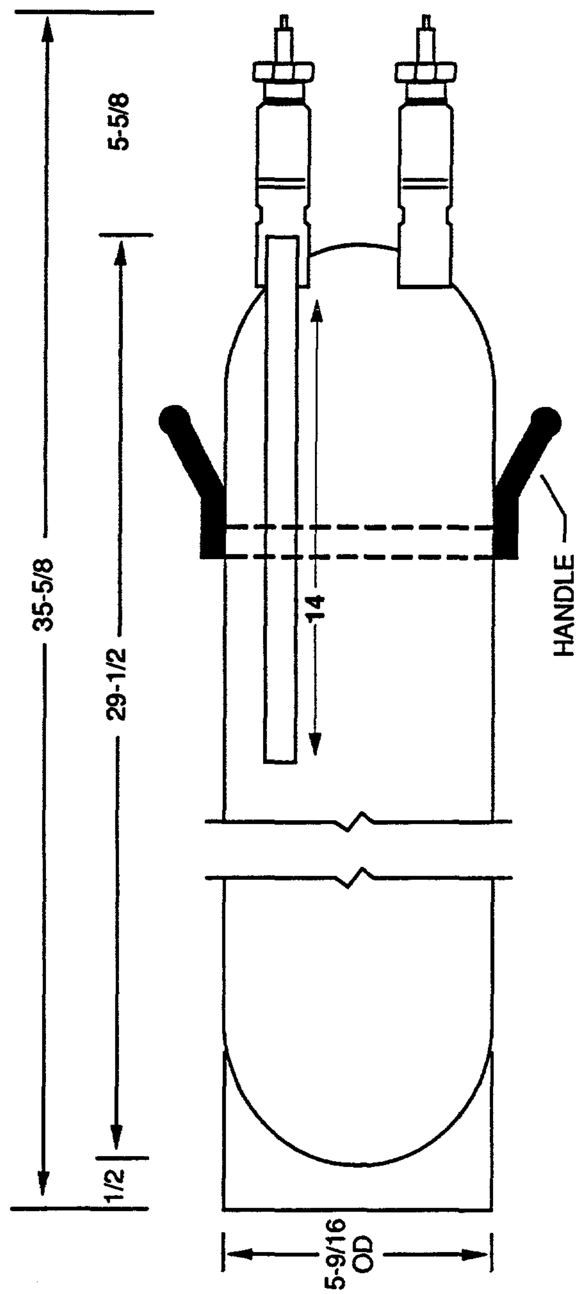


Figure 12
Schematic of Cylinder Models 5A and 5B

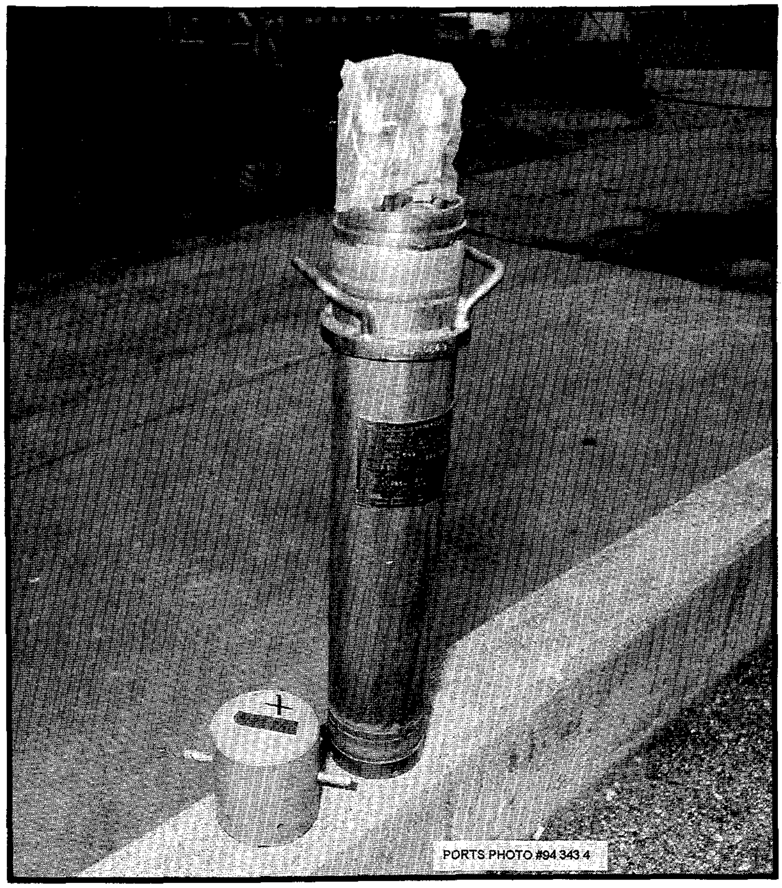


Figure 13
Cylinder Models 5A and 5B

Nominal Diameter	5 in. (127 mm)
Nominal Length	36 in. (914 mm)
Wall Thickness	1/4 in. (6.5 mm)
Nominal Tare Weight	55 lb (24.95 kg)
Maximum Net Weight	55 lb (24.95 kg)
Nominal Gross Weight	110 lb (without cap) (49.9 kg)
Minimum Volume	0.284 ft^3 (8.04 liters)
Basic Material of Construction 5A	Monel
Basic Material of Construction 5B	Nickel
Service Pressure	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	100% ^{235}U
Valve Used - 3/4-in. valve	

6.5 UF_6 Cylinder Model 8A

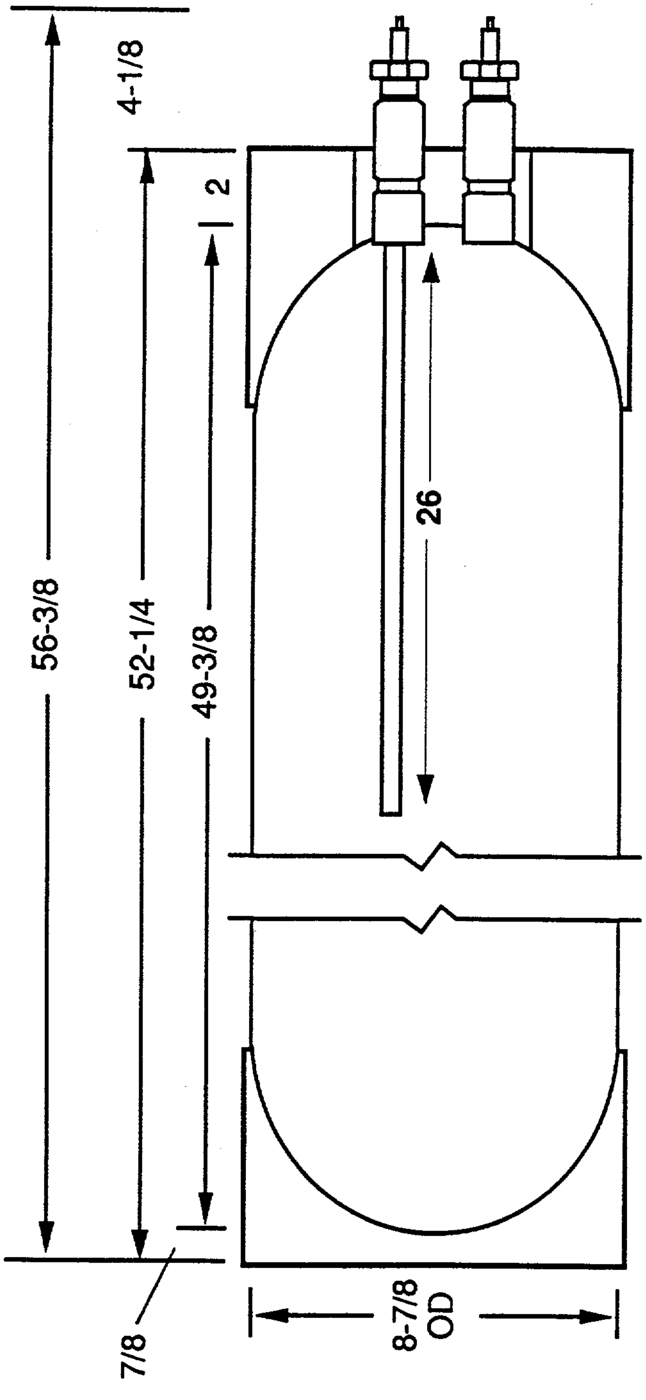


Figure 14
Schematic of Cylinder Model 8A

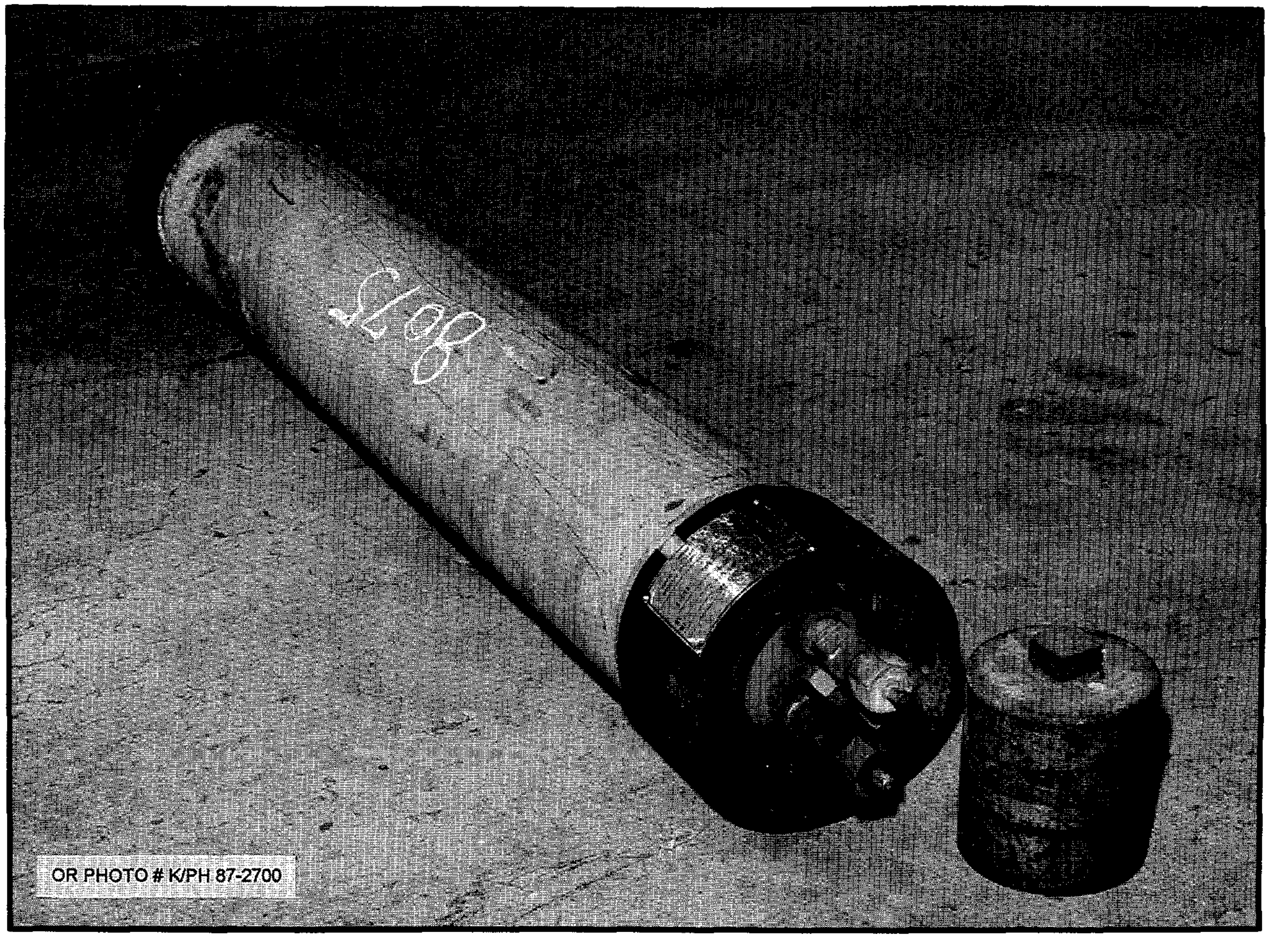


Figure 15
Cylinder Model 8A

Nominal Diameter	8 in. (20 cm)
Nominal Length	56 in. (142 cm)
Wall Thickness	3/16 in. (0.5 cm)
Nominal Tare Weight	120 lb (54.43 kg)
Maximum Net Weight	255 lb (115.67 kg)
Nominal Gross Weight	375 lb (without cap) (170.10 kg)
Minimum Volume	1.319 ft^3 (37.4 liters)
Basic Material of Construction	Monel
Service Pressure	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	12.5% ^{235}U (max.)
Valve Used - 3/4-in. valve	

6.6 UF_6 Cylinder Model 12B

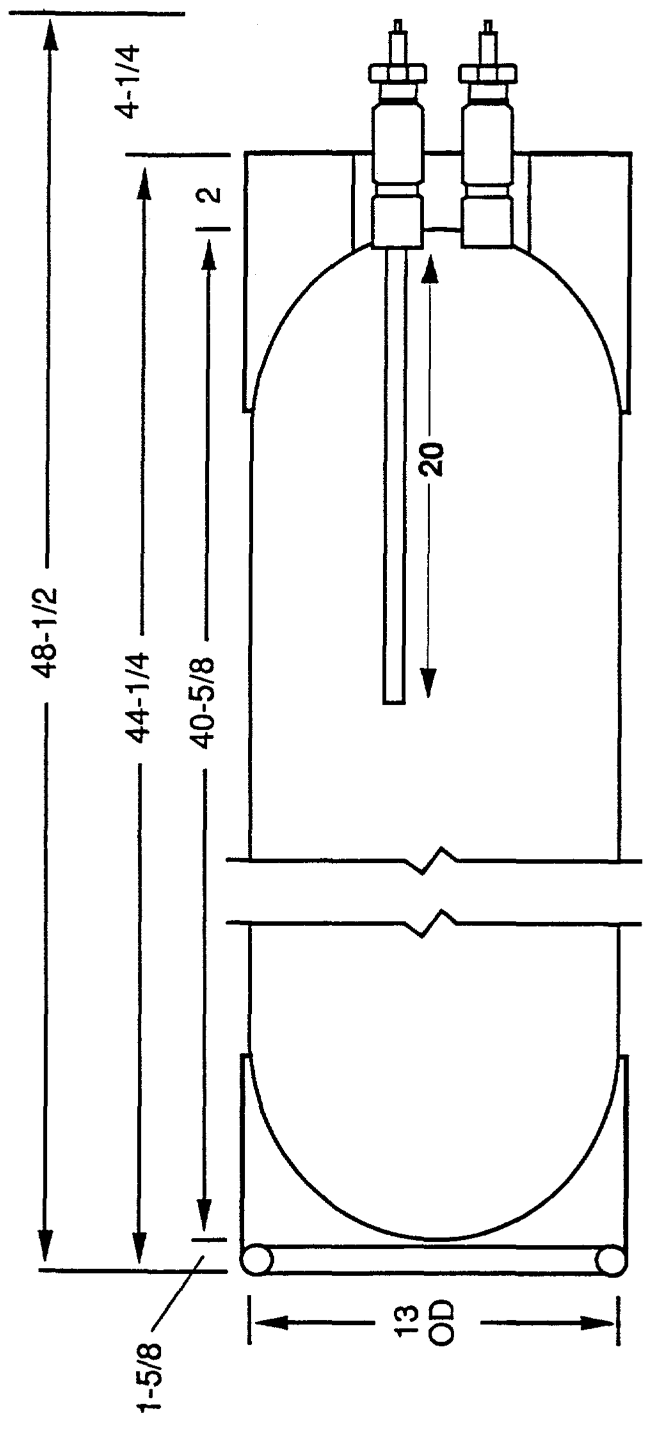


Figure 16
Schematic of Cylinder Model 12B

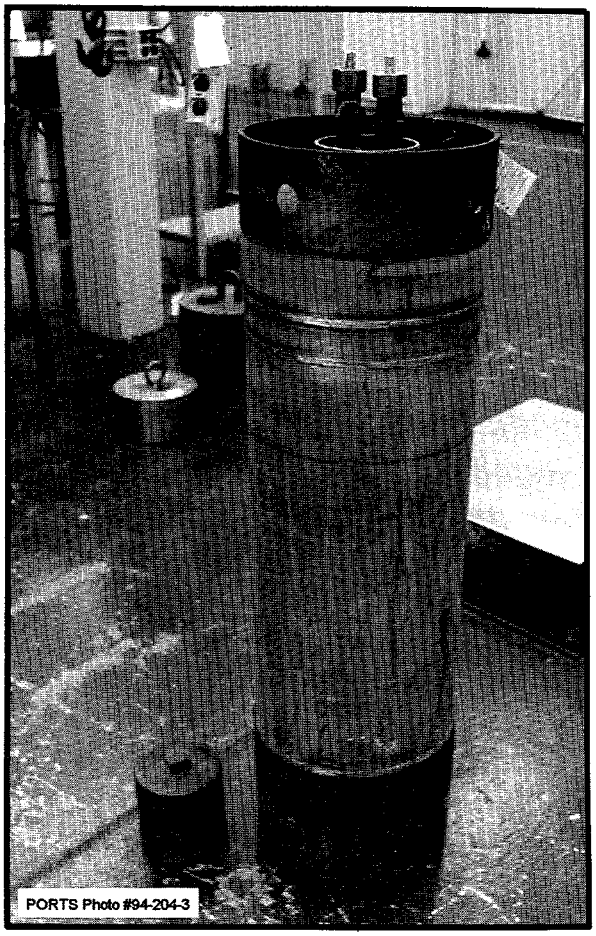


Figure 17
Cylinder Model 12B

Nominal Diameter	12 in. (30.5 cm)
Nominal Length	49.5 in. (126 cm)
Wall Thickness	0.250 in. (0.65 cm)
Nominal Tare Weight	185 lb (84 kg)
Maximum Net Weight	460 lb (208.7 kg)
Nominal Gross Weight	645 lb (without cap) (293 kg)
Minimum Volume	2.38 ft^3 (67 liters)
Basic Material of Construction	Monel
Service Pressure	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	5.0% ^{235}U (maximum)
Valve Used - 3/4-in. valve	

6.7 UF_6 Cylinder Model 30B

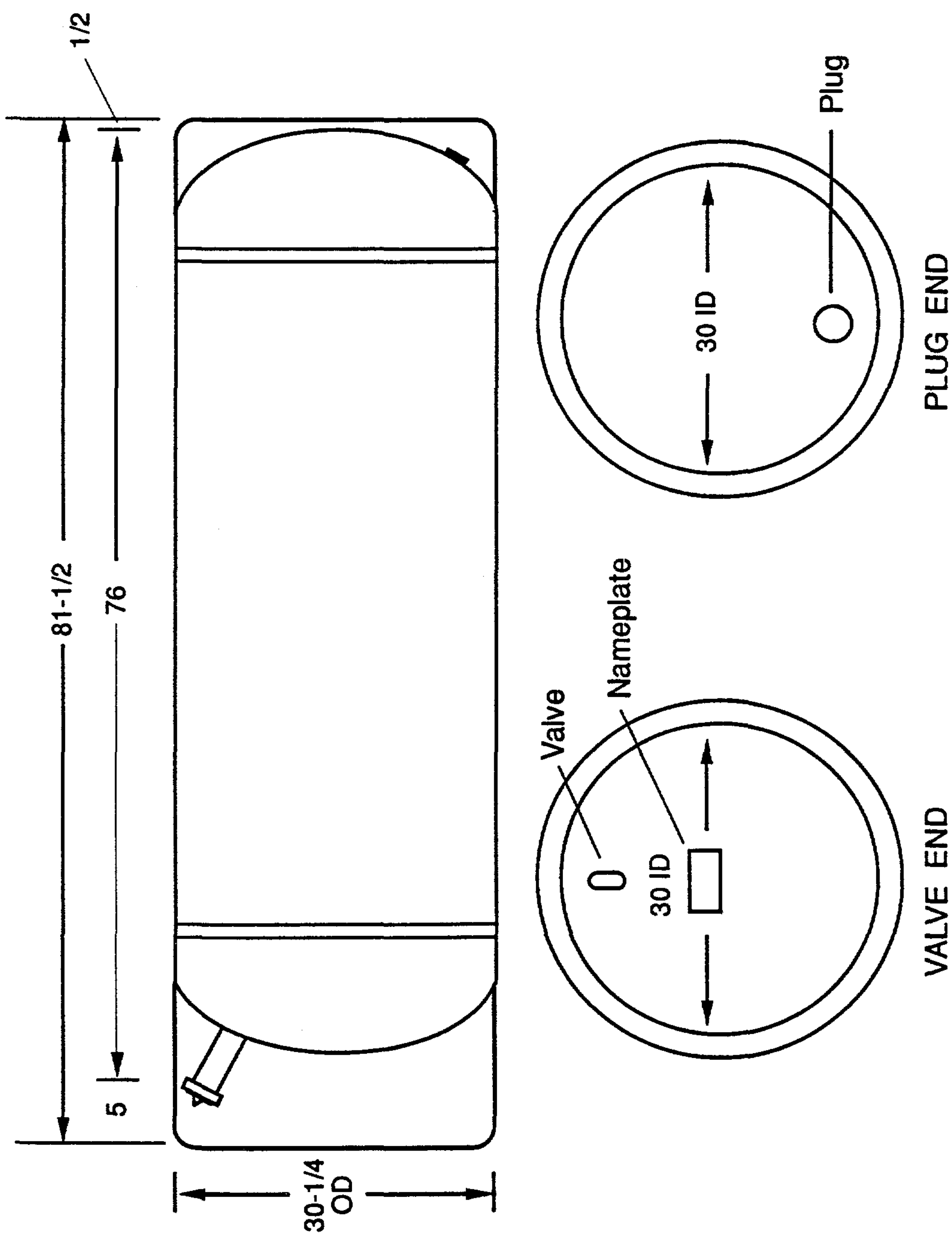


Figure 18
Schematic of Cylinder Model 30B

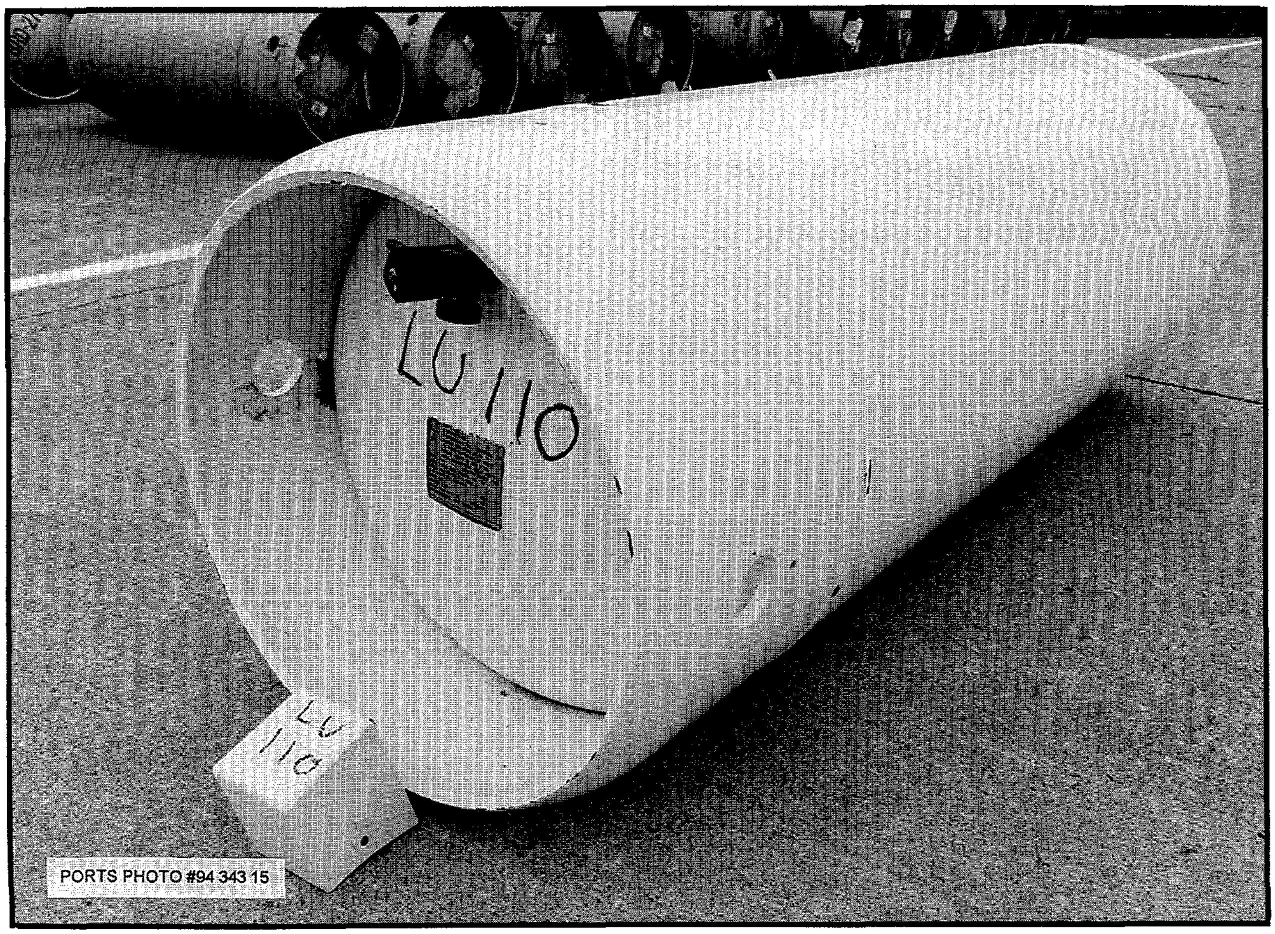


Figure 19
Cylinder Model 30B

Nominal Diameter	30 in. (76 cm)
Nominal Length	81 in. (206 cm)
Wall Thickness	1/2 in. (1.25 cm)
Nominal Tare Weight	1,400 lb (635 kg)
Maximum Net Weight	5,020 lb (2,277 kg)
Nominal Gross Weight	6,420 lb (2,912 kg)
Minimum Volume	26 ft^3 (736 liters)
Basic Material of Construction	Steel (ASTM A-516)
Service Pressure	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	5.0% ^{235}U (max. with moderation control)

Valve Used - 1-in. valve

6.8 UF_6 Cylinder Model 48X

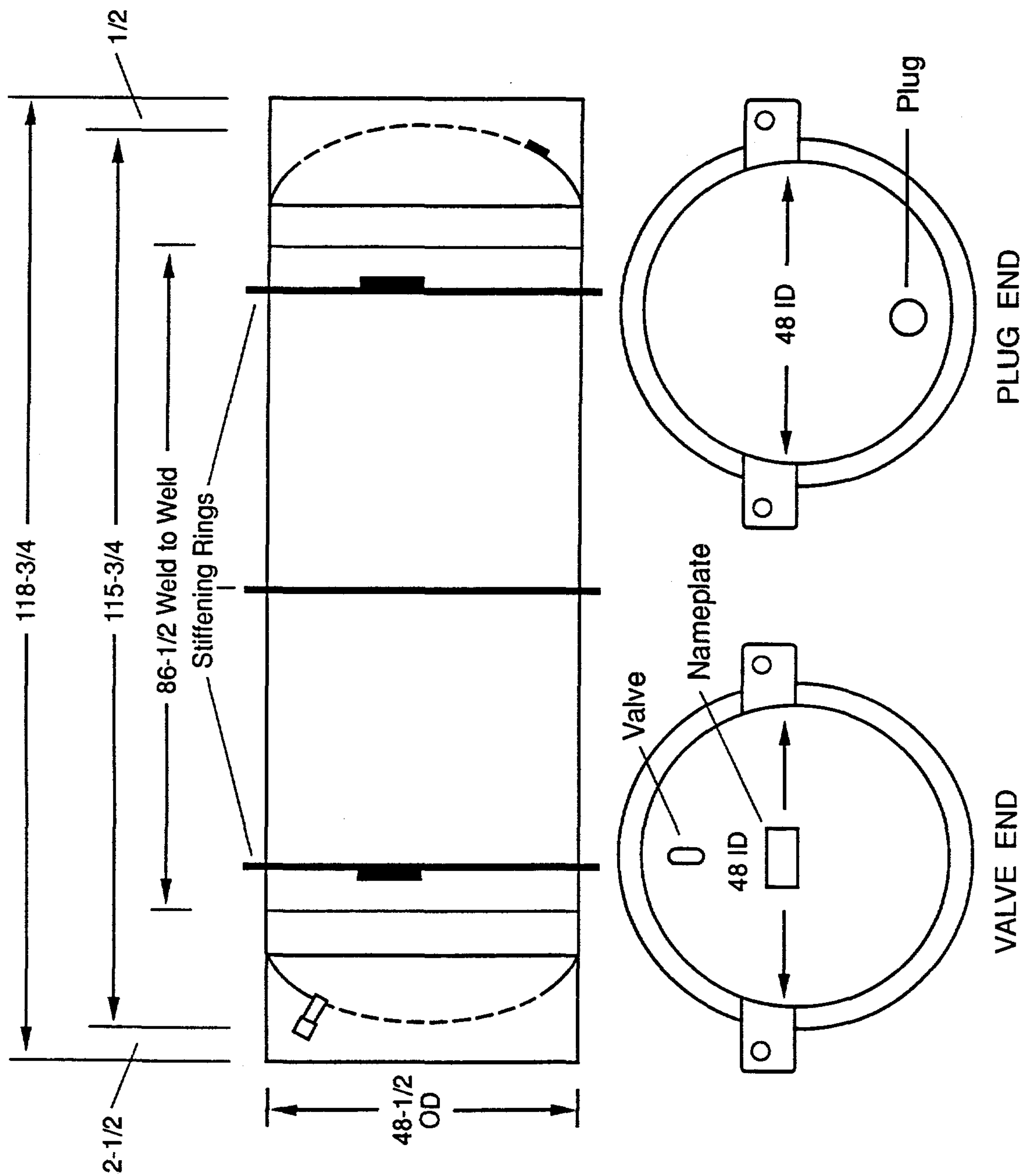


Figure 20
Schematic of Cylinder Model 48X

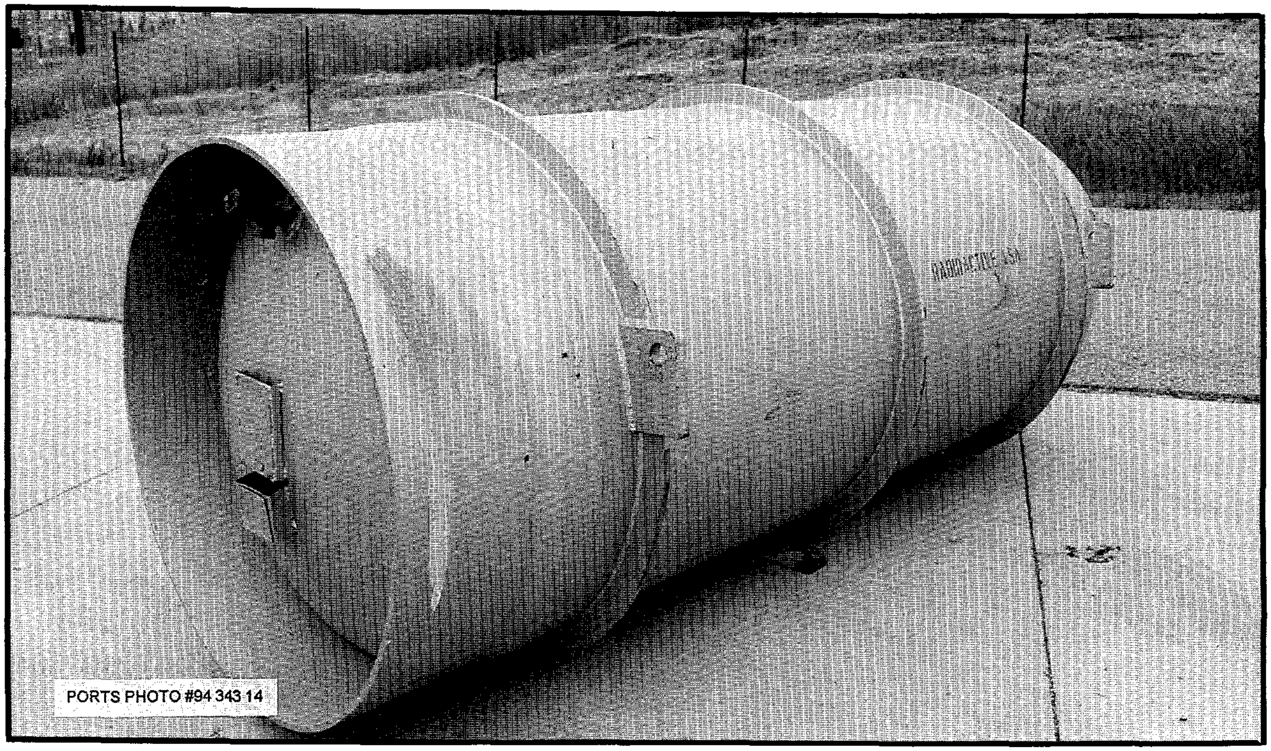


Figure 21
Cylinder Model 48X

Nominal Diameter	48 in. (122 cm)
Nominal Length	119 in. (302 cm)
Wall Thickness	5/8 in. (1.6 cm)
Nominal Tare Weight	4,500 lb (2,041 kg)
Maximum Net Weight	21,030 lb (9,539 kg)
Nominal Gross Weight	25,530 lb (11,580 kg)
Minimum Volume	108.9 ft^3 (3.084m^3)
Basic Material of Construction	Steel (ASTM A-516)
Service Pressure	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	4.5% ^{235}U (max. with moderation control for transport, 5.0% for in-plant use.)
Valve Used - 1-in. valve	

NOTE: Previously built 48A cylinders are similar in design, but do not have certified volumes; refer to Table 2 for fill limits and other data applicable to this cylinder.

Some model 48X cylinders have a tapered skirt on the plug end.

6.9 UF_6 Cylinder Model 48Y

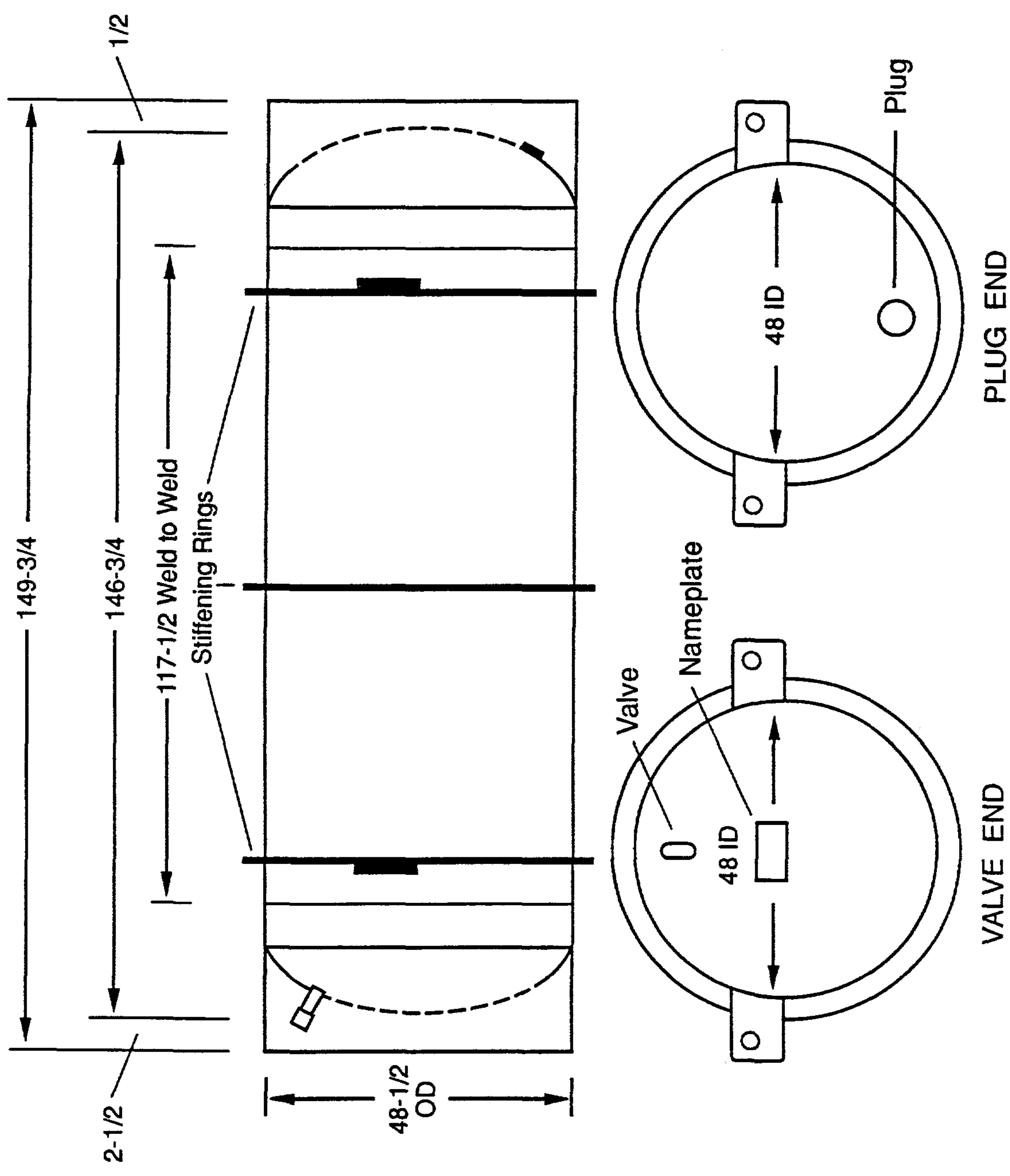


Figure 22
Schematic of Cylinder Model 48Y

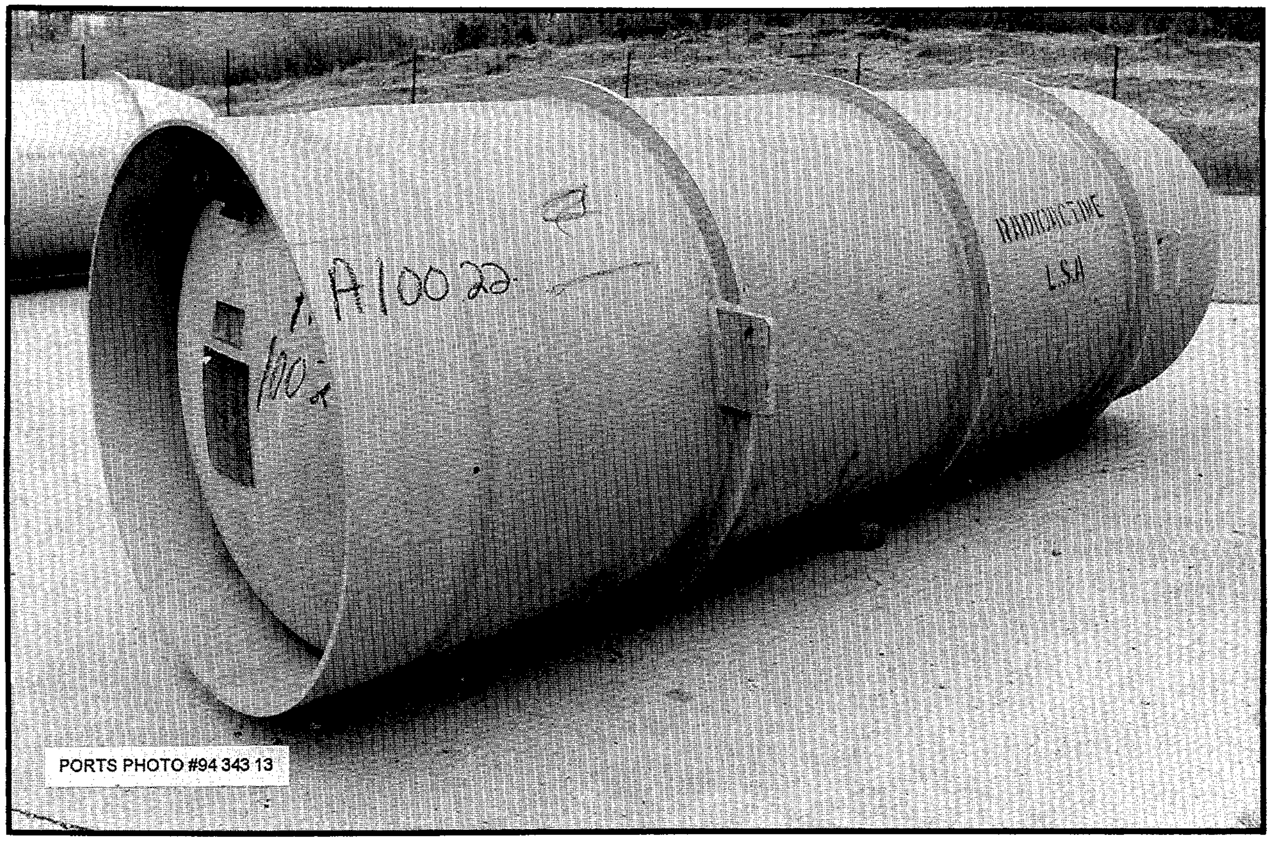


Figure 23
Cylinder Model 48Y

Nominal Diameter	48 in. (122 cm)
Nominal Length	150 in. (380 cm)
Wall Thickness	5/8 in. (1.6 cm)
Nominal Tare Weight	5,200 lb (2,359 kg)
Maximum Net Weight	27,560 lb (12,501 kg)
Nominal Gross Weight	32,760 lb (14,860 kg)
Minimum Volume	142.7 ft^3 (4.04 m^3)
Basic Material of Construction	Steel (ASTM A-516)
Service Pressure	200 psig (1380 kPa gage)
Hydrostatic Test Pressure	400 psig (2760 kPa gage)
Isotopic Content Limit	4.5% ^{235}U (max. with moderation control)

Valve Used - 1-in. valve.

NOTE: Previously built 48F cylinders are similar in design, but do not have certified volumes; refer to Table 2 for fill limits and other data applicable to this cylinder.

6.10 UF_6 Cylinder Model 48G

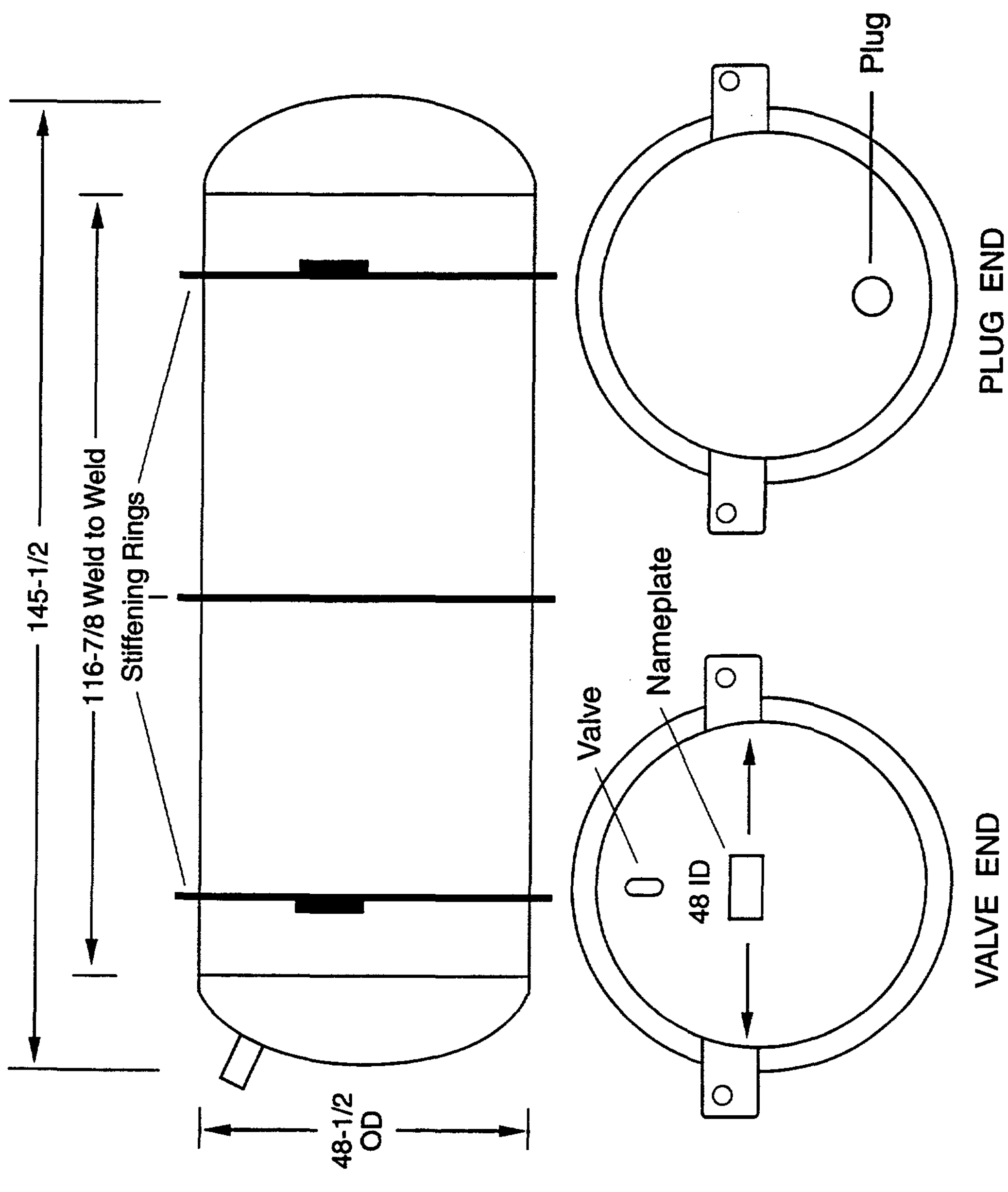


Figure 24
Schematic for Cylinder Model 48G

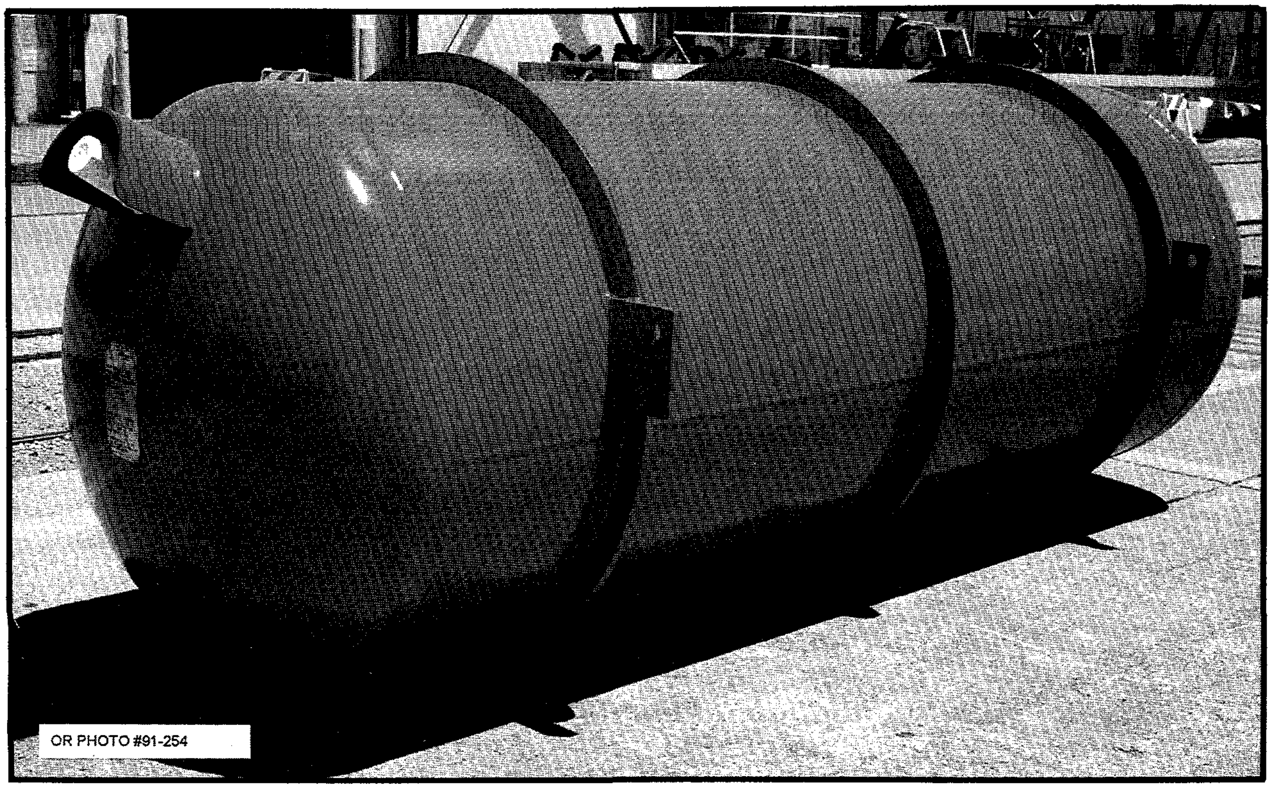


Figure 25
Cylinder Model 48G

Nominal Diameter	48 in. (122 cm)
Nominal Length	146 in. (370 cm)
Nominal Wall Thickness	5/16 in. (0.8 cm)
Nominal Tare Weight	2,600 lb (1,179 kg)
Maximum Net Weight	28,000 lb (12,701 kg)*
Nominal Gross Weight	30,600 lb (13,800 kg)
Minimum Volume	139 ft^3 (3.94 m^3)
Basic Material of Construction	Steel**
Service Pressure	100 psig (690 kPa gage)
Hydrostatic Test Pressure	200 psig (1380 kPa gage)
Isotopic Content Limit	1% ^{235}U
Valve Used - 1-in. valve	

* Based on 235°F (113°C).
** Steel specification changed from A-285 to A-516 for cylinders ordered after 1978.

NOTE: For depleted uranium storage only. Cylinders with serial numbers below 111821 do not have certified volumes. An earlier design was designated Model OM.

6.11 UF_6 Cylinder Model 48H

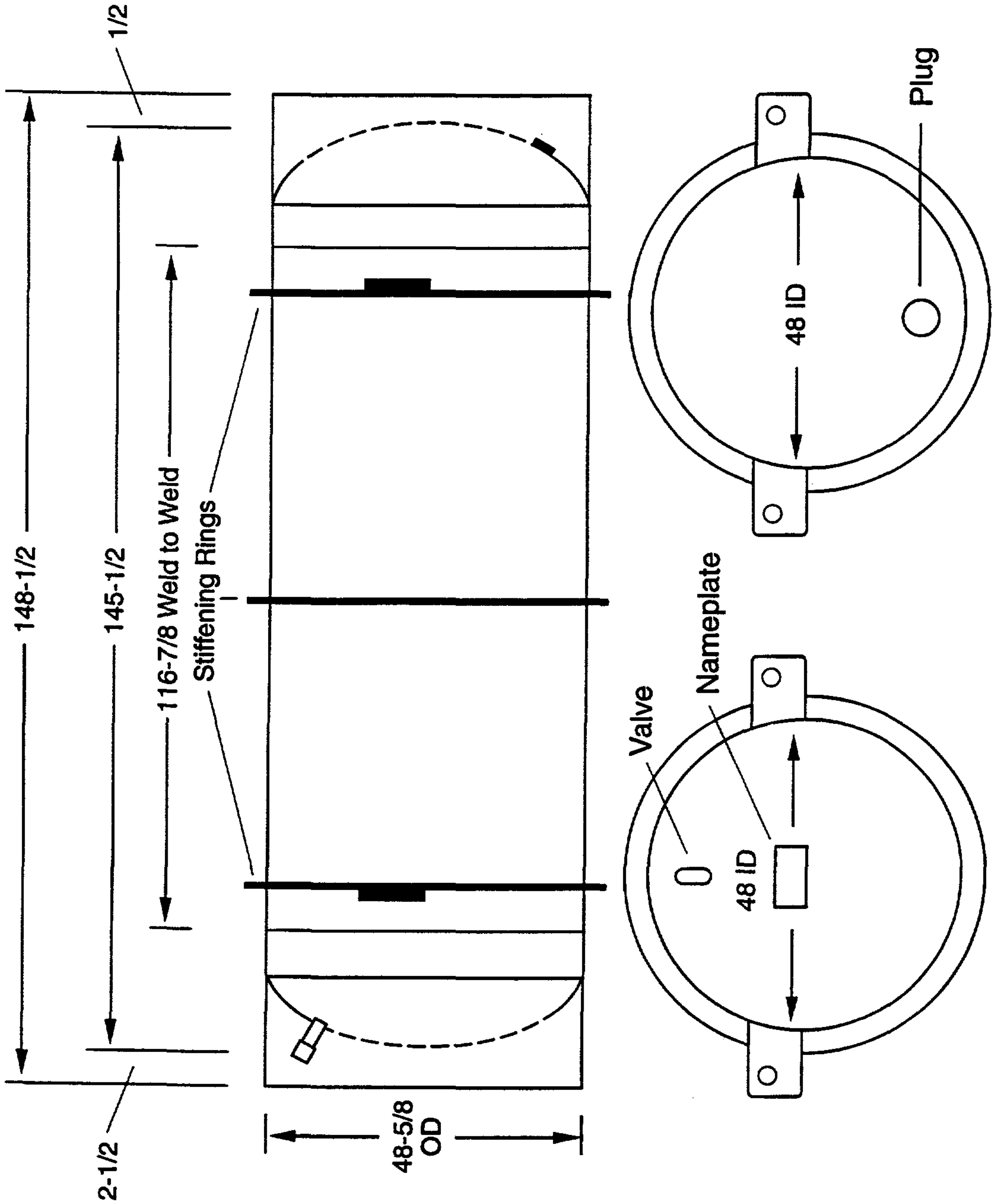


Figure 26
Schematic for Cylinder Model 48H

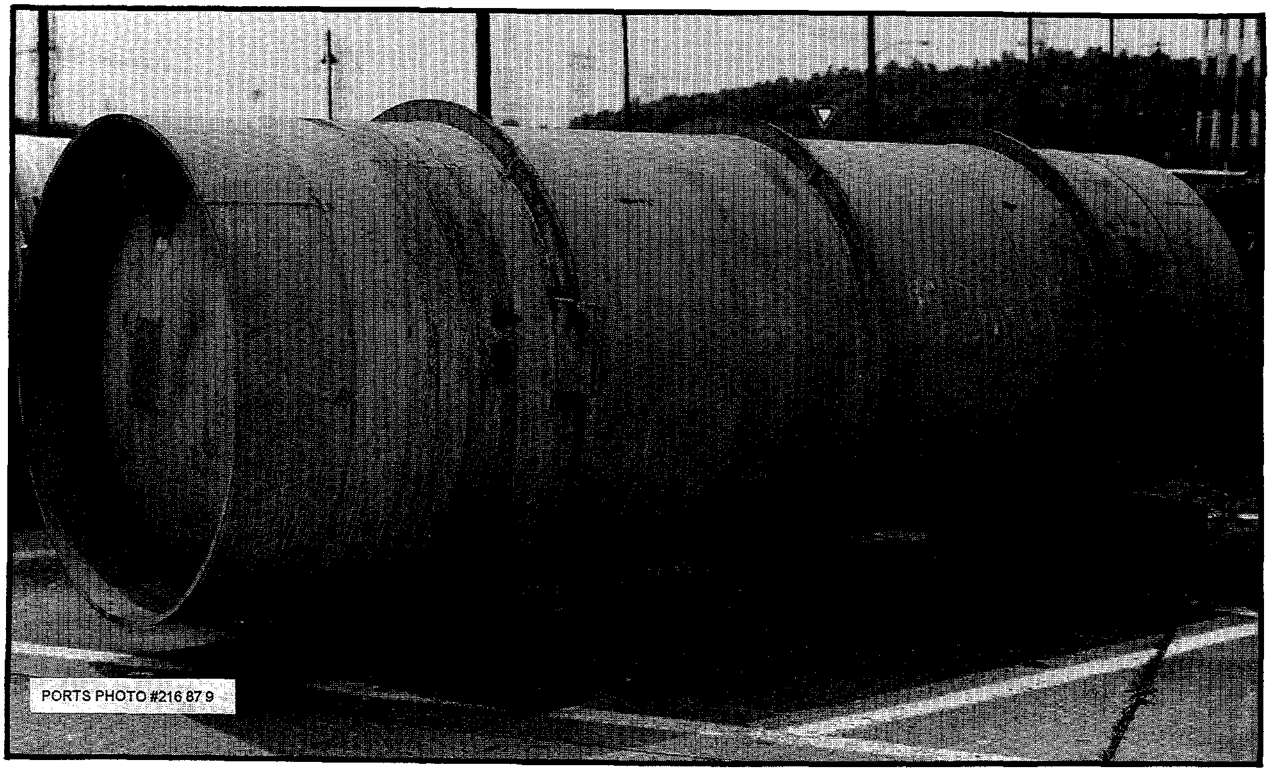


Figure 27
Cylinder Model 48H

Nominal Diameter	48 in. (122 cm)
Nominal Length	146 in. (370 cm)
Nominal Wall Thickness	5/16 in. (0.8 cm)
Nominal Tare Weight	3,170 lb (1,438 kg)
Maximum Net Weight	27,030 lb (12,261 kg)
Nominal Gross Weight	30,200 lb (13,700 kg)
Minimum Volume	140 ft^3 (3.96 m^3)
Basic Material of Construction	A-516 Steel
Service Pressure	100 psig (690 kPa gage)
Hydrostatic Test Pressure	200 psig (1380 kPa gage)
Isotopic Content Limit	1% ^{235}U
Valve Used - 1-in. valve	

6.12 Sample Cylinder Valve

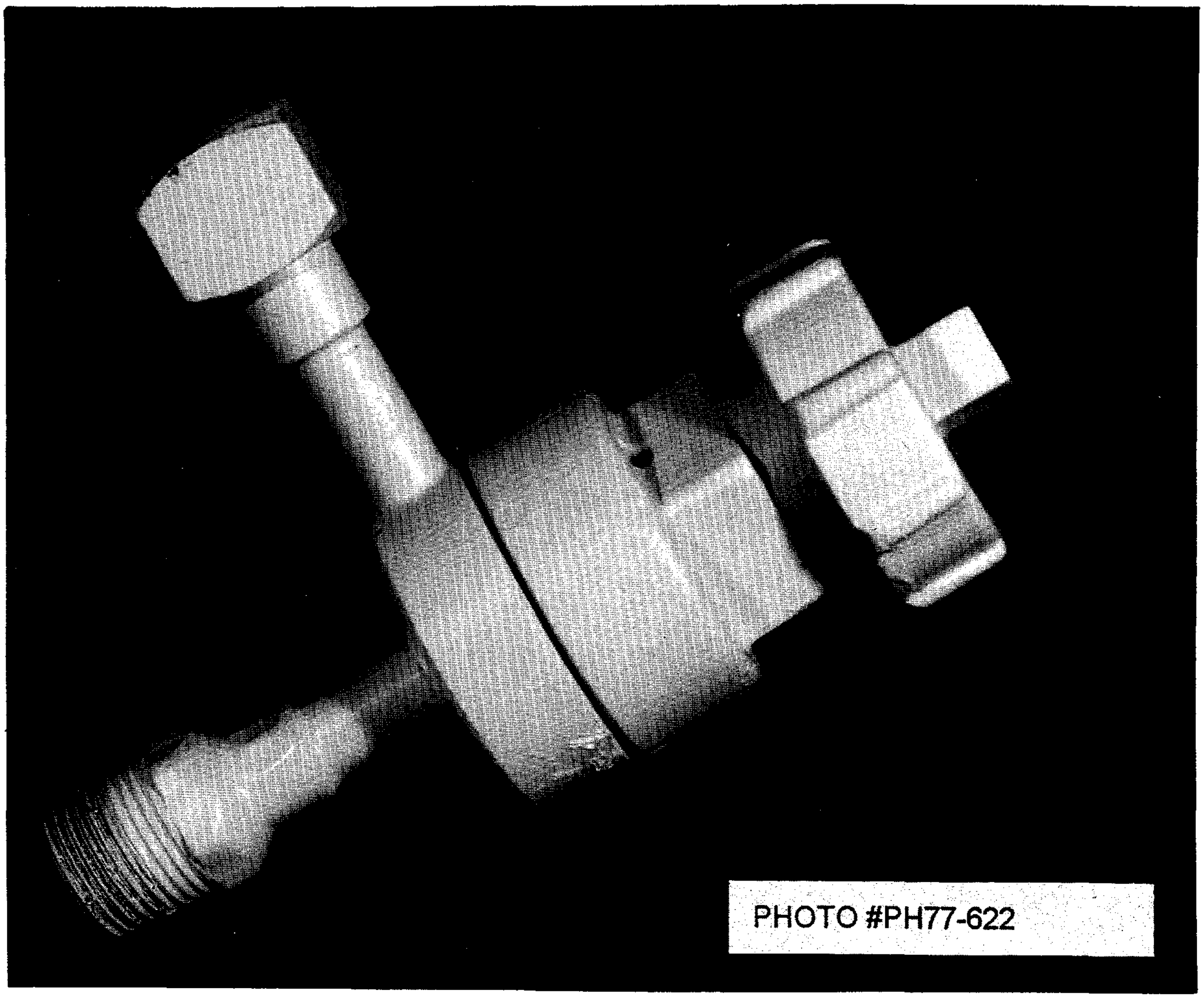


Figure 28
Sample Cylinder Valve

6.13 Cylinder Valves

Below are cutaway views of 3/4-inch and 1-inch cylinder valves.

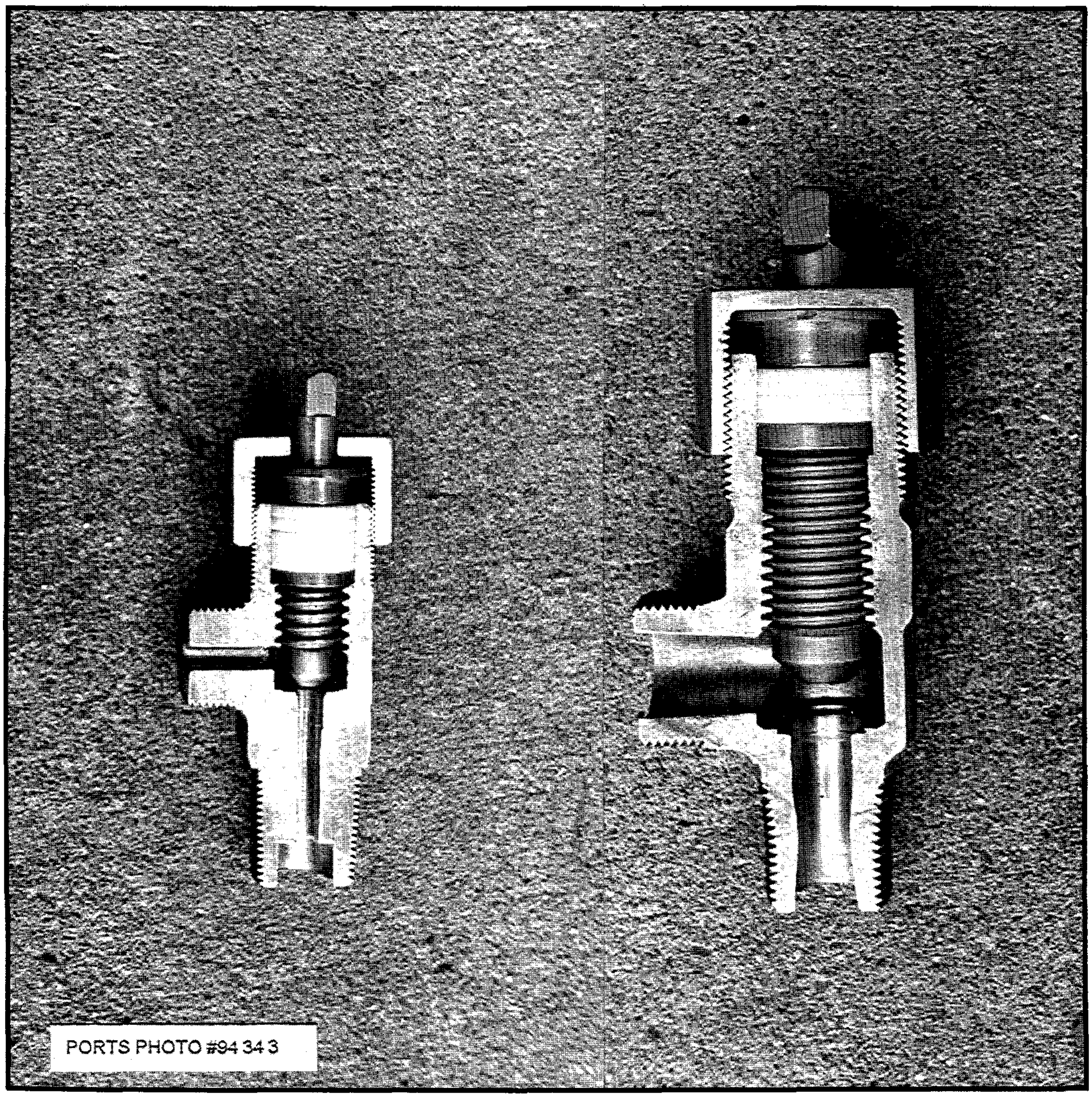


Figure 29
Cutaway Views of 3/4-inch and 1-inch Cylinder Valves

7. TYPICAL UF_6 COLD TRAP

7.1 Equipment Description

In the processing of UF_6, it is necessary to be able to purge or remove the UF_6 from piping when cylinders are disconnected from valve manifolds. The goals of purging are twofold:

1. to remove the UF_6 from the connection to the extent that when the system is opened to moist atmospheric air, only minor quantities of HF and UO_2F_2 can be formed by reaction with residual UF_6, and

2. to collect the small quantity of UF_6 contained in the piping rather than release it to the environment.

A convenient way to do this is to employ a UF_6 cold trap. As the name implies, it consists of a vessel cooled to a low temperature so that the UF_6 gas will desublime to the solid phase when it comes in contact with the trap's surface.

The colder the surface, the more UF_6 will be solidified according to the gas-solid relationship shown in the phase diagram (see previous Figure 3 and Figure 30). At the final equilibrium temperature, however, some small amount of UF_6 does remain in the gas phase. Therefore, it is also necessary to provide a chemical trap to collect the remaining UF_6 by absorption. A vacuum pump removes the non-condensable purge gases. Figure 30 is the phase diagram of UF_6 for the temperature range of -40°F to +60°F. A schematic of the components of a typical cold trap installation is shown in Figure 31.

The cold trapping vessel is usually a two-valve Monel or nickel UF_6 cylinder of 5-, 8-, or 12-in. diameter because the cylinder design includes a dip pipe connected to one valve to distribute the gas flow. The inlet piping and the two cylinder valves are heated to assure that the UF_6 remains in the gas phase until it enters the cylinder. The design temperature range for these cylinders is -40°F to +250°F (ANSI N14.1 latest revision). The cylinder is usually submerged in a liquid heat transfer medium that is cooled by mechanical refrigeration. The bath, cylinder, and refrigeration unit are mounted on a scale to indicate the weight increase as UF_6 collects. When filled, the cylinder can be removed from the bath, weighed, and heated to return the UF_6 to the process.

The chemical traps are arranged for series flow and are usually filled with dried activated alumina. The UF_6 reacts with chemisorbed water and the activated alumina, which is principally an AlO(OH) producing UO_2F_2, AlF_3, and H_2O. A large amount of heat is given off at the reaction site, and the degree of trap loading can be determined by following the progression of the temperature rise along the beds of alumina. When the first trap begins to break through, as shown by the UF_6 detector, the alumina must be replaced. The uranium can be recovered from the spent alumina by leaching with nitric acid followed by solvent extraction.

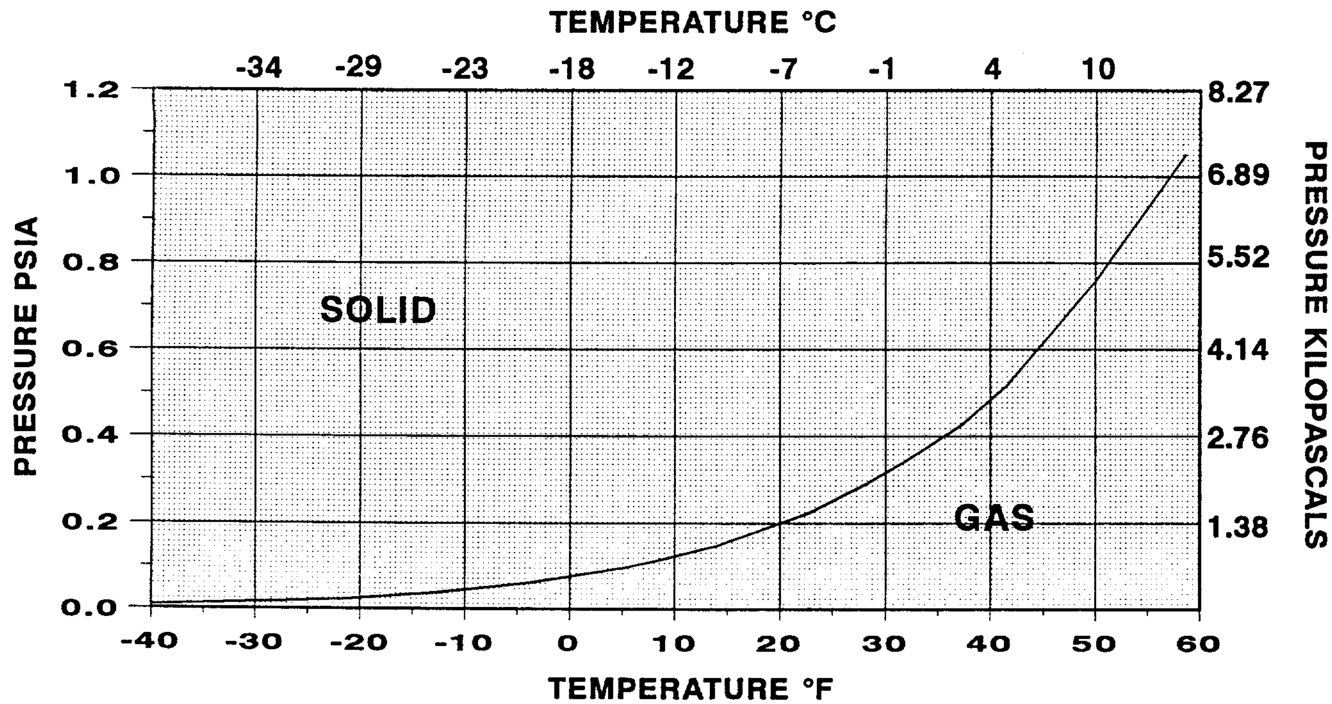
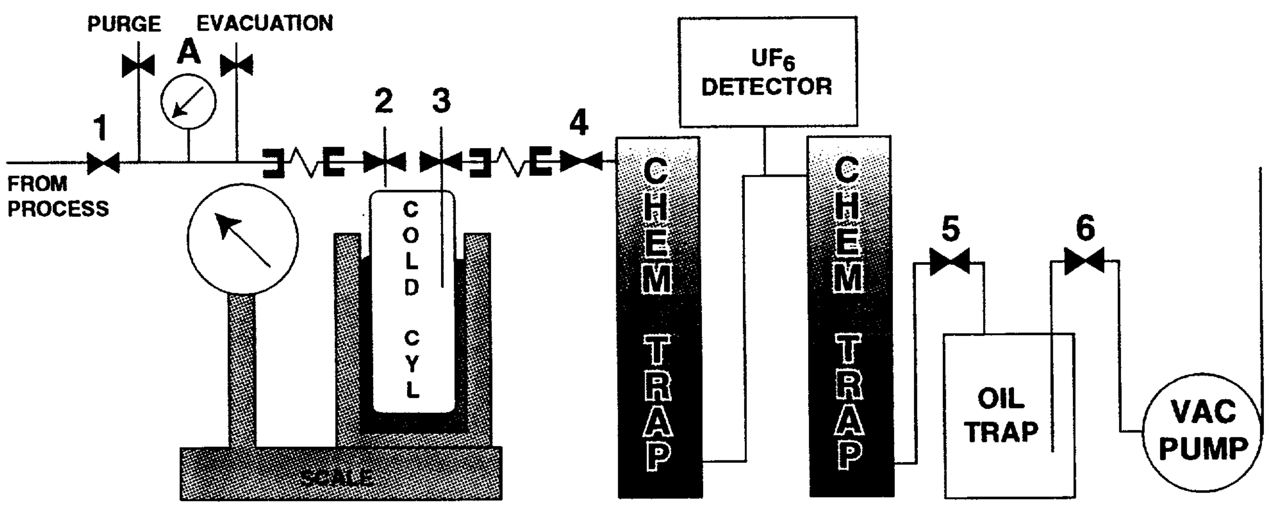


Figure 30
Phase Diagram of UF_6 Over the Range of -40° to +60° F



A. Manifold Vacuum Gage
1 - 6. Valves

Figure 31
Typical Cold Trap

The oil trap is provided to assure that no pump oil can flow into the UF_6 equipment if the vacuum pump should stop because of a power or drive belt failure. Such a failure would permit the atmospheric pressure on the discharge side to force pump oil into the suction side of the system. The piping is arranged so that any oil entering the trap will return to the vacuum pump when the pump is restarted.

7.2 Cold Trap Operation

To avoid the possibility of blowing oil out of the vacuum pump, the operating procedure for starting a cold trap unit is to close all the valves, start the vacuum pump, then slowly open the valves in the sequence of 6, 5, 4, 3, and 2. After opening valve 2, the vacuum gage on the manifold must be checked to ensure a lower pressure than the process before valve 1 may be opened. (See Figure 31).

For the same reason, the procedure to shut down a cold trap unit is to close the valves in the reverse sequence, 1, 2, 3, 4, 5, 6, and shut down the vacuum pump last.

7.3 Principles of Purging

Merely blowing dry gas through the piping manifold connecting a UF_6 cylinder to a process system will not adequately purge the system. This is because the manifolds contain dead-end sections that will not be swept out by the purge gas flowing through the main piping path. To purge all of the piping, it is first necessary to desublime as much of the pure UF_6 as possible into the cold cylinder and then, with dry oil-free inert gas such as air, nitrogen or carbon dioxide, repeatedly dilute and evacuate the contents of the piping manifold until the remaining concentration of UF_6 is less than 10 ppm.

This is accomplished by closing valve 2 on the cold trap (Figure 31), closing the manifold process block valve, and opening the evacuation valve. This will permit the pure UF_6 gas in the manifold to flow into the cold cylinder and desublime. The evacuation should be continued until no pressure decrease is observed in the system. If the cylinder operation involves liquid UF_6, the manifold pressure will decrease to 22 psia at which point it will remain steady until all remaining liquid solidifies. Since the system now contains only solid UF_6, sufficient time should be allowed for it to vaporize and be desublimed into the cold cylinder. When the initial transfer is completed, open valve 2 and pressurize the manifold to 20 psia with dry oil-free inert gas such as air, nitrogen, or carbon dioxide and evacuate to the cold trap. This will fill all parts of the manifold and pigtail with purge gas to mix with and dilute the UF_6. Several repeated purges in this manner will reduce the concentration of UF_6 to less than 10 ppm. At this concentration, the pigtail can be disconnected from the cylinder valve. The pigtail nut should be plugged as soon as possible to minimize the absorption of airborne moisture on UF_6-wetted surfaces.

8. EMPTYING A UF_6 CYLINDER

8.1 External Inspection

Prior to heating, while the cylinder is cold and the internal pressure is subatmospheric, it is important to thoroughly inspect the cylinder for defects that could cause problems when the cylinder is hot and the pressure is above atmospheric. The inspection should ensure proper thread engagement of the valve and plugs, absence of dents, bulges, or cracks in the shell, and no broken stiffening rings. The cylinder should be weighed to verify that the content of UF_6 does not exceed the fill limit.

8.2 Positioning the Cylinder

After assurance of physical integrity and proper net weight, the cylinder should be moved to the cylinder emptying system schematically represented in Figure 32. The lifting fixture used to attach the crane hook to the cylinder should be designed for the task, and should be visually inspected for obvious defects before lifting the cylinder. The cylinder valve should be oriented in the 12 o'clock position. The heated enclosure may be a low-pressure steam autoclave or an electrically heated hot air chamber. The important consideration is to protect the cylinder from being heated above its design temperature. The piping is a manifold equipped with connections to the process, evacuation source, and the purge gas supply. The pressure gage must measure from full vacuum to the process pressure. All parts of the manifold are insulated and heated to maintain a temperature of 250°F to assure that the UF_6 remains in the gas phase.

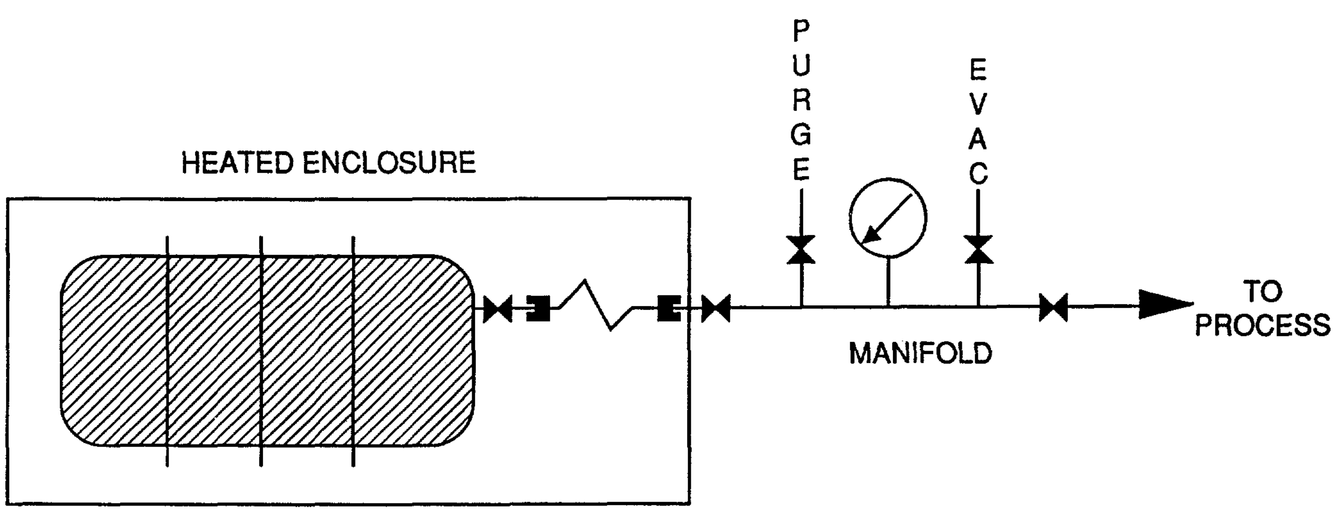


Figure 32
Cylinder Emptying System

8.3 Pigtail

The term pigtail is used to describe the flexible tubing that connects the cylinder valve to the piping manifold of the process system. It must be flexible to accommodate the lateral and vertical misalignments that occur because the cylinder positioning is not exact. Uranium hexafluoride pigtails are designed utilizing tubing with screwable connections. These unique features need special attention during design, fabrication, testing, and use. Drawings and specifications shall be produced utilizing design techniques and materials developed and proven by USEC, operating contractors and companies with experience in handling UF_6. UF_6 pigtails shall be fabricated and tested to well-documented, approved procedures. A schematic cross section of a typical pigtail connection to a UF_6 cylinder valve is shown in Figure 33.

The pigtail tube can be annealed copper tubing or a braid-covered hose made of a suitable material, for example Monel. The end connection consists of a follower with a raised lip to compress a Teflon gasket when the pigtail nut is tightened on the valve port or manifold connection. Either wrench flats or a hex nut is provided on the follower to prevent it from twisting when the pigtail nut is turned. The nut is made of a material that will not gall on the valve threads. The gasket is virgin Teflon and a new one is used for every connection. After the pigtail is connected to the valve, the assembly is pressure and vacuum tested to assure no

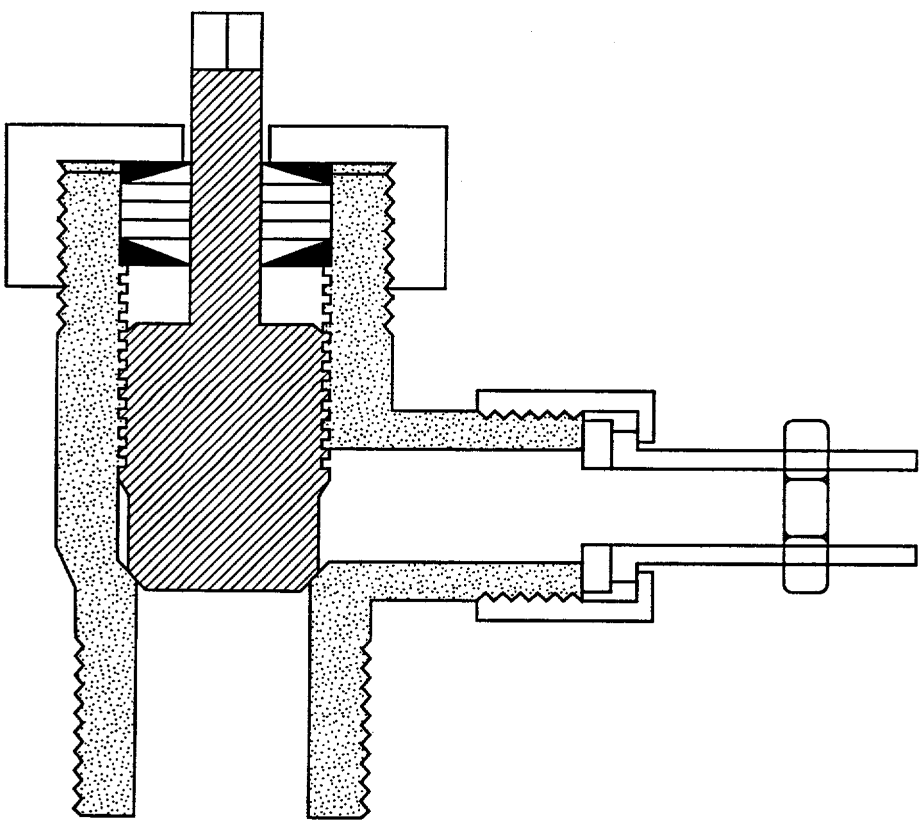


Figure 33
Typical Valve and Pigtail Connection

leakage. The pressure test should be at a pressure greater than the operating pressure, and the vacuum test should be made at the lowest vacuum the evacuation source can achieve. Because of the loose fit of the stem and body threads, the cylinder valve packing is a boundary on these two tests. If no leakage is observed, there is no need to tighten the valve packing nut. Excessive tightening of the packing nut can cause it to crack.

8.4 Valve Flow and Cold Pressure Check

The sequence of pressure test followed by vacuum test is preferred so that upon completion of the tests, the pigtail has been evacuated to a low pressure. When the cylinder valve is opened, an increase in the pressure of the manifold indicates that the valve is not plugged, and the observed pressure is the cylinder cold pressure. If the cylinder contains only pure UF_6, the cold pressure will be the vapor pressure of UF_6 for the solid temperature. It is difficult to know the temperature of the solid in a cylinder by other means. In the large cylinders containing tons of UF_6, the thermal inertia of the mass of solid UF_6 does not permit the solid to follow changes in ambient temperature. For example, cylinders stored outside in the hot summer sun, with surfaces that were burning hot to the touch, have been shown to contain solid UF_6 at a temperature of 71°F. Figure 34 is the portion of the UF_6 phase diagram for the temperature range of 70°F to 150°F showing the vapor pressure of the solid.

Solid UF_6 has a density of approximately 317.8 lb/ft^3 and occupies only about 60% of the volume of the cylinder. The remainder of the cylinder, approximately 40% of the volume, contains UF_6 vapor and may also contain small quantities of other impurities such as hydrogen fluoride, coolant, and air. These impurities can be detected by measuring the gas phase pressure and comparing it to the UF_6 phase diagram (cold pressure check). Because these impurities have a higher vapor pressure than UF_6, they can be removed by evacuating some of the gas contents from the cold cylinder. This is referred to as "cold burping." If these impurities remain in the cylinder, they will be compressed by the expanding liquid UF_6 volume during heating, resulting in a high internal cylinder pressure.

For example: A 140 ft^3 cylinder filled with 27,030 lb UF_6 and enough air to measure 10 psia internal pressure on a cold pressure check at ambient conditions, when heated to 235°F could have an internal pressure of approximately 145 psia which, if in a Model 48G, H or HX cylinder, would exceed the design pressure of the cylinder. The internal pressure increases from 10 to 145 psia because in changing from a solid at 60°F to a liquid at 235°F, the UF_6 expands from a volume of 85 ft^3, about 60.8% of the cylinder volume, to a volume of 130.5 ft^3, about 93.2% of the cylinder volume. The expanding UF_6 resulting from the rise in temperature increases the partial pressure of the air from approximately 8.5 psia at 68°F to approximately 65 psia at 235°F. The partial pressure of UF_6 increases from approximately 1.5 psia at 68°F to about 79 psia at 235°F, and the summation of these partial pressures results in a total pressure of nearly 145 psia. If heated to 250°F, the total pressure could approach 190 psia. In reality, the pressure would not get that high because some of these impurities would be dissolved in the liquid UF_6.

Caution

To avoid over-pressurization due to light-molecular-weight gases, it is desirable to evacuate cylinders to below 5 psia before heating. Cylinders with a cold pressure greater than 10 psia should not be heated without cold burping to reduce cold pressure.

8.5 Heating the Cylinder

Never heat a UF_6 cylinder when the cylinder valve is closed or the cylinder is not valved to a pressure-monitoring system. The cold cylinder shall be isolated from other cylinders when it is first heated. If it were valved to a manifold with another hot cylinder, the hot UF_6 would desublime on the solid in the cold cylinder, resulting in overfilling. After sufficient preheating to liquify the UF_6, this is no longer a concern.

When the heating equipment is first turned on, the cylinder pressure instrumentation should be observed closely to determine that the pressure is rising. If the pressure does not increase, the heat should be turned off because this could indicate that the pigtail is plugged or the cylinder valve could be closed or plugged.

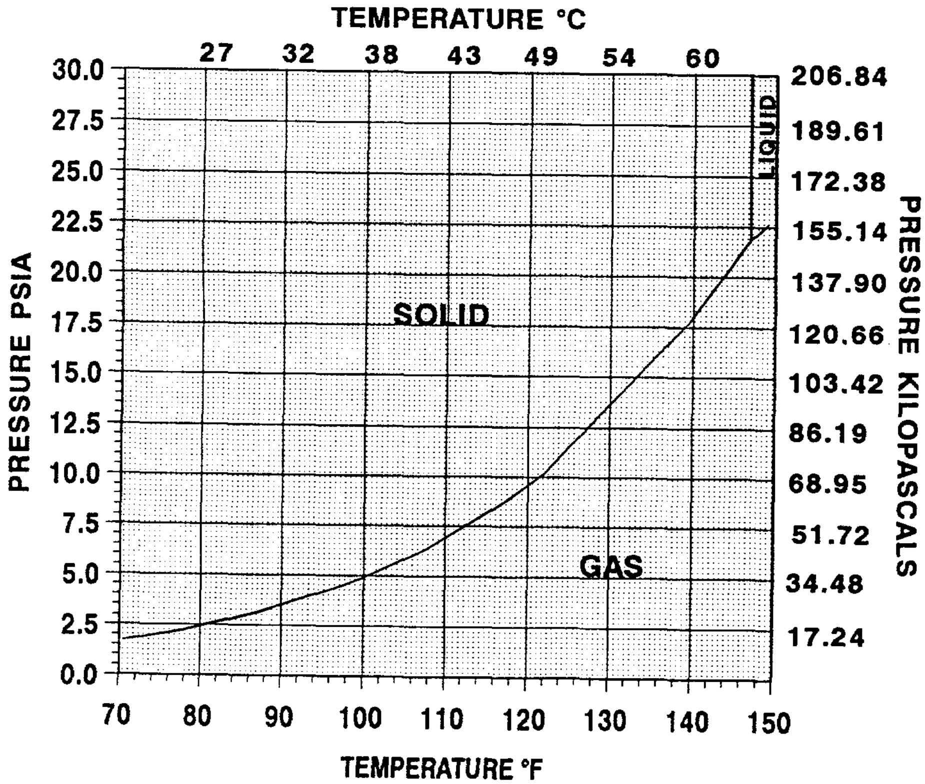


Figure 34
UF_6 Phase Diagram
70°F to 150°F

The cylinder pressure should be monitored during heating. Any indication of a high pressure is cause to discontinue heating. Figure 35 is the portion of the UF_6 phase diagram applicable to feeding operations.

8.6 Completion of Feeding

When the cylinder can no longer maintain the required process pressure, close the manifold valve and watch for a pressure rise in the cylinder. If a rise occurs, bleed the pressure off to the process system and repeat the manifold isolation until there is no pressure rise. If the cylinder is to be refilled with UF_6, a best practice is to leave the UF_6 heel in it. The gas will desublime as the cylinder cools, and there will be no air or volatile contaminants in the cylinder to hinder the next filling.

8.7 Reducing Cylinder Heels

Cylinders shipped to USEC with heels weighing in excess of the maximum heel values shown previously in Table 3 may require removal of this heel at a cost to the shipper. Removal of UF_6

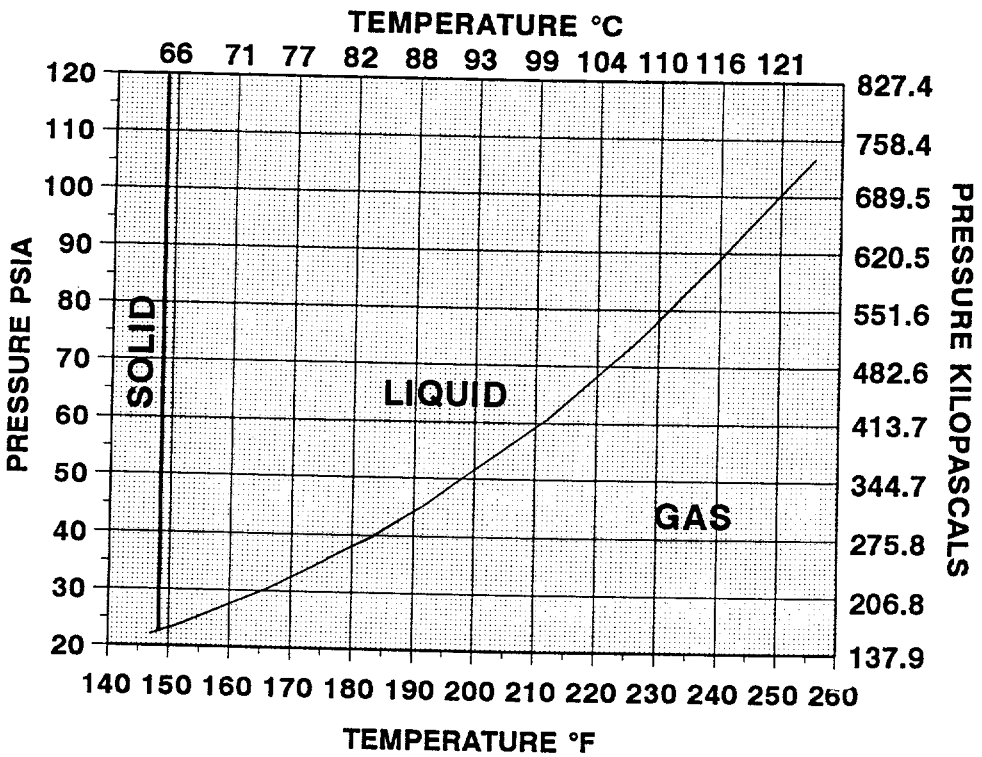


Figure 35
UF_6 Phase Diagram
140°F to 260°F

to less than the maximum heel values can be accomplished using cold traps and vacuum pumps. If this equipment is not available at UF_6 handling facilities, an evacuation system to reduce these heels can be provided by utilizing an empty UF_6 cylinder and taking advantage of the vapor pressure characteristics of UF_6. The vacuum is provided by a UF_6 cylinder at ambient temperature, containing only solid and gaseous UF_6, i.e., no non-condensable gases like air or nitrogen. Pure UF_6 at 75°F has a vapor pressure of 2 psia. Therefore, when a hot (~235°F) UF_6 cylinder at 15 to 20 psia and a cold (~75°F) cylinder at 2 psia are valved together, the heel in the hot cylinder will flow to the cold cylinder. The gaseous UF_6 in the cold cylinder will desublime to solid UF_6, thereby reducing the pressure and causing continuous heel reduction. The time required to obtain an acceptable heel is usually short and is a function of the proportional volumes of the hot and cold cylinders, the quantity of UF_6 accumulated in the cold cylinder, and the absence of non-condensable gases. The heels from many hot cylinders can be transferred into a cold cylinder before the effectiveness of the system is diminished. Care must be taken to avoid introduction of non-condensable gases into the system during the purging of UF_6 from pigtails. External cooling of the cold cylinder may be used to increase the transfer rate, but is usually not required because of the small quantity of UF_6 involved. A schematic of a typical evacuation system is shown in Figure 36. At the conclusion of a series of these transfers, the cold cylinder shall be weighed to assure that it has not been overfilled and can be heated to feed back into the process system.

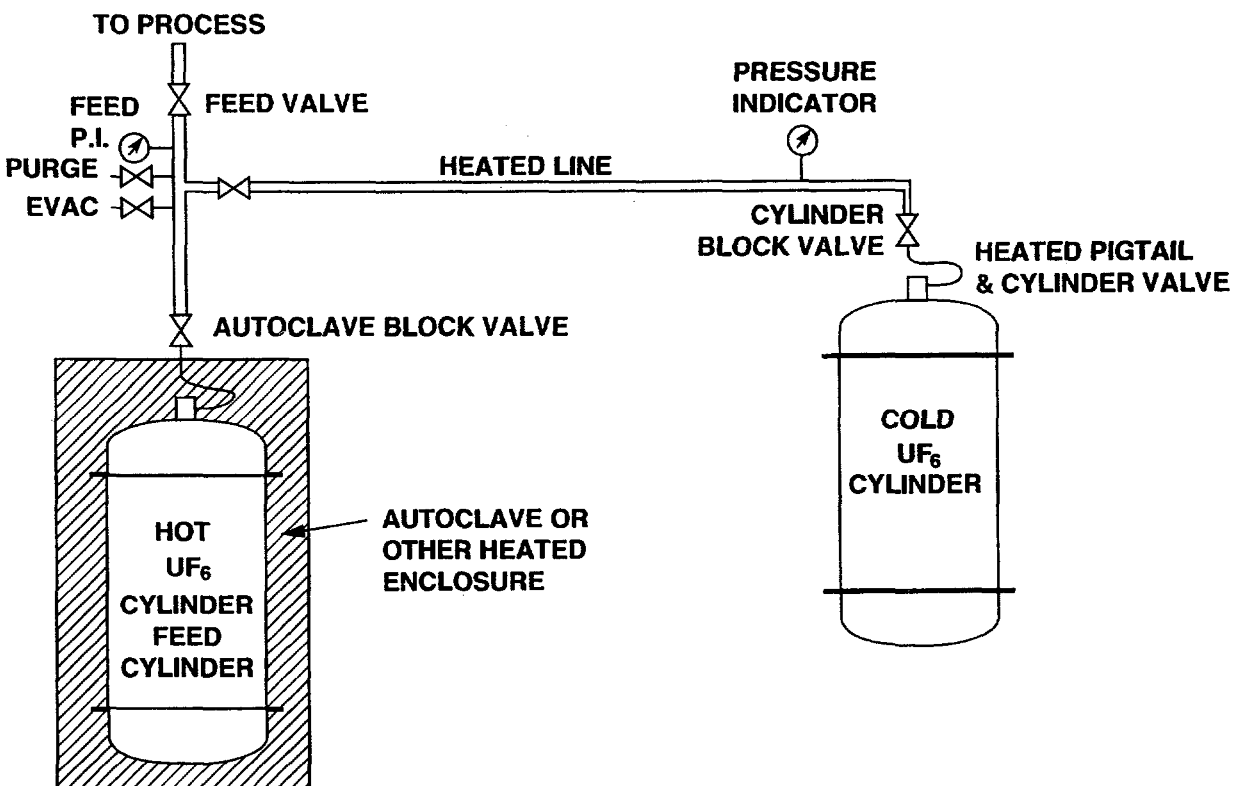


Figure 36
UF_6 Cylinder Evacuation System

9. FILLING A UF_6 CYLINDER

9.1 External Inspection

Before filling a cylinder with UF_6, it is important to thoroughly inspect and document the findings for defects that might invalidate its ANSI Code qualification as a pressure vessel and thus cause problems when it contains hot liquid and the pressure is above atmospheric pressure. The inspection should include assurance of proper thread engagement of the valve and plugs, lack of dents, bulges, or cracks in the shell, and no broken stiffening rings (see Figure 1). The cylinder should be weighed to verify the tare weight.

9.2 Filling System

After assurance of cylinder integrity and verifying the tare weight, the cylinder should be moved to the filling system. The system consists of a supply of liquid UF_6, a heated and insulated manifold with purge, evacuation, and pressure measuring provisions, a cylinder pigtail connection, and a scale. Figure 37 shows a typical cylinder filling system.

Temperature control of the manifold and pigtail is important to avoid freezing or flashing (sudden changing from liquid to gas) of the flowing liquid. The exact temperature depends on the pressure of the liquid, and will normally be in the range of 160° to 180°F. The pressure of the liquid will be the UF_6 vapor pressure for the temperature plus the head developed by the elevation of the supply above the manifold. Based on the liquid density of about 220 lb/ft^3, one foot of head is equivalent to about 1.5 psi.

9.3 Empty Cylinder Pressure

After the pigtail is connected and leak tested, the cylinder valve is opened and the cylinder pressure determined. If the cylinder is one that has been emptied of UF_6 and not purged, the pressure will be the vapor pressure of UF_6 for the ambient temperature, probably about 5 psia, and this condition is desirable. However, if it is a new cylinder, or one that has been hydrotested, the pressure observed will be an indication of the amount of air remaining in the cylinder. Specifications call for this pressure to be 5 psia or less. If it is greater than this, the excess should be evacuated utilizing a cold trap.

9.4 Establishing Liquid UF_6 Flow

The 5 psia pressure in the empty cylinder is below the triple point pressure of 22 psia required for liquid UF_6 to exist. Opening the supply valve will produce a roaring noise as the vacuum in the cylinder is broken by the liquid UF_6 changing phase to a mixture of gas and solid particles that enter the cylinder through the valve. Because the solid UF_6 thus produced may plug the intake valve, additional heat may need to be applied by wrapping heaters around the valve. After several hundred pounds of liquid UF_6 have changed phase, and the UF_6 pressure in the cylinder exceeds 22 psia, liquid flow will be established. During cylinder filling, the incoming liquid UF_6 will compress the initial quantity of air into a diminishing volume, resulting in a total cylinder pressure that can exceed the supply pressure, thus stopping the filling. If this were to happen, the liquid supply valve should be closed and some of the air/UF_6 gas mixture should be evacuated to the cold trap. This will lower the cylinder pressure sufficiently to permit resumption of liquid flow.

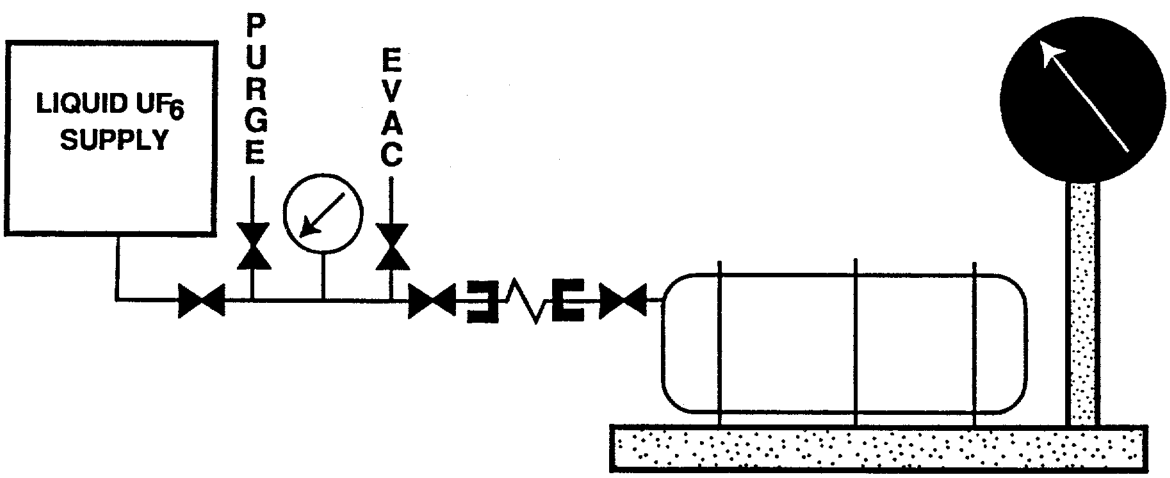


Figure 37
UF_6 Cylinder Filling System

10. UF_6 CYLINDER FILL LIMITS

For transportation and storage, a number of different sizes of UF_6 cylinders are used. These vessels are all fabricated in full conformance with the specifications contained in ANSI N14.1 (latest revision). It is not the purpose of this text to discuss specific criteria for cylinders. It is useful, however, to present the method of calculating safe UF_6 fill limits for cylinders and the meaning of these limits.

A safe fill limit must accommodate the internal volume of the cylinder, the density of the UF_6 at a specified temperature, and an allowance for ullage or the gas volume above the liquid in the container.

Uranium hexafluoride exhibits a significant expansion when undergoing the phase change from solid to liquid. The expansion factor from a solid at 70°F to a liquid at 235°F is approximately 1.53, a 53% increase in volume. In addition, the high coefficient of expansion in the liquid phase gives a substantial increase in volume between the normal fill temperature and the maximum temperature permitted by the cylinder design. Since UF_6 is normally charged into cylinders at temperatures of about 160°F, the quantity of material that can be added to a cylinder can greatly exceed the safe fill limit. A 140 ft^3 cylinder, with a shipping fill limit of 27,030 lb, could accept up to 31,430 lb UF_6 at 160°F. When heated above 160°F, the liquid UF_6 would completely fill the cylinder and would hydraulically deform and rupture the cylinder. Quantities of UF_6 above 28,995 lb would rupture the cylinder if heated above 235°F. To avoid possible hydraulic rupture, overfilled cylinders should never be heated indiscriminately nor should properly filled cylinders be overheated. Hydraulic rupture is a well understood phenomenon that is prevented by adhering to established fill limits based on the cylinder certified minimum volume and a UF_6 density at 250°F for all cylinders (except cylinders for UF_6 depleted uranium storage where 235°F is the design temperature).

Each UF_6 cylinder model has a certified specified minimum volume. This means that any cylinder in the model series is guaranteed to have at least the certified volume. The guarantee is provided by the fabricator by filling the cylinder with 60°F water, measuring the capacity, and stamping the capacity on the cylinder nameplate. This weight, when divided by 62.37 (the density of water at 60°F in pounds per cubic foot), determines the actual volume of the cylinder in cubic feet. It shall not be less than the minimum volume specified in ANSI N14.1 (latest revision). This means that every cylinder has more capacity than the minimum, so that fill calculations based on the certified minimum volume are safely applicable to any cylinder of the model series.

The gaseous diffusion plants use controlled pressure steam to heat UF_6 cylinders. The maximum steam pressure is 8 psig, equivalent to 235°F. To provide a safety factor, UF_6 cylinder fill limits are based on the density of UF_6 at 250°F, i.e., 203.3 lb/ft^3. In addition, an allowance for ullage has been set at 5% of the certified minimum cylinder volume.

The following sample calculation of the fill limit for a Model 48X cylinder illustrates the application of these factors.

Certified Minimum Volume --- 108.9 ft^3
Density of Liquid UF_6 at 250°F --- 203.3 lb/ft^3
95%(108.9 ft^3) = 103.45 ft^3
103.45ft^3(203.3 lb/ft^3) = 21,031 lb.

The weight is rounded down to the published value of 21,030 lb. Similar calculations have been made for all models of UF_6 cylinders and are published in the ANSI N14.1 standard. This document (USEC-651) lists the limits as Shipping Limits meaning that these are the maximum weights that can be shipped out of a plant to another plant that may have different operating conditions. Within a plant, where the operating conditions are known, deviations above these values may be safely accommodated. For example, if a mechanical or operator error causes a cylinder to be filled with 500 lb more liquid UF_6 than the limit, several safe measures can be taken. The first and easiest is to valve the cylinder to a low-pressure system, such as a cold trap or the gaseous diffusion cascade, and allow the heat stored in the liquid UF_6 in the cylinder to vaporize and transfer the excess material out of the cylinder.

If the overfilled condition is not found until after the cylinder has cooled, the water capacity of the cylinder stamped on the nameplate should be used to determine its actual volume. Using this volume, the net weight of UF_6, and the liquid UF_6 density data, it may be found that heating at a controlled temperature less than 250°F may be employed and still maintain the 5% ullage for safety.

If the excess is too large to permit re-liquefying, the additional material shall be removed by evacuation without heating. This is a very slow operation because the heat transfer rate from the ambient air through the cylinder skin to the solid UF_6 is low. When sufficient UF_6 has been removed, controlled heating as outlined above may be employed.

In summary, to avoid cylinder overfilling:

1. assure personnel are aware of the cylinder fill limits,

2. require the cylinder manufacturer to measure the water weight of each cylinder,

3. maintain calibrated scales to permit accurate determination of cylinder weight (net contents),

4. operate the withdrawal stations to yield high-purity UF_6,

5. measure the cold cylinder vapor pressure before heating the cylinder to verify the amount of volatile impurities present,

6. comply with the specifications indicated on the cylinder nameplate, and

7. never heat a cylinder with the cylinder valve closed, or without valving the cylinder into a pressure monitoring system with pressure relief capabilities.

11. WEIGHING[4]

11.1 General

Accurate measurements of gross and tare weights, percent uranium, and uranium isotopic ratio (weight percent) are required. The individual measurements are important because the uranium and uranium-235 weights are obtained as follows:

1. Gross weight minus tare weight provides the net weight of UF_6.

2. Net weight of UF_6 multiplied by the percent uranium provides the uranium weight.

3. Uranium weight multiplied by the weight percent uranium-235 provides the uranium-235 weight.

Thus, at USEC facilities, careful attention is given to the type, capacity, precision, maintenance, and calibration of scales and balances used for weighing the various sizes of UF_6 cylinders. Table 8 provides information regarding USEC scales. Figure 38 shows a typical platform scale.

It is important that isotopic and weighing data be reported in a similar manner by both the shipper and receiver. Form 741, *Nuclear Material Transaction Report*, used in the United States, is a satisfactory report format and has been in use for many years. The computers used for tracking the shipments, country of origin, and country of enrichment are programmed to handle the data as shown on the form whether in pounds, kilograms, or grams.

All scales used for official weighing, except the equal-arm balance, are equipped with a printweight attachment that provides a permanent record for audit and weight verification. A preliminary weight is obtained on a platform scale equipped with a printweight attachment to provide a printed record supporting the official weight obtained on an equal-arm balance.

Scales are normally enclosed or covered to ensure cleanliness and to reduce wind effects while weighing. Scale pans, tare and weight beams, platforms, scale carts, and related equipment must be maintained in a clean condition. If necessary, all building doors are closed to reduce drafts before weighing operations.

---

[4]All measurement references in this chapter are in kilograms because uranium accountability is done in kilograms and scales are so calibrated.

Table 8. USEC Scale Descriptions

Cylinder Model Number	Typical Scale Type	Normal Capacity of Scale	Allowable Deviation[a]
1S, 2S	Electronic	11 lb (5 kg[b])	±1 g
5B	Equal-arm	132 lb (60 kg[b])	±0.3 g
30B	Electronic	8,000 lb (3,629 kg)	±2 lb (±1 kg)
48A, 48F, 48X, 48G, 48Y,48H, 48HX	Platform	36,000 lb (16,330 kg)	±6 lb (±3 kg)

[a] From the established value during check weighing operations.
[b] USEC gross, tare, and net weights are reported to the nearest gram.

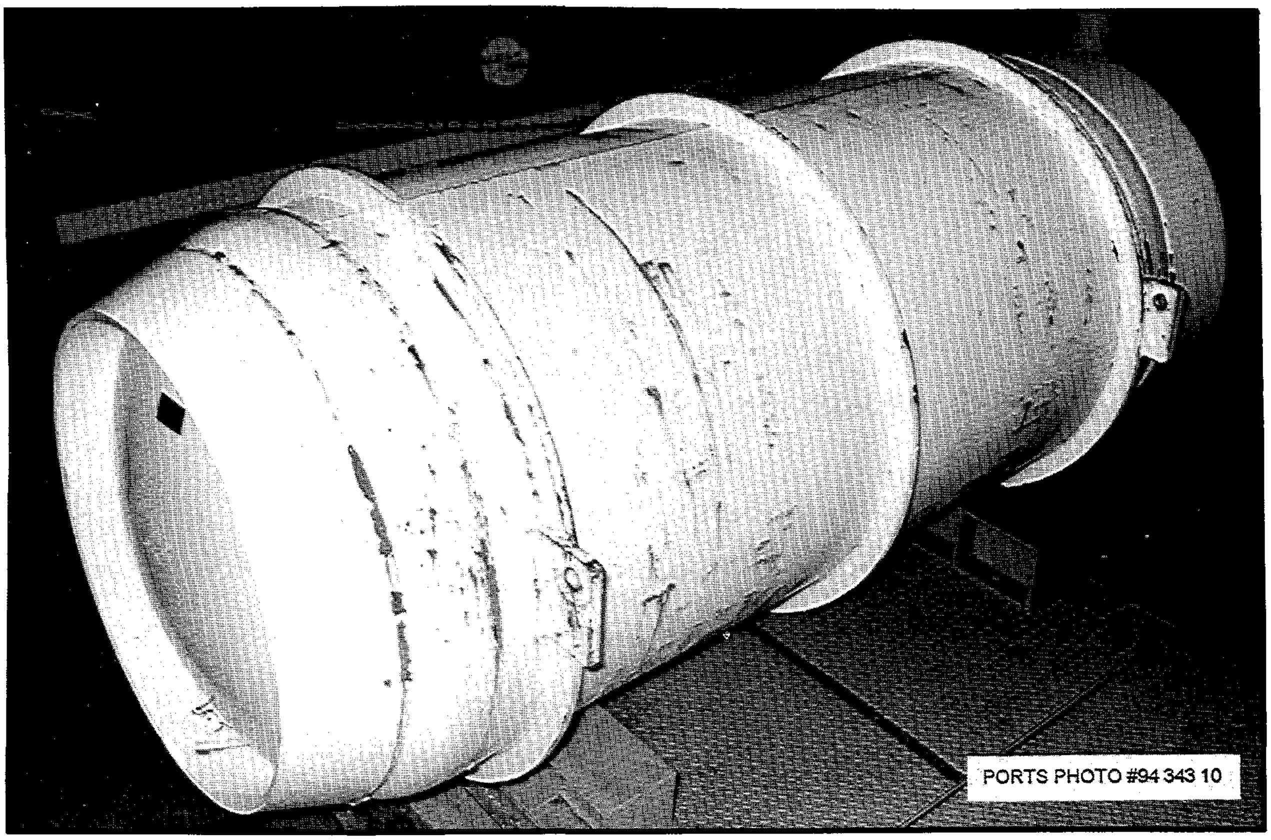


Figure 38
Typical Platform Scale for Weighing 30-inch and 48-inch UF_6 Cylinders

Scales and balances are locked while they are being loaded or unloaded to prevent damage to the weighing system. Special devices, such as lifting mechanisms and scale carts operated on and off the scale platform on a steel track, are frequently used to load and center the cylinders on the scale platform to protect the scale from damage and to attain maximum weighing precision.

The tare weight for a cylinder is established only after the completely cleaned cylinder has been evacuated, thus eliminating the weight of contained air. Cylinders are always weighed without valve protectors, skids, saddles, and other removable accessories. Valve protectors vary in weight and are not identified with a specific cylinder.

When a significant shipper-receiver weight difference is observed, the cylinder in question is subjected to the following check:

1. After the weight is rechecked, the cylinder is removed from the scale and the scale zero is checked.

2. The appropriate check weights are used on the scale to verify the linearity of the scale.

3. The cylinder in question is again placed on the scale and weighed. If the two weights agree within the allowable deviation, as shown previously in Table 8, the first weight is considered to be acceptable. If the weight difference persists, the shipper is contacted to resolve the difference.

11.2 Weighing Principles and Calibration

The primary equipment required includes National Institute of Standards and Technology (NIST) certified standard weights, test weights, check weights (or known weights), and scales or balances of appropriate capacity and sensitivity. Weight checks are performed each day the scale is being used, utilizing both full and empty UF_6 cylinders, to verify that the scale is in proper working order. To facilitate handling, check weights are normally the same size and shape as the UF_6 cylinders being weighed. Check weights contain an attached locked box for variation of the check weight value by the scale control group. Weights are randomly added or removed from the locked box. The amount of added or removed weight is restricted to weight control personnel. The observed value of the check weight is independently verified to determine if it is within the allowable deviation. If the observed value of the check weight exceeds the allowable deviation, the scale is rezeroed and the check weight reweighed and independently verified. If the indicated weight differs the second time, the scale cannot be used and must be recalibrated.

The appropriate check weights are weighed on each day of use. Cylinder weights are not established until the check weights have been completed. The procedure for weighing the check weight (to verify scale performance) is the same as for weighing UF_6 cylinders. The value assigned to each check weight is verified by comparison with a like mass of standard test weight. [5] The weight is reestablished at any time that the check weight is altered, e.g., by painting.

All certified primary standard weights used in the calibration of standard test weights (working standards) are submitted to an acceptable standards laboratory (NIST or the equivalent state agency) prior to use. Recertification of these primary standards is performed per ANSI N15.18-1975. Test weights are calibrated annually using certified standards or using a weight control program based on the guidelines in ANSI N15.18.

All scales are calibrated with test weights at least annually and at other times as the need arises. Before the calibration, the scale is inspected for damage and thoroughly cleaned. All poises are set at zero and the platform inspected to ensure that it is level and moves freely. If any increment checked is found to deviate by more than the scale precision from the value assigned to the weights on the scale, an adjustment to the scale is made. The scale is not considered to be in calibration until the addition or subtraction of the test weights in prescribed increments has been completed throughout the usable weighing range, without any adjustments to the scale or deviation greater than the allowable at each weight increment.

11.3 Scale Performance

In addition to the weight re-check performed in the preceding weight verification procedure, a resident check weight is used to validate the performance of the scale. Should the scale not return to zero or not reproduce the check weight value within the allowable deviation, the scale is removed from service until repaired. All cylinders weighed on the faulty scale since the last successful check-weighing are thus considered "in error" and are reweighed on a different scale, if available, or the same scale after it has been repaired and recertified for use following the principles of Section 11.1 of this manual. To minimize the need for reweighings because of the "in error" concept, check weighings are conducted at intervals such as the beginning and ending of a weighing sequence, at the operator's discretion, or at the beginning and ending of each work shift or day of use. Check weights should be provided to demonstrate a linearity check over the normal range of scale use, i.e., " full-range", "mid-range", along with the scale "zero". Typically "full" and "empty" cylinders similar to normal production weighings are used for this linearity check. Additionally, small weights may be randomly added or removed from a locked compartment on the check weight without the operator's knowledge.

Scale audit weighings are also conducted periodically to determine the linearity of scale performance as well as sensitivity. As an example, a 20,000-kg capacity scale would be incrementally loaded with 500-kg or 1,000-kg tertiary standards from zero to full capacity and then unloaded in the reverse order. Each observed weight must match the known load within the scale precision. Randomly throughout the procedure, additions of 0.5, 1.0, and 2.0 kg are made

[5] As outlined in ANSI N15.18-1975, Mass Calibration Techniques for Nuclear Material Control.

to the load and compared to the observed readings to demonstrate sensitivity to small load changes and to determine the position of the performance curve within the ±1 kg allowable deviation.

11.4 Weight Standards and Artifacts

Weight standards used for calibrating and verifying operation of scales consist of NIST primary and artifact (check weight) standards and the following three levels of derived standards:

1. Primary standards

2. Secondary standards - prepared from primary standards

3. Tertiary standards - prepared from secondary standards.

All standards are maintained in pairs when possible so that a basic substitution procedure can be followed for preparation of secondary and tertiary standards.

Generally, the procedures for preparation of standards, which are based on ANSI N15.18 or National Bureau of Standards (NBS) Handbook 145, include:

1. Operation of a highly sensitive balance is validated using two NIST primary standards (25 kg). The standards are reversed and the balance is again validated.

2. One primary standard is replaced with a working standard (secondary) whose weight is adjusted to match that of the primary. The primary and secondary standards are reversed on the balance and the weight confirmed. Twenty (20) or more working standards (secondary) will be prepared in a similar manner.

3. On a highly sensitive balance of sufficient capacity, twenty 25-kg secondary standards will be balanced against a 500-kg audit standard (tertiary) whose weight will be adjusted to match that of the collection of secondary standards. As many 500-kg audit weights (tertiary) as necessary are prepared in this manner to test the performance of the largest capacity production scale.

4. Large check weights (up to 18,000 kg) are prepared on a production scale using multiple weighings. A minimum of five weighings of the intended check weight are made, and at each weighing a predetermined random weight, unknown to the operator, is added to minimize any possible bias due to prior knowledge. Five weighings, minimum, on the same scale are

then made using audit weights with random additions. The observed values of all the weighings are then evaluated until the value of the intended check weight is known within ±2 kg.

To support government weighing programs, NIST artifact weights have been obtained and are made available by request to USEC for scale performance evaluations or preparation of check weights.

12. SAMPLING

12.1 General

An acceptable sample of UF_6 must represent both the chemical and isotopic content of a defined quantity of UF_6. Experience has shown that the most representative sample of the UF_6 in a cylinder is one withdrawn from the liquid phase after complete homogenization. Achieving isotopic homogeneity in a heated cylinder is not difficult since the convection currents in the liquid UF_6 will perform the necessary homogenization. However, achieving chemical homogeneity is more difficult, particularly in the presence of insoluble particles or excessive volatile impurities. If the presence of excessive volatile impurities is indicated, cylinders being prepared for shipment from USEC facilities are vented to a process system.

Prior to heating a cylinder for sampling, a vapor pressure measurement is made at ambient temperature (cold pressure check). Pressure instrumentation is attached and the pressure monitored throughout the required heating period to assure that the pressure does not exceed 75 psia at 200°F (93°C) or 125 psia at 235°F (113°C). Models 48G, H, and HX cylinders, designed for 100-psig service, shall not be allowed to exceed 115 psia.

12.2 Sampling Principles

Model 30B and all Model 48 cylinders are sampled in a horizontal position with the valve below the liquid level in the 3-5 o'clock or the 7-9 o'clock positions.

The temperature of the cylinder and its contents is maintained throughout the required heating period and during the actual sample withdrawal as presented in Table 9. The entire sampling system, including the sample cylinder valves, is maintained at approximately the same temperature to assure liquid flow.

The cylinder is connected to a fixed sampling volume between the two valves with a length of Monel, nickel, or copper tubing (pigtail). The fixed sampling volume permits the metering of a measured portion of UF_6 from the cylinder. New virgin Teflon gaskets are used at all connections. Prior to admission of UF_6, the sampling system, including the sample cylinders, is evacuated to about 1 psia or as low a vacuum as possible, and then leak rated. Additionally, the system is pressure tested, using dry oil-free inert gas such as air, nitrogen or carbon dioxide to a level greater or equal to the UF_6 working pressure.

Table 9. Sampling Information		
Cylinder Model Number	Minimum Heating Time at 200°F (93°C) in hours	Minimum Heating Time at 220°F (104°C) in hours
5B	2	2
30B	8	3
48A, 48F, 48X, 48Y, 48G, 48H, 48HX	12	6

After all leak testing is satisfactorily completed, the sampling valve is opened, permitting the UF_6 to fill the fixed sampling volume. Flow to the sampling volume is then blocked by closing the inlet valve, and the sampling container valve is opened to admit the fixed volume of UF_6 to the sampling cylinder. As the liquid UF_6 is drained into the sampling cylinder, a liquid nitrogen bath is raised around the sampling cylinder to draw residual gases from the sampling manifold into the sampling cylinder. Refrigeration with liquid nitrogen is continued until the pressure in the sampling cylinder drops to 1 psia, after which the sampling cylinder valve can be closed.

Two independent samples are normally removed from each cylinder. One sample is analyzed. The second sample is normally retained for use by a referee as an audit, if the results of the first sample are disputed. Following the sample withdrawal and prior to opening the sampling system to atmosphere, the system is purged of UF_6 and evacuated to about 1 psia or as low a vacuum as possible.

Steam or electrically heated air is used as the heating medium. Saturated steam is considered the safest medium for best temperature control. Nuclear safety shall be considered for enrichments above 1.0% uranium-235. When steam is used, provision shall be made to drain the condensate to prevent the accumulation of an unsafe uranium mass in the event the UF_6 cylinder should rupture.

Overfilled sample cylinders are not to be used for analytical purposes. In the event a sample cylinder is overfilled, a new sample is obtained.

UF_6 is withdrawn into a large USEC-owned cylinder, sampled, and then transferred into smaller customer-owned cylinders. Such transfers may involve the filling of up to four Model 30B cylinders from one Model 48X cylinder.

12.3 Sample Containers

The Model 1S and 2S cylinders are used for UF_6 sample containers. To permit thorough cleaning after each use, they have been designed with no internal sharp corners or crevices. Only sample cylinders may have the threaded valve connections sealed with Teflon tape; all other UF_6 cylinders have tinned valve threads or brazed connections.

Because the sample integrity would be violated if any material were removed, the sample cylinders are first weighed to assure compliance with fill limits, and then heated in a laboratory hood with closed valves and therefore without pressure monitoring. The heating medium is hot water, assuring a maximum temperature of 212°F. The fill limit guarantees a 10% free volume above the liquid at this temperature. Overfilled sample containers cannot be used for analytical purposes.

For special sampling applications in the Toll Enrichment program, P-10 tubes, pinch tubes and Hoke tubes (shown in Figure 39) are used. The P-10 tube holds 10 grams and is made of clear polyurethane. It consists of four pieces including the container, two brass fittings and a cap which is secured by the fittings. Sampling is done to determine purity, assay and the presence of other elements. A pinch tube holds 10 grams of UF_6 while a Hoke tube can hold 65 grams of UF_6.

12.4 Shipping Sample Containers

P-10 tubes are shipped from USEC plants as a Uranium Hexafluoride, Fissile Excepted, Radioactive Material in 1A2 (formerly 17C) drums (shown in figure 40). This packaging has been tested and approved to meet the requirements of a DOT 7A Type A five (5) gallon drum. (The cardboard mailing tubes are no longer used.) Typically, 30-40 of the P-10 tubes are shipped in a 1A2 drum, depending on the enrichment of the UF_6.

Sample cylinders are normally shipped from USEC plants in a DOT specification 17C Drum. Appropriate packing material, such as styrofoam sheets, is used to cushion the P-10 tubes or sample cylinders in the 17C Drum (shown in Figure 41). Up to four 2S sample cylinders or nine 1S sample cylinders can be shipped in a 17C Drum, depending on the enrichment of the UF_6.

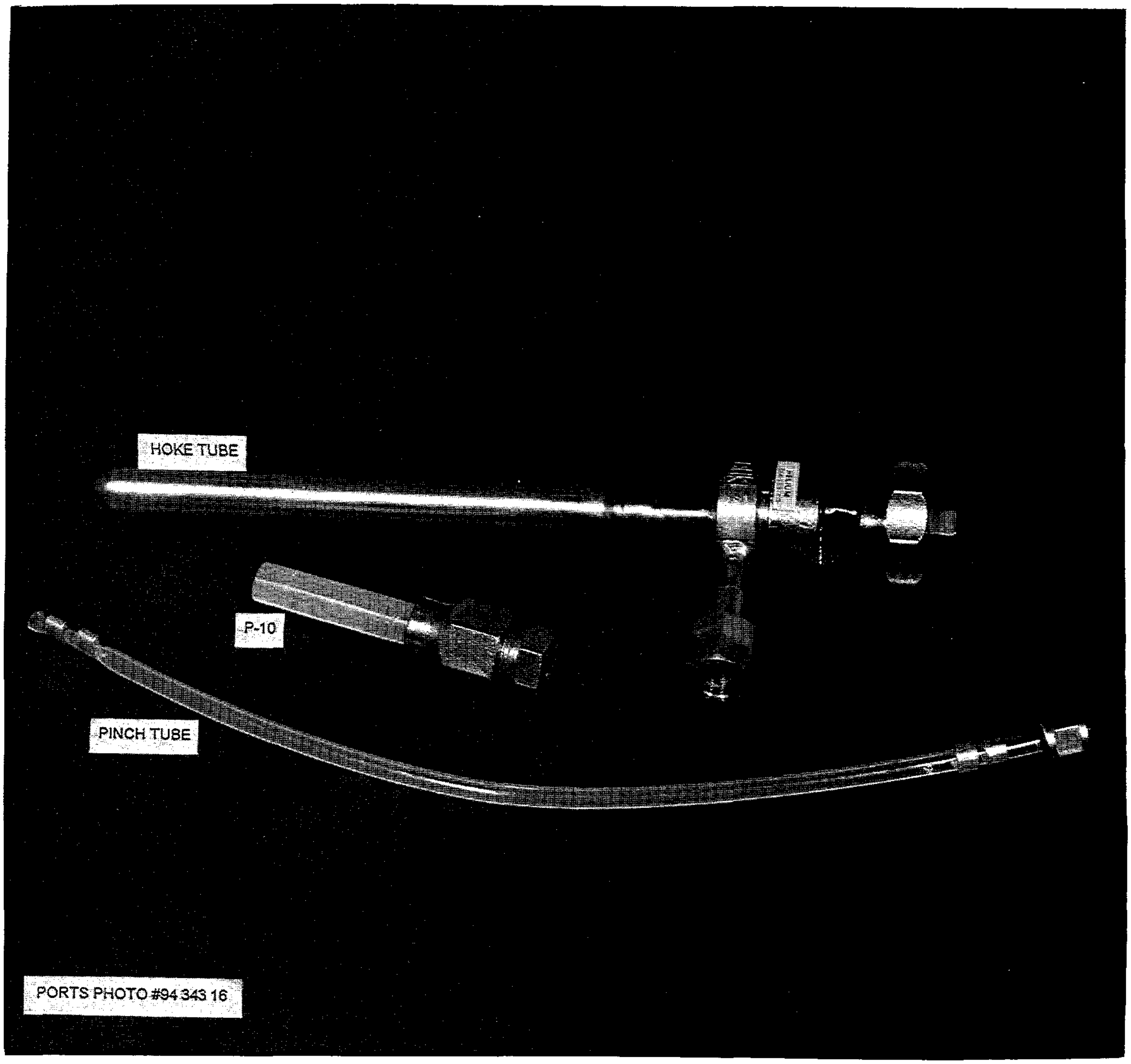


Figure 39
Sampling Tubes for Special Applications

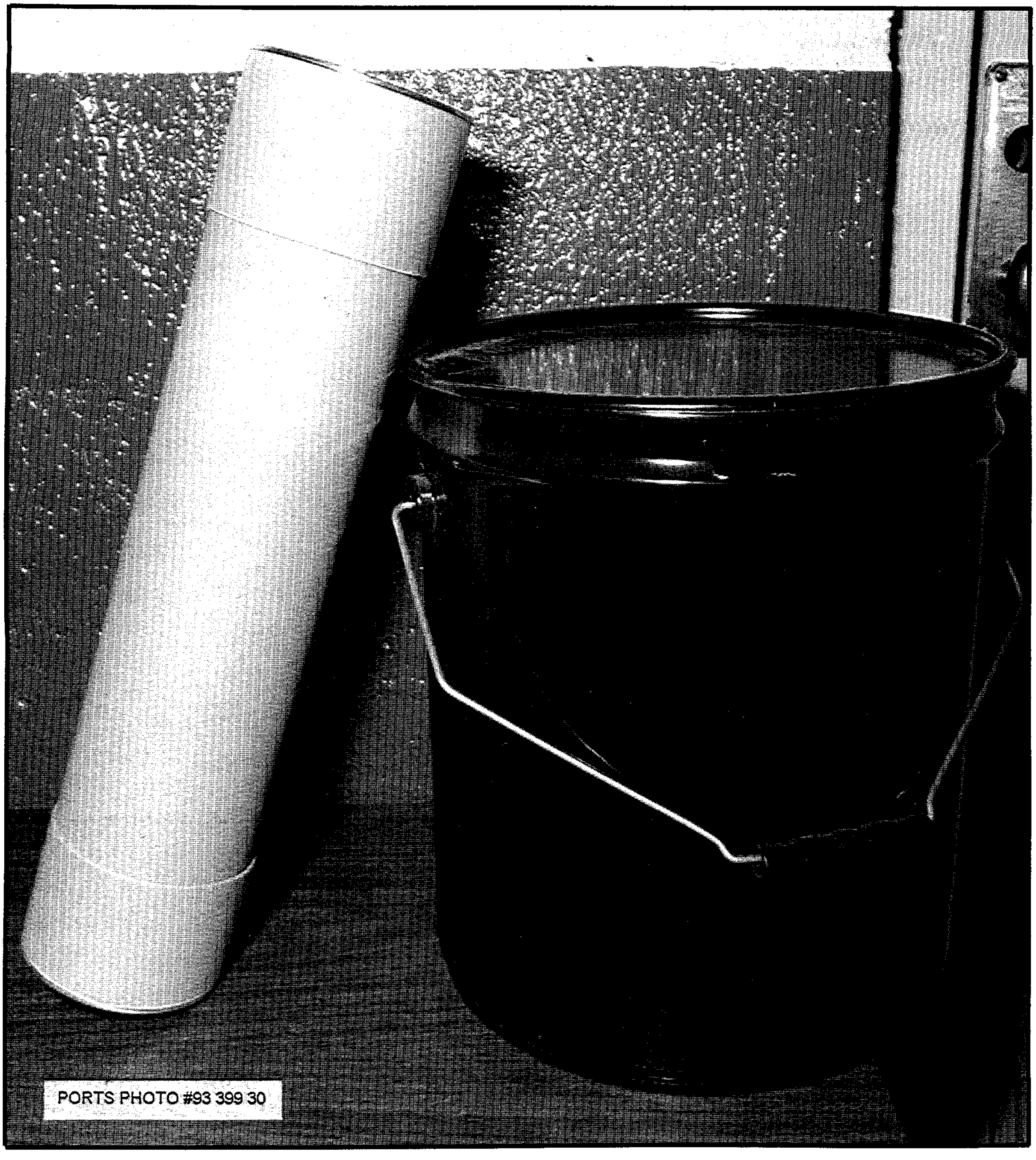


Figure 40
17C Drum and Cardboard Mailing Tube

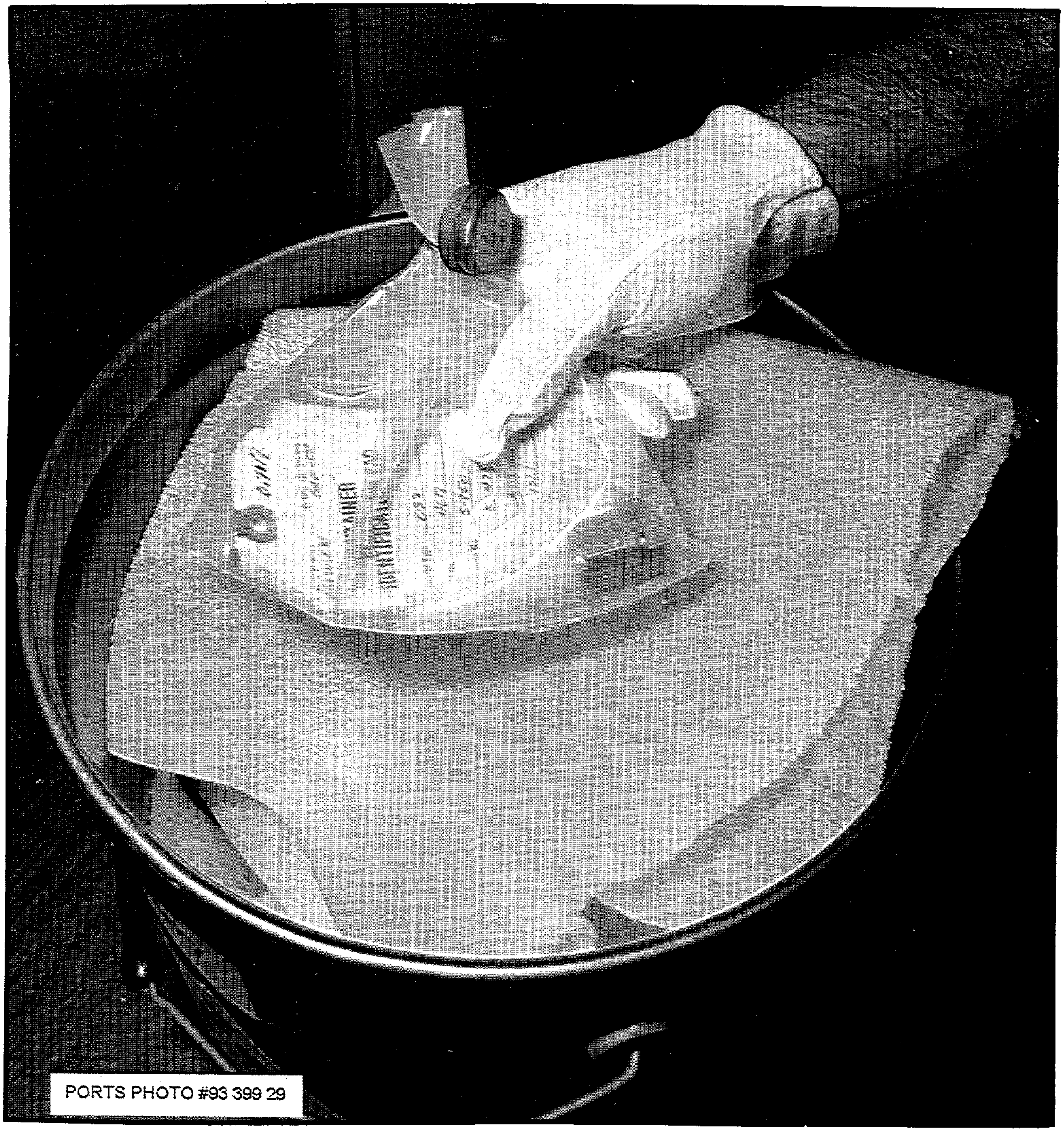


Figure 41
Packing a 17C Drum

13. SHIPPING

13.1 General

Uranium hexafluoride is shipped between USEC facilities, and to and from nuclear enterprises such as natural uranium feed suppliers and fuel fabricators. Essentially all of these shipments are by rail or truck using specially designed rail cars or flatbed trailers. USEC provides dedicated rail cars for transportation of UF_6 between its facilities, and commercial users provide their own dedicated flatbed trailers that are transported by commercial carriers.

Rail cars and flatbed trailers that carry UF_6 cylinders containing natural feed material (0.711% uranium-235) are constructed with heavy tie downs and saddle devices to completely immobilize the cylinders being transported as shown in Figure 42. When the UF_6 in the cylinders has a uranium-235 assay of greater than 1%, the cylinders shall be transported in protective overpacks. A protective overpack is not required, however, for an empty cylinder containing a permissible heel (see Section 13.4). Ten-ton cylinders containing solid UF_6 are enclosed in specially designed overpacks called "Paducah Tigers," shown in Figure 43. These are used for transporting UF_6 cylinders between the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky. USEC has dedicated rail cars that hold up to five Paducah Tigers, or they can be transported on dedicated trailers.

Cylinders of UF_6 destined for commercial users are usually the 2-1/2-ton size shipped in 21PF-1 overpacks, and are carried on flatbed trailers pulled by commercial carriers (Figure 44). Uranium hexafluoride cylinders going to overseas customers are loaded onto special steamship container trailers that carry three or four 21PF-1 overpacks (Figure 45).

Each UF_6 cylinder not in a protective overpack, whether empty or full, is secured for shipping with a valve protector and a numbered tamper-indicating device (TID) (Figure 46). In both cases, the shipper provides protective seal numbers to the receiver. The receiver verifies the TID numbers and confirm that the TIDs are intact when the containers arrive at his facility. No regulations specify the type of device.

Uranium hexafluoride is shipped only after it has solidified, and the vapor pressure of the cylinder is below atmospheric pressure.

Figure 42
Shipment of Natural Uranium

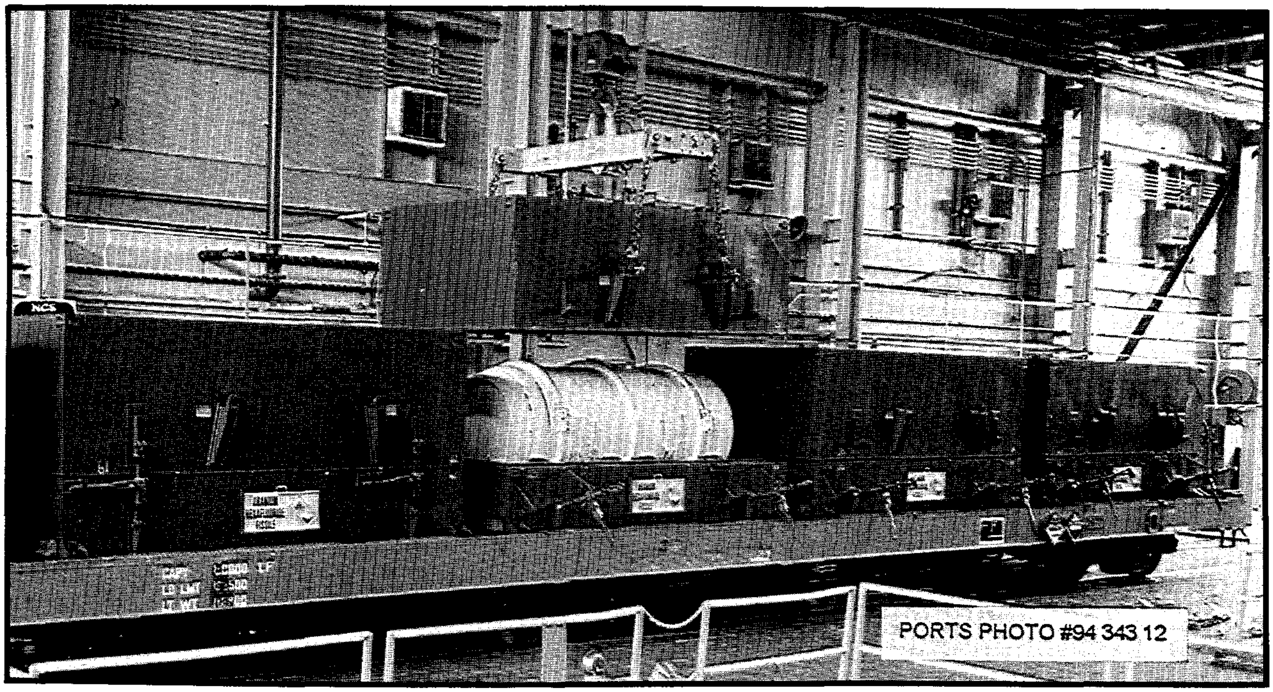


Figure 43
10-ton Cylinder Overpacks (Paducah Tigers)

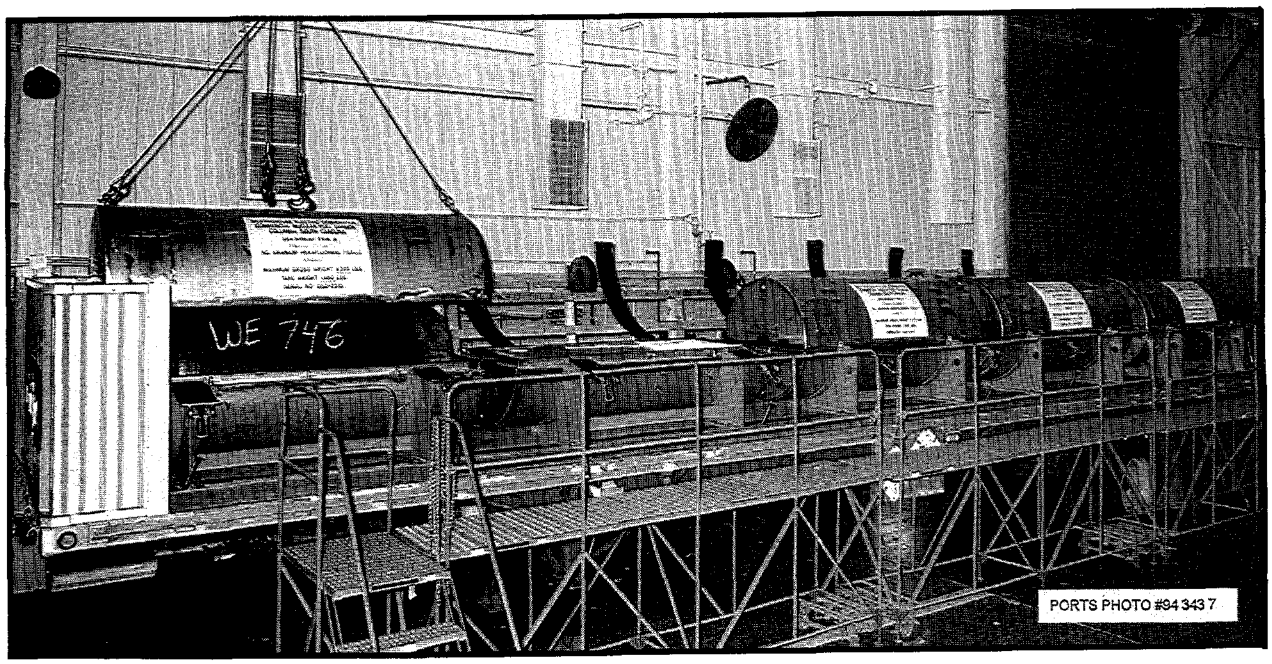


Figure 44
Flatbed Trailers Designed for Transport of UF_6 Cylinders

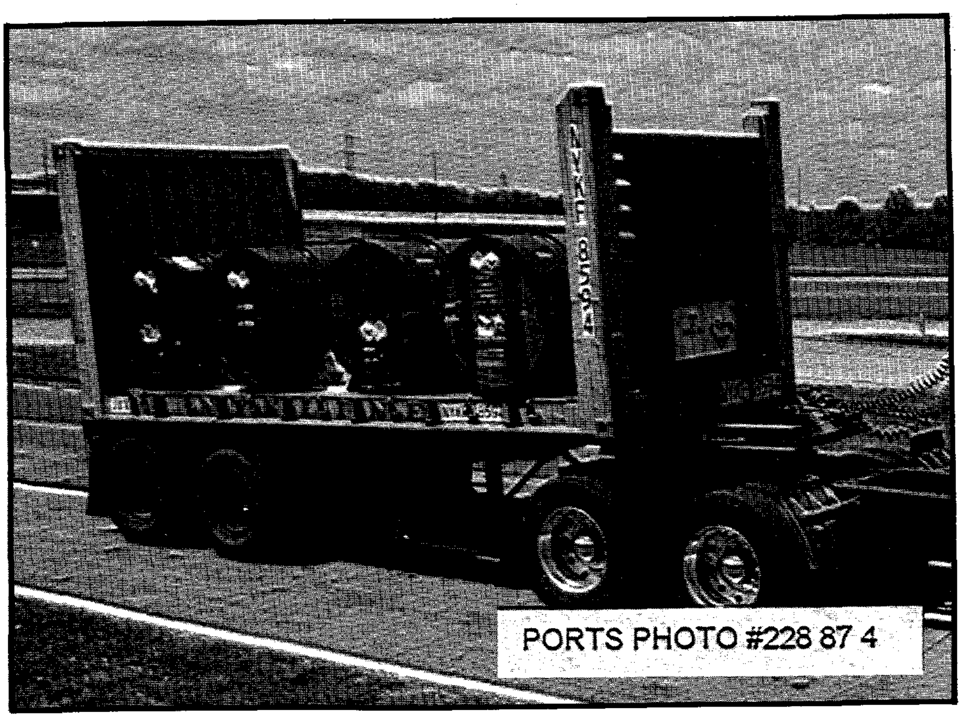
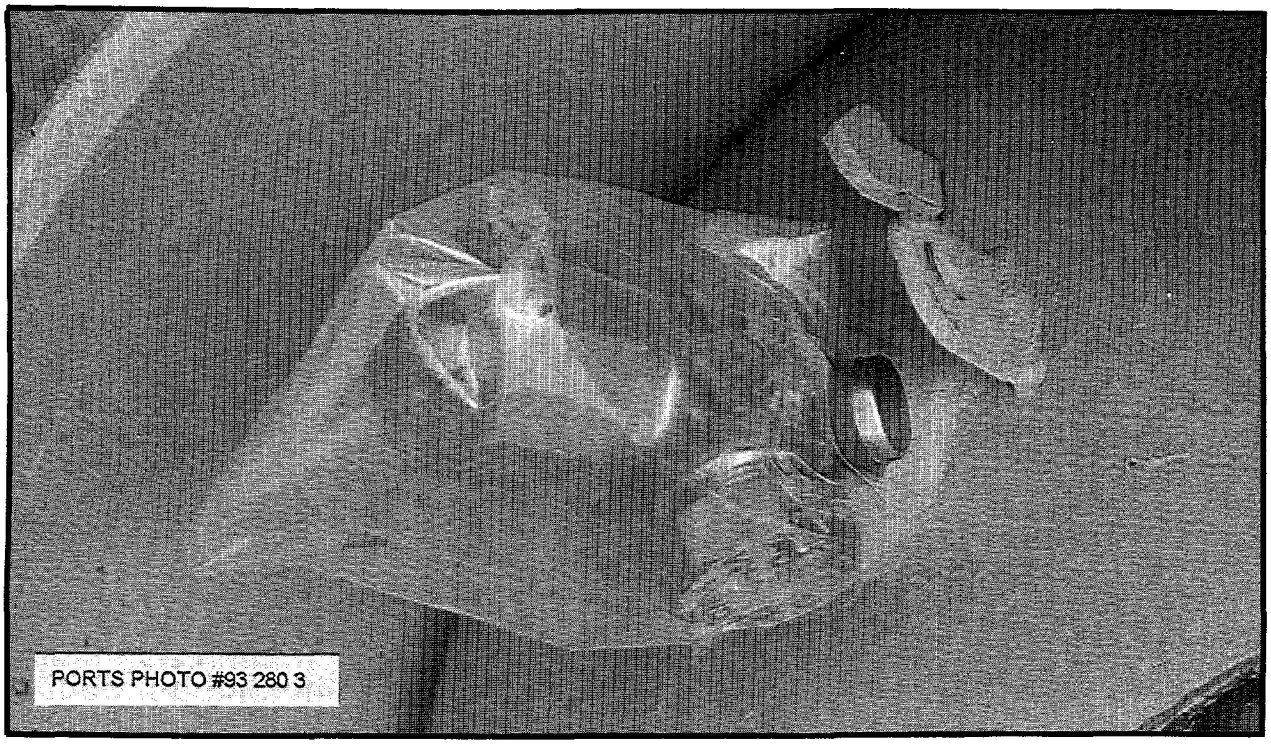


Figure 45
Steamship Container Trailers for Transport of UF_6 Cylinders



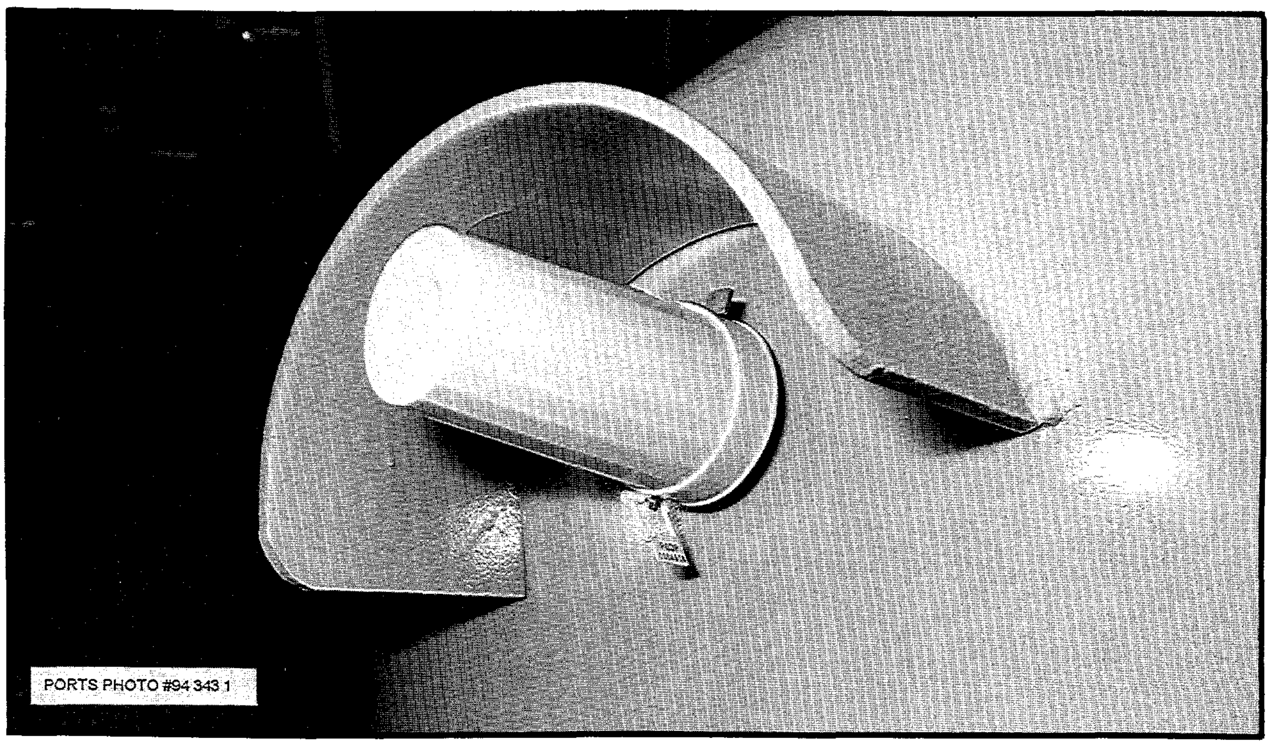


Figure 46
Tamper-indicating Devices

13.2 Overpacks/Protective Structural Packages

Cylinders of UF_6 enriched to 1.0% uranium-235 or more with quantities greater than the heel listed in Table 3 must be shipped in protective overpacks. Overpack designs are licensed for use by DOT or a Nuclear Regulatory Commission (NRC) Certificate of Compliance for domestic shipments, or by an IAEA Certificate of Competent Authority for international shipments. Refer to Table 10 for appropriate information.

A protective structural package (PSP) for Model 30B cylinders consists of two symmetrical sections of a cylindrical double shell, divided longitudinally to make bottom and top halves. Inner and outer carbon steel or stainless steel structural casings are supported lengthwise by hardwood framework and are insulated with a fire resistant material, generally a phenolic foam. Rolled angle sections form an internal framework for each shell half. An angle iron cradle is welded to the bottom section and is supported by footplates with bolt holes for attachment to a trailer. Figure 47 shows a Model 30B cylinder and a PSP.

The bottom and top halves mate, and a rubber gasket is used to prevent water from leaking into the package. Four shock absorber pads are cemented to the interior base and lid to help secure the cylinder and provide a cushion. Twenty vent holes per base and lid allow gases to escape in the event of a fire, and are sealed with plastic plugs for waterproofing. The base and lid are secured together with 14 ASTM A193 Grade B7 bolts and 14 ASTM A194 Grade 2H nuts. Alternate securements are latch levers or ball lock pins.

Drawings and specifications for PSPs are available as CAPE Package Number 1662, 1662 Revision 1, and 1662 Revision 1 Supplement 1. They may be obtained from the U.S. Department of Energy Office of Scientific and Technical Information (OSTI), Post Office Box 62, Oak Ridge, Tennessee 37831, telephone (615) 576-8401 for a nominal fee.

13.3 Protective Overpack Inspection

Protective overpacks should be visually inspected and findings documented by the shipper prior to each use. Conditions that normally require further investigation or removal from service include:

1. excessive warping, distortion or other damage of liner or shell that prevents a tight closure of the package;

2. excessive clearances for inner container within the liner;

3. fastener damage or loss;

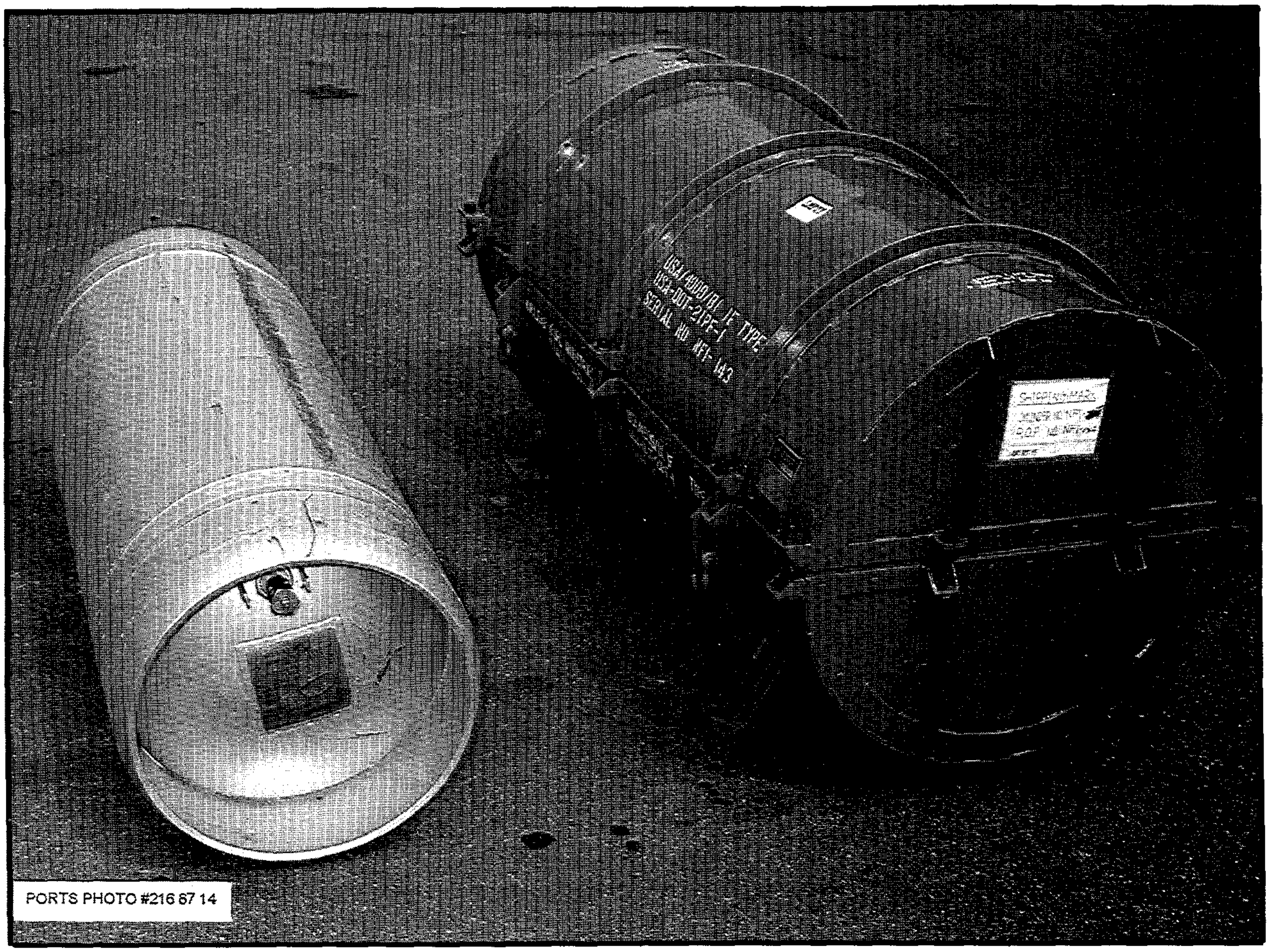


Figure 47
Model 30B Cylinder and Protective Structural Package

4. any other damage or condition (e.g., corrosion, pitting, cracks, broken welds and pinholes) that would bring into question the integrity of the protective overpack as a fire- and shock-resistant housing.

5. any condition out of compliance with regulations of DOT or NRC.

The vent holes should be inspected and sealed with silicon or cap plug if necessary, and the gaskets replaced or resealed, as required. The protective overpacks for Model 30B cylinders shall be weighed annually to determine if water has leaked into the overpack. A weight gain of more than 25 pounds per base or lid is reason for rejection. Overpack tie-downs should be inspected to assure that they are not damaged and are adequate for their intended use. Figures 48 and 49 show two types of overpack inspection sheets.

13.3.1 21PF Protective Overpack 5 Year Recertification

Owners are responsible for recertifying each protective overpack every five years to meet original design specifications. Certification should be performed by a company having a quality assurance plan equivalent to NRC requirements of 10CFR71, Subpart H or ANSI/ASME NQA-1-1989, and ANSI/ASME NQA-1a-1989 or both. As per ANSI.N14.1 (latest revision), the recertification only applies to 21PF overpacks and is not applicable to Paducah Tiger overpacks. Only welders qualified according to Section IX of the ANSI/ASME Boiler and Pressure Vessel Code or Section 5 of ANSI/AWS D1.1-90 shall perform welding repairs.

The following inspections shall be performed:

1. Weigh each protective overpack half (base and lid) individually. If either section exceeds 25 pounds weight gain, the package must be removed from service and dried to within 10 pounds of its original certified weight.

2. Check the base and lid for warpage and/or distortion which prevents tight closure.

3. Probe all base vent and lid vent holes to ascertain the rigidity and presence of insulation. Assure that vent holes are properly sealed.

4. Inspect and replace gaskets as necessary to assure that they are not damaged or deteriorated. Check that gasket sealing surfaces meet design specifications.

5. Verify that inner and outer shells are free of corrosion, pitting, cracks, broken welds and pinholes.

6. Confirm that wooden cover plates are sound.

7. Check that lifting U-bolts, metal frames and tie-down supports have no weld cracks and are not damaged or deteriorated.

8. Assure that security seal holes are functional and capable of maintaining their integrity when seals are used.

9. Permanently mark the exterior nameplate listing the date of recertification, the individual base and lid weights, and the name of the recertifying company.

21PF-1A overpacks which have previously been refurbished, and which have continued corrosion of 10% of surface area shall be decertified and scrapped. The nameplate shall be removed and all distinguishing marks shall be obliterated.

13.4 Empty Cylinders

Empty cylinders with valve protectors may be shipped without protective overpacks, provided the residual heel does not exceed the limits shown previously in Table 3.

13.5 Regulations and Other Reference Information

The packaging and transportation of radioactive materials are regulated by many organizations including DOT, NRC, DOE, U.S Postal Service, and state and local governments. Radioactive materials are also regulated by the International Civil Aeronautics Organization (ICAO), the International Atomic Energy Agency (IAEA), and the International Air Transport Association (IATA).

Attention should be given to meeting surface radiation requirements defined by DOT in 49 CFR 173. Newly emptied cylinders often require a cool down period of up to 45 days since the self adsorption phenomenon provided when the cylinder was full is no longer present.

Table 10 lists NRC and DOT regulations, and certificates, standards, and resource material pertaining to UF_6 handling and transport.

The NRC is developing new requirements for oversight of the USEC gaseous diffusion plants. The requirements will be contained in a new 10 CFR Part 76 entitled "Certification of Gaseous Diffusion Plants" which was published as a proposed rule in the Federal Register on February 11, 1994 at 59 CFR 6792. It is expected that the NRC will issue a final rule in order for the USEC gaseous diffusion plants to be certified by the NRC by July 1, 1995. Until the NRC certification begins, the USEC gaseous diffusion plants will be regulated by DOE.

UCN-10633
(5 1-84)

PADUCAH TIGER OVERPACK INSPECTION SHEET

RAIL SHIPMENT ONLY

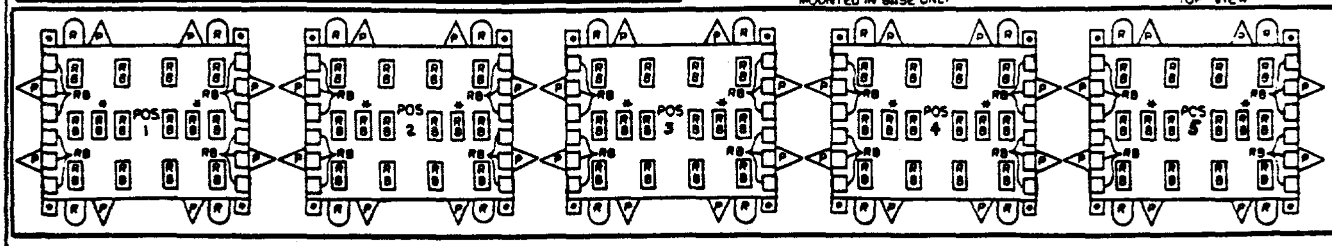
Tally-In or Tally-Out No. ____________
Uranium Control-741* ____________

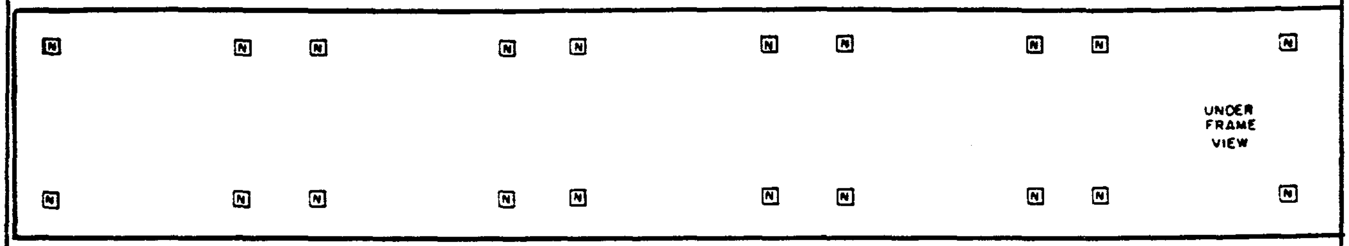
VEHICLE NO.	RECEIVED / SHIPPED	DATE	TIME	INSPECTED BY	OVERPACK MODEL NO.

	OVERPACK NO.	SEAL NO.	CYLINDER NO.		OVERPACK NO.	SEAL NO.	CYLINDER NO.
POSITION NO. 1				POSITION NO. 4			
POSITION NO. 2				POSITION NO. 5			
POSITION NO. 3							

*MOUNTED IN BASE ONLY

TOP VIEW





UNDER FRAME VIEW

ITEM INSPECTED	SKET. CODE	CONDITION POS. NO. 1	POS. NO. 2	POS. NO. 3	POS. NO. 4	POS. NO. 5	REMARKS (Circle Location of Unacceptable Item on Above Sketch Indicate Repair Required and/or Action Taken Below.)
Rubber Bumpers-Lid and Base	RB						
Skin-Inside and Outside							
Gasket							
Water Leakage/Free of Debris							
Tie Down Lugs, Bolts, and Retain's	B						
Tie Down Nuts	N						
Gap Between Lid and Base							
Ball Lock Pins	P						
Ratchets	R						
D.O.T. Labels							
Vehicle Placards							
Package Placards							
Hazardous Info. and Emerg. Instr. Signs							
Emergency Notification Signs							

SECTION A

THIS SECTION TO BE COMPLETED BY A QUALIFIED INSPECTOR (For Damage Referred to the Inspection Dept.)

Remarks (Indicate number of overpack involved): ____________

THE ABOVE ITEM(S) IS ☐ Acceptable ☐ Unacceptable	DATE	QUALIFIED INSPECTOR

SECTION B

THIS SECTION TO BE COMPLETED WHEN THE DAMAGE INDICATED ABOVE IS INSPECTED AND APPROVED BY OTHER THAN INSPECTION DEPARTMENT PERSONNEL

The following damage has been inspected and approved (with the indicated limitations, if any) (indicate number of overpack involved): ____________

DAMAGE APPROVED BY	TITLE	DATE

Figure 48
Paducah Tiger Overpack Inspection Sheet

A-2725 (1-92) Rev.

OVERPACK INSPECTION

– USE BLACK INK ONLY –

DATE RECEIVED: ______________ DATE SHIPPED: ______________

CARRIER: ______________________________ TRAILER: ______________________________

OWNER: ______________________________ X-ORDER #: ______________________________

OVERPACK NUMBER	OK	DAMAGED			REJECT CODE	DAMAGE/REJECT DESCRIPTION
		NO	YES	CODE		

DAMAGE CODES:

1. Water Inleakage	2. Step Joint	3. Shell Exterior	4. Lid Interior
5. Base Interior	6. Welds	7. Feet	8. Gaskets
9. Cavity Pads	10. T.I.D. Rings	11. Bolts & Nuts	12. Puncture
13. Shackles	14. Markings	15. ID Plate	16. Contaminated
17. Shell Alignment	18. Vent Holes	19. Latches	20. Other

REJECT CODES:

1. Weight Increase	6. Pitting
2. Puncture	7. Cracks
3. Weight Increase	8. Broken Welds
4. Type 1 PSP	9. Pinholes
5. Corrosion	10. Other

OVERPACK TYPE ☐ DT ☐ 5" ☐ 8" ☐ 12" ☐ 30" ☐ 48" ☐ Other

BUILDING: ____________________ OPERATOR ____________________ DATE ____________________
Sign/Print

SUPERVISOR ____________________ DATE ____________________
Sign/Print

Figure 49
Typical Overpack Inspection Sheet

Table 10. UF_6 Transport Reference Material

Regulations

<u>Nuclear Regulatory Commission</u>

10 CFR 50	Domestic Licensing of Production and Utilization Facilities
	Appendix B Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants
10 CFR 71	Packaging and Transportation of Radioactive Material
10 CFR 830	Nuclear Safety Management

<u>Department of Transportation</u>

49 CFR 171	General Information, Regulations, and Definitions
49 CFR 172	Hazardous Materials Tables and Hazardous Materials Communications Regulations
49 CFR 173	Shippers - General Requirements for Shipments and Packaging (Subpart I - Radioactive Materials)
49 CFR 174	Carriage by Rail
49 CFR 175	Carriage by Aircraft
49 CFR 176	Carriage by Vessel
49 CFR 177	Carriage by Public Highway
49 CFR 178	Shipping Container Specifications

Table 10. UF_6 Transport Reference Material (continued)

Department of Energy

Regulatory Oversight Agreement Between the U.S. Department of Energy and the United States Enrichment Corporation, Appendix A: Safety Basis and Framework for DOE Oversight of the Gaseous Diffusion Plants, Section 3.14, Packaging and Transporting Nuclear Materials. (These DOE requirements will be in effect until the Nuclear Regulatory Commission assumes control over the gaseous diffusion plants.)

International Atomic Energy Agency

Safety Series #6	Regulations for the Safe Transport of Radioactive Material (latest revision)

International Air Transportation Association

Dangerous Goods Regulations, (latest revision)

Technical Instructions for the Safe Transport of Dangerous Goods by Air, (latest revision)

Table 10. UF_6 Transport Reference Material (continued)

NRC Certificates of Compliance		
4909	Model Nos.:	GE-21PF-1
6553	Model No.	Paducah Tiger
9196	Model No.:	UX-30
9234	Model No.:	NCI-21PF-1
IAEA Competent Authority Certificates		
0411	Model Nos.:	5A, 5B, 8A, 12A, 12B, 30A, 30B, 48A, 48X, 48G, 48F, 48Y, 48H, 48HX (heels only for all models)
4909	Model Nos.:	GE-21PF-1 DOT 21PF-1A DOT 21PF-1B
9196	Model No.:	UX-30
9234	Model No:	NCI-21PF-1
American National Standards		
ANSI N14.1		Uranium Hexafluoride - Packaging for Transport
ANSI N14.30		Semi-trailers Employed in the Highway Transport of Weight-Concentrated Radioactive Loads - Design, Fabrication, and Maintenance
ANSI/ASME NQA-1		Quality Assurance Program Requirement for Nuclear Facilities

Table 10. UF_6 Transport Reference Material (continued)

Other	
WHC-EP-0558	Test and Evaluation Document for DOT Specification 7A Type A Packaging

14. STORAGE OF URANIUM HEXAFLUORIDE

14.1 Storage of Solid UF_6 Cylinders

Uranium hexafluoride storage is handled with consideration for the material's chemical and radiological activity, and in the case of enriched materials, for criticality control. Long-term storage yards should be located away from the general plant populations, but with good access for cylinder handling equipment. Storage is either within the general plant security fence or separately fenced to control access.

The solid-phase storage of UF_6, which is characteristic of ambient conditions, minimizes the potential for material releases that might result from damage during cylinder stacking or transport activities. Long-term storage of UF_6, however, requires close control and monitoring of the stored cylinders.

When a cylinder is removed from storage, procedures are followed to maintain accountability and ensure that the cylinder meets the criteria for the intended application or destination, and the safety, criticality, and environmental concerns are satisfied. The cylinder is subjected to a cold-pressure test to ensure interior subatmospheric pressure, and is then inspected for further compliance with handling and shipping criteria when being transferred to a qualified carrier. When the cylinder is found to be suitable for shipping, it is 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 are identified and submitted for corrective action or marked and set aside for later correction of defects as appropriate.

14.2 General Storage Considerations

Storage of UF_6 cylinders must consider stacking/spacing arrays accountability, security, and emergency planning. Cylinder storage at enrichment plants in the United States is guided by these considerations:

1. Cylinders for storage of UF_6 should be equipped with a data plate, legibly and durably marked with the manufacturer's name and serial number, the maximum allowable working pressure and temperature, the certified volume and fill limit, the tare weight, and the date of the initial and most recent hydrostatic test.

2. Cylinder storage is supported by an accountability records system that identifies cylinder contents, current location, and movement histories. Other site records contain nameplate information as well as pertinent fabrication and test data, transportation data, inspection results, and maintenance and repair information.

3. Cylinders scheduled for storage of UF_6 have all defects, deviations, and damage identified and recorded at the time they are placed in storage.

4. Cylinder storage areas are kept clear of combustible materials. The use or presence of such materials in the proximity of stored cylinders is strictly limited.

Appendix. UF_6 Cylinder Data Summary

Cylinder Model	Nominal Diameter inches	Material of Construction	Minimum Volume ft^3	Minimum Volume liters	Approximate Tare Weight Without Valve Protector lb	Approximate Tare Weight Without Valve Protector kg	Maximum Enrichment U^{235} wt%	Shipping Limit Maximum,[a] UF_6 lb	Shipping Limit Maximum,[a] UF_6 kg
1S	1.5	Nickel	0.0053	0.15	1.75	0.79	100.00	1.0	0.45
2S	3.5	Nickel	0.026	0.74	4.2	1.91	100.00	4.9	2.22
5A	5	Monel	0.284	8.04	55	25	100.00	55	24.95
5B	5	Nickel	0.284	8.04	55	25	100.00	55	24.95
8A	8	Monel	1.319	37.35	120	54	12.5	255	115.67
12A	12	Nickel	2.38	67.4	185	84	5.0	460	208.7
12B	12	Monel	2.38	67.4	185	84	5.0	460	208.7
30B[c]	30	Steel	26.0	736.0	1,400	635	5.0[b]	5,020	2,277
48A	48	Steel	108.9	3,084	4,500	2,041	4.5[b]	21,030	9,539
48X[d]	48	Steel	108.9	3,084	4,500	2,041	4.5[b,g]	21,030	9,539
48F	48	Steel	140.0	3,964	5,200	2,359	4.5[b]	27,030	12,261
48G	48	Steel	139.0	3,936	2,600	1,179	1.0[f]	26,840[e]	12,174[e]
48Y[d]	48	Steel	142.7	4,041	5,200	2,359	4.5[b]	27,560	12,501
48H	48	Steel	140.0	3,964	3,170	1,438	1.0[f]	27,030	12,261
48HX	48	Steel	140.0	3,964	3,170	1,438	1.0[f]	27,030	12,261
48OM	48	Steel	140.0	3,964	3,050	1,386	1.0	27,030	12,261

[a] Shipping limits are based on 250°F (121°C) maximum UF_6 temperature (203.3 lb UF_6/ft^3), certified minimum internal volumes for all cylinders, which provides a 5 percent ullage for safety. The operating limits apply to UF_6 with a minimum purity of 99.5 percent. More restrictive measures are required if additional impurities are present. The maximum UF_6 temperature must not be exceeded.
[b] Maximum enrichments indicated require moderation control equivalent to a UF_6 purity of 99.5 percent. Without moderation control, the maximum permissible enrichment is 1.0 wt percent uranium-235.
[c] The 30B cylinder replaces the Model 30A cylinder which is no longer in use.
[d] Models 48X and 48Y replace Models 48A and 48F whose volumes have not been certified.
[e] For USEC gaseous diffusion plant depleted uranium with UF_6 purity in excess of 99.5 percent, the shipping limit is 28,000 lb for cylinders with 8,800-lb water capacity or greater.
[f] Enrichment to 4.5 wt percent is safe with moderation control equivalent to a UF_6 purity of 99.5 percent, but limited to 1.0 wt percent uranium-235 for shipment.
[g] Enrichment to 5.0 wt percent is safe with moderation control equivalent to a UF_6 purity of 99.5 percent, but limited to 4.5 wt percent for shipment.