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A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees

Final Report

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S. A. McGuire

Division of Reactor Accident Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

observed.* Thus, neither radiation doses nor chemical toxicity from licensed materials is a concern with respect to the need for prompt protective actions.

In the event of such a fire, the licensee would be required by existing NRC regulations to take certain actions. Among these, the licensee would be required by §20.201(b) to conduct surveys (offsite if appropriate) to determine whether the NRC's limits on radioactivity in effluents to unrestricted areas in §20.106 were exceeded. A major fire would also require immediate notification of NRC by telephone and telegraph (§20.403). If appropriate, the NRC could elect to immediately send an inspector to the site to make any necessary radiation measurements or evaluate the situation.

With respect to tailing dam failures, rapid emergency response is not needed to avoid doses exceeding protection action guides because dose rates at a spill site are very low. An appropriate response is to monitor drinking water, especially for radium-226, to be sure that drinking water standards are met. Gamma ray monitoring of the ground is also appropriate to determine where the tailings have been deposited. However, ground contamination presents little immediate hazard to the public because the gamma dose rates are low. Gamma dose rates in contact with tailings should be less than 0.1 mR/hr. Since the EPA's protective action guides would not be exceeded, a rapid emergency response is not needed. A clean-up of the spilled tailings would be expected, but this could be done effectively without preexisting emergency preparedness.

2.2.3 UF_6 Conversion Plants

Conversion plants convert yellowcake shipped from uranium mills into uranium hexafluoride (UF_6). Heated liquid UF_6 is put into 10-ton or 14-ton cylinders. The cylinders are cooled for several days until the UF_6 solidifies. Eventually, the filled cylinders are shipped to enrichment plants to enrich the uranium in U-235. There are two NRC-licensed conversion plants: Kerr-McGee in Oklahoma and Allied Chemical in Illinois.

The uranium is handled in many different chemical forms in UF_6 conversion plants, but the UF_6 itself is the only chemical form of uranium that is readily dispersible. For example, the dispersibility of yellowcake is essentially the

*R. A. Just and V. S. Emler, "Generic Report of Health Effects for the U.S. Gaseous Diffusion Plants," DOE Report K/D 5050, Section VIII, Part 1, page 6, 1984.

same as that of yellowcake at uranium mills. Accidents involving yellowcake were previously discussed and found not to require offsite emergency preparedness.

The release of UF_6 in significant quantity is possible because UF_6 is volatile above room temperature. The UF_6 released will react with water in the air as follows:

$$UF_6 + 2H_2O = UO_2F_2 + 4HF + 52.2 \text{ kcal/mole*}$$

The UO_2F_2 forms a particulate, very soluble in the lungs, which will be carried away by wind and will settle onto the ground. The HF is a corrosive acid vapor that can severely harm the lungs if sufficiently concentrated. The release of 1 kg of UF_6 combining with 0.1 kg of water results in release of 0.88 kg of UO_2F_2 (which contains 0.68 kg of uranium) and 0.23 kg of HF.

2.2.3.1 Accident History

Table 4 lists significant releases of UF_6 that have occurred from all types of facilities, not just conversion plants. There have been many releases of UF_6. The releases have caused at least three prompt fatalities and several injuries. The significant UF_6 releases have consistently been with UF_6 heated above its melting point (65°C). The releases have generally been fairly rapid--lasting from less than a minute to an hour. The plumes, where they are highly concentrated, have been visible and immediately irritating to the lungs. The escape of UF_6 can be diminished greatly if the leak can be sprayed with water.

Inhalation of uranium due to a UF_6 release can be verified by measurements of uranium concentrations in urine taken within 48 hours of the exposure. The uranium from UF_6 has a biological half-life for expulsion via the urine of 4 to 6 hours.** Workers exposed to high concentrations have suffered edema of the lungs, presumably from exposure to HF, and kidney damage due to heavy metal

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*Minton Kelly, Oak Ridge National Laboratory, Sept. 1983.

**M.W. Babcock and R. C. Heatherton, "Bioassay Aspects of a UF_6 Fume Release," Proceedings of the 12th Annual Bio-Assay and Analytical Chemistry Meeting, AEC Report CONF-661018, 1966, pp 147-159.

Table 4. Accidents Involving UF_6 Releases through 1986

Date	Facility	Type of facility	Quantity of UF_6 released	Cause and consequence
9-2-44*	Philadelphia Naval Yard	R & D for thermal diffusion	200 kg accompanied with live steam	Rupture or explosion of large tank. Two workers killed. Three other workers seriously injured, 13 others less seriously injured or not injured.
Pre 1949	AEC facility	Not identified	Believed to be 13 kg	Sudden leak in a hot cylinder. One worker received injury to respiratory tract, eyes, and kidneys.
5-10-60	Babcock & Wilcox, Apollo, PA	Fuel fabrication	Not reported	Leak in heat exchanger allowed UO_2F_2 to escape to river water. 60 x MPC at discharge point.
11-17-60	Union Carbide, Oak Ridge, TN	Uranium enrichment	Not reported	Rupture of 10-ton cylinder.
5-25-62	Nuclear Fuel Services, Erwin, TN	Fuel fabrication metal	15 kg HEU in 5 min. 6 kg recovered in plant	An overheated 15-kg cylinder ruptured and released its contents in the building.
3-20-64	Nuclear Fuel Services, Erwin, TN	Fuel fabrication metal	1 kg in 2 hrs. Half recovered onsite	Overpressure burst tube
2-14-66	National Lead, Fernald, OH	Feed material production	2300 kg in 1 hr. Much absorbed by water spray	Operator accidentally removed valve on a hot 10-ton cylinder, developed lung edema, hospitalized 6 days. No observed injury to kidney.
6-29-67	Kerr-McGee, Gore, OK	UF_6 conversion	45 kg in 15-20 min	Gasket leaked due to overheating.
7-19-68	Kerr-McGee Crescent, OK	Fuel fabrication	45 kg of 1.6% enriched U in 15-20 min	Valve accidentally left open during heating.

*Ronald Kathren and Robert Moore, "Acute Accidental Inhalation of U : A 38-year follow-up," Health Physics, 51, 609, 1986.

Table 4. (continued)

Date	Facility	Type of facility	Quantity of UF_6 released	Cause and Consequence
11-12-68	Allied Chemical, IL	UF_6 conversion	43 kg	Valve failure
5-2-73	Goodyear Atomic Oak Ridge, TN	UF processing	100 kg in 20 min (inside)	Worker broke valve on 10-ton cylinder.
4-20-74	Numec, Apollo, PA	Mixed oxide fuel fabrication	6 kg, slightly enriched	
12-2-76	Exxon Nuclear, Richland, WA	Fuel fabrication	Small	Worker disconnected line but had forgotten to close valve.
3-7-78	Portsmouth Gaseous Diffusion Plant, OH	Enrichment plant	9500 kg in 1/2 to 1 hour	Rupture of dropped hot 14-ton UF_6 cylinder.
12-3-78	GE	Fuel fabrication	not known	Block valve opened
8-7-79	NFS, Erwin TN	Fuel fabrication	<3 kg	Accidental venting of cylinder to stack.
5-20-80	GE	Fuel fabrication	<1 kg	Pipe flange failure
9-15-81	GE	Fuel fabrication	<<74 kg	Gasket leak
10-12-81	NFS, Erwin, TN	Fuel fabrication	0.05 to 0.1 kg, HEU	Release via main scrubber stack.
2-25-82	Exxon	Fuel fabrication	<<25 kg	Gasket leak
12-83	Edlow International, East St. Louis, IL	Warehouse	None	Fire in warehouse.
1-4-86	Sequoyah Fuels Corp., Gore OK	UF_6 conversion	14,000 kg in less than a minute. Between 10% and 50% of the uranium became airborne	Heating of overfilled cylinder. One worker killed. Several injured from HF.

poisoning from uranium. At least two workers were killed. Persons injured or killed in this manner have all been workers in a room working close to a UF_6 cylinder.

Two of the cases involving the most serious exposures were reported by Howland.* He reported two fatalities, four serious injuries, and slight injury to 13 other people. One of the fatalities showed by autopsy roughly 1000 mg of uranium in the lungs. Howland concluded that the most serious injuries (observed on the skin, eye, mucous membrane of the upper respiratory tract, esophagus, larynx, and bronchi) were all caused by the action of the fluoride ion on the exposed tissues. Uranium produced transient urinary-tract changes. A long-term follow-up of three of the workers was reported by Kathren and Moore†. The three men were estimated to have initial depositions in the lung of 40 to 50 mg of uranium. Medical and health physics examinations of two of the men 38 years after the accident revealed no detectable deposition of uranium nor any physical injury or changes attributable to uranium exposure. The conclusion is that HF and uranium both have adverse effects, but that the HF effects are the more severe.

In the National Lead-Fernald accident, one worker suffered lung edema, presumably from exposure to HF.** No injury to his kidneys was observed. He excreted in urine over 1 mg of uranium in the first two days after the accident, suggesting a total intake of roughly 2 to 3 mg of uranium.

The largest release of UF_6 occurred in 1986 when a cylinder filled with UF_6 beyond its 14-ton capacity ruptured while being heated at Sequoyah Fuels Corporation in Gore, Oklahoma. Heating an overfilled cylinder was prohibited by company procedures and the NRC license and was widely recognized in the industry as a dangerous and unacceptable practice. The cylinder ruptured because of hydrostatic pressure. The pressure was caused because UF_6 expands significantly when the solid melts and becomes a liquid, but there was not enough room in the cylinder for this expansion. There was not enough room because the cylinder had been overfilled.

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*Joe W. Howland, "Studies on Human Exposures to Uranium Compounds," in <u>Pharmacology and Toxicology of Uranium Compounds</u>, edited by Carl Voegtlin and Harold Hodge, McGraw-Hill, New York, 1949, p 993.

†Kathren and Moore, op. cit.

**Babcock and Heatherton, op. cit.

The rupture was about four feet long and most the contents, approximately 14,000 kg, escaped in less than a minute. Of the uranium that escaped the cylinder, most was later found to be on the ground near the release point. The company estimated that 35 percent of the uranium could not be found near the release point, but other estimates were that 50 percent escaped. Thus, the amount of uranium that became airborne would be between about 3300 kg and 4700 kg.

One worker was killed because of pulmonary edema caused by HF. Several others experienced skin burns, irritation to the eyes and mucous membranes, and respiratory tract irritation (Reference: NUREG-1189). No symptoms were found among people exposed offsite.

Bioassay results for 36 workers showed an average uranium intake of about 6.5 mg and a maximum intake of about 28 mg. Nine of the workers were exposed to uranium in excess of NRC's regulatory limit (9.6 mg intake within a week), but no symptoms of kidney injury were observed.

Another large release of UF_6 was the 1978 accident at the Portsmouth, Ohio gaseous diffusion plant. In this accident a heated thin-walled cylinder containing 14 (short) tons of natural UF_6 was dropped 8 to 10 inches and ruptured below the liquid level.* Within one hour, about 9500 kg of UF_6 escaped. This is equal to about 6400 kg of uranium. The release was outdoors. The air temperature was 32°F, the wind speed was 2 meters/sec, and a mixture of snow and freezing rain was falling. Snow covered the ground. About 550 kg of uranium were recovered on the ground afterwards. Agglomeration is likely to have increased the settling. About 4800 kg of uranium (75% of the release) were estimated to have become airborne and dissipated in the air, much thereby leaving the site. The site boundary in the downwind direction was at a distance of 2.2 km.

*"Investigation of Occurrence Involving Release of Uranium Hexafluoride from a Fourteen-Ton Cylinder at the Portsmouth Gaseous Diffusion Plant on March 7, 1978," DOE Report ORO-757, June, 1978.

Water samples from a drainage ditch located near the release had a peak uranium concentration of 450 mg/l, 10 times the NRC's radiological limit for water to be released to unrestricted areas.*

The reported environmental effects were minimal. Workers who drove through the plume showed no detectable uranium in samples of their urine. Significant ground and water contamination were confined to distances of a few hundred yards from the release point. Airborne concentrations at the site boundary (2.2 km) were calculated to be not high enough to be harmful for brief exposures.

Another large release of UF_6 occurred in France in 1977.† As the result of a handling error a valve ruptured on a container heated to 90-95°C. The UF_6 immediately started to spill out onto the ground. The liquid flow lasted 10 to 15 minutes until the level of liquid in the container had fallen below the valve opening. Then UF_6 continued escaping as a gas until the valve was plugged with a wooden peg 30 minutes after the rupture. Of the 8800 kg of liquid UF_6 in the container, 7100 kg escaped.

Water and carbon dioxide were used to prevent the escaped UF_6 from becoming airborne. However, 330 kg of uranium and 1600 kg of HF were not recovered. Thus 7% of the uranium and 98% of the HF that escaped the container apparently became airborne. Weather conditions favored rapid dilution. It was a warm and sunny afternoon with a windspeed of 9 m/s.

The French workplace limit for HF of 2.4 mg/m^3 was exceeded up to a distance of 1200 meters. Ground contamination by uranium of up to 10 mg/m^2 was observed up to 600 meters. The area on which virtually all the solid uranium compounds settled did not exceed 1000 m^2.

No injuries were observed. Urine samples were taken from 449 people. Two workers excreted more than 0.5 mg during the first day, but no physiological symptoms were observed. No symptoms of the HF exposure were observed.

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*The NRC limit for water in unrestriced areas in 10 CFR Part 20, Appendix B is 3×10^{-5} microcuries/ml. Using the specific activity of natural uranium of 6.77×10^{-7} microcuries/microgram, the effluent water standard is equivalent to 44 milligrams/liter.

†A.J. Docouret, "An Experience of Accidental Release of UF_6," Comurtex Plant, Pierrelatte, France.

In addition to gaseous UF_6 releases, conversion plants have released uranium to rivers. On Dec. 1, 1978 the Kerr-McGee conversion plant accidentally released 750 kg of natural uranium in the form of uranyl nitrate into a river. The liquid released had a uranium concentration of 1.4 times the MPC for water, which would then be diluted by the river water.

2.2.3.2 Accident Source Terms

The NRC staff, Sutter at Pacific Northwest Laboratory, and M. Simon-Tov* at Oak Ridge National Laboratory have recently analyzed potential accidents at UF_6 conversion plants to estimate potential releases of UF_6.

The largest release postulated by the NRC staff is contained in an Environmental Impact Appraisal for the Allied Chemical conversion plant.** The NRC staff assumed that the largest release of UF_6 would be caused by the rupture of a heated 14-ton cylinder. The staff assumed that 9500 kg of UF_6 would escape and that the material would hydrolyze. As a result, 4800 kg of natural uranium would be released with the chemical form UO_2F_2, a highly soluble compound.

Sutter*** considered a number of possible accidents. These include:

1. The rupture of two 14-ton UF_6 cylinders outdoors in conjunction with a fire fed by 100 gallons of gasoline due to a truck crash
2. A leak of UF_6 from a pipe
3. A tornado strike
4. Fires
5. Chemical explosions
6. Natural gas explosions

The accident determined by Sutter to cause the most significant release is the rupture of two 14-ton UF_6 cylinders along with a gasoline fire. The initiation is assumed to be a truck accident in which the truck hits the

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*M. Simon-Tov et al., "Scenarios and Analytical Methods for UF_6 Releases at NRC-Licensed Fuel Cycle Facilities," NUREG/CR-3139, 1984.

**Environmental Impact Appraisal for Renewal of Source Material License, No. SUB-526, Allied Chemical Company UF_6 Conversion Plant, Office of Nuclear Material Safety and Safeguards, NUREG-1071, May, 1984, page 4-28.

***S.L. Sutter, et al., op. cit.

cylinders, ruptures its gas tank, and catches on fire. A total release of up to 3800 kg of UF_6 was calculated. The amount of material that could be released is limited by the amount of heat available to vaporize the solid UF_6. Heat required to raise the temperature of the cylinder and UF_6 is neglected. If the UF_6 cylinder is not ruptured, the heat is sufficient to raise the temperature of the UF_6 from 20 to 100°F. The pressure produced would not be enough to rupture the cylinder.

Simon-Tov's work was directed toward determining accident scenarios and analysis methods for UF_6 releases. His work is the most recent and most comprehensive. Twenty-five release scenarios are described in his report (Chapter 5). The scenario most appropriate for this analysis is the rupture of a heated liquid-filled cylinder outdoors. At a temperature of 100°C, 57% of the liquid UF_6 could be vaporized. At 120°C, 65% could be vaporized (Figure 11, page 58). The most important parameter for determining the release is the temperature of the cylinder. Thus the largest release is from a cylinder just-filled. Analyses of plausibile fire scenarios involving cooled cylinders show that the UF_6 cannot be heated sufficiently to cause as large a release as from a hot cylinder.

For the purpose of this regulatory analysis, the release to be evaluated for UF_6 conversion plants will be one similar to the ones that occurred at the Portsmouth gaseous diffusion plant and the Sequoyah conversion plant. Those accidents involved the ruptures of hot 14-ton UF_6 cylinders outdoors. At Portsmouth, there was a release of 9500 kg of UF_6 (equivalent to 6400 kg of natural uranium). It is assumed that 4800 kg of natural uranium becomes air-borne and the remainder settles on the ground due to agglomeration and impaction. At Sequoyah, the amount of uranium becoming airborne was probably between 3300 kg and 4700 kg. A Portsmouth release was calculated by W. Reid Williams as likely to occur in about 15 minutes. There would be no advance warning. Because the release is assumed to be outdoors, no automatic detection or alarm system would detect the release. Rather, plant personnel are assumed to detect the release and then take emergency measures.

The plume would be readily detectable to the human senses because of the HF and its resulting irritation. Therefore no monitoring instruments are needed to detect high concentrations.

2.2.3.3 Calculations of Doses

The release of UF_6 presents a chemical rather than radiological hazard. Exposures lethal due to uranium chemical toxicity or HF burns on lung tissue would not result in radiation doses exceeding 1 rem effective dose equivalent. Therefore, radiation doses are not calculated. The release assumed is the escape of 9500 kg of UF_6 in 15 minutes due to the rupture outdoors of a heated 14-ton cylinder. The mass of uranium in 9500 kg of UF_6 is 6400 kg. Some of the uranium will be removed from the air initially by agglomeration and impaction. We assume 4800 kg of uranium becomes airborne. The corresponding mass of HF is 1620 kg.

Intakes are calculated for atmospheric stability class F with a wind speed of 1 m/s as well as stability Class D with wind speed of 4.5 m/s. The plume is assumed initially to have a centerline near ground level. The heat from the chemical reaction of UF_6 combining with the moisture in the air will cause the plume to become buoyant. Calculations by W. Reid Williams indicate the plume would lift off within 20 to 30 meters and a plume centerline height of about 20 meters would be obtained within 200 to 300 meters. Thus, we assume a plume centerline height of 20 meters.

The equation for uranium intake I is:

$$I = Q \times B \times \frac{\chi}{Q}$$

where Q = the released quantity (4800 kg),

B = the breathing rate (2.66×10^{-4} m^3/s), and

χ/Q = the atmospheric dispersion value from Figure 1.

Uranium intake due to the airborne release of 4800 kg of uranium

Distance (meters)	Uranium intake (mg)	
	F, 1 m/s buoyant	D, 4.5 m/s buoyant
200	6	53
300	46	59
500	110	40
700	110	28
1,000	92	17
1,500	62	10
2,000	44	6
5,000	11	1.6
10,000	3	0.5
15,000	1	0.3
20,000	0.6	0.2

The exposure to concentrations of HF can be calculated similarly. Exposures due to the airborne release of 1620 kg of HF are shown below.

HF exposure due to the airborne release of 1620 kg of HF

Distance (meters)	HF exposure (mg/m^3)	
	F, 1 m/s buoyant	D, 4.5 m/s buoyant
200	9	77
300	68	86
500	160	59
700	160	41
1,000	140	25
1,500	92	14
2,000	65	9
5,000	16	2.3
10,000	5	0.8
15,000	1.8	0.4
20,000	0.9	0.3

2.2.3.4 Implications for Emergency Preparedness

Of all the accidents considered in this Regulatory Analysis, the rupture of a heated 14-ton cylinder of UF_6 is clearly and by far the most hazardous to people offsite. The corrosive effects of exposure to HF and heavy metal poisoning due to uptake of uranium are discussed separately below.

Heavy metal poisoning: We consider the best estimates of the health effects of uranium intake to be those in two DOE reports* based on the work of a panel of experts on uranium toxicity. The effects are summarized below:

Health Effect	Intake (mg)
50% Lethality	243
Permanent damage	45
Renal effect (transient)	8.6
No effect	4.5

It is not likely from the calculated results that lethal intakes are actually plausible for outdoor releases of UF_6. In order to calculate lethal intakes it is necessary to assume little or no buoyancy, which is believed to be incorrect, and little or no effort on the part of the exposed individual to escape the plume, which may not be a reasonable assumption. We conclude that lethal intakes of uranium by people offsite are not really plausible under realistic conditions.

Permanent kidney damage, on the other hand, may be possible. From the intakes calculated above permanent kidney damage could occur as far as 2000 m (1.2 miles) under very adverse weather (F, 1 m/s) and no attempt to escape the plume, Under more typical conditions (D, 4.5 m/s, some buoyancy, and attempted escape) permanent kidney damage would not be expected offsite.

Transient kidney effect appears to be quite plausible. Under highly adverse conditions (F, 1 m/s) it might be possible as far as five miles away. Under more typical conditions (D, 4.5 m/s and some escape attempt) transient effect might occur as far as 1 mile away.

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*R. A. Just and V. S. Emler, "Generic Report on Health Effects for the U.S. Gaseous Diffusion Plants," DOE Report K/D 5050, Section VIII, Part 1, 1984.

It is Commission policy for nuclear power plant accidents to plan to avoid acute fatalities and serious injuries for the worst case accidents. With this in mind, the recommended protective action distance for rupture of a 14-ton cylinder would be 1 mile. The protective actions could be movement out of the plume, sheltering in buildings, or ad hoc respiratory protection, depending on practicality and feasibility in the actual situation. This would avoid acute fatalities and serious injuries for worst-case accidents and transient kidney injury under more typical conditions.

HF: Estimates of the health effects are from a recent DOE report.* The effects described here are based on concentration as applied to a 15 minute exposure:

Health effect	HF concentration (mg/m^3)
Lethal (15 min)	3500
Unbearable for 1 min	100
Irritation (15 min)	13
Detectable by smell but no health effects	2.5

From the calculated HF exposures given above, lethal exposures offsite are not plausible.

Levels for permanent injury are not known. As a consequence we are substituting the concentration of 100 mg/m^3 as the level considered to be "unbearable" for more than a minute. Such levels may occur out to about 1500 meters under adverse conditions. Generally, they would not be expected to occur offsites under typical conditions (D, 4.5 m/s) if one discounts somewhat the ground level release values.

Irritation appears possible out to at least 5000 meters (3 miles) under adverse meteorology and roughly 1500 m (1 mile) under typical conditions.

Thus the consequences of HF exposure are similar in severity to those from uranium intake. Consequently the one-mile evacuation suggested for the rupture of a 14-ton cylinder of UF_6 is appropriate for protection against both uranium and UF_6.

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*R. A. Just and V. S. Emler, "Generic Report on Health Effects for the U.S. Gaseous Diffusion Plants," DOE Report K/D 5050, Section VIII, Part 1, 1984.

The U.S. Department of Transportation has also established evacuation guides for HF releases.* For small leaks (drum, small container, small leak from a tank) the DOT recommends isolation in all directions to a distance of 150 feet (45 meters). For a large spill from a tank (i.e. railroad tank car) the DOT recommends isolation in all directions to a distance of 300 feet (90 meters) and then evacuation in a downwind direction to a distance of 1.5 mile and a width of 0.8 mile. The DOT distances, however, are based on a larger quantity of HF. Thus, the one-mile action distance suggested here is consistent with DOT recommendations. DOT distances are based on atmospheric stability Class D and wind speed of 4.5 m/s. DOT states that distances based on those assumptions have proven to be adequate under actual accident situations.

2.2.4 Enrichment Plants

At present there are no NRC-licensed enrichment plants, nor are there any immediate prospects for one. Basically, however, enrichment plants receive UF_6 from conversion plants and ship UF_6, enriched in U-235, to fuel fabrication plants. Thus the types of potential accidents are similar to those at conversion plants and fuel fabrication plants.

2.2.4.1 Accident History

Several large releases of UF_6 have occurred at enrichment plants, as shown in Table 4. These have been the result of the ruptures of heated large 10-ton or 14-ton cylinders. The largest release was the 1978 cylinder rupture at the Portsmouth, Ohio gaseous diffusion plant, which released 9500 kg of UF_6.

*"Hazardous Materials-Emergency Response Guidebook," U.S. Department of Transportation report DOT-P5800.4, 1987.