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URANIUM HEXAFLUORIDE:
HANDLING PROCEDURES AND CONTAINER DESCRIPTIONS

OAK RIDGE OPERATIONS
UNITED STATES DEPARTMENT OF ENERGY

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URANIUM HEXAFLUORIDE: HANDLING PROCEDURES AND CONTAINER DESCRIPTIONS

SEPTEMBER 1987

Prepared for the
OAK RIDGE OPERATIONS

by the
Marketing Support Division
Oak Ridge, Tennessee
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

FOREWORD

The U.S. Department of Energy (DOE) guidelines for packaging, measuring, and transferring uranium hexafluoride (UF_6) have been undergoing continual review and revision for several years to keep them in phase with developing agreements for the supply of enriched uranium. Initially, K-1323 "A Brief Guide to UF_6 Handling," was issued in 1957. This was superceded by ORO-651, first issued in 1966, and reissued in 1967 to make editorial changes and to provide minor revisions in procedural information.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 issued as part of the continuing effort to present updated information. Revision 4 issued in 1977 included revisions to UF_6 cylinders, valves, and methods to use. Revision 5 adds information dealing with pigtails, overfilled cylinders, definitions and handling precautions, and cylinder heel reduction procedures. Weighing standards previously presented in ORO-671, Vol. 1 (*Procedures for Handling and Analysis of* UF_6) have also been included. This revision, therefore, supercedes ORO-671-1 as well as all prior issues of this report. These guidelines will normally apply in all transactions involving receipt or shipment of UF_6 by DOE, unless stipulated otherwise by contracts or agreements with DOE 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 Department of Energy, P.O. Box E, Oak Ridge, Tennessee, 37831, Attention: Director, Uranium Enrichment Operations Division.

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1. INTRODUCTION

This report has been prepared to acquaint the nuclear industry with UF_6 shipping containers and handling procedures. The information contained herein covers the essential aspects of packaging, cylinder filling and emptying, and the general principles of weighing and sampling. Shipping methods are discussed in very general terms. All UF_6 shipments to or from the Department of Energy (DOE) facilities are free on board the DOE facilities. It is the responsibility of industry to provide the necessary shipping containers and transportation.

A considerable effort was made by the nuclear industry to standardize UF_6 cylinders which culminated in 1971 in the issuance of Standard N14.1, "Packaging of Uranium Hexafluoride for Transport," issued by the American National Standards Institute (ANSI). A revised standard, N14.1-1982 was issued by ANSI. The latest revision currently in preparation is scheduled for issuance in 1987.

It should be noted that equipment and procedures described are general and may vary at different DOE facilities. As a specific example, weighing devices are not identical at all sites; however, basic operating principles are followed at all sites.

The quality of feed material is important to the safe and efficient operation of DOE enriching facilities. The purity of product UF_6 from DOE enriching facilities is also important to product users. These considerations have been the impetus for an aggressive effort by DOE and its contractors to develop accurate chemical and isotopic analytical techniques. Also, a quality control program is maintained to ensure that the required accuracy and precision are obtained for the various DOE measurements.

It is important that weights and related analytical data be reported in a similar manner by both shipper and receiver. Appropriate material transfer forms on which the data may be reported are available from DOE.

The procedures for safe handling of UF_6 presented in this document have been developed and evaluated in DOE facilities during more than 40 years of handling vast quantities of UF_6. Aside from nuclear considerations, UF_6 can be safely handled in essentially the same manner as any other corrosive and/or toxic chemical. A brief description of the physical and chemical properties of UF_6 are given in Sect. 7.5 and Appendix A.

2. STANDARD PACKAGING INFORMATION

2.1 CYLINDER PACKAGING LIMITS

The UF_6 supplied by DOE is packaged in cylinders which vary in shape and size, depending on the total quantity and/or the uranium-235 assay (wt % uranium-235) involved. The shipping limits for each standard cylinder are shown in Table 9. The UF_6 shipped to DOE facilities in the standard cylinders must conform to the shipping limits and maximum uranium-235 assay listed in this Table.

A charge is made by DOE for withdrawing UF_6 from the enriching facilities and packaging it. A list of fees for enriching services can be obtained from DOE, Oak Ridge Operations Office, Business Operations Division, 55 Jefferson Circle, Oak Ridge, Tennessee 37830.

2.2 INSPECTION, CLEANING, TESTING, AND REPAIRING OF PRIVATELY OWNED CYLINDERS

Companies providing cylinders for use at DOE facilities must comply with DOE policy on inspection, cleaning, testing, and repairing privately owned cylinders.

2.2.1 General

It is the policy of DOE to inspect externally all UF_6 cylinders at the time of their delivery to and receipt from the carrier at DOE facilities. These inspections are designed to minimize risks associated with filling, emptying, or shipping damaged cylinders. Both the shippers and receivers should inspect the cylinders at their facilities and record the necessary data to facilitate the resolution of any claims for damage. Examples of acceptable and unacceptable cylinder damage are given in Fig. 1. A typical cylinder inspection data sheet is shown in Fig. 2.

Occasionally, UF_6 cylinders require cleaning to remove excessive buildup of impurities. In addition, it may be desirable to remove the *heel** when UF_6 of a different isotopic assay is to be added to the cylinder. DOE does not normally clean privately owned cylinders.

A standard for UF_6 cylinders has been established by ANSI. This standard, N14.1, includes only those cylinders which 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.

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*Heel refers to the residual quantity of uranium material which remains in a cylinder after routine evacuation procedures have been followed.

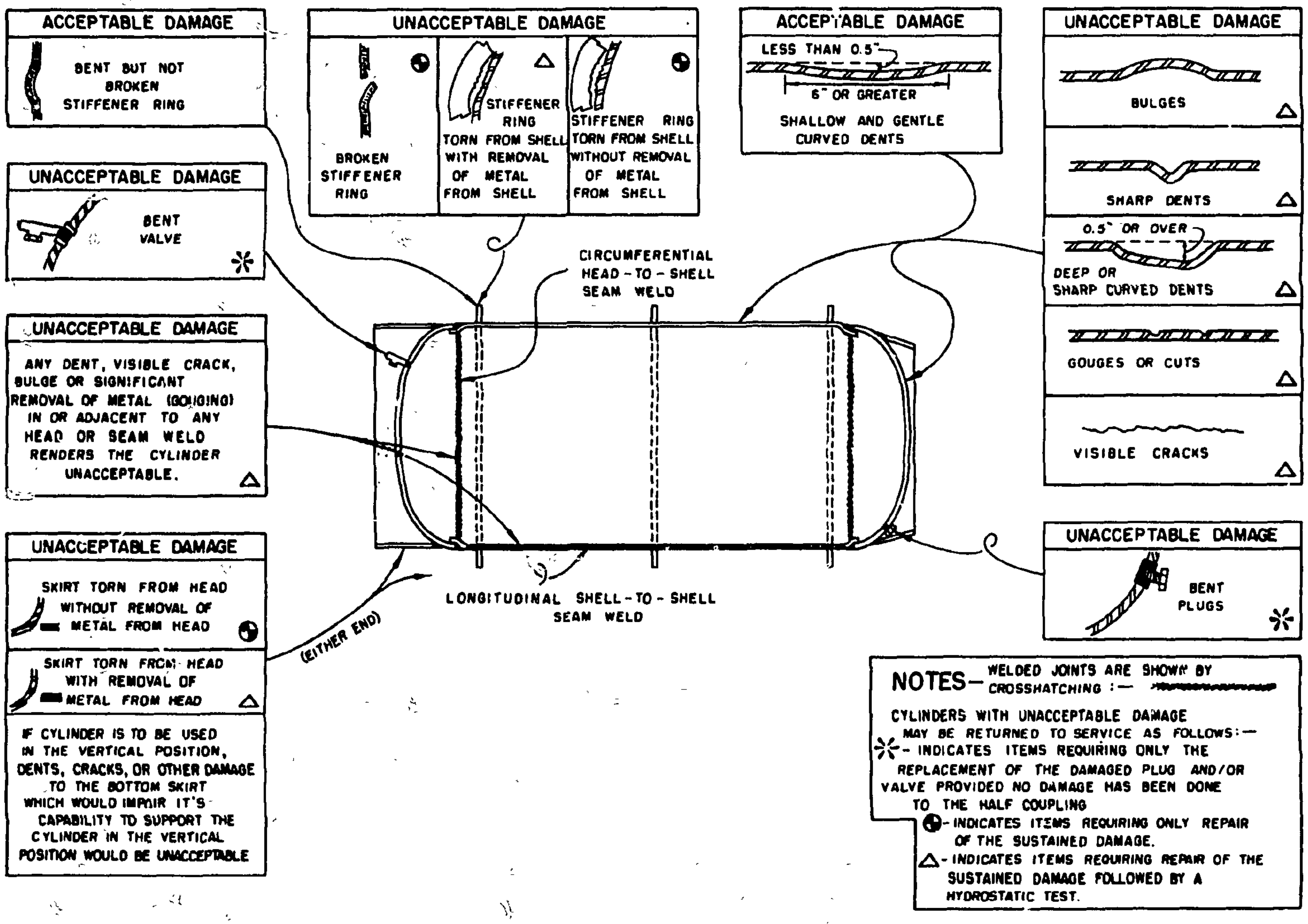

Figure 1

EXAMPLES OF
ACCEPTABLE AND UNACCEPTABLE DAMAGE TO UF_6 CYLINDERS

UF_6 CYLINDER INSPECTION DATA SHEET

CYLINDER NUMBER

Cylinder Is Code Stamped ☐ No ☐ Yes

CYLINDER MODEL
☐ 30A (2½-ton) ☐ 48F (14-ton HW) ☐ ______
☐ 30B (2½-ton) ☐ 48Y (14-ton HW) ☐ ______
☐ 48A (10-ton) ☐ 48G (14-ton LW) ☐ ______
☐ 48X (10-ton) ☐ 48H (14-ton LW) ☐ ______

CYLINDER STATUS ☐ Full ☐ Empty

☐ Date Shipped
☐ Date Received

Hydrostatice Pressue Test Date of ______
is ☐ Acceptable ☐ Not Acceptable

CYLINDER'S CONTENTS ARE SOLIDIFIED ☐ Yes ☐ No

CYLINDER BEING INSPECTED
☐ Prior to being shipped
☐ After being received
☐ Prior to being filled
☐ Prior to being heated

Cylinder Is Overfilled.
☐ No ☐ Yes, 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			
	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			
	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			
	Description of Damage (if any):			
III. CYLINDER SHEEL 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

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

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

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

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

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Figure 2
TYPICAL CYLINDER INSPECTION DATA SHEET

Cylinders and/or valves not covered by the standard must receive appropriate approval from DOE and the Department of Transportation (DOT) before the cylinders are accepted for shipments to or from DOE facilities.

2.2.2 Feed Cylinders

Upon receipt, cylinders of feed material are inspected externally and cold pressure checked (vacuum checked at ambient temperature) to determine that the internal pressure is 10 psia (52 cm Hg) or less. 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 must provide authorization for valve repair by teletype or letter. If the internal pressure is greater than 10 psia, the shipper is requested to provide instructions either to return the cylinder or cold burp* the cylinder at the receiving site. The costs incurred for valve repair and/or cold burping are billed to the shipper. The receiver 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 DOE shall be that determined to be the difference between the weights of the cylinder before and after emptying (gross full weight minus gross empty weight). A reasonable effort is made to evacuate the feed cylinders so that heel weight is minimized. After routine evacuation has been accomplished, the heel should not exceed the weight as shown in Table 1.

Table 1. Cylinder heel weights

UF_6 Cylinder Model	Heel Weight lb	Heel Weight kg
5A/5B	0.1	0.05
8A	0.5	0.23
12A or 12B	1	0.45
30A or 30B	25	11.34
48A, 48X, 48F, 48G, 48Y, 48H, or 48HX	50	22.68

Heels weighing in excess of the above values may require removal by cylinder cleaning.

2.2.3 Product and Tails Cylinders

Empty, clean cylinders which are received for filling with product or *tails*** material are cold pressure checked to assure a pressure less than 5 psia

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*Cold burp refers to evacuating low molecular weight gases from a cylinder without application of heat to the cylinder.

***Tails* material refers to the uranium-235-depleted UF_6 from DOE enriching facilities.

(26 cm Hg), inspected, and weighed. The inspection may also include a borescopic examination of the interior of the cylinder. The empty cylinders must be free of impurities. These impurities, particularly hydrogenous materials, could contaminate or react with UF_6 added to the cylinder.

Cylinders failing to meet these criteria are rejected until proper repair and/or cleaning is completed. If the cylinder is rejected because of a faulty valve or plug, the shipper may verbally authorize repair and payment of incurred cost, and confirm this authorization by letter or teletype. Unacceptability for any reason other than a faulty valve or plug may be cause for returning the cylinder to the shipper unused. In leak checking, the empty cylinders are pressured with dry air to 100 psig and soap tested. Acceptable cylinders should then be evacuated to 5 psia, or less.

2.2.4 Cylinder Heel Recycle (Model 30A or 30B)

Before a cylinder is filled with product UF_6, DOE requires the cylinder to be clean and dry. However, frequent and routine movement of UF_6 from the uranium enriching plants to a fuel fabricator presents a technically and economically attractive alternative in the recycle of cylinders containing heels.

Approval to recycle cylinders at DOE facilities must be requested by the UF_6 processor. There are three basic criteria for the recycle of cylinders. 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 must be at a pressure less than 5 psia (26 cm Hg), and the third is that the heel must weigh 25 lb (11.34 kg) or less. Further, cylinders received for recycle must meet all specifications as shown in Sect. 7, meet cleanliness standards, and have a current hydrostatic test and inspection date. Failure to meet these criteria will require cleaning, testing, and inspecting the cylinder before it can be filled with product.

There is only one safety check that is available to plant personnel for the internal condition of the cylinder. It is a cold pressure check that can be made upon receipt of the recycle cylinders. Therefore, it is necessary to have a high degree of confidence and assurance in the integrity of the UF_6 processor's procedures and equipment. Hence, recycle with a UF_6 processor is entirely at DOE's option and is not only contingent on adequate procedures, but also on their continued implementation.

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

1. Recycle cylinders containing heels are filled from a parent cylinder previously filled and sampled 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 DOE-furnished material are resolved by recourse to the official DOE 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.

3. CYLINDER FILLING AND EMPTYING PROCEDURES

3.1 GENERAL

Systems and procedures used by DOE are designed to accommodate the physical and chemical properties of UF_6 and to provide maximum safety and efficiency. The efficient transfer of UF_6 is made through a leak-tight, adequately heated system. Safety considerations require compound pressure indicators and temperature control throughout the system.

3.2 TYPICAL PLANT SYSTEMS

The systems shown in Fig. 3 are typical of those used to fill or empty UF_6 cylinders. All lines are heated to maintain a temperature in the range of 175° to 250°F (79° to 121°C). UF_6 undergoes large volume increases (as much as 53%) on melting and, in the liquid state, presents situations capable of leading to hydraulic rupture. Therefore, systems and operating procedures are designed to avoid trapping material without room for expansion [e.g., between two closed valves; or between two plugs in a line formed by wet air inleakage (UO_2F_2), or solidified UF_6 due to low temperature].

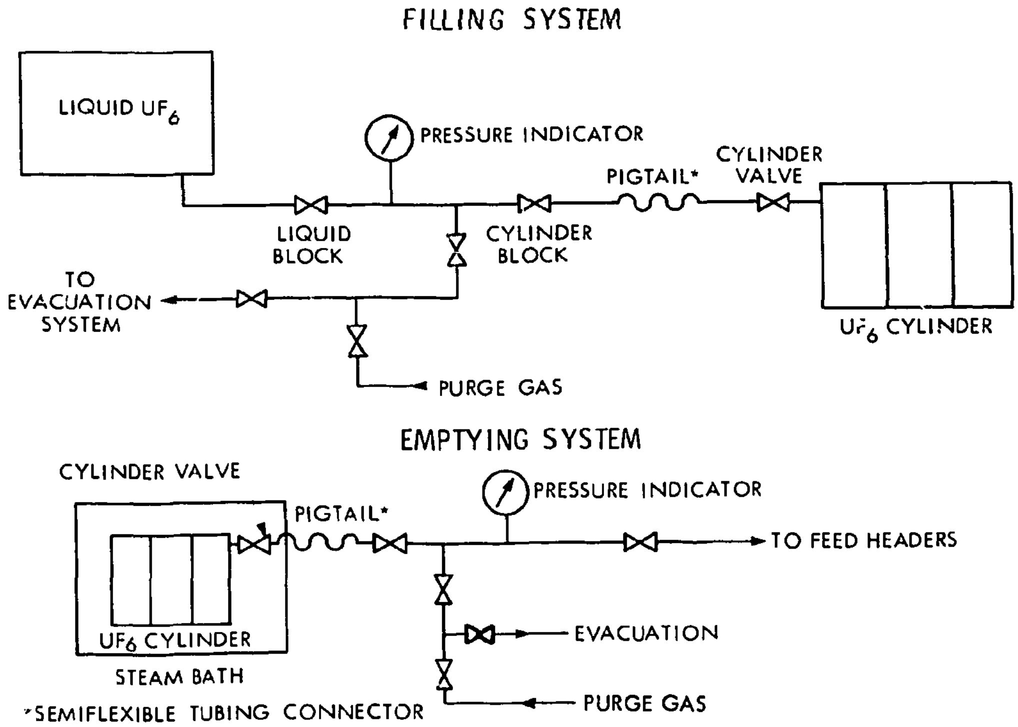

Figure 3

TYPICAL UF_6 CYLINDER FILLING AND EMPTYING SYSTEMS

Evacuation systems are designed to preclude backflow of oil into the system or into a cylinder by use of oil backflow reservoir above each vacuum pump or by use of air ejector equipment. Piping systems for UF_6 service are designed utilizing rigid construction and welded connections. UF_6 pigtails require an exception to this practice because of the need for some degree of flexibility and the ability to connect and disconnect UF_6 containers. To meet this requirement, UF_6 pigtails are designed utilizing tubing with screwable connections. These unique features need special attention during design, fabrication, testing, and use. Drawings and specifications must be produced utilizing design techniques and materials developed and proven by DOE, DOE operating contractors, and companies with experience in handling UF_6. UF_6 pigtails must be fabricated and tested to well-documented, approved procedures. An example of a fabrication flowsheet developed from an approved procedure is shown in Fig. 4. During use, UF_6 pigtails require a full visual inspection for damaged threads or tubing kinks prior to each use. Pigtails must also be pressure tested to assure leak tightness and clarity after installing in the system but prior to use. Teflon gaskets should be changed for each use and should be new virgin material. Fig. 5 shows a typical pigtail installation.

Typical specification and drawing references for pigtail fabrication are shown in Table 2. Detailed DOE documentation can be obtained at the Paducah and Portsmouth Gaseous Diffusion Plants.

Table 2. Pigtail specifications

	Portsmouth Gaseous Diffusion Plant	Paducah Gaseous Diffusion Plant
Material Specifications	GSP-6.21A	M5E-14280-A
Drawing Specifications	DX-761-892M	M5E-14280-F
Brazing Specifications	GSP-4.330	W-705
Test and Inspection Procedure	QC-C307	QE-102
Fabrication Procedures		MP-M-8
Quality Assurance Assessment and Plans	QA-761-005	CO-A-24

Additionally, continual field inspections must be conducted to ensure that the pigtails have not been damaged during use. Kinks, damaged threads, or inoperable heaters are cause for discontinuing use of the pigtail.

3.3 CYLINDER FILLING PROCEDURES

Cylinders may be filled using two possible procedures (1) filling with liquid UF_6 and (2) under certain conditions, filling by desublimation of UF_6 gas.

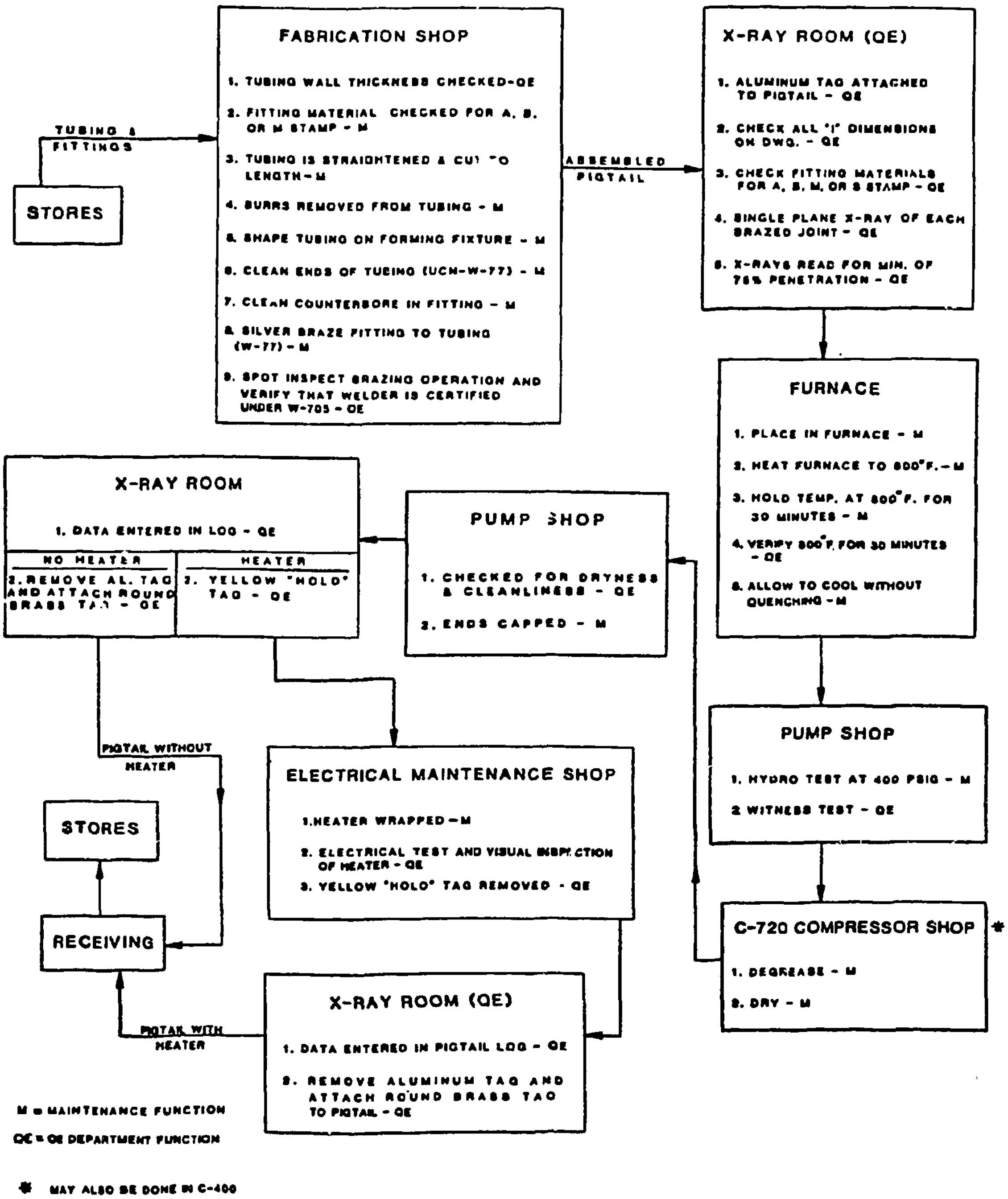

Figure 4

UF_6 CYLINDER PIGTAIL FABRICATION, INSPECTION, AND TESTING FLOWSHEET

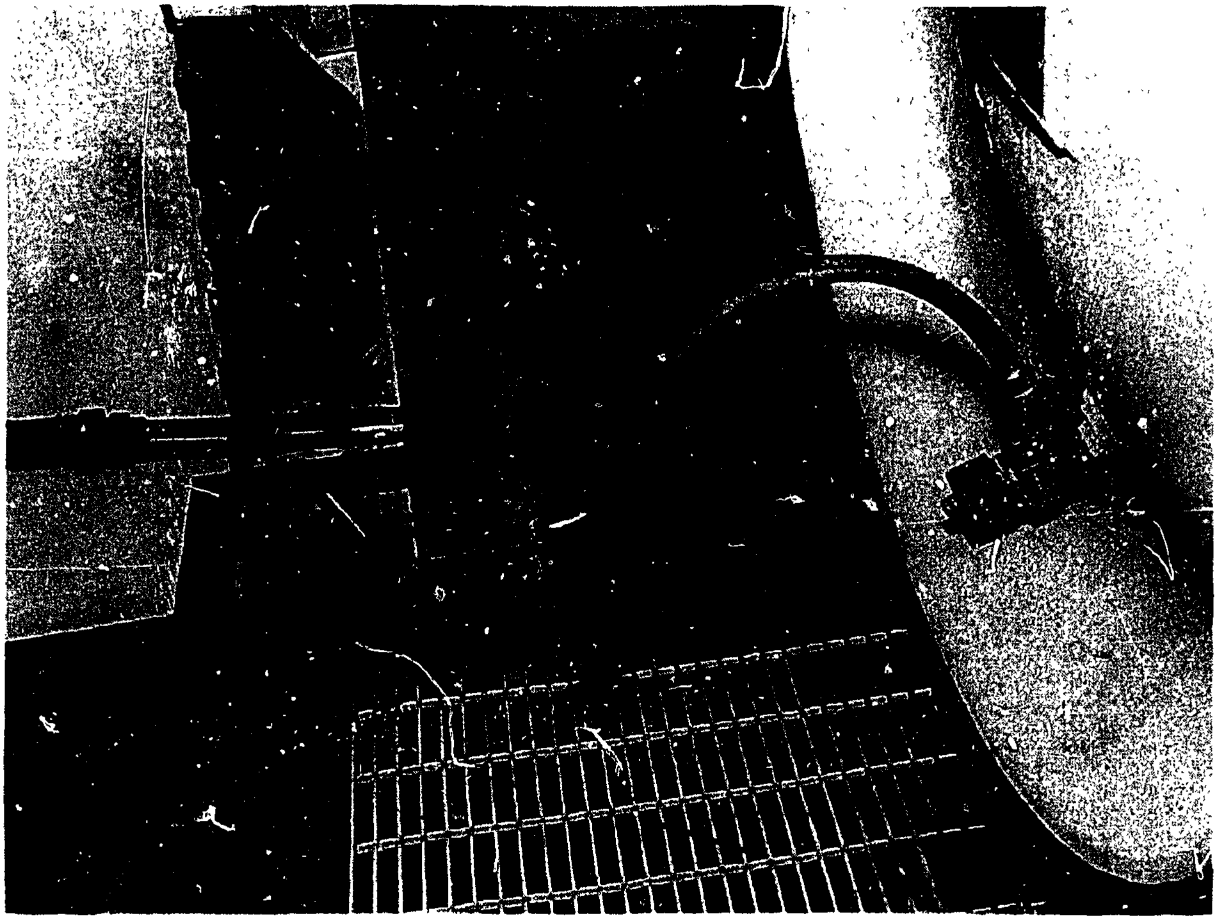

Figure 5
TYPICAL PIGTAIL INSTALLATION

3.3.1 Filling With Liquid UF_6

Liquid UF_6 is drained by gravity through heated lines and valves into evacuated cylinders. The liquid is controlled in a temperature range of 160° to 250°F (71° to 121°C). After the UF_6 has solidified, the cylinder is vented if necessary, to a low-pressure trapping system to remove contaminants which are volatile at room temperature.

The following procedural steps are commonly used for filling UF_6 cylinders by liquid transfer:

1. The valve protector and other attachments to the cylinder, as well as foreign material which could cause shipper-receiver weight discrepancies, are removed before the cylinder is weighed (see Sect. 4.1).
2. The evacuated cylinder is weighed, cold pressure checked, and connected to the withdrawal system.
3. To ascertain system tightness, all connections are leak-rated at a pressure level equal to or greater than the expected UF_6 working pressure and vacuum leak-rated at 0.5 psia or less. Any pressure change in one minute is unacceptable.
4. The scale is zeroed to take into account the cylinder tare weight.
5. The cylinder valve and pigtail are heated to prevent the solidification of UF_6.
6. When the connecting lines are sufficiently hot to maintain the UF_6 in the liquid phase, the cylinder and liquid system valves are opened. There will be an initial flashing of the liquid to gas until the cylinder pressure is >22 psia, after which liquid will flow into the cylinder.
7. The valves are closed when the cylinder contains the required amount of UF_6, as determined by the observed weight gain.
8. All connections are evacuated to 0.5 psia (2.6 cm Hg) and purged of UF_6 with nitrogen or dry air.
9. The evacuated section is brought to atmospheric pressure with dry purge gas and the pigtail is cautiously disconnected.
10. With careful handling and minimum lift height, the cylinder is weighed to determine the gross weight, and allowed to cool with the valve in the 12 o'clock position. Valve protectors should be installed as soon as practical.
11. The cylinder is not shipped until the UF_6 has solidified and the vapor pressure in the cylinder is less than atmospheric pressure. Cooling times for 30-inch and 48-inch cylinders are typically 3 and 5 days, respectively.

3.3.2 Filling By Desublimation of UF_6 Gas

It is sometimes desirable to fill small cylinders by desubliming gaseous UF_6 directly into the cylinder. This method is applicable to two-valve cylinders such as Models 5A, 5B, 8A, and 12B. The source of gaseous UF_6 is connected to the valve with the dip-pipe, and the other valve is connected to a low-pressure system. The cylinder is cooled in a dry ice slush bath or a mechanically refrigerated system to a temperature range of 10° to 25°F. Gaseous UF_6 is then routed into the cylinder for solidification. If these cylinders are being used as a cold trap, then the connections to the valves may need reversing to avoid freeze-out in the dip leg and the temperature lowered to a range of -25° to -120°F.

3.4 CYLINDER EMPTYING PROCEDURE

Uranium hexafluoride is removed from cylinders by vaporization or liquid transfer and is subject to the potential hazards of heating UF_6 as described in Sect. 7.5.2.3. With the exception of sample cylinders, a UF_6 cylinder should never be heated when the cylinder valve is closed or disconnected from a pressure monitoring system. ***Never heat a UF_6 cylinder with an unknown quantity of UF_6.*** The procedure for liquid draining is similar to that described in Sect. 3.3 and will not be discussed here.

Uranium hexafluoride is usually vaporized from cylinders heated with either steam or electrically heated air. High heat sources should never be applied directly to the cylinder surface because of the hydraulic rupture hazard associated with localized heating. Heat must be controlled to prevent temperatures in excess of their design temperature. To determine when vaporization from a cylinder is complete, the system block valve is closed and the cylinder pressure observed. The absence of a pressure-rise indicates that the vaporization of volatile material is complete. The following procedural steps are commonly used for emptying UF_6 cylinders by vapor transfer:

1. After the cylinder is gross weighed to verify that it is not overfilled and cold pressure checked, it is placed in the vaporizing position (valve at 12 o'clock) and connected to the feed system.

2. To ascertain system tightness, all connections are leak-rated at a pressure level equal to or greater than the expected UF_6 working pressure and vacuum leak-rated at 0.5 psia or less. Any pressure change in one minute is unacceptable.

3. The *cylinder is valved to a continuous pressure indicator,* preheated as necessary to liquify the UF_6, and the system valves are opened to start feeding.

4. Feeding is stopped when the desired amount of UF_6 has been vaporized or when the cylinder is empty. The latter is indicated by flow instruments or lack of pressure rise as described above.

5. Valves are closed and all connections are evacuated and purged of UF_6 with dry air or nitrogen.

6. The evacuated pigtail is brought to atmospheric pressure with dry purge gas, and the pigtail is cautiously disconnected.

7. The cylinder is weighed to determine the actual amount of material removed.

Table 1 lists maximum allowable heels for standard cylinders.

3.5 OVERFILLED CYLINDERS

An overfilled UF_6 cylinder is one that contains a quantity of UF_6 which, when heated to working temperature, would expand sufficiently to reduce the gas volume above the liquid (ullage) to less than 5% of the cylinder volume. If the quantity of UF_6 is sufficiently large, the ullage can be completely filled at which point hydraulic deformation and possible rupture of the cylinder can occur.

Varying degrees of overfill can occur; however there are practical and safe methods to handle overfilled cylinders depending on the degree of overfill.

The Shipping Fill Limits of cylinders shown in Table 9 are calculated from the known liquid UF_6 density-temperature relationship and the minimum volume for the kind of cylinder. This minimum cylinder volume is certified by the requirement for the cylinder fabricator to fill each cylinder with water, weigh the water, and stamp the water weight on the cylinder name plate. This procedure provides the data to assure that the cylinder exceeds the minimum volume and also determines the actual volume of each individual cylinder. (Some 48A and 48F cylinders do not have certified minimum volumes and this method does not apply to them.)

If a cylinder is filled with more than the shipping limit, and this is discovered shortly after filling while the UF_6 is still liquid, the safest way to reduce the fill is to use the latent heat in the liquid to vaporize the excess material. This can be accomplished by valving the cylinder to a UF_6 receiver at a lower pressure than the cylinder.

However, if there is insufficient heat contained in the liquid UF_6, controlled heating can be used. Using the net weight of the UF_6, the cylinder actual volume from the name plate, and the liquid UF_6 density-temperature relationship, a safe heating regime assuring the 5% ullage can be determined. With proper instrumentation to measure and control the cylinder temperature, this weight reduction operation can be performed safely.

To illustrate this concept, Figs. 6, 7, and 8 plot safe UF_6 fill limits versus cylinder temperature for this controlled heating as a function of actual cylinder name plate volume expressed as cubic feet or pounds (kilograms) of water. As with any UF_6 cylinder heating operation, the cylinder pressure must be continuously monitored with provisions to terminate the heating if the pressure exceeds the cylinder design pressure.

If the overfill is so great that the 5% ullage cannot be assured at any liquid UF_6 temperature, the excess material must be removed by evacuation without heating. This is a slow operation because the heat of sublimation for the UF_6 has to come from the ambient air. The heat transfer rate from the air through the cylinder skin to the solid UF_6 is low. When sufficient UF_6 has been removed, controlled heating, as described above, can safely be employed.

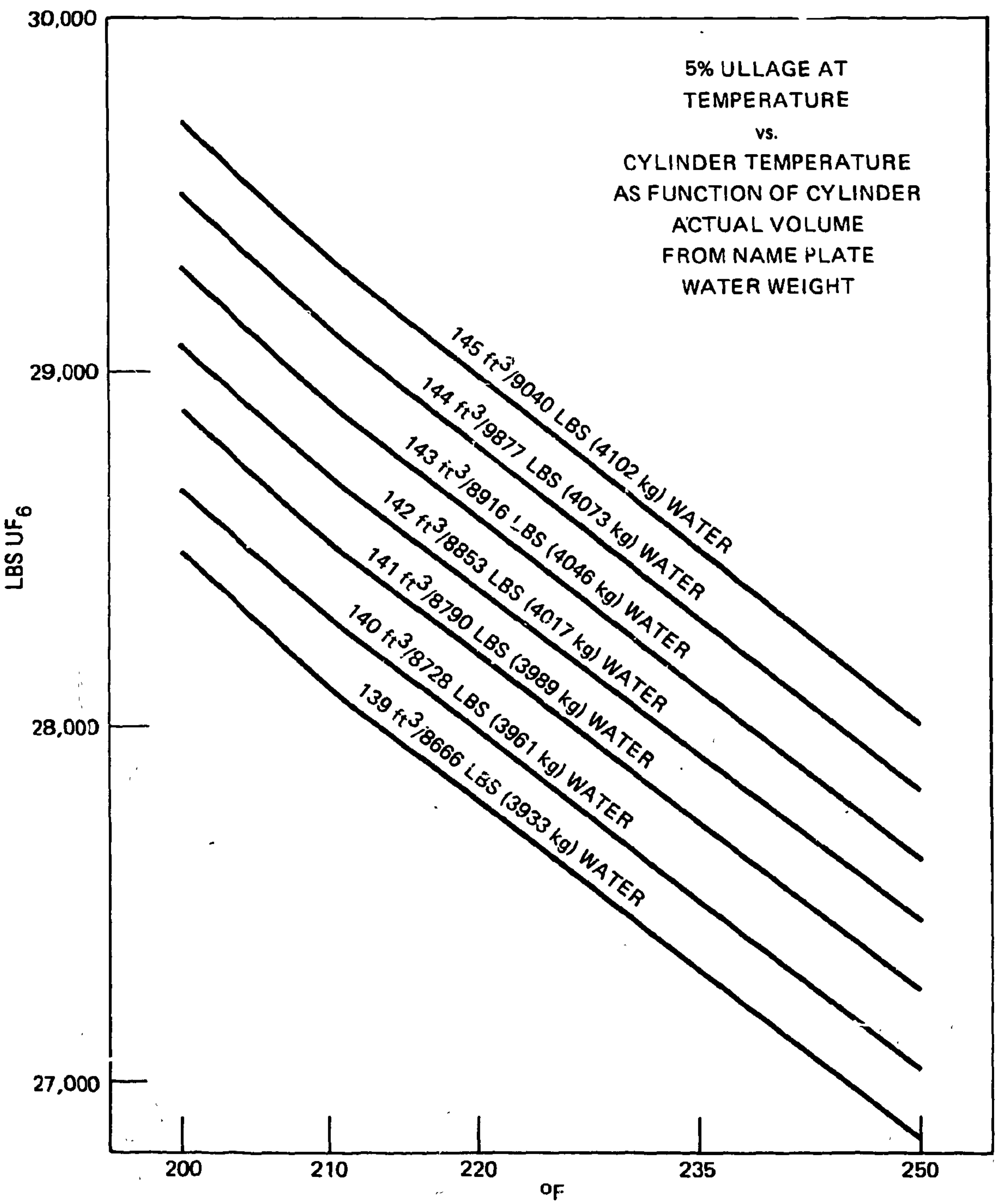

Figure 6

MODEL 48 (F, Y, G, H, HX) CYLINDER SAFE FILL LIMITS

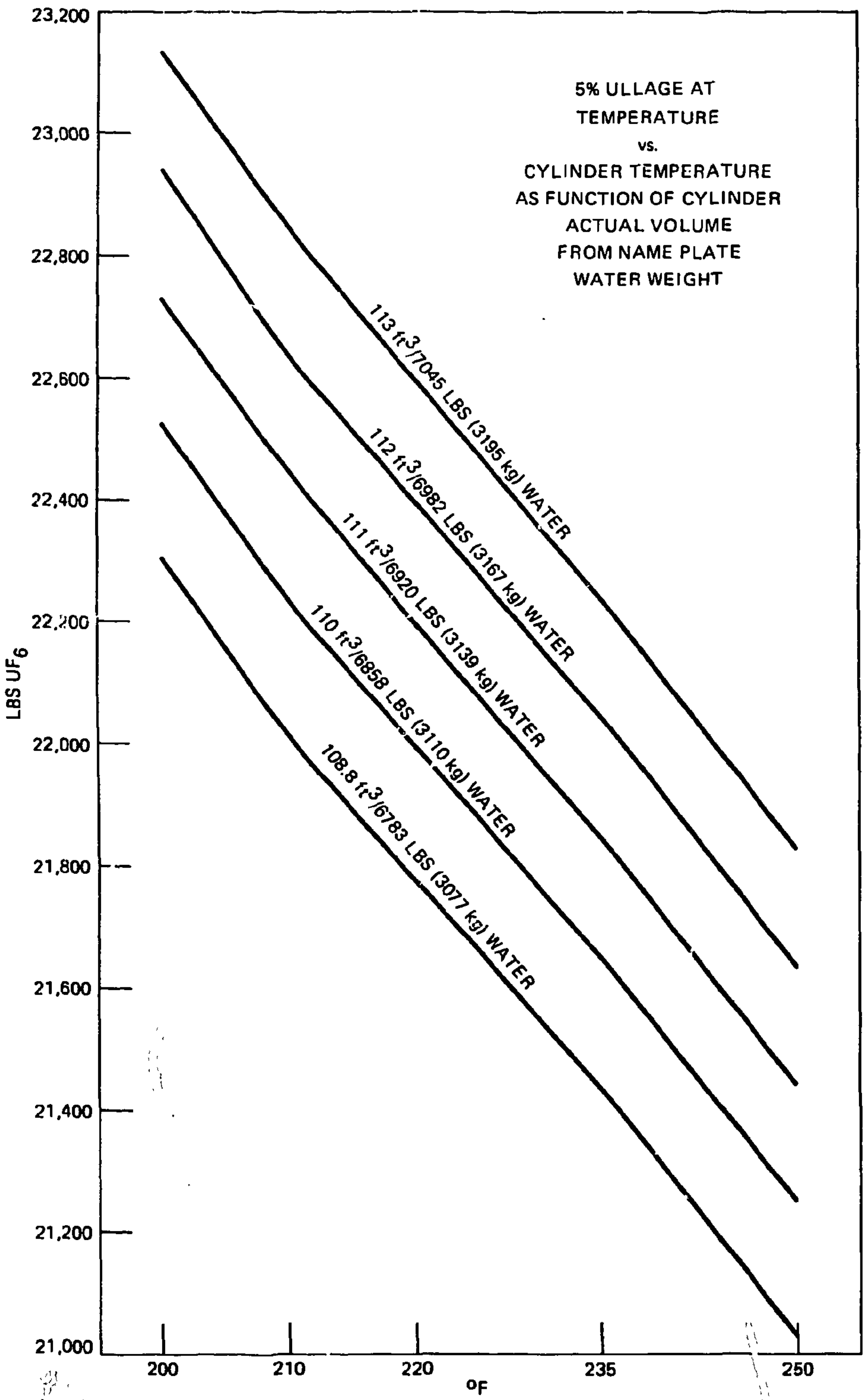

Figure 7
MODEL 48 (A, X) CYLINDER SAFE FILL LIMITS

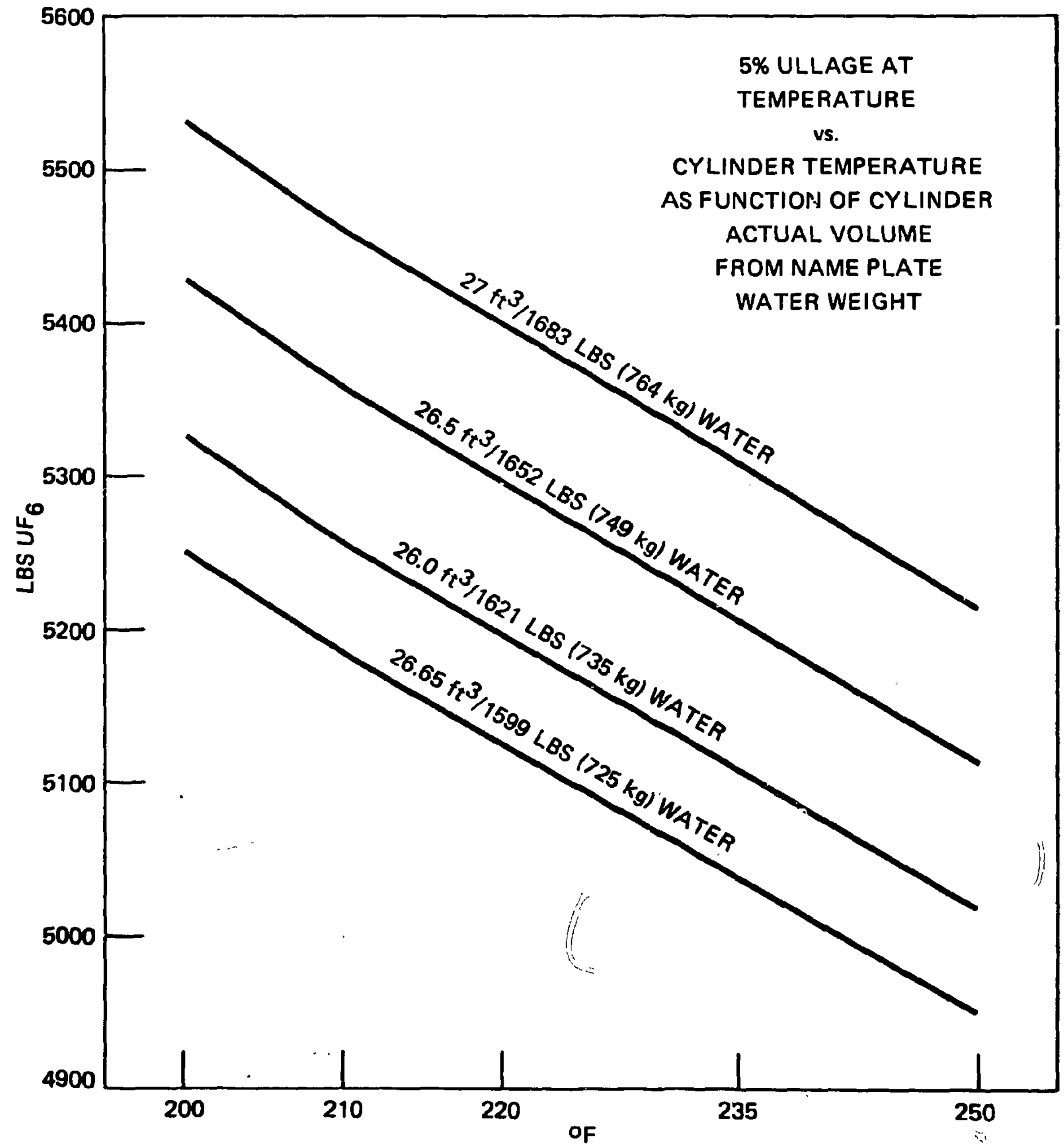

Figure 8

MODEL 30 (A, B) CYLINDER SAFE FILL LIMITS

3.6 REDUCING CYLINDER HEELS

Cylinders shipped to DOE with heels weighing in excess of the maximum heel values shown in Table 1 may require removal of this heel at a cost to the shipper. Removal of UF_6 to less than the maximum heel values can be accomplished by utilizing 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 the vapor pressure characteristics of UF_6 and an empty UF_6 cylinder. 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 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 cylinders, and the absence of noncondensable 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 purging UF_6 from pigtails. External cooling of the cold cylinder may be used but, is usually not required because of the small quantity of UF_6 involved. A schematic of a typical evacuation system is shown in Fig. 9. At the conclusion of a series of these transfers, the cold cylinder must be weighed to assure that it has not been overfilled, and heated to feed back into the process.

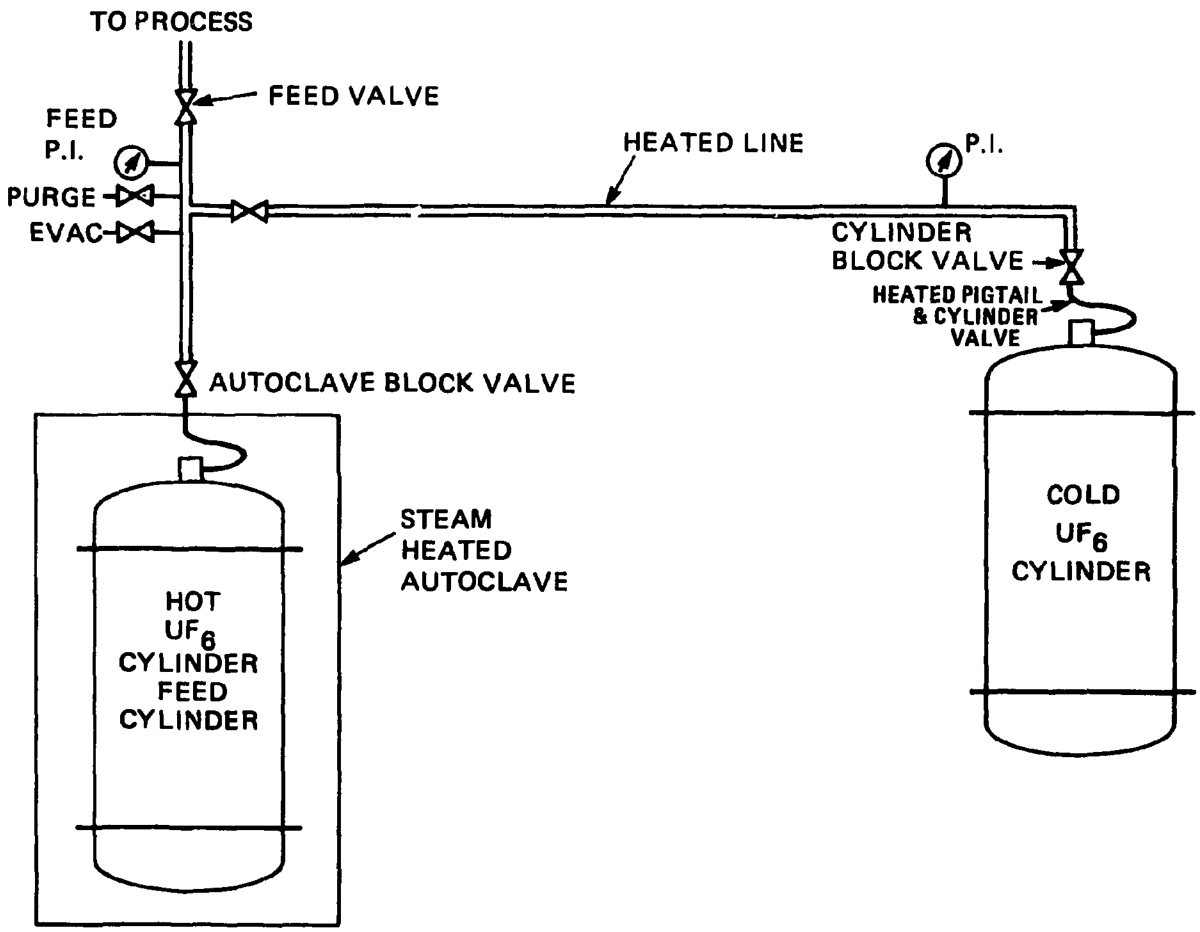

Figure 9

TYPICAL CYLINDER HEEL EVACUATION SYSTEM

4. WEIGHING PROCEDURES

4.1 GENERAL

Accurate measurements of gross, tare, net 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:

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

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

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

Thus, at DOE facilities, careful attention is given to the type, capacity, precision, and maintenance of scales used for weighing the various sizes of UF_6 cylinders. Table 3 provides information regarding DOE scales. Figures 10 through 13 are examples of typical scales and standard weights used by DOE.

Table 3. DOE scale descriptions

Cylinder Model Number	Typical Scale Type	Normal Capacity of Scale	Scale Precision	Allowable Deviation[1]
1S, 2S	Fan	5 kg	<±0.5 g[2]	±0.5 g
5A, 5B	Equal-Arm	60 kg	<±0.1 g[2]	±0.1 g
8A, 12A, 12B	Platform	360 kg	±20.0 g[2]	±20.0 g
30A, 30B	Platform	10,000 lb	±2 lb (±1 kg)	±2 lb (±1 kg)
48A, 48F, 48X, 48G, 48Y, 48H, 48HX	Platform	40,000 lb	±2 lb (±1 kg)	±2 lb (±1 kg)

[1]From the established value during check weighing operations.
[2]DOE gross, tare, and net weights are reported to the nearest gram.

All scales used for official weighing, except the fan scale and the equal-arm balance, are equipped with a printweight attachment which 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.

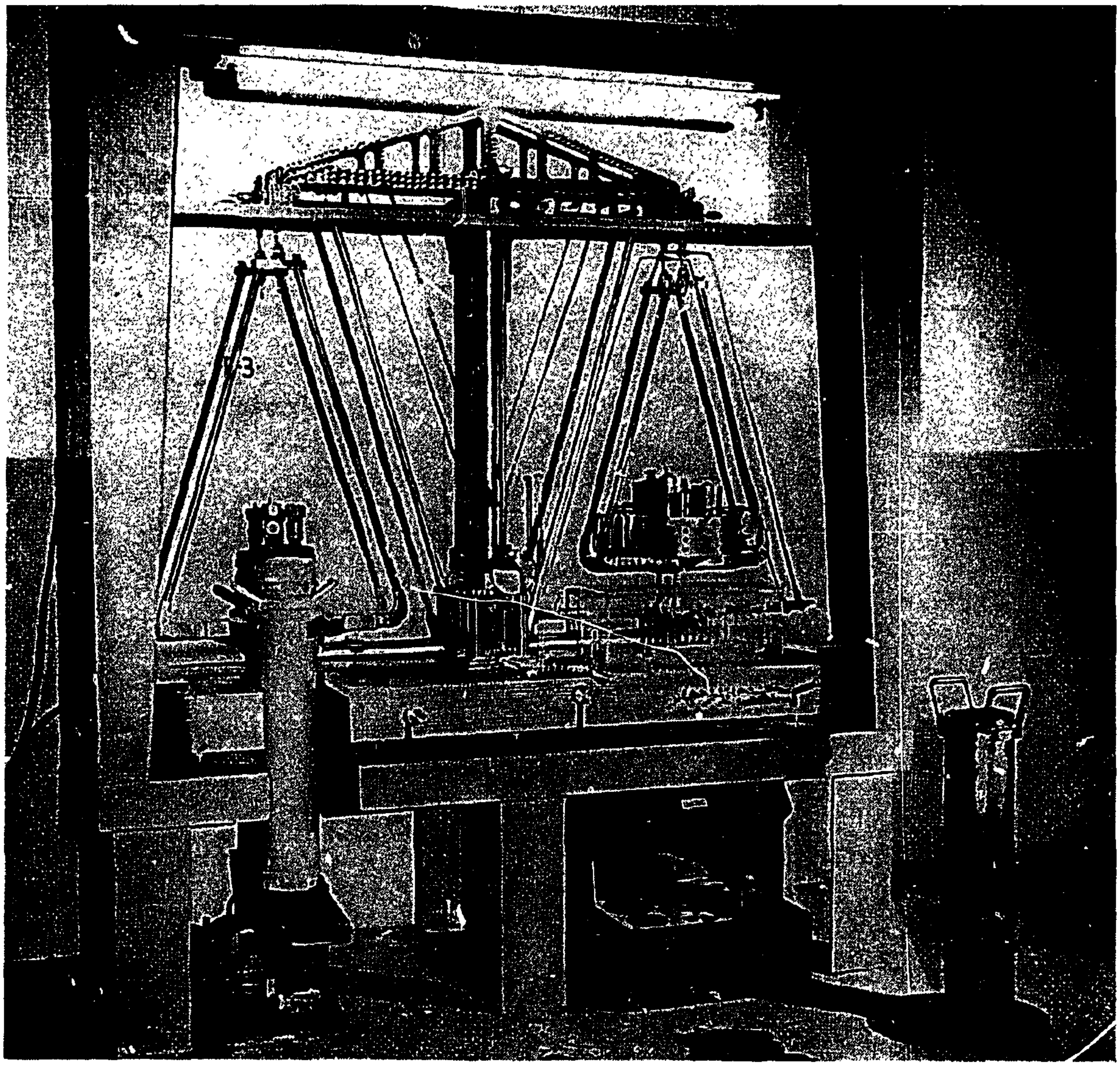

Figure 10
TYPICAL EQUAL–ARM BALANCE FOR WEIGHING UF_6 CYLINDERS
MODEL 5A AND 5B

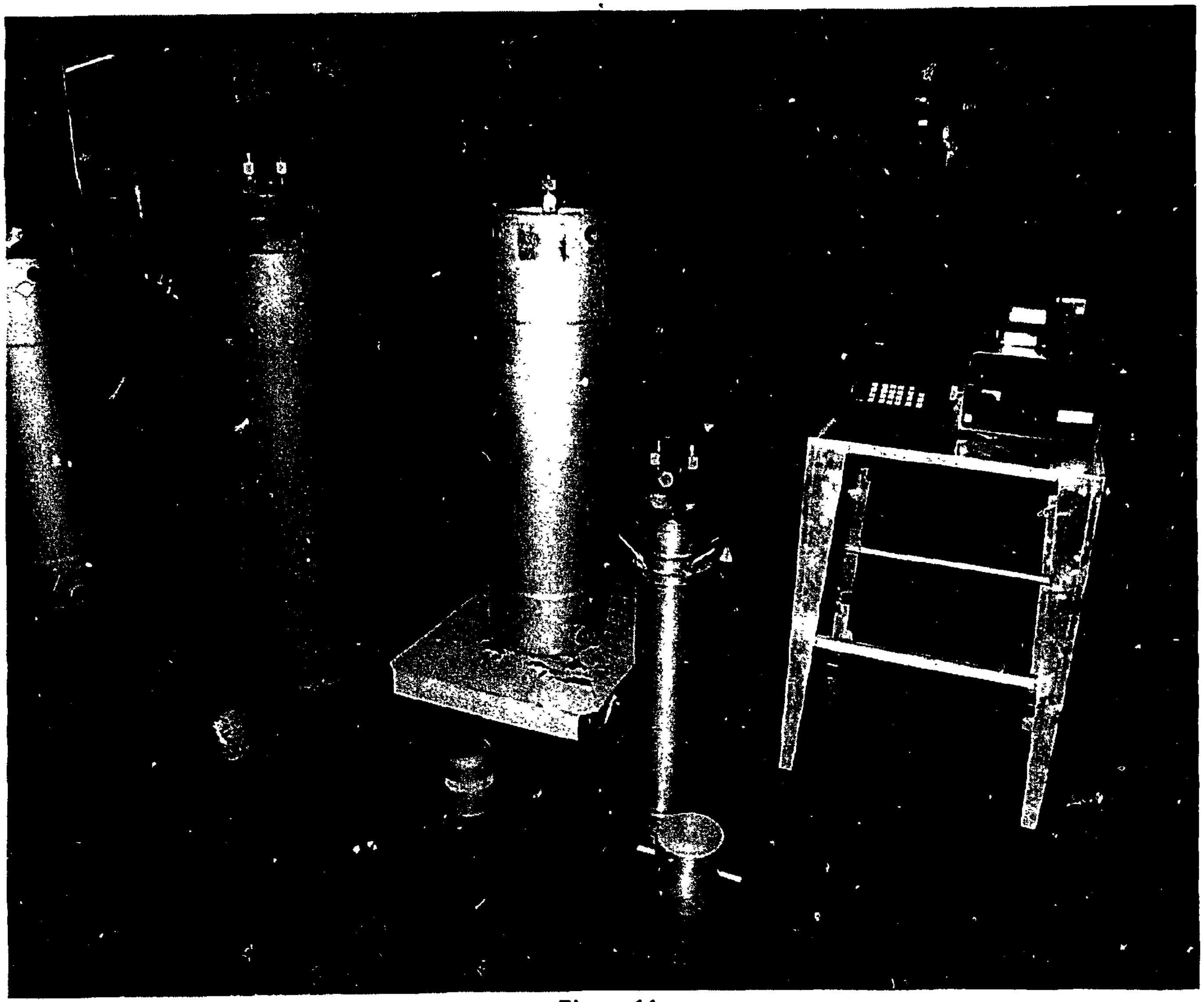

Figure 11

TYPICAL LOAD CELL SCALE FOR WEIGHING 5-INCH, 8-INCH, AND 12-INCH UF_6 CYLINDERS

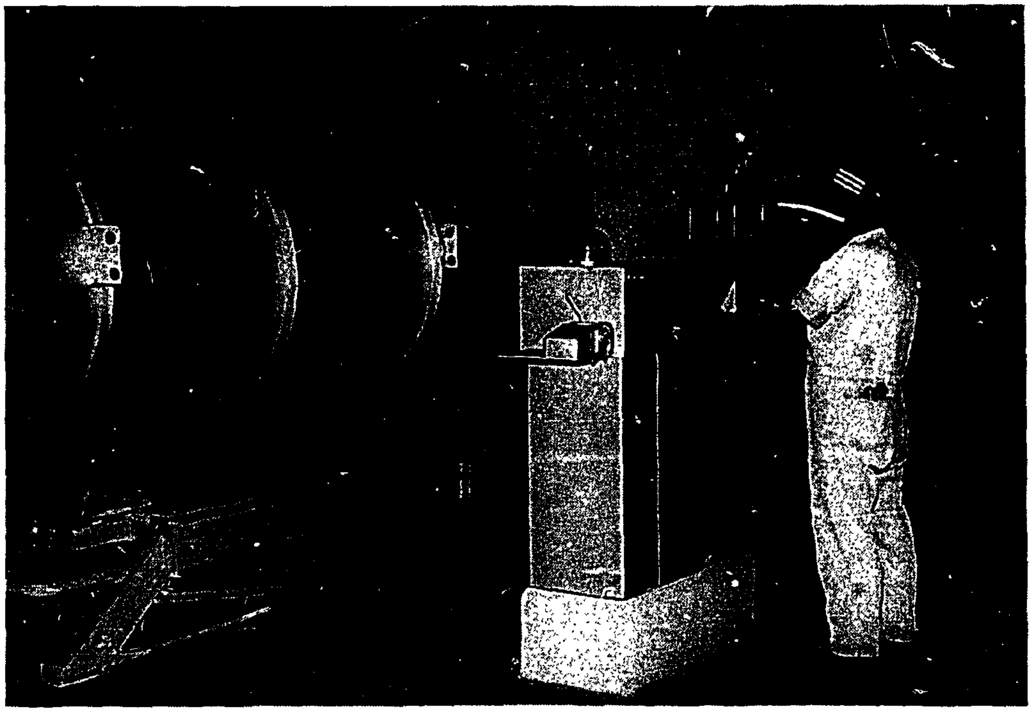

Figure 12

TYPICAL PLATFORM SCALE FOR WEIGHING 30-INCH AND 48-INCH UF_6 CYLINDERS

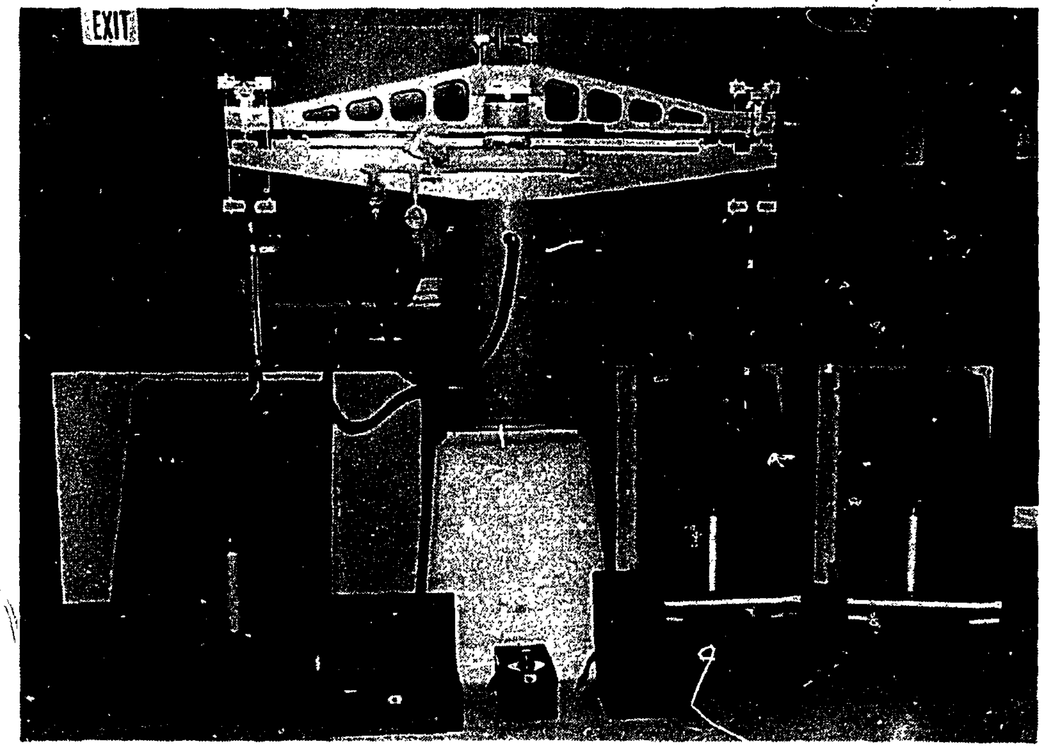

Figure 13

TYPICAL EQUAL-ARM BALANCE FOR CALIBRATING TEST WEIGHTS

Scales are normally enclosed or covered to ensure cleanliness and to prevent damage to the instrument. Scale pans, tare and weight beams, platforms, cars, etc., are cleaned, and all building doors are closed to reduce drafts before any weighing operations are initiated.

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 cars 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 which would affect the tare weight. At least two independent weighings are obtained to establish the tare weight.

Cylinders are always weighed without valve protectors, skids, saddles, and other removable appurtenances. Valve protectors vary in weight and are not identified with a specific cylinder.

When a significant shipper-receiver 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 weight is placed on the scale to verify the reliability 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 in Table 3, the first weight is considered to be acceptable.

4.2 WEIGHING PRINCIPLES

The primary equipment required includes National Bureau of Standards (NBS) certified standard weights, test weights, check weights (or known weights), and scales or balances of appropriate capacity. The check weights, which are commensurate with the weight levels of both full and empty containers being weighed, are used to verify that the scale is in proper working order. To facilitate handling, check weights are normally of the same size and shape as the UF_6 cylinders being weighed. If the weight obtained for a check weight differs from its established weight by more than the scale precision, the scale is rezeroed and the check weight reweighed. If the indicated weight still differs from the established weight by more than the allowable deviation, the scale is recalibrated.

The appropriate check weight is weighed either (1) prior to the first weighing and after the last weighing of any group of empty or full cylinders, or (2) on a periodic time schedule determined by the frequency of use of the scale. 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 weights.* 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 [NBS or the equivalent State agency] prior to use. Recertification of these primary standards is performed per ANSI N15.18-1975. Test weights are calibrated using certified standards on an annual basis 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. Prior to beginning the calibration, the scale is inspected for damage and thoroughly cleaned. All poises are set at zero and the platform inspected for levelness and freedom of movement. If any increment checked is found to deviate by more than the scale precision (as shown in Table 3) 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 either 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 that allowable at each weight increment checked.

4.3 SCALE PERFORMANCE

In addition to the weight re-check performed in the preceding weight verification procedure (Sect. 4.2), 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, then 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 following the principles of Sect. 4.1. As a result of the "in error" concept, check weighings are conducted at frequent intervals such as the beginning and ending of a weighing sequence, at the operators discretion, or at the beginning and ending of each work shift. Check weights are provided in the load sizes typically measured with each scale. Additionally, small weights are 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, 0.5, 1, or 2 Kg additions are made

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*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.

4.4 WEIGHT STANDARDS AND ARTIFACTS

Weight standards used for calibrating and verifying operation of scales consist of NBS primary and artifact standards and the following three levels of derived standards:

1. Secondary Standards - Prepared from primary standards.

2. Tertiary Standards - Prepared from secondary standards.

3. Check Weights - Prepared from tertiary 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, which are based on ANSI N15.18, for preparation of standards are:

- Operation of a highly sensitive balance is validated using two NBS primary standards (25 Kg). The standards are reversed and the balance is again validated.

- 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.

- 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 as 500 Kg audit weights (tertiary) as necessary are prepared in this manner to test the performance of the largest capacity production scale.

- Large check weights (up to 20,000 Kg) are prepared on a production scale using multiple weighings. A minimum of five weighings of the intended check weight is made and at each weighing a predetermined random weight, unknown to the operator, is added to minimize effect of prior knowledge. A minimum of five weighings on the same scale is 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 ±0.5 Kg.

To support government weighing programs, NBS artifact weights (Table 4), have been obtained and are made available by request to DOE for scale performance evaluations or preparation of check weights.

Table 4. Artifact standards

Cylinder size	Cylinder number	NBS bouyancy corrected wt lb	NBS bouyancy effect lb	NBS apparent wt lb
$2\frac{1}{2}$-ton	300181	6341.520	1.23	6340.290
$2\frac{1}{2}$-ton	D24137	6348.500	1.23	6347.270
$2\frac{1}{2}$-ton	300180	1555.133	1.98	1553.153
$2\frac{1}{2}$-ton	D52119	1523.197	1.98	1521.217
$2\frac{1}{2}$-ton	RMS001	1396.238	1.98	1394.277
$2\frac{1}{2}$-ton	RMS002	6355.999	1.23	6354.772
10-ton	001270	25322.780	5.14	25317.640
10-ton	001403	25338.420	5.14	25333.280
10-ton	003146	4474.203	8.24	4465.963
10-ton	000012	4460.413	8.24	4452.173
10-ton	RMS003	4463.809	8.24	4455.630
10-ton	RMS004	25332.124	5.14	25327.089
14-ton	009622	32492.270	6.43	32485.840
14-ton	009517	32493.800	6.43	32487.380
14-ton	RMS005	5284.925	10.71	5274.215
14-ton	RMS006	32507.502	6.43	32501.116

5. SAMPLING PROCEDURES

5.1 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 is not difficult since the convection currents in the liquid UF_6, during the heating of the cylinder for sampling, 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 facilities are vented to reduce such impurities.

Prior to heating a cylinder for sampling, a vapor pressure measurement at ambient temperature (cold pressure check) is made which does not involve the withdrawal of a sample. The cylinder is heated (heating time is shown in Table 5) with the valve open and in the 12 o'clock position. 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 must not be allowed to exceed 115 psia.

Sampling techniques may be divided into (1) those applicable to cylinders which may be composited and (2) those cylinders which are sampled individually. A tabulation of sampling data applicable to each cylinder model is presented in Table 5. A typical sampling system is shown schematically in Fig. 14.

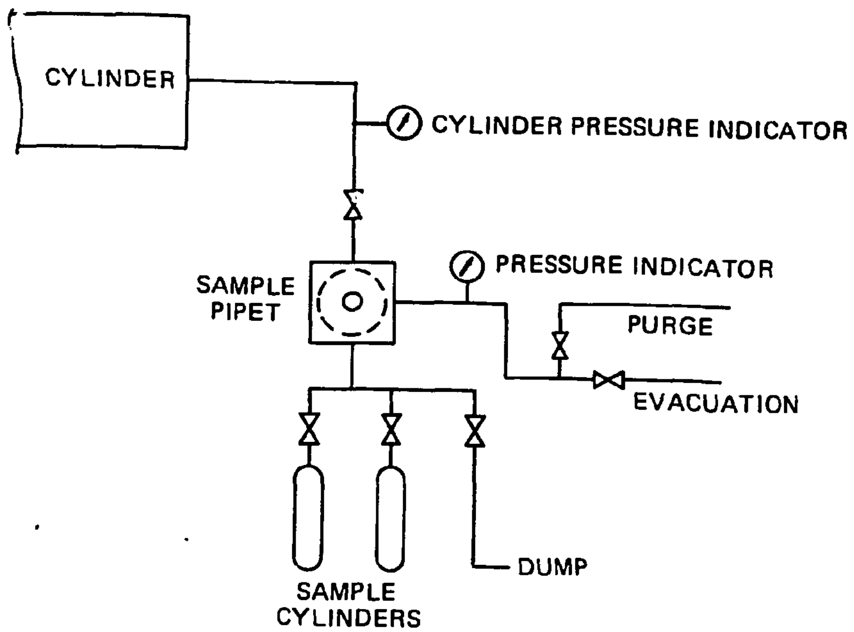


Figure 14
TYPICAL SAMPLING SYSTEM

Table 5. Sampling information

Cylinder Model Number	Sampling cylinders normally used: Model No.	Fill limits: lb	Fill limits: g	Maximum number of cylinders composited	Approximate Sample Size/Cylinder, g UF_6: Single Cylinders	Approximate Sample Size/Cylinder, g UF_6: Composited Cylinders	Minimum heating time at 200°F (93°C), hour
5A, 5B	1S	1.0	450	6	400	65	2
8A	1S	1.0	450	6	400	65	3
12A, 12B	1S	1.0	450	6	400	65	4
30A, 30B	2S	4.9	2,200	4	1,700	340	8
48A, 48F, 48X, 48Y, 48G, 48H, 48HX	2S	4.9	2,200	1	1,700	No Composite	12*

*Minimum heating time at 220°F is 6 hours.

NOTES:

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

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

3. UF_6 may be withdrawn into a large DOE-owned cylinder, sampled and then transferred into smaller customer-owned cylinders. Such transfers may involve the filling of up to ten Model 12A or 12B cylinders from one Model 30A or 30B cylinder, filling up to four Model 30A or 30B cylinders from one Model 48A or 48X cylinder.

5.2 SAMPLING PRINCIPLES

Models 30A, 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. Models 12A, 12B, and smaller cylinders are inverted for sampling.

The temperature of the cylinder and contents are maintained at 200° to 235°F (93° to 113°C) throughout the required heating period (Table 5) and during the actual sample withdrawal procedure. 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 (e.g., sample pipet) with a length of monel, nickel, or copper tubing (pigtail). If the cylinder has two valves, one of which is attached to a dip-pipe, the tubing is connected to the other valve. The fixed sampling volume permits the metering of a measured aliquot 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 0.5 psia (2.6 cm Hg) or less and leak rated. Additionally the system is pressure tested, using dry air or nitrogen, to a level equivalent to or greater than the UF_6 working pressure.

After all leak testing is satisfactorily completed, UF_6 is then permitted to fill the fixed sampling volume. Flow to the sampling volume is then blocked, and the sampling container valve is opened to admit the fixed volume of UF_6 to the sampling cylinder. After the liquid UF_6 has drained into the sampling cylinder, a liquid nitrogen bath is raised around the sampling cylinder to draw residual gases into the sampling cylinder. Refrigeration with liquid nitrogen is continued until the pressure in the sampling cylinder drops to 1 psia (5.2 cm Hg), after which the sampling cylinder valve can be closed.

One or two independent samples are removed from each cylinder or composite group. One sample is analyzed. The second sample, if taken, is normally retained for potential umpire use.

Following the sample withdrawal and prior to opening the sampling system to atmosphere, the system is purged of UF_6, evacuated to 0.5 psia (2.6 cm Hg), and back filled with dry air or nitrogen to atmospheric pressure.

5.3 SAMPLE CYLINDERS

The Model 1S and 2S cylinders are used for UF_6 sample containers. To permit thorough cleaning between uses, they have been designed with no internal sharp corners or crevices and the valves are easily removable. These are the only UF_6 cylinders for which Teflon tape is permitted for use to seal the threaded valve connections; all other UF_6 cylinders have tinned valve threads.

Because the sample integrity would be violated if any material were removed, the cylinders are heated in a laboratory hood 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 are not used for analytical purposes.

6. SHIPPING

6.1 GENERAL

Essentially all UF_6 shipments made to and from DOE facilities are by rail or truck. For repetitive bulk shipments, particularly of the large cylinders, transportation safety is promoted through the use of specially designed trucks. Rail cars have been equipped to accommodate four or five Model 48 (A, X, F, H, G, or Y) cylinders. Heavy-duty tie-down devices and saddles are utilized. Typical examples of appropriate equipment are shown in Figs. 15 through 18. Examples of lifting fixtures are shown in Figs. 19 through 21. Each full cylinder must be shipped in a protective shipping package (if the assay is 1% or above and the quantity of UF_6 is greater than the permissible heel) or it must be equipped with a valve protector if not enclosed in an overpack. Each protective overpack (containing a UF_6 cylinder) shall be secured with a numbered tamper-indicating device during shipment. Each UF_6 cylinder, whether empty or full, not enclosed in a protective shipping package should have the valve protected by a numbered tamper-indicating device during shipment. (DOE is currently evaluating tamper indicating devices that cover the valve and are attached with a pin and numbered seal. Figure 22 shows one of the devices being tested.) Seal number data is supplied by the shipper to the intended receiver. The receiver verifies the seal numbers when the containers arrive at his facility to reveal any violation of container integrity that might have occurred during transit. Uranium hexafluoride is shipped only after it has solidified and the vapor pressure of the cylinder is below atmospheric pressure. For the 48- and 30-inch cylinders, a cooling time of 5 days and 3 days, respectively, is required to achieve subatmospheric pressures.

6.2 REGULATIONS

Various agencies have rules and regulations pertaining to the packaging and transportation of radioactive materials. In addition, many states and localities have their own regulations. The regulatory agencies include DOE, Department of Transportation (DOT), the Nuclear Regulatory Commission (NRC), the U.S. Postal Service, the International Atomic Energy Agency (IAEA), and the International Air Transport Association (IATA). Detailed information regarding the packaging and transportation of UF_6 may be found in publications of these agencies. The regulations of the agencies are referenced as shown in Table 6.

Table 6. Packaging and transportation regulations

Agency	Regulations
DOE	Orders 54803, 1540.1, 1540.2
NRC	10 CFR 71
DOT	49 CFR 85, 100-199
U.S. Postal Service	Publication 52, "Acceptance of Hazardous or Perishable Articles"
IAEA	Safety Series No. 6
IATA	Dangerous Goods Regulations (latest edition)

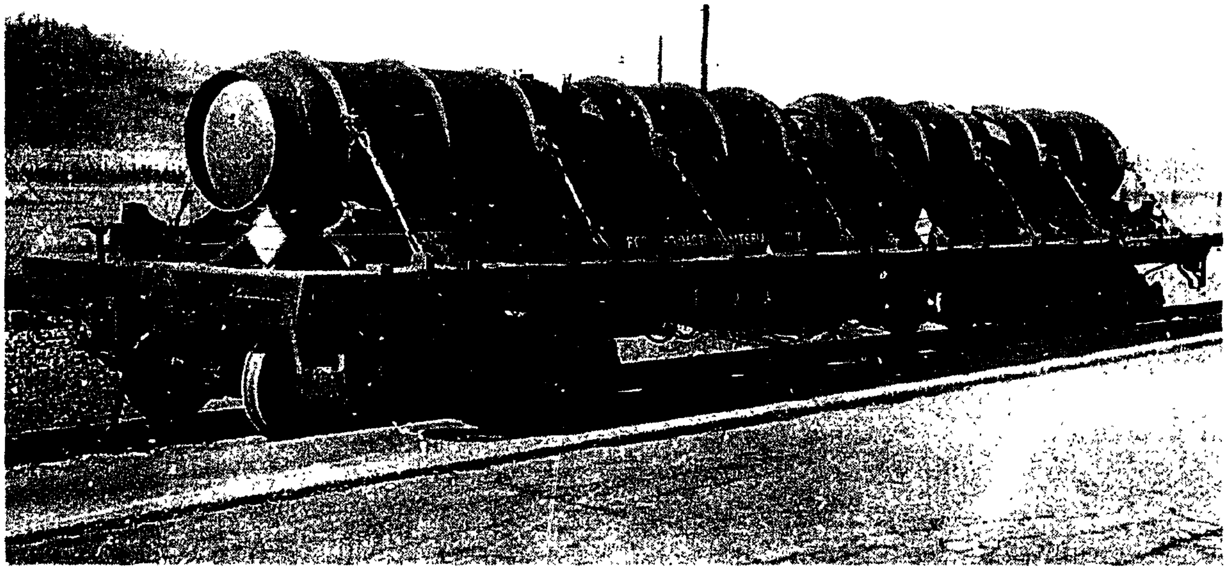


Figure 15
FOUR MODEL 48X CYLINDERS

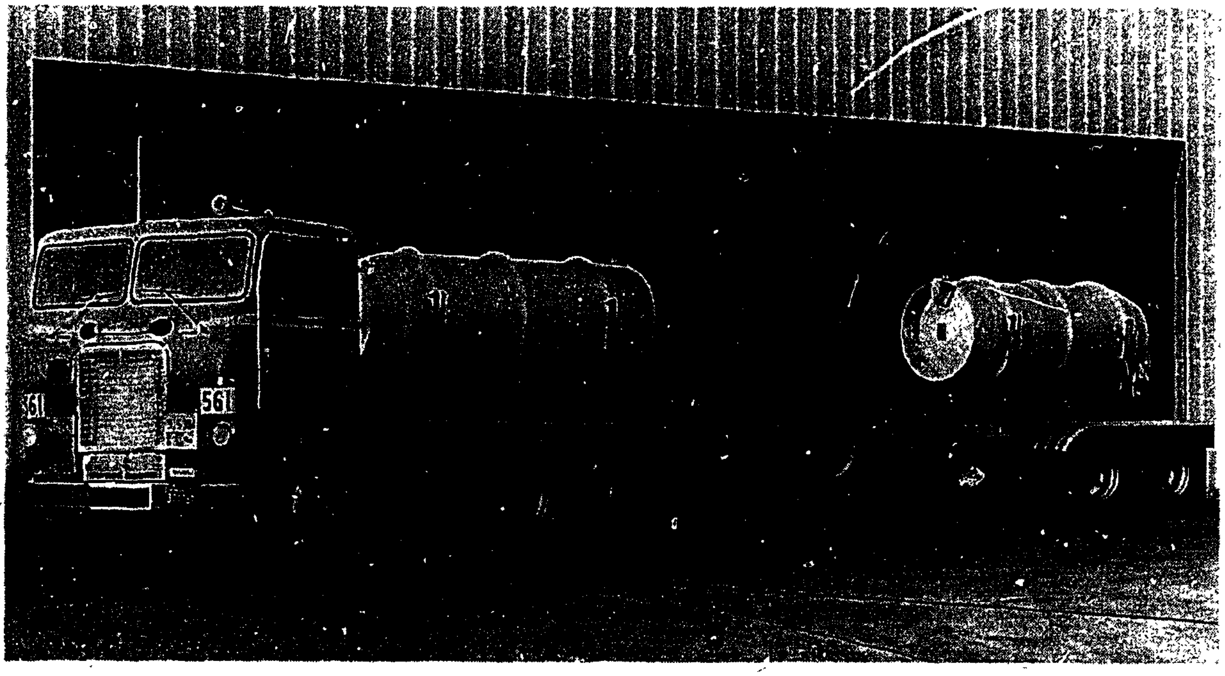


Figure 16
TWO MODEL 48X CYLINDERS

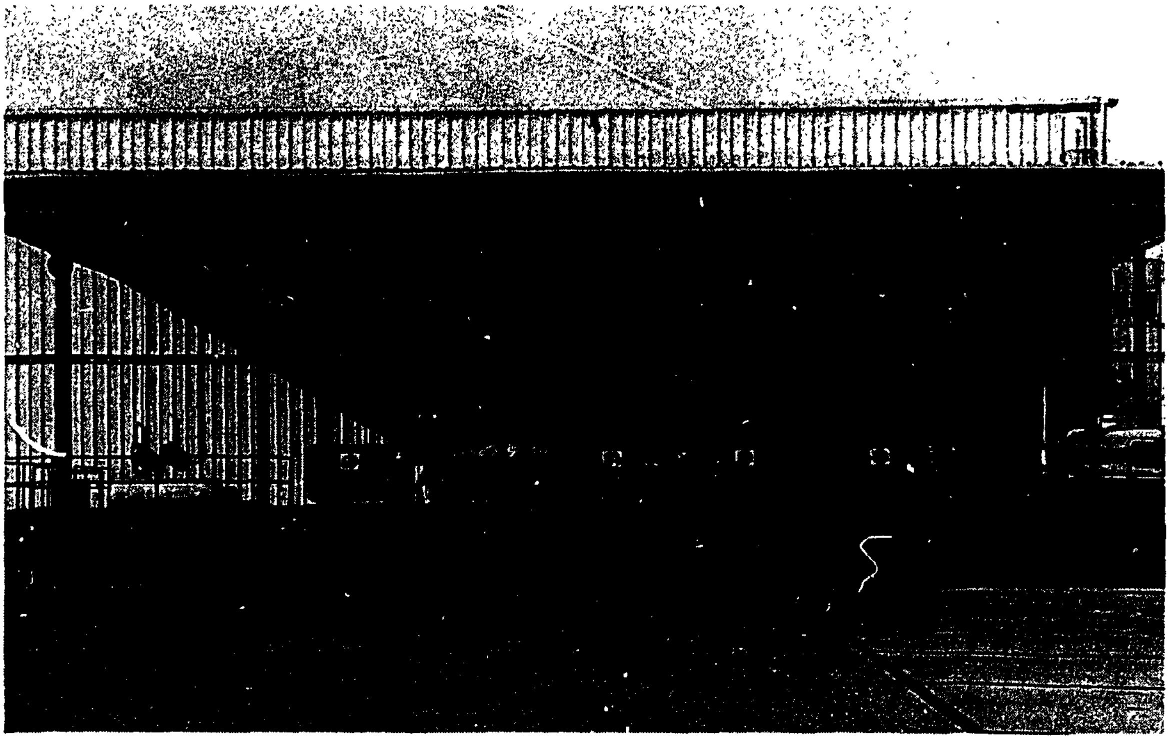


Figure 17
FIVE MODEL 30B CYLINDERS IN PROTECTIVE OVERPACKS

Figure 18
FOUR MODEL 48X CYLINDERS IN PROTECTIVE OVERPACKS

Figure 19
STIFF BACK FOR CYLINDER MODELS 30A AND 30B

Figure 20
H FRAME FOR CYLINDER MODELS 48X, 48G, 48H, AND 48Y

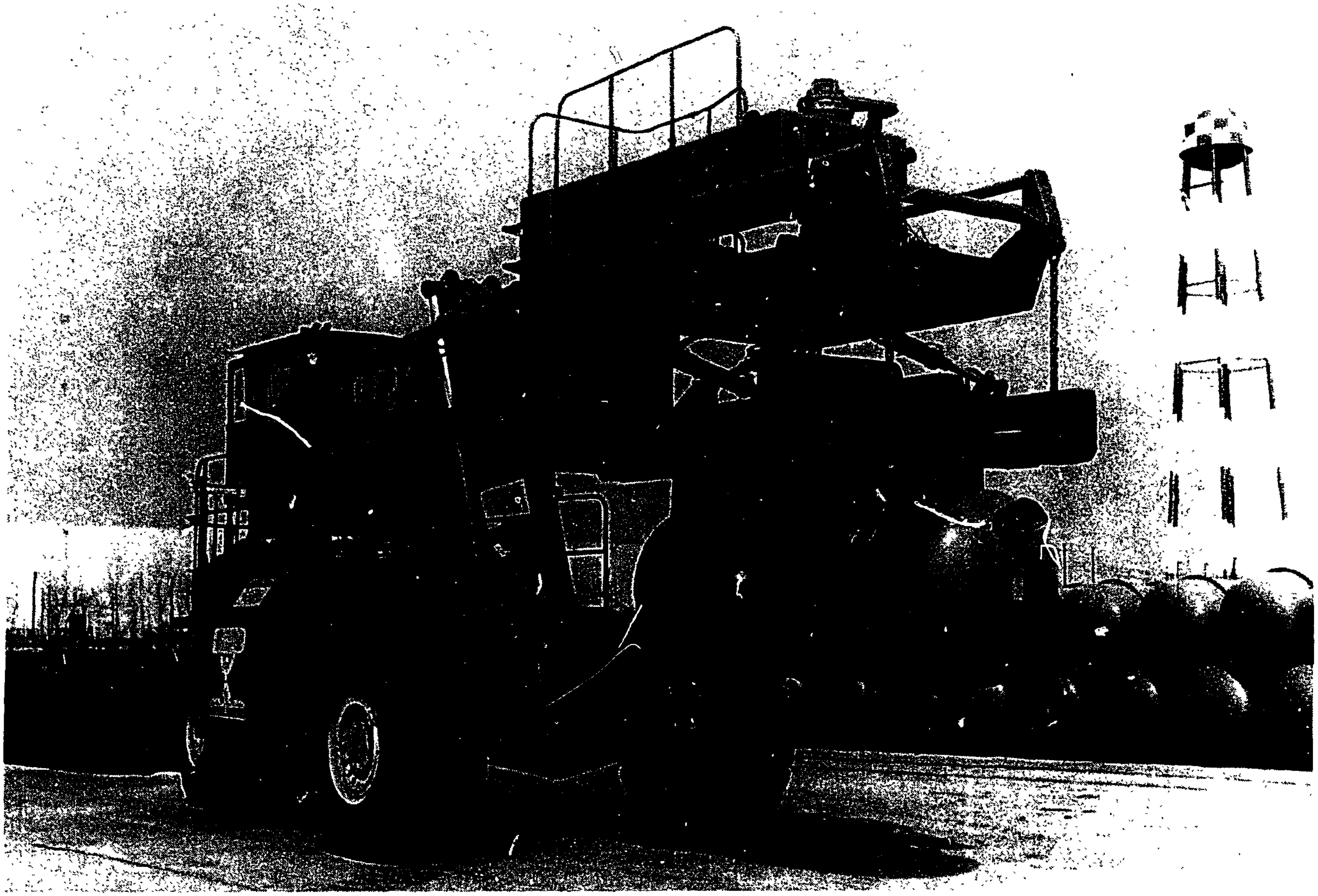


Figure 21

RAYGO WAGNER CYLINDER STACKER

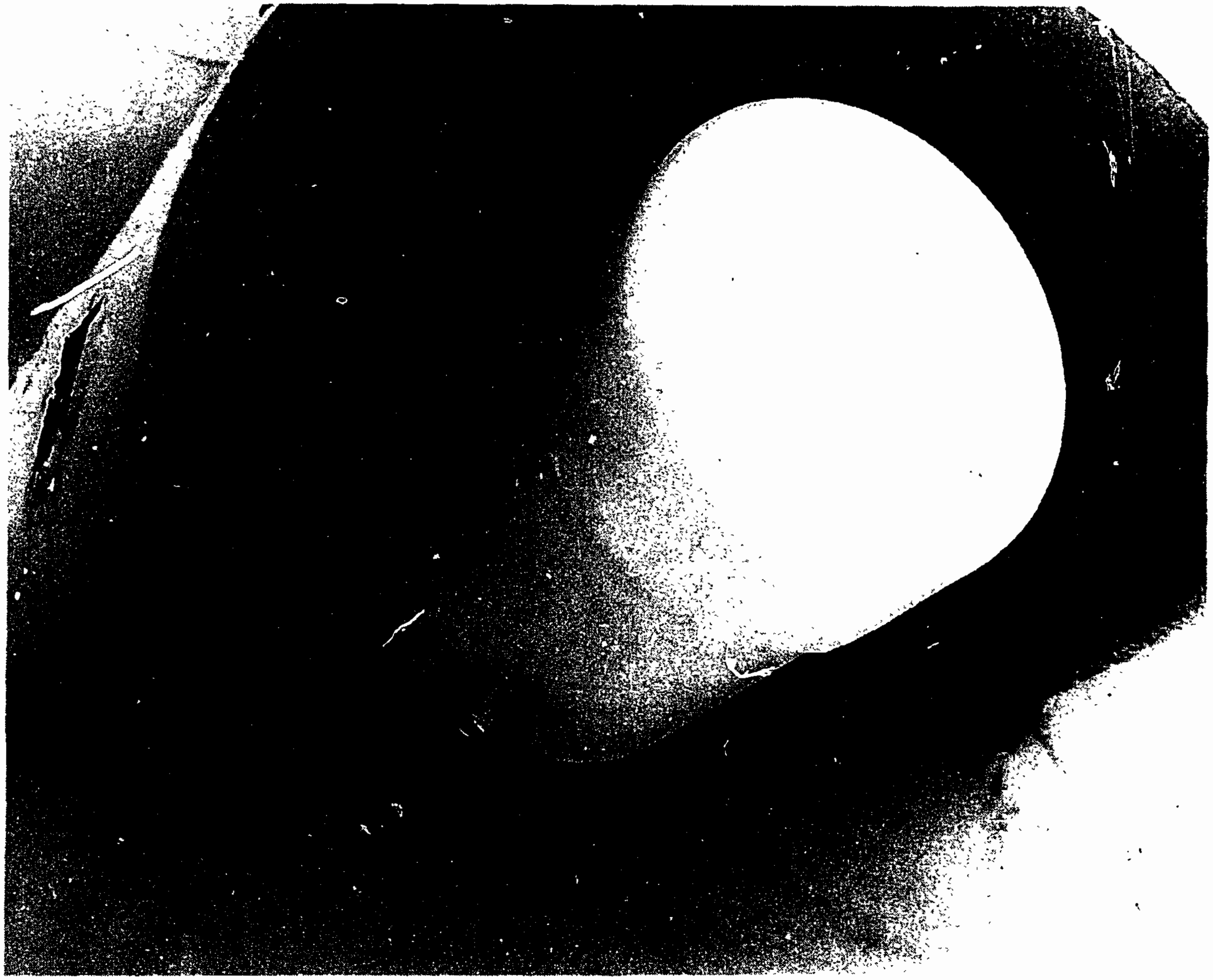


Figure 22

TYPICAL CYLINDER VALVE TAMPER INDICATOR

6.3 PROTECTIVE OVERPACKS FOR FULL CYLINDERS

Except for exempt quantities of fissile material, cylinders containing UF_6 enriched to greater than 1.0 wt % uranium-235 must be shipped in protective overpacks. Provisions to adequately space, protect against accident conditions, and ensure criticality prevention have been incorporated in the designs of the protective overpacks. Protective overpacks which have been designed and tested in accordance with applicable DOE and DOT regulations for UF_6 cylinder Models 5A, 5B, 8A, 12A, 30A, and 30B are shown in Figs. 23 through 26. Drawings and specifications for these protective packages, are available as CAPE PACKAGE No. 1662 from the NTIS Energy Distribution Center, P.O. Box 300, Oak Ridge, Tennessee, 37830, telephone (615) 576-1301. The Model UX-30 protective overpack, manufactured by Nuclear Packaging, Inc., is authorized under NRC Certificate of Compliance USA/9196/AF for transport of Model 30 cylinders. The 48A and 48X overpacks are described in USDOE Report KY-665, *Safety Analysis Report on Paducah Tiger Protective Overpack for 10-Ton Cylinders of Uranium Hexafluoride*, and Supplement 1 to KY-665. Both reports are also available from NTIS.

6.4 PROTECTIVE OVERPACK INSPECTION

Protective overpacks shall be visually inspected by the shipper prior to each use. The following shall be cause for further investigation or removal from service until the defective condition is satisfactorily corrected:

> excessive warping, distortion or other damage of liner or shell which prevents a tight closure of the package; excessive clearances for inner container within the liner; fastener damage; reduction in thermal insulation thickness in any area; or any other damage or condition which would otherwise make the integrity of the protective overpack questionable as a fire- and shock-resistant housing.

The vent holes should be inspected and resealed with an epoxy, if necessary, and the gaskets replaced or resealed, as required. The protective overpacks for Model 30 cylinders should be weighed periodically to determine if water has leaked into the overpack. A weight gain of more than 25 pounds will be grounds for rejection. Overpack tie-downs should be inspected to assure that they are not damaged and are adequate for their intended use. Figure 27 shows a typical overpack inspection sheet.

6.5 EMPTY CYLINDERS

Empty cylinders with valve protectors may be shipped without protective overpacks, provided the residual heel does not exceed the limits shown in Table 7.

Figure 23

PROTECTIVE OVERPACK FOR UF_6 CYLINDER MODEL 5A & 5B
DOT SPECIFICATION 20-PF-1

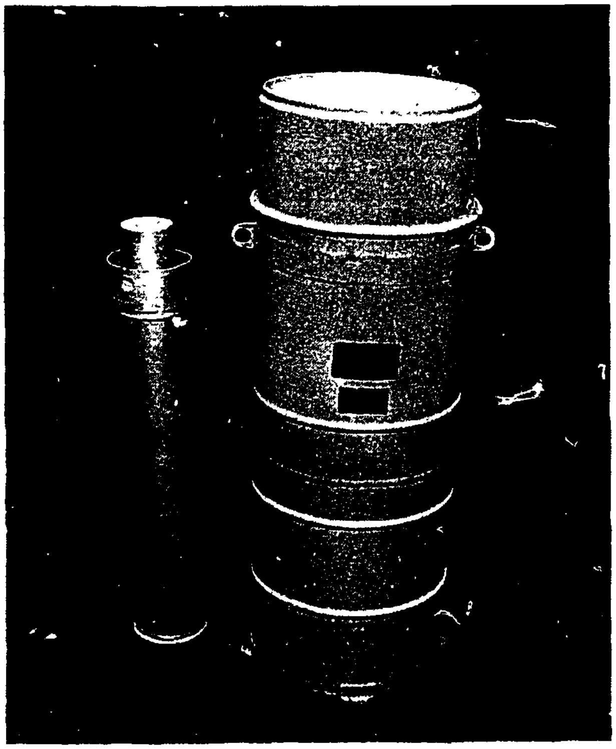


Figure 24

PROTECTIVE OVERPACK FOR UF_6 CYLINDER MODEL 8A
DOT SPECIFICATION 20-PF-2

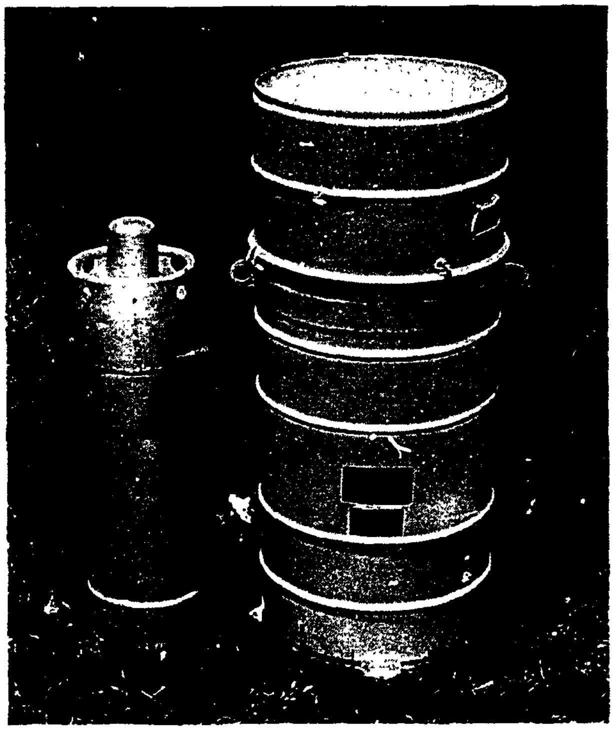


Figure 25

PROTECTIVE OVERPACK FOR UF_6 CYLINDER MODEL 12A
DOT SPECIFICATION 20-PF-3

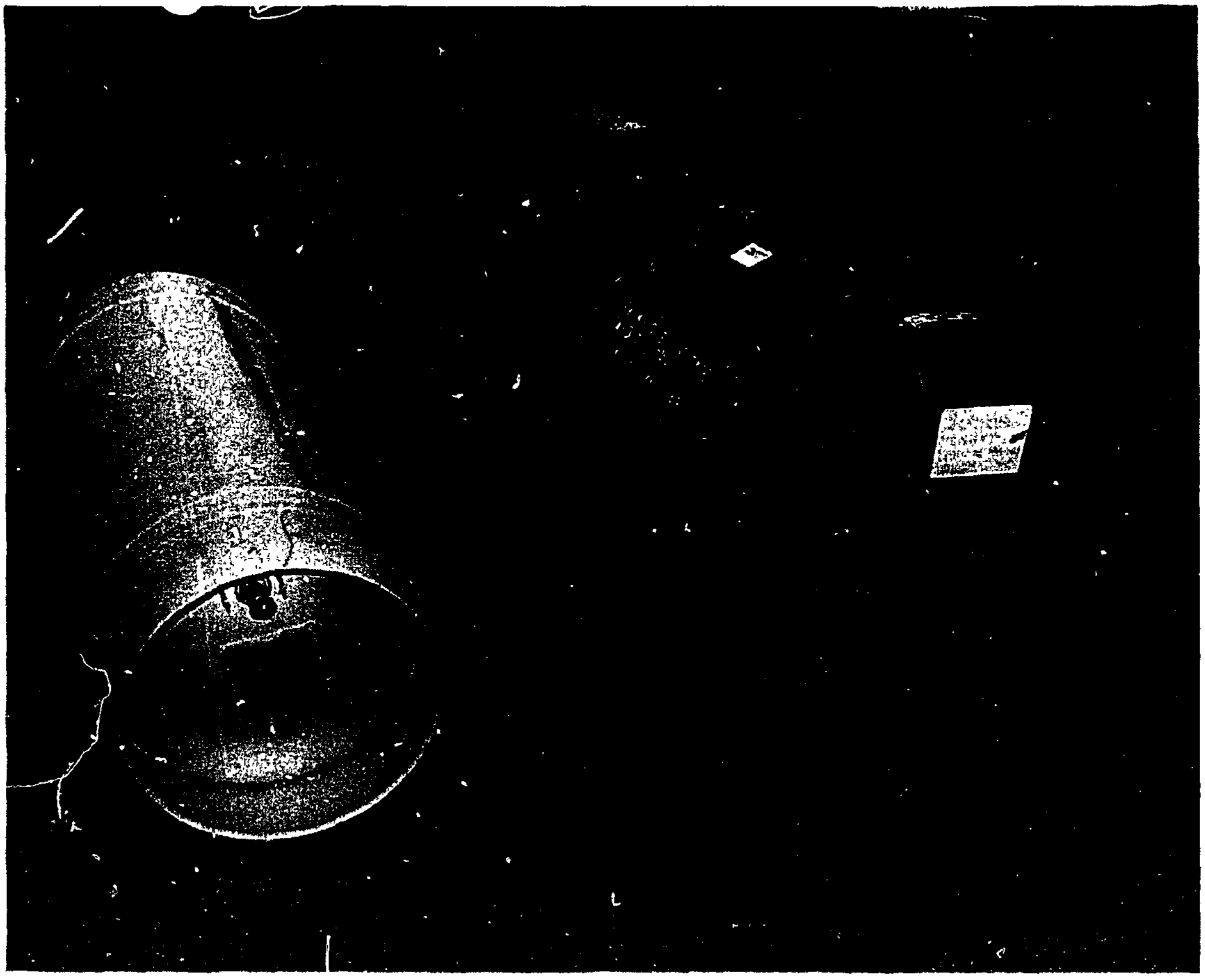


Figure 26
HORIZONTALLY-LOADED PROTECTIVE OVERPACK FOR UF_6 CYLINDER
MODELS 30A AND 30B
DOT SPECIFICATION 21-PF-1

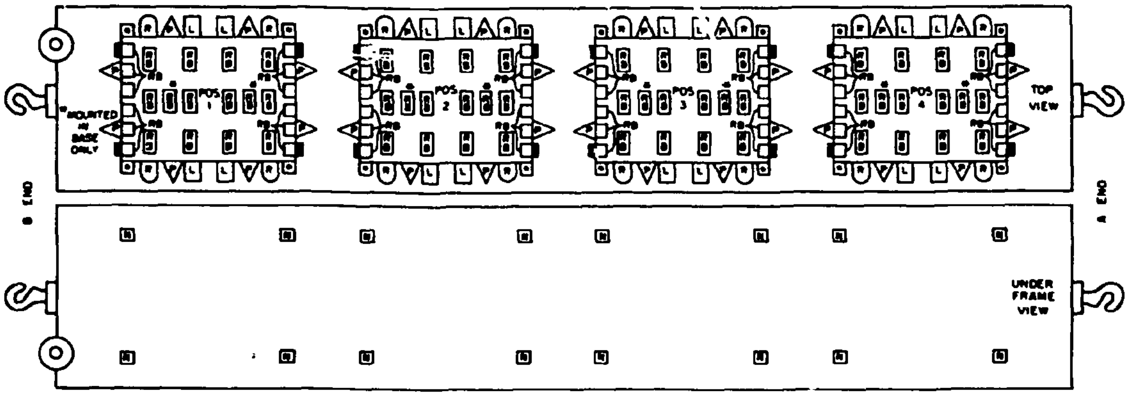
UCN-10633
(5 10-74)

PADUCAH TIGER OVERPACK INSPECTION SHEET

Tally-In or Tally-Out No. ______

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

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



ITEM INSPECTED	SKET. CODE	CONDITION POS. NO. 1	POS. NO. 2	POS. NO. 3	POS. NO. 4	REMARKS (CIRCLE LOCATION OF UNACCEPTABLE ITEM ON ABOVE SKETCH INDICATE REPAIR REQUIRED AND/OR ACTION TAKEN BELOW.)
RUBBER BUMPERS-LID AND BASE	B					
SKIN-INSIDE AND OUTSIDE						
GASKET						
LIFTING LUGS	L					
TIE DOWN LUGS, BOLTS, AND RETAIN'S	D					
TIE DOWN NUTS	N					
TOEPLATES AND SHIMS						
PINS IN PLACE	P					
RATCHETS	R					
D. O. T. LABELS						
PERMIT NUMBER						
PACKAGE PLACARDS						
HAZARDOUS INFO. AND EMERG. INSTR. SIGNS						
VEHICLE PLACARDS						
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

DISTRIBUTION
WHITE - URANIUM CONTROL (KYRC)
BLUE - INSPECTION (WHEN SECTION A IS COMPLETED)
BUFF - ORIGINATOR

CONDITION LEGEND
A - ACCEPTABLE
U - UNACCEPTABLE
NA - NOT APPLICABLE

Figure 27

OVERPACK INSPECTION FORM

Table 7. Maximum cylinder heel weights for shipping

Cylinder Model No.	Heel lb	Heel kg	Maximum Uranium-235, %
5A*, 5B	0.1	0.045	100.00
8A*	0.5	0.227	12.50
12A or 12B*	1.0	0.454	5.00
30A or 30B*	25.0	11.3	5.00
48A, 48X, 48F, or 48Y*	50.0	22.7	4.50
48G, 48H, 48HX*	50.0	22.68	1.00

*49-CFR-173.417(a)(7) authorizes shipment of these cylinders without a protective overpack.

7. STANDARD CYLINDER INFORMATION

7.1 CYLINDER VALVES

The choice of valves used on UF_6 cylinders is very important. The valves described herein have been used by DOE and have proved satisfactory.

7.1.1 Hoke Nos. 4618N4M and 4628N4M (or Approved Equal)

These valves may be used on the Model 1S sample cylinder. Both the angle type, 4628N4M, and the straight-through type, 4618N4M, 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 OD tube connectors, and 1/8-inch orifice.

7.1.2 Hoke No. 2422L64M2 (or Approved Equal)

This valve 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.

7.1.3 Three-Quarter Inch Valve (Superior or Approved Equal per Energy Systems Specification ES-M-176)

Two each of these valves are used on Models 5A, 5B, 8A, and 12B cylinders. A single valve is used on the 12A cylinder. The body, packing gland, and collar are an aluminum-silicon-bronze alloy. The stem is monel and the packing is virgin Teflon. The ports are 3/8-inch diameter.

7.1.4 One-Inch Valve (Superior or Approval Equal per Energy Systems Specification JSP-532)

This valve is used on Models 30A, 30B, 48A, 48F, 48X, 48Y, 48H, 48HX, and 48G cylinders and is referred to as a 1-inch valve because of its outlet port size. The body, packing nut, packing ring, and packing follower are an aluminum-silicon-bronze alloy, while the stem is monel. The packing and cap gasket are virgin Teflon.

7.2 REQUIREMENTS FOR UF_6 CYLINDERS

Uranium hexafluoride cylinders must adhere to rigid standards for design, fabrication, and certification. New fabrication of non-U.S.-made cylinders must comply with the standards specified in the latest revision of ANSI N14.1, Packaging of Uranium Hexafluoride for Transport.

7.2.1 Approval for Cylinder Modification

The cylinder designs in ANSI N14.1 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 provided if installed and tested in the manner specified in ANSI N14.1; however, DOE approval will be required before filling with UF_6.

7.2.2 Reports, Certification, and Records

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

The manufacturer shall provide, if required by the purchaser, a copy of the as-built drawing pertaining to the cylinder or cylinders involved. 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 on the applicable specification. The certified water capacity and hydrotest date shall also be stamped on the cylinder as part of the nameplate data.

The manufacturer shall retain fabrication and inspection records in accordance with ASME Code requirements. The purchaser shall retain his copies of the Manufacturer's Data Report, drawings, certifications, and other related papers on file throughout his 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.

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

Users of non-U.S.-made cylinders shall be required to certify that the design, fabrication, tests, cleanliness, and volume of their cylinders are in compliance with requirements specified herein and in ANSI N14.1 Packaging of Uranium Hexafluoride for Transport, before they are accepted for sampling, filling, or material transfer in DOE facilities. This certification shall be in the English language. 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 shall be required. In all instances where the certification data was 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 be required to certify that the design, fabrication, materials, and testing meet the requirements specified herein and as described in ANSI N14.1 (ANSI N14.1-50 and ANSI N14.1-51).

Allowable deviations from established standards for valves and/or cylinders require written DOE approval with concurrence from DOE operating facilities before the deviating equipment will be used.

7.3 CLEANLINESS

Cleanliness is of primary importance whether the UF_6 cylinder is new or one that is already in-service.

> ***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 appreciably 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 is preferred and recommended to preclude introduction of reactive contaminants into cylinders.*

7.3.1 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 surfaces shall be left clean, dry, and free of all contamination.

7.3.2 In-Service Cylinders

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

7.3.3 Cylinder Outer Surfaces

Cylinder surfaces shall be monitored and cleaned of surface contamination when required to meet applicable radiation requirements.

7.3.4 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.

7.4 SERVICE INSPECTIONS, TESTS, AND MAINTENANCE

In order to maintain safe, usable UF_6 cylinders, routine and periodic cylinder tests must be performed. Cylinder repairs, and valve and plug replacement, must follow the standards explained in Sections 7.4.3 through 7.4.6.

7.4.1 Routine Inspections

All UF_6 cylinders shall be routinely inspected as-received, and prior to sampling, emptying, filling, or shipping to assure that they remain in a safe, usable condition.

7.4.2 Periodic Inspections and Tests

All cylinders shall be periodically inspected and tested throughout their service lives at intervals not to exceed five years, except that full cylinders need not be internally inspected and hydrostatically tested until emptied. However, cylinders which have not been inspected and tested within the required five-year period shall not be refilled until properly reinspected, retested, and restamped on the nameplate. Prior to shipment, cylinders which have not been recertified within the five-year requirement shall be visually inspected for degradation of the cylinder wall. Any questionable conditions should be investigated further including ultrasonic wall thickness measurements if appropriate.

The periodic inspection shall consist of an internal and external examination of the cylinder by a qualified inspector (a qualified inspector is 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. The hydrostatic test shall be applied at a pressure equal to the original test pressure. The air test shall be at a pressure of 100 psig, and it shall be applied after the cylinder has been dried and after all valves and fittings have been reinstalled. Cylinders which 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 a period of 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 in its existing condition. Cylinders shall no longer be used in UF_6 service when their shell and/or head thicknesses have decreased below the values shown in Table 8:

Table 8. Minimum cylinder thickness

Cylinder Model	Minimum thickness, inch
1S	1/16
2S	7/64
5A, 5B	1/8
8A	1/8
12A, 12B	3/16
30B	5/16
48A, 48F, 48X, 48Y	1/2
48H,* 48HX,* 48G,* 480M*	1/4

*Low Specific Activity UF_6 Cylinders.

A tagging system will be used to 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 will be used to identify cylinders exceeding the five-year test date limit.

7.4.3 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, and (3) they are performed by an ASME code shop or a shop possessing a National Board Inspection Code Repair Stamp.

Welded repairs or alterations to pressure parts shall require the use of ASME Code-qualified welding procedures, welders, and inspectors.

Repairs or alterations to pressure parts shall 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 repair of torn or deformed areas of pressure-containing materials are involved.

A careful inspection of cylinders and valves is an important prerequisite to any operation. Filled cylinders are easily dented or otherwise damaged; therefore, all cylinder movements must be performed carefully and slowly.

7.4.4 Cylinder Valve and Plug Replacement

Replacement of brazed 3/4-inch valves in 5-, 8-, and 12-inch cylinders can only be successfully accomplished by following the brazing specifications referenced with each type of cylinder using this method of installation. Field replacement should not be attempted, since the valve coupling will likely crack due to the presence of contaminant materials.

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. With adequate safety equipment, slowly loosen the valve. 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 nor more than 400 ft-lb for the 1-inch valve and the 3/4-inch valve. After insertion, the number of threads inserted should not be less than seven (7) nor more than twelve (12) for either valve size. These valves have 13 to 14 threads as manufactured. If possible, the seal at the valve coupling should be soap tested at 5 psig, or as an alternative, the vacuum after the valve change should be recorded and if unchanged after five days, the seal was successfully made. Cold burping may be required after a valve change to remove air and preclude high pressures during subsequent heating of the repaired cylinder.

Plug changes are accomplished in a similar manner. Specification components are required to obtain proper thread engagement for both valves and plugs.

The inspection procedure for the cylinder plug(s) for damage 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 threads engaged by subtracting the threads showing from the total threads. A minimum of five threads engaged 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 by Quality Evaluation 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 gives assurance that the minimum requirement for at least five threads engaged into the cylinder is met. Plugs that have been seal welded into the cylinder are acceptable providing a minimum of five threads are engaged. When the seal weld on a seal welded plug 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 criteria, the total number of plug threads should be stamped on the end of the plug.
>
> Cylinder plugs which do not pass the criteria for threads engaged in the cylinder or which are damaged shall not be shipped or used until the defect is corrected or the apparent defect has been determined to be acceptable. For cylinder plugs which appear to have an excessive number of threads extending out of the cylinder, the actual number of threads engaged should be determined ultrasonically.

7.4.5 Three-Quarter Inch Valve Wear Inspections

Because of the brazed joint required of the 3/4-inch valve in 5-, 8-, and 12-inch cylinders, these valves cannot be easily replaced; therefore, if possible, the 3/4-inch valve is 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 adverse corrosion, erosion, distortion, or other damage which would make it unserviceable. This inspection is followed by a 100-psig air test and a helium leak test. Other tests, such as radiographic examination, may be conducted prior to use.

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

7.4.6 One-Inch Valves - Defects/Acceptability

Over the years, a number of one-inch valves or valve components have been found to be unsatisfactory for service in DOE 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 bonnet nuts which have been inspected and found satisfactory have been marked as follows: A, A6, 6A, 636A, 51-1, or PGDP. Valve bonnets without these markings have split during service allowing stem packing rings to be forcefully ejected from the valve.

Superior Model 11246 valves showing a small raised "8" on the side or Rego Model 11246 valves showing an "LH" have been broken at the thread while opening or closing the stem. The Superior raised "8" valve should not be used for liquid or gaseous 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.

One-inch valves of the French/DESCOTE manufacture with the marking "No. 1000 M14-1-51" also should be replaced before cylinder use.

7.5 SAFETY CONSIDERATIONS

DOE has developed and evaluated procedures which include all the necessary precautions used for safe handling of UF_6.

7.5.1 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 DOE facilities during the more than 40 years of handling vast quantities of UF_6. 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 the atmospheric moisture to form HF gas and particulate UO_2F_2 which 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 quite 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 uranium of uranium-235 enrichment less than 10%, the chemical toxicity is more significant than the radiotoxicity.

The UO_2F_2 and HF which form during a release to the atmosphere is readily visible as a white cloud. A concentration of 1 mg of UO_2F_2 per cubic meter of air is visible and the cloud from large releases may obscure vision.

7.5.2 Hazards and Precautions

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

7.5.2.1 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 when the valve protector is correctly installed. Liquid UF_6 is hot, pressurized, and very mobile. Movements of partially filled cylinders result in surges of the dense liquid which can upset handling equipment and cause loss of control. A 3-day cool-down period should be observed for Model 30 cylinders and a 5-day period for Model 48 cylinders.

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.

7.5.2.2 Filling Cylinders

Cylinders can be overfilled by filling with liquid, by desubliming the UF_6 as a solid in the cylinder from a gaseous system, and by condensing light-weight contaminants into the UF_6 cylinder. If the cylinder is overfilled, it may be hydraulically deformed and rupture upon heating. Overfilling is prevented by adhering to weight limitations, and maintaining a high purity in the UF_6 system. If overfilling occurs, the cylinder can be connected to an evacuation system and the excess UF_6 removed until the correct fill limit is obtained. See Section 3.5 Overfilled Cylinders.

7.5.2.3 Heating UF_6 Cylinders

Never heat a UF_6 cylinder (except a sample cylinder) when the cylinder valve is closed or when the cylinder is not valved to a pressure monitoring system. Heating UF_6 cylinders must be carefully controlled to avoid overpressuring the cylinder causing possible cylinder rupture. Heating UF_6 cylinders is normally required during liquid sampling and emptying the cylinder. UF_6 when below the triple-point temperature of 147.3°F exists as a solid and vapor. The solid UF_6 has a density of approximately 317.8 lbs/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 plus possibly other impurities such as hydrogen fluoride (HF), refrigerant gases, and air. The presence of these impurities can be detected by measuring the gas phase pressure and comparing it to the UF_6 phase diagram, Fig. A-3. 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 lbs UF_6 and enough air to measure 10 psia internal pressure on a cold pressure check, when heated to 235°F will have an internal pressure of approximately 144 psia which, if in a Model 48G, H or HX cylinder, will exceed the design pressure of the cylinder. The internal pressure increases from 10 to 144 psia because the UF_6 expands from about 85 ft^3 volume, ~60.8% of the cylinder volume, at 60°F to about 130.5 ft^3 volume, ~93.2% of the cylinder volume, at 235°F. This expanding UF_6 and temperature change 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 result in a total pressure of near 144 psia. If heated to 250°F the total pressure would approach 190 psia.

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

Overheating cylinders can cause the expanding UF_6 liquid to hydraulically deform and rupture the cylinder. UF_6 exhibits a significant "expansion factor" when going from a solid to a liquid. The "expansion factor" of UF_6 from a solid at 70°F to a liquid at 235°F is approximately 1.53, a 53% increase in volume. Since cylinders are normally filled with UF_6 at temperatures of about 160°F the quantity 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 lbs, could accept up to 31,430 lbs UF_6 at 160°F, however, 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 lbs would rupture the cylinder if heated above 235°F. To avoid possible hydraulic rupture, overfilled cylinders should never be heated indiscriminately nor should non-overfilled cylinders be overheated. Hydraulic rupture is a well understood phenomenon, and is prevented by establishing cylinder fill limits based on UF_6 density at 250°F for all cylinders, except cylinders for UF_6 tails storage where 235°F is the basis. For added safety in DOE owned facilities, cylinders are heated in autoclaves with a controlled steam pressure of less than 8 psig to guarantee that the contents will not exceed a temperature of 235°F. In addition to taking the temperature into account, standard minimum volumes for cylinders are used. At least a 3% ullage allowance is provided for UF_6 tails storage and 5% ullage allowance for feed and product storage, to reduce the possibility of exceeding the cylinder service pressure due to the presence of high-vapor pressure contaminants. In the case of the 48G cylinder with tails material, the UF_6 fill limit, based on a minimum certified volume of 139 ft^3 and 3% ullage at 235°F, is 28,000 lb. Adherence to these conditions is assured by (1) publishing the cylinder fill limits, (2) requiring the cylinder manufacturer to measure the cylinder volume by water weighing (3) maintaining accurate scales to determine the net contents of a cylinder, (4) operating the withdrawal stations to yield high purity UF_6, (5) controlling the maximum steam heating pressure, (6) utilizing the cold cylinder vapor pressure measurements to verify the amount of volatile impurities present before heating the cylinder, and (7) complying with the conditions indicated on the cylinder nameplate.

7.5.2.4 Localized Heating

Localized heating of a manifold system to remove a UF_6 plug is very hazardous. Liquefying a quantity of UF_6 in a restricted space, such as between two solid UF_6 sections or between two valves, can readily result in hydraulic rupture of the system and UF_6 release. Since the valve packing and plastic gaskets used soften at elevated temperatures, localized heating should be avoided. Solid UF_6 plugs usually can be vaporized by evacuation to a low pressure source.

7.5.2.5 Damaged Cylinder Valves

Occasionally, valves are damaged in handling full cylinders of UF_6 which 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 available emergency equipment similar to that shown in Fig. 28.

7.5.2.6 Manifold Connection Leaks

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

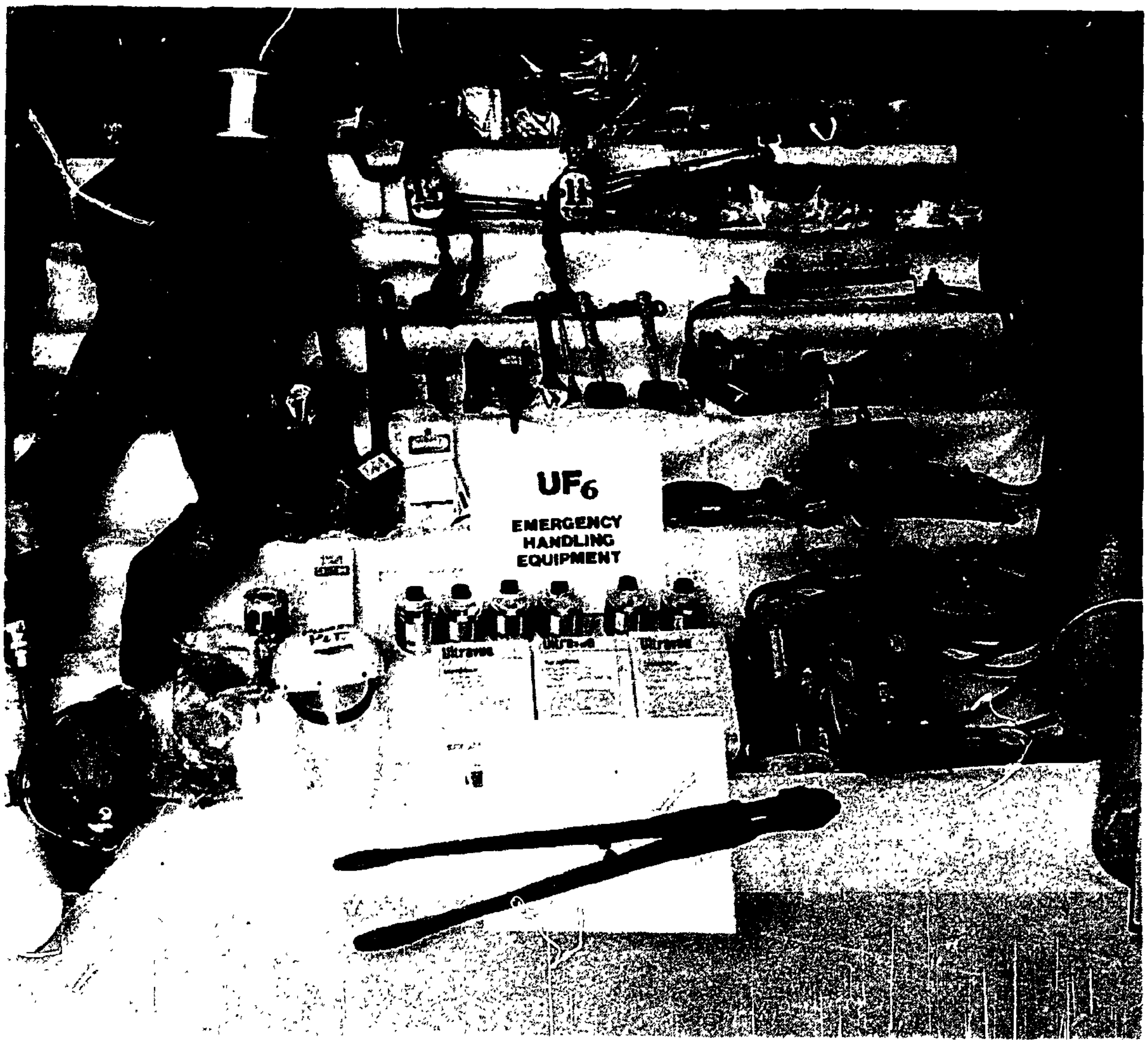
7.5.2.7 Release of UF_6

The control of UF_6 releases requires pre-planning with respect to emergency procedures and equipment. Respiratory protective 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 dense clouds from UF_6 releases requires 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 smoke of the release. The wooden plugs should be designed to be inserted into holes which might occur as a result of broken or defective valves, line breakage, etc. Patches should be shaped to fit contours of the UF_6 cylinders.

A UF_6 release may be terminated 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 (see Section 7.5.3). In no case should water be streamed directly into a cylinder opening. Dry ice or pressurized CO_2 from large-capacity fire extinguishers may be used safely with any enrichment to freeze off leaks. If the cylinder content is liquid, extended freeze off periods will be required. However, nuclear safety evaluations should be made beforehand to assure the absence of possible unsafe accumulations of uranium.

7.5.2.8 Radiation

The radioactivity of UF_6 produced from the unirradiated uranium varies with the uranium-235 enrichment. Naturally occurring uranium has a specific



MAJOR ITEMS INCLUDE:

- FULL COVERAGE ACID SUIT
- SELF CONTAINED BREATHING APPARATUS
- CONTOURED INFLATABLE CYLINDER LEAK PATCH EQUIPMENT
- FULL FACE RESPIRATOR WITH HF AND RADIONUCLIDE CANNISTER
- WOOD PLUGS FOR BROKEN VALVES
- PIGTAIL CRIMPING TOOL

Figure 28
EMERGENCY EQUIPMENT

activity of 1.5 disintegrations per minute per microgram (d/m/μg). Of this activity, the isotopes of uranium-235 and uranium-234 each contribute about half. As the enrichment in uranium-235 is increased, the activity from uranium-234, which enriches faster than uranium-235, increase very rapidly. Highly enriched uranium produced from natural uranium feed has a specific activity (SA) of about 200 d/m/μg which is almost entirely from uranium-234. While the exact specific activity of slightly enriched uranium depends on the history of the particular material, it may be approximated by:

$$SA(d/m/\mu g) = 0.75 + 1.06 \text{ (wt \% uranium-235)}$$

Alpha particles resulting from the primary disintegration of uranium present no external radiation problem, since they do not penetrate the skin. However, the decay products of uranium include isotopes which 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. 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 transuranium elements which may be present in UF_6 produced from irradiated uranium is not considered in this report.

7.5.2.9 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.

7.5.3 Criticality Control

A paramount consideration in the handling and shipping of cylinders of UF_6 is the application of stringent controls to prevent an inadvertent nuclear chain reaction or criticality condition. 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 which may be contained in an individual cylinder and the total number of cylinders which may be transported together are determined by the nuclear properties of the UF_6. Spacing of cylinders of enriched UF_6 in transit is assured through the use of DOT specification packages or DOE and/or NRC approved packages which also provide protection against impact and fire.

The use of Models 30 (A and B) and 48 (A, F, X, G, H, HX, and Y) cylinders at uranium-235 enrichments of 5.0% and 4.5%, respectively, is dependent on 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 as given in the Federal Register. For shipment of UF_6 above the 5.0% uranium-235, geometric or mass limits are employed. Shipment of enriched UF_6 in Models 48G, H, and HX cylinders without overpacks is limited to 1 wt % uranium-235.

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

8. STANDARD DOE UF_6 CYLINDER AND VALVE DATA

8.1 GENERAL

The information included for each standard DOE UF_6 cylinder is as follows:

1. Photograph of cylinder and valve.

2. General data.

All privately owned cylinders which are utilized in shipments to and from DOE facilities must meet the specifications of ANSI N14.1, latest revision unless deviations have been approved by DOE and DOT prior to use. All cylinders must be certified for structural integrity, as described in Sect. 2.2.

All cylinders and valves which do not meet the described standards will be categorically rejected for use at the DOE facilities unless approved by DOE in writing.

The 30A cylinder is obsolete, having been replaced by 30B. After December 31, 1992, DOE will no longer accept 30A cylinders for filling at its facilities.

Table 9. UF_6 cylinder data summary

Cylinder model no.	Nominal diameter, inch	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 wt % uranium-235	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	0.0254	0.72	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
30A	30	Steel	25.65	726.0	1,400	635	5.0[b]	4,950	2,245
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]	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

[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% ullage for safety. The operating limits apply to UF_6 with a minimum purity of 99.5%. 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%. Without moderation control, the maximum permissible enrichment is 1.0 wt % uranium-235.

[c]This cylinder replaces the Model 30A cylinder.

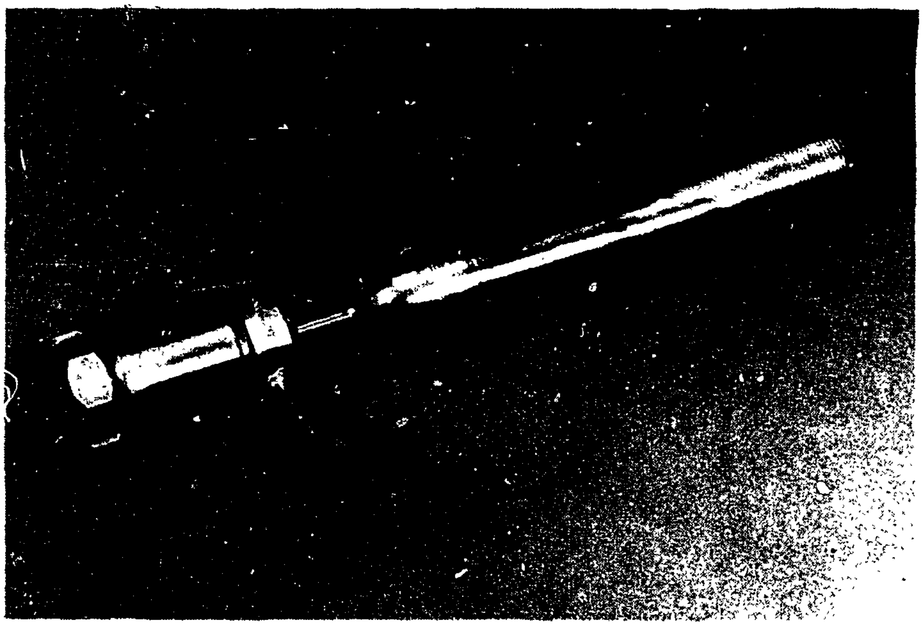
[d]Models 48X and 48Y replace Models 48A and 48F whose volumes have not been certified.

[e]For DOE gaseous diffusion plant tails with UF_6 purity in excess of 99.5%, the shipping limit is 28,000 lbs for cylinders with 8880 lbs water capacity or greater.

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

8.2 UF_6 CYLINDER MODEL 1S

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

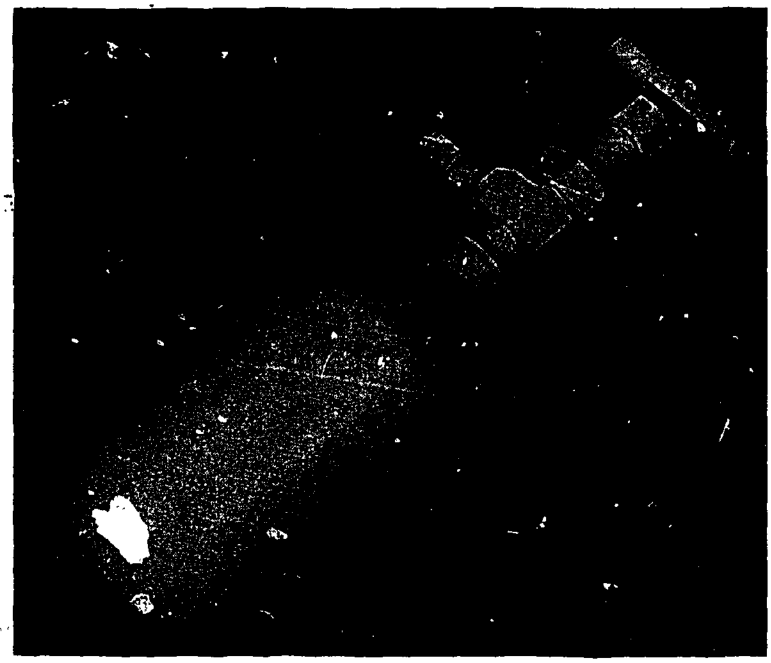
Other Descriptive Terminology Used - None

Nominal Diameter	1-1/2 in.
Nominal Length	11 in.
Wall Thickness	1/16 in.
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	200 psig
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	100% U-235

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

8.3 UF_6 CYLINDER MODEL 2S

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

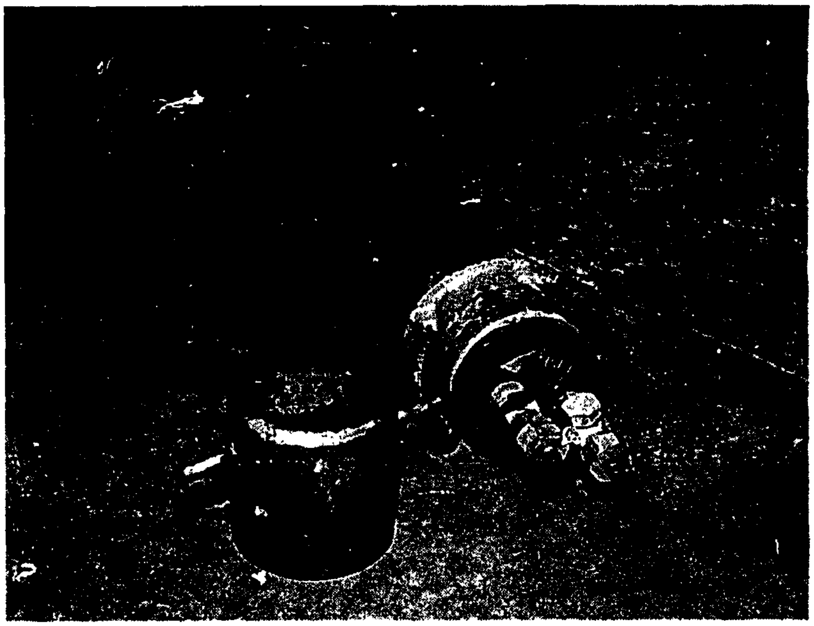
Other Descriptive Terminology Used - Harshaw Tpe

Nominal Diameter	3-1/2 in.
Nominal Length	11-1/2 in.
Wall Thickness	0.112 in. (min)
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
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	100% U-235

Valve Used - Hoke No. 2422L64M2, or equal.

8.4 UF_6 CYLINDER MODEL 5A AND 5B

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

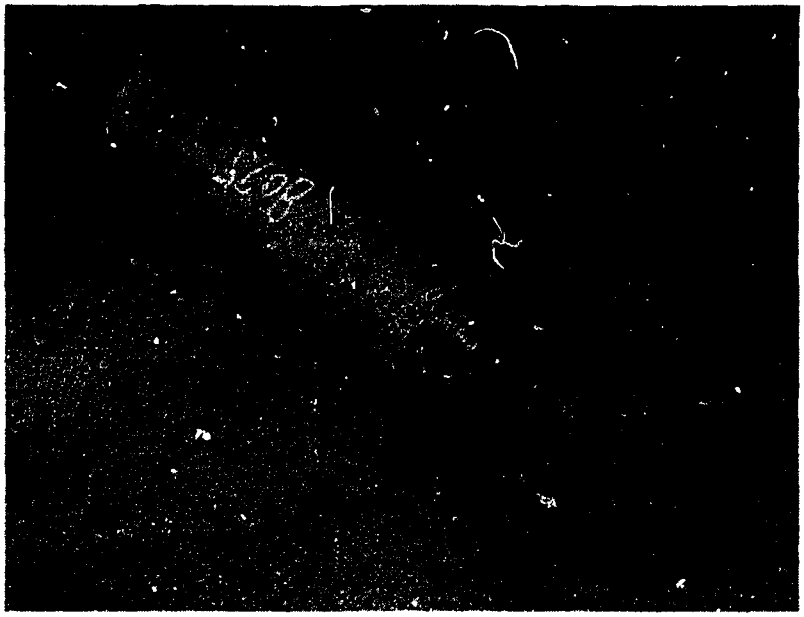
Other Descriptive Terminology Used - 5-in. product

Nominal Diameter		5 in.
Nominal Length		36 in.
Wall Thickness		1/4 in.
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
	5B	Nickel
Service Pressure		200 psig
Hydrostatic Test Pressure		400 psig
Isotopic Content Limit		100% U-235

Valve Used - 3/4-in. Valve

8.5 UF_6 CYLINDER MODEL 8A

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

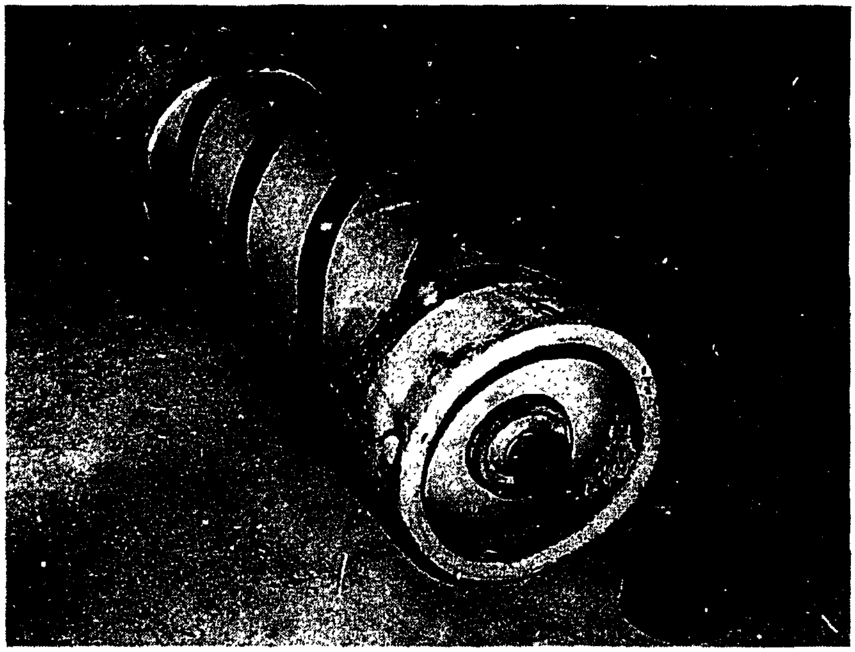
Other Descriptive Terminology Used - 8 in.

Nominal Diameter	8 in.
Nominal Length	56 in.
Wall Thickness	3/16 in.
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
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	12.5% U-235 max

Valve Used - 3/4 in. Valve

8.6 UF_6 CYLINDER MODEL 12A*

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

Other Descriptive Terminology Used - 12-in., MD

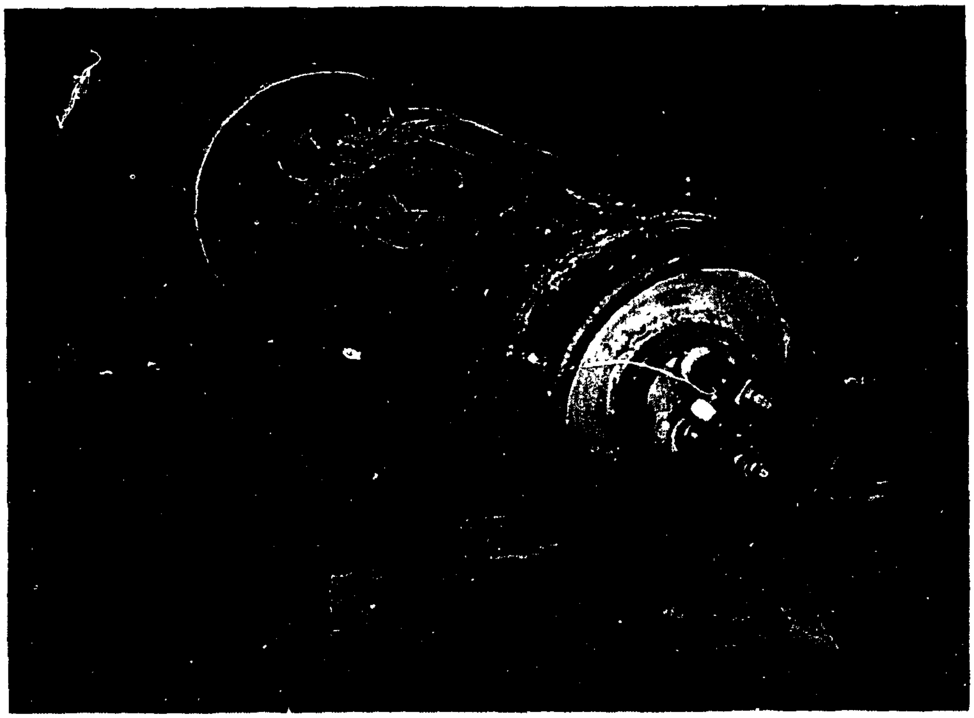
Nominal Diameter	12 in.
Nominal Length	54 in.
Wall Thickness	0.200 in.
Nominal Tare Weight	185 lb (84 kg)
Maximum Net Weight	460 lb (208.7 kg)
Nominal Gross Weight	645 lb (without cap)(293 kg)
Minimum Volume	2.38 ft^3 (67.4 liters)
Basic Material of Construction	Nickel
Service Pressure	200 psig
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	5.0% U-235 max

Valve Used - 3/4-in. Valve

*OBSOLETE – SUBSTITUTE MODEL 12B

8.7 UF_6 CYLINDER MODEL 12B

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

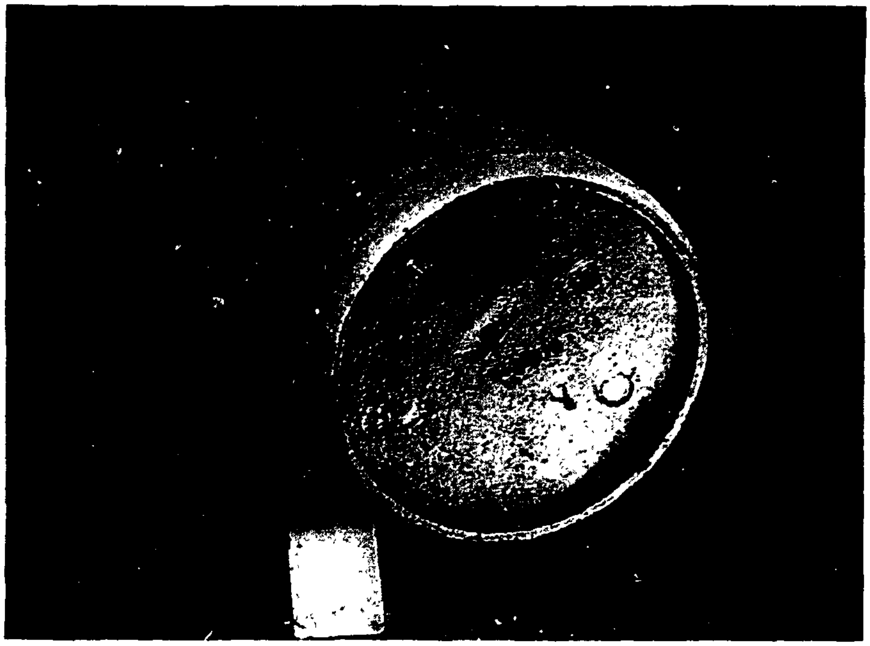
Other Descriptive Terminology Used - 12 in. - 2 Valves.

Nominal Diameter	12 in.
Nominal Length	49.5 in.
Wall Thickness	0.250 in.
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
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	5.0% U-235 max

Valve Used - 3/4-in. Valve

8.8 UF_6 CYLINDER MODEL 30A*

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

Other Descriptive Terminology Used - 2-1/2-ton UF_6, 1-ton chlorine

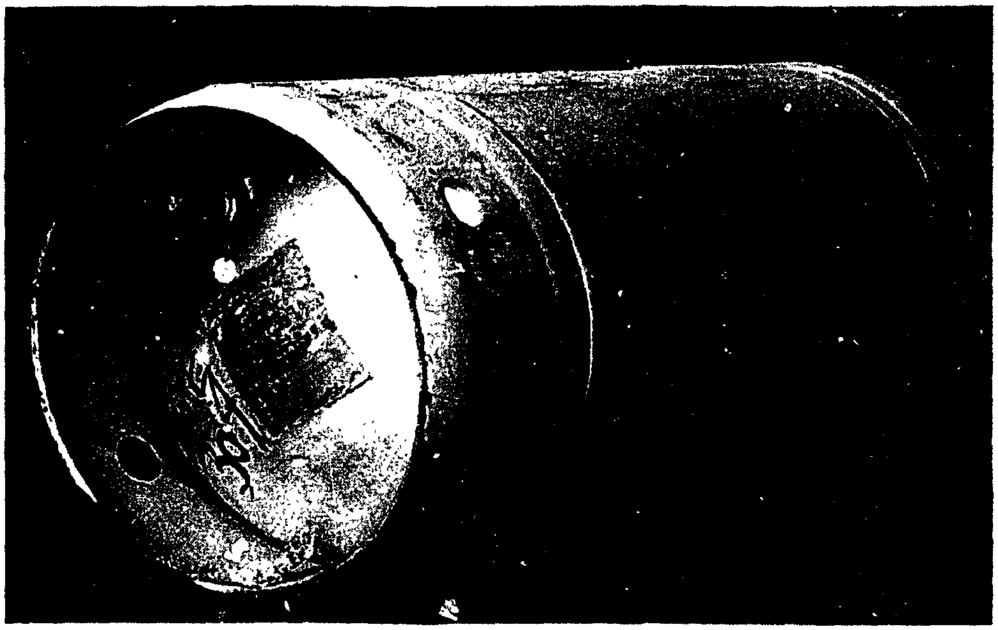
Nominal Diameter	30 in.
Nominal Length	81 in.
Wall Thickness	13/32 in.
Head Thickness	3/4 in.
Nominal Tare Weight	1,400 lb (635 kg)
Maximum Net Weight	4,950 lb (2,245 kg)
Nominal Gross Weight	6,350 lb (2,880 kg)
Minimum Volume	25.65 ft^3 (726 liters)
Basic Material of Construction	Steel
Service Pressure	192 psig (approximately)
Hydrostatic Test Pressure	500 psig
Isotopic Content Limit	5.0% U-235 max with moderation control

Valve Used - 1-in Valve.

*OBSOLETE – SUBSTITUTE MODEL 30B – DOE WILL NOT FILL 30A CYLINDER AFTER DEC 31, 1992.

8.9 UF_6 CYLINDER MODEL 30B

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

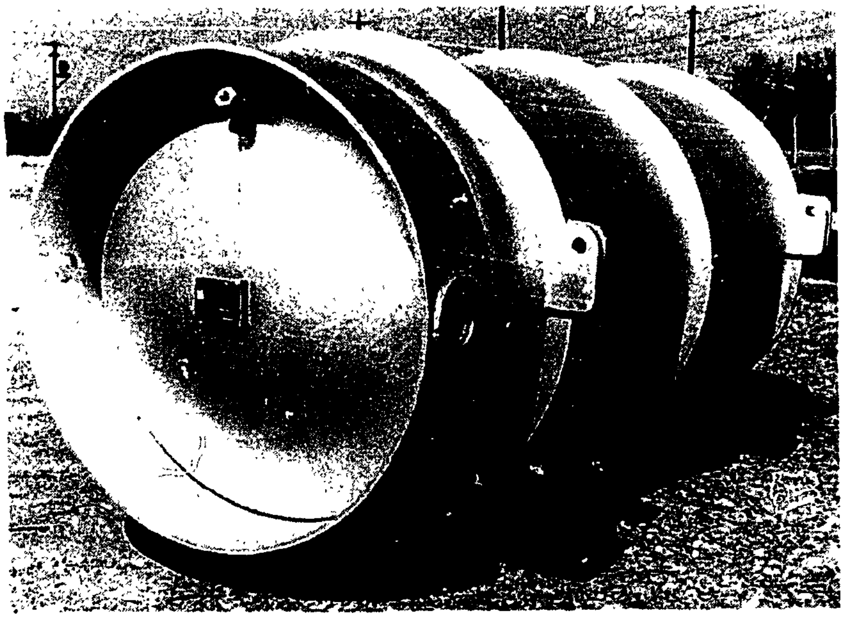
Other Descriptive Terminology Used - 2-1/2-ton

Nominal Diameter	30 in.
Nominal Length	81 in.
Wall Thickness	1/2 in.
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
Service Pressure	200 psig
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	5.0% U-235 max with moderation control

Valve Used - 1-in. Valve.

8.10 UF_6 CYLINDER MODEL 48X

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

Other Descriptive Terminology Used - 10-ton

Nominal Diameter	48 in.
Nominal Length	121 in.
Wall Thickness	5/8 in.
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 (3.084 m^3)
Basic Material of Construction	Steel
Service Pressure	200 psig
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	4.5% U-235 max with moderation control

Valve Used - 1-in Valve.

NOTE: Previously built 48A cylinders are similar in design, but do not have certified volumes; refer to Table 9 for fill limits and other data applicable to this cylinder.

8.11 UF_6 CYLINDER MODEL 48Y

Below is a photograph of the cylinder and valve and general data.

GENERAL DATA

Other Descriptive Terminology Used - 14-ton

Nominal Diameter	48 in.
Nominal Length	150 in.
Wall Thickness	5/8 in.
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
Service Pressure	200 psig
Hydrostatic Test Pressure	400 psig
Isotopic Content Limit	4.5% U-235 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 9 for fill limits and other data applicable to this cylinder.

8.12 UF_6 CYLINDER MODEL 48G

Below is a photograph of the cylinder and valve and general data.

GENERAL DATA

Nominal Diameter	48 in.
Nominal Length	146 in.
Nominal Wall Thickness	5/16 in.
Nominal Tare Weight	2,600 lb (1,179 kg)
Maximum Net Weight	28,000 lb (12,701 kg)*
Nominal Gross Weight	30,600 lb (13,880 kg)
Minimum Volume	139 ft^3 (3.94 m^3)
Basic Material of Construction	Steel**
Service Pressure	100 psig
Hydrostatic Test Pressure	200 psig
Isotopic Content Limit	1% U-235

Valve Used - 1-in. Valve.

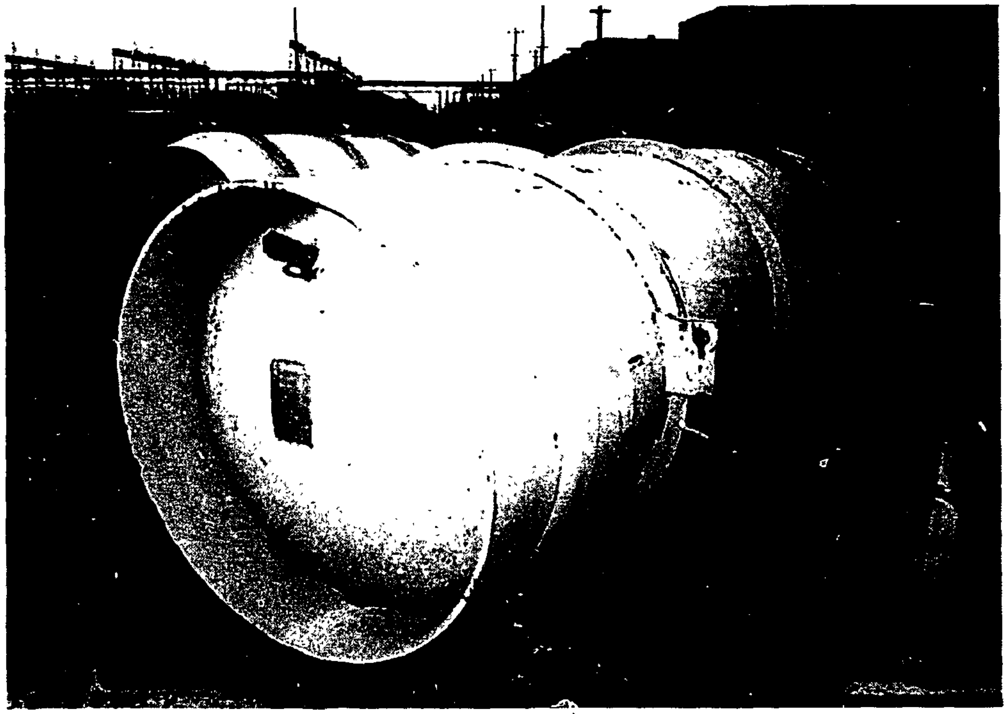
*Based on 235° F (113° C).

**Steel specification changed from A-285 to A-516 for cylinders ordered after 1978.

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

8.13 UF_6 CYLINDER MODEL 48H AND 48HX

Below is a photograph of the cylinder and valve and general data.



GENERAL DATA

Other Descriptive Terminology Used - 14-ton.

Nominal Diameter	48 in.
Nominal Length	146 in.
Wall Thickness	5/16 in.
Nominal Tare Weight	3,170 lb (1,438 kg)
Maximum Net Weight	27,030 lb (12,261 kg)
Nominal Gross Weight	30,200 lb (13,699 kg)
Minimum Volume	140 ft^3 (3.96 m^3)
Basic Material of Construction	Steel*
Service Pressure	100 psig
Hydrostatic Test Pressure	200 psig
Isotopic Content Limit	1% U-235

Valve Used - 1-in Valve.

*48HX cylinders are fabricated with A-285 steel, 48H cylinders are fabricated with A-516 steel.

8.14 SAMPLE CYLINDER VALVES

The photograph below shows sample cylinder valves.

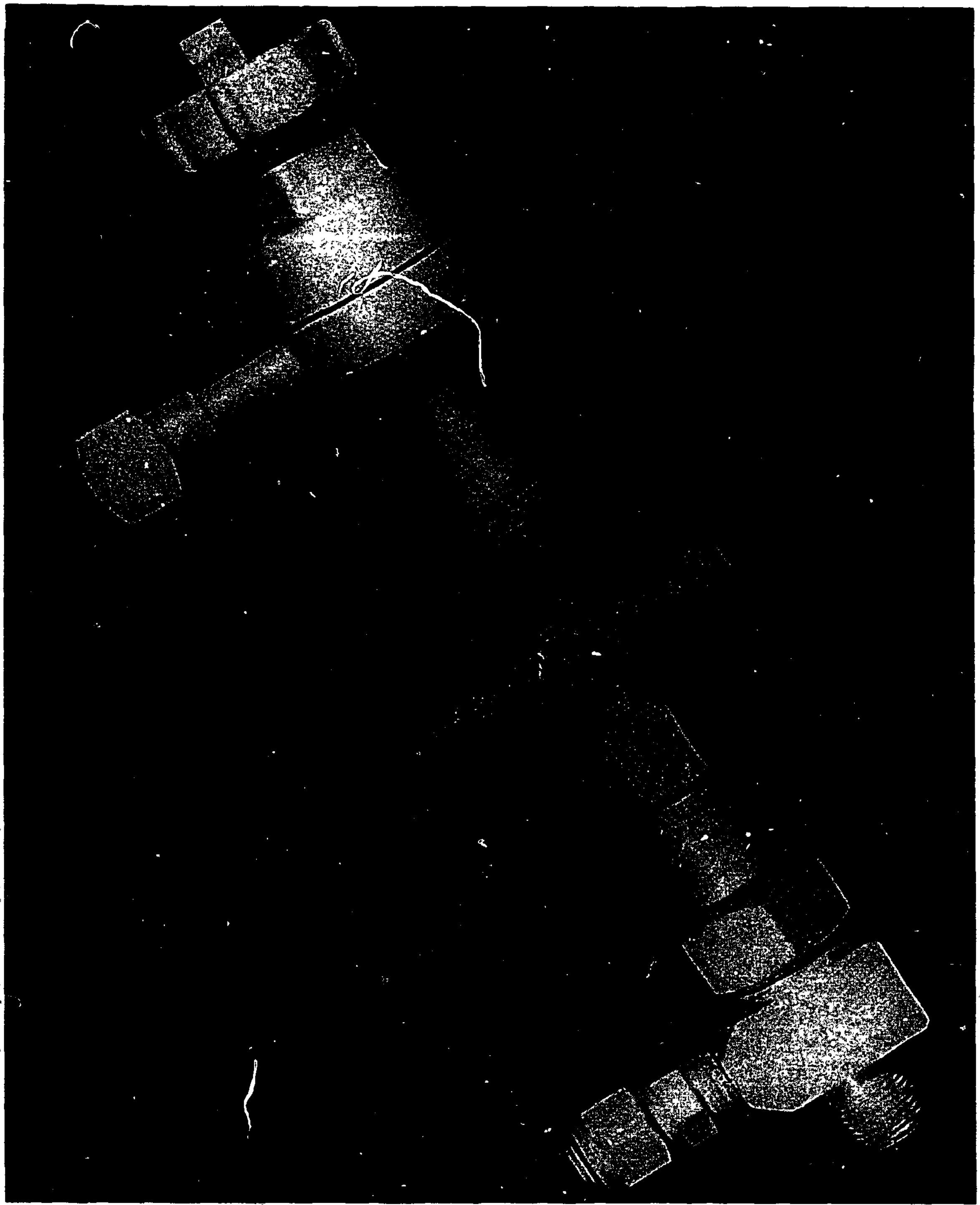


Figure 29
SAMPLE CYLINDER VALVES

8.15 SHIPPING CYLINDER VALVES

Below is a photograph of a 3/4-inch shipping cylinder valve and a 1-inch shipping cylinder valve.

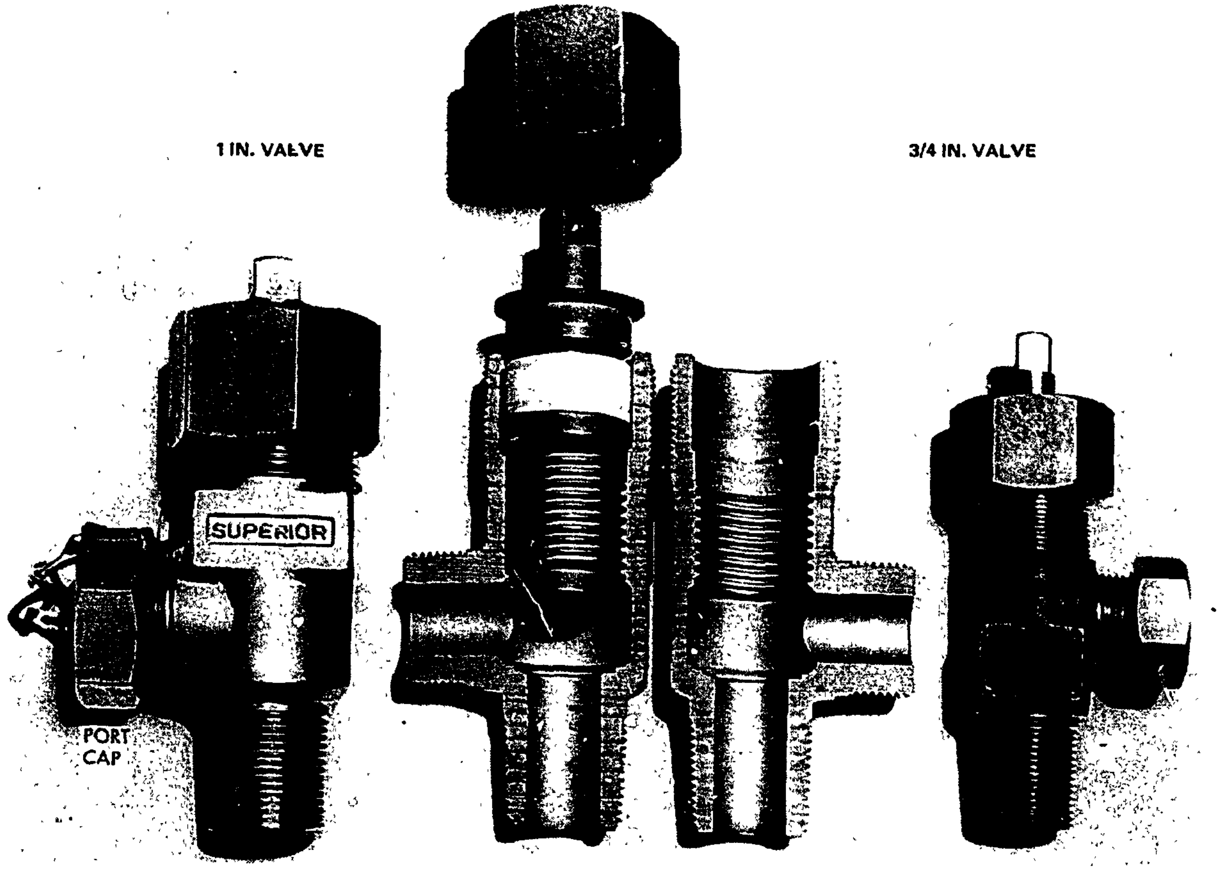


Figure 30

1-INCH AND 3/4-INCH SHIPPING CYLINDER VALVES

APPENDIX A

CHEMICAL AND PHYSICAL PROPERTIES OF UF_6

GENERAL

General information on the properties of UF_6 is presented in Table A.1 for convenient reference.

Table A.1 Physical properties of UF_6

Sublimation Point (14.7 psia) (76 cm Hg)	133.8°F (56.6°C)
Triple Point	22 psia (114 cm Hg), 147.3°F (64.1°C)
Density, Solid (68°F) (20°C)	317.8 lb/ft³ (5.1 g/cc)
Liquid (147.3°F) (64.1°C)	227.7 lb/ft³ (3.6 g/cc)
Liquid (200°F) (93°C)	215.6 lb/ft³ (3.5 g/cc)
Liquid (235°F) (113°C)	207.1 lb/ft³ (3.3 g/cc)
Liquid (250°F) (121°C)	203.3 lb/ft³ (3.3 g/cc)
Heat of Sublimation (147°F) (64°C)	58.2 Btu/lb
Heat of Fusion (147°F) (64°C)	23.5 Btu/lb
Heat of Vaporization (147°F) (64°C)	35.1 Btu/lb
Heat of Solution in Water (77°F) (25°C), Heat Evolves	258.2 Btu/lb
Critical Pressure	668.8 psia (3,458 cm Hg)
Critical Temperature	446.4°F (230.2°C)
Specific Heat Solid (81°F) (27°C)	0.114 Btu/lb
Specific Heat Liquid (162°F) (72°C)	0.130 Btu/lb

CHEMICAL PROPERTIES

Uranium hexafluoride is a highly reactive substance. It reacts chemically with water, ether, and alcohol forming soluble reaction products. It reacts with most organic compounds and with many metals. The reaction with hydrocarbon oil can be violent at elevated temperatures. Its reactivity, with most saturated fluorocarbons is very low. It does not react with oxygen, nitrogen, or dry air. It is sufficiently inert to clean and dry aluminum, copper, monel, nickel, steel, and aluminum bronze; therefore, they can be exposed to UF_6 without excessive corrosion.

Uranium hexafluoride reacts very readily with H_2O to form UO_2F_2 and HF. A saturated solution of UO_2F_2 in water has the composition shown in Table A.2:

Table A.2. UO_2F_2 solubility in water

Temperature, °C	Wt % UO_2F_2
1	61.4
25	65.6
60	71.0
100	74.1

Conversion factors, or stoichoimetric equivalent, for seven chemical forms of uranium enriched to 3 wt % uranium-235 are listed in Table A.3.

Table A.3. Conversion factors

	U	UF_4	UF_6	UO_2	U_3O_8	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_8	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

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 uranium; the uranium in 1.3037 kg of UF_6 will produce 1 kg UO_2.

PHYSICAL PROPERTIES

At room temperature, UF_6 is a white, volatile solid. At a temperature of 147.3°F (64.1°C) and a pressure of 22 psia, UF_6 melts to form a colorless liquid of high density.

The liquid density, gas density, and phase diagram for UF_6 are presented graphically in Figs. A-1, A-2, and A-3.

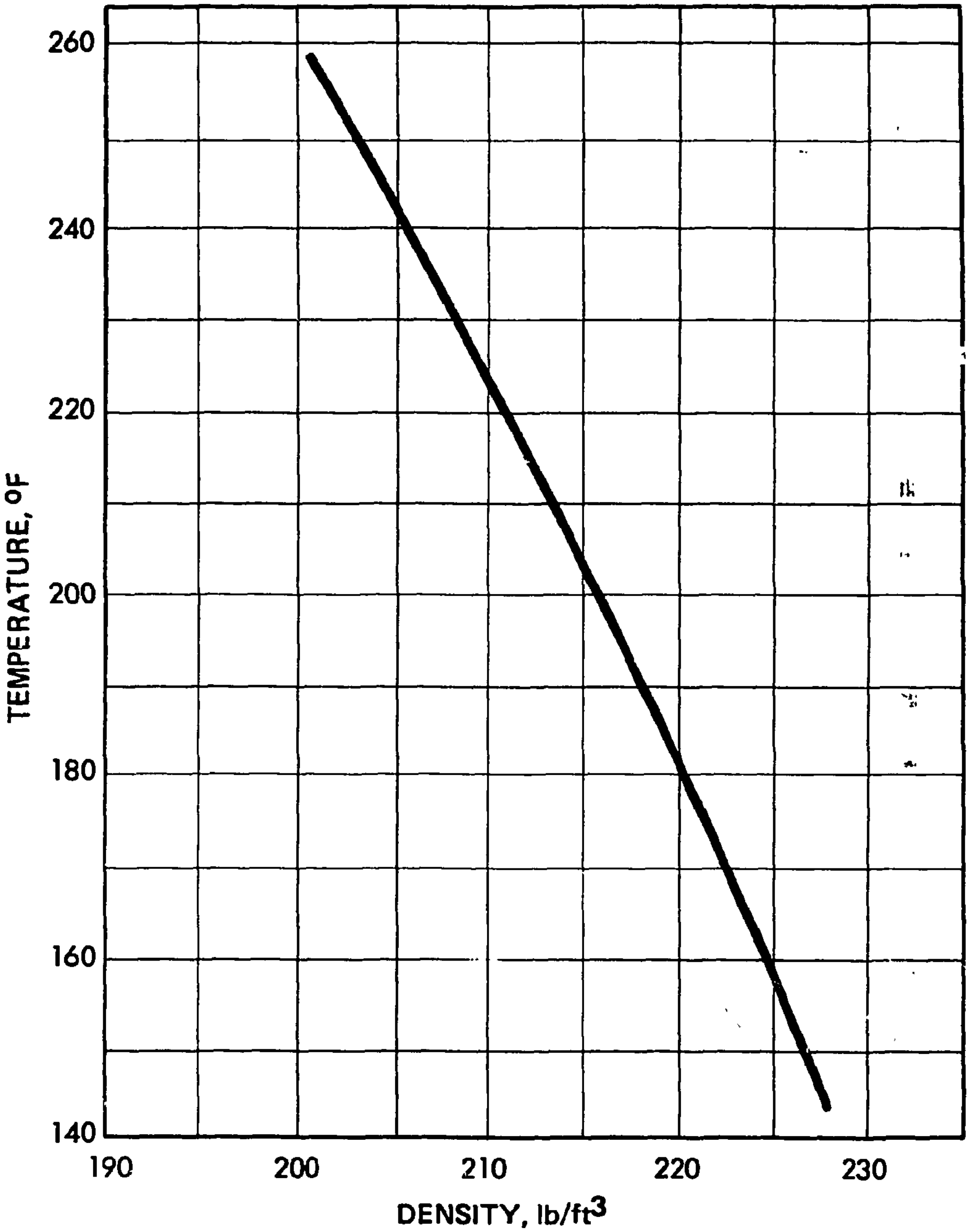


Figure A-1
DENSITY OF LIQUID UF_6

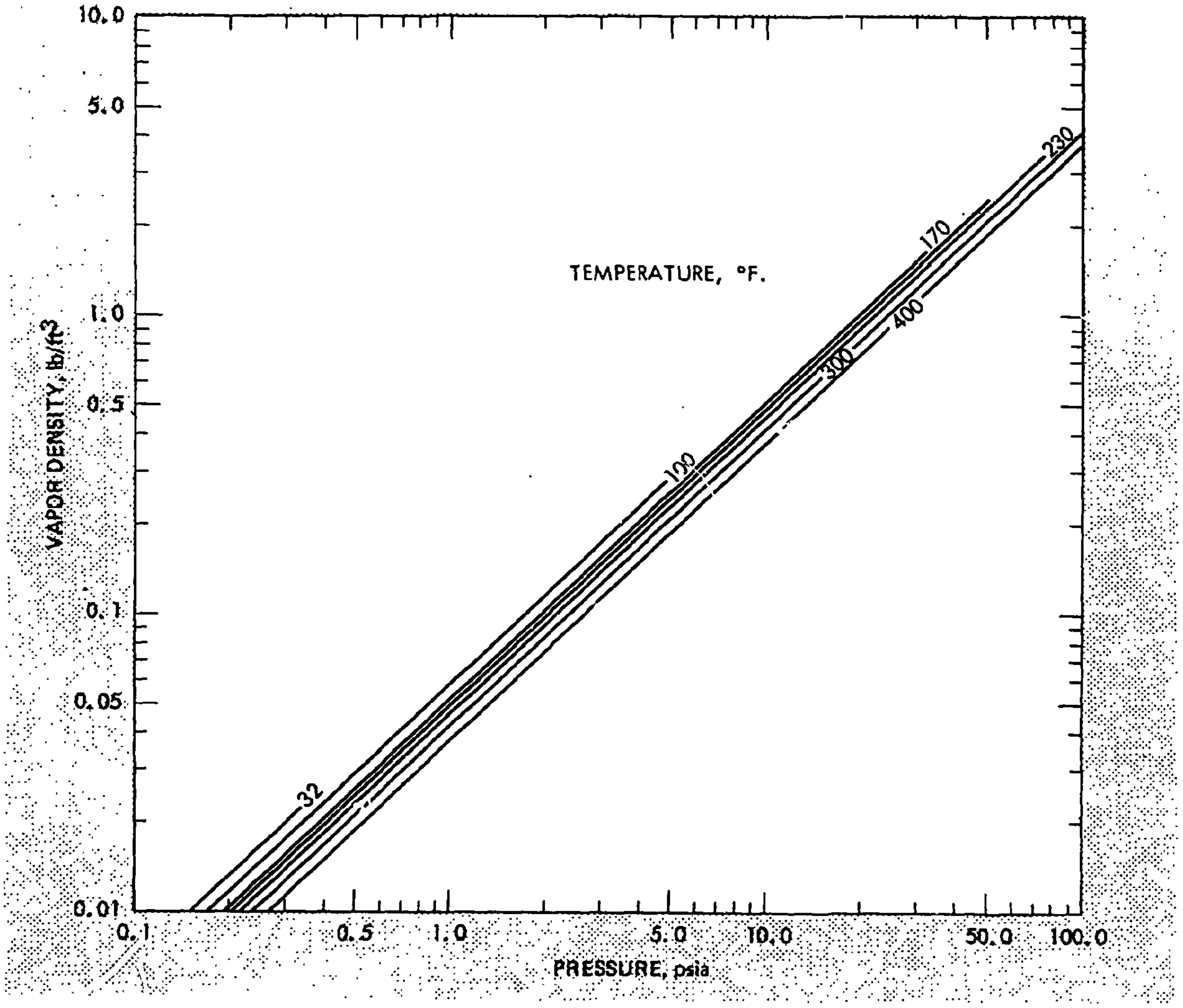


Figure A-2
DENSITY OF GASEOUS UF_6

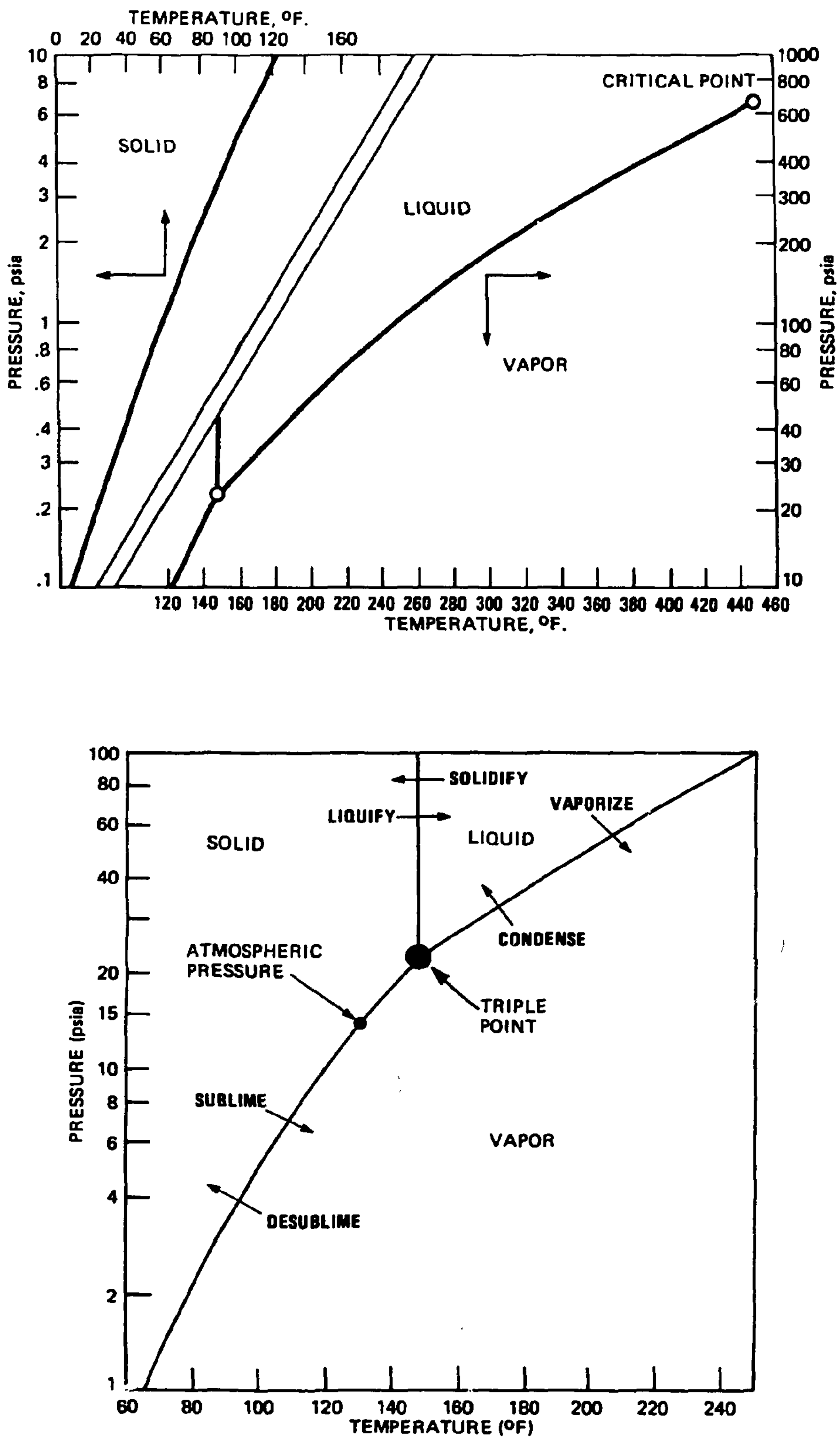


Figure A-3

PHASE DIAGRAM OF UF_6

UF_6 cylinder data summary

[For your convenience, this table (Table 9, page 60) is being repeated on the last page of this report.]

Cylinder model no.	Nominal diameter, inch	Material of construction	Minimum volume		Approximate tare weight (without valve protector)		Maximum, enrichment wt % uranium-235	Shipping Limit Maximum,[a] UF_6	
			ft³	liters	lb	kg		lb	kg
1S	1.5	Nickel	0.0053	0.15	1.75	0.79	100.00	1.0	0.45
2S	3.5	Nickel	0.0254	0.72	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
30A	30	Steel	25.65	726.0	1,400	635	5.0[b]	4,950	2,245
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]	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

[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% ullage for safety. The operating limits apply to UF_6 with a minimum purity of 99.5%. 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%. Without moderation control, the maximum permissible enrichment is 1.0 wt % uranium-235.

[c]This cylinder replaces the Model 30A cylinder.

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

[e]For DOE gaseous diffusion plant tails with UF_6 purity in excess of 99.5%, the shipping limit is 28,000 lbs for cylinders with 8880 lbs water capacity or greater.

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