APPENDIX B:

CYLINDER CORROSION AND MATERIAL LOSS FROM BREACHED CYLINDERS

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The following is a list of acronyms and abbreviations, including units of measure, used in this appendix.

ACRONYMS AND ABBREVIATIONS

General

DOE	U.S. Department of Energy
PEIS	programmatic environmental impact statement
USEC	United States Enrichment Corporation

Chemicals

HF	hydrogen fluoride
UF_4	uranium tetrafluoride
UF_6	uranium hexafluoride
UO_2F_2	uranyl fluoride

UNITS OF MEASURE

cm	centimeter(s)
in.	inch(es)
kg	kilogram(s)
lb	pound(s)
mil	mil(s)
psi	pound(s) per square inch
ton(s)	short ton(s)
yr	year(s)

APPENDIX B:

CYLINDER CORROSION AND MATERIAL LOSS FROM BREACHED CYLINDERS

The U.S. Department of Energy (DOE) is proposing to develop a strategy for long-term management of the depleted uranium hexafluoride (UF_6) inventory currently stored at three DOE sites near Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee. This programmatic environmental impact statement (PEIS) describes alternative strategies that could be used for the long-term management of this material and analyzes the potential environmental consequences of implementing each strategy for the period 1999 through 2039. This appendix provides detailed information describing cylinder corrosion and material loss from breached cylinders.

Depleted UF_6 has been stored in steel cylinders in outdoor yards at three DOE storage sites since the 1950s. Most cylinders have either a 10- or 14-ton (9- or 12-metric ton) capacity and a nominal wall thickness of 5/16 in. (0.79 cm, or 312.5 mil). The DOE-generated inventory consists of 46,422 cylinders, the oldest of which will have been in storage for about 45 years at the time of the PEIS record of decision and the youngest of which will have been in storage for about 5 years. United States Enrichment Corporation (USEC)-generated cylinders are considerably newer than the majority of DOE-generated cylinders.

An important criterion for the selection of a preferred management strategy for the depleted UF_6 cylinders is the expected condition of the cylinders throughout the time frames considered for various actions in the PEIS (i.e., 1999 through 2039). The condition of the cylinders is generally expressed in terms of remaining wall thickness (Nichols 1995), which determines whether the cylinders can be transported (thickness must be greater than 250 mil), pressurized in an autoclave (thickness must be greater than 200 mil), or lifted (thickness must be greater than 100 mil).[1] Cylinders that are breached (i.e., wall thickness at some part of the cylinder is 0) can produce environmental impacts by release of material.

All metals corrode to some extent when their surfaces are unprotected. In the past, depleted UF_6 cylinders have been stored in outdoor yards, and some groups of cylinders have been in contact with wet ground surfaces. An extensive cylinder maintenance program that began in the earlier 1990s has substantially improved storage conditions (e.g., paving of cylinder yards, restacking of cylinders onto concrete saddles, regular inspection of cylinders, and cylinder painting). However, accelerated corrosion has occurred on some cylinder surfaces, and eight breached cylinders have been identified

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[1] The wall thickness criteria were obtained from Hanrahan (1996). The transportation requirement is from the American National Standards Institute (ANSI 14.1, "American National Standards for Nuclear Materials — Packaging of Uranium Hexafluoride for Transport"); the pressurization standard is based on a requirement of the American Society of Mechanical Engineers ("Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessel") that pressure vessels pass a 100 psi rating; no source for the lift limit was cited.

in the inventory. The properties of depleted UF_6 in the solid form are such that release of material from breached cylinders occurs at a slow rate because the UF_6 degrades to a solid form of uranium that serves to "plug" the hole. To provide estimated impacts of continued storage for all or part of the cylinder inventory for an extended time period, it was necessary to estimate both the numbers of cylinders that might be breached and the amount of uranium compounds and hydrogen fluoride (HF) that would be expected to be released from any cylinder breaches that might occur in the future.

B.1 CYLINDER CORROSION MODELS

Efforts began in the mid 1970s and are ongoing to estimate the extent of corrosion of the depleted UF_6 cylinders and the numbers of breaches that might occur in the future. These studies are summarized in Nichols (1995). Generally, ultrasonic test measurements are used to estimate the current wall thickness at many locations on a single cylinder (current methods obtain 100,000 measurements for 0.1-in. [0.25-cm] squares on a single cylinder [Lyon 1996a]). In the simplest method for predicting breaches, the minimum wall thickness measurement is subtracted from a value assumed to be the initial wall thickness; this value is divided by the age of the cylinder to estimate an annual corrosion rate; the corrosion rate is then extrapolated forward from the cylinder age to arrive at an estimated year of breach. Because the ultrasonic tests are time-consuming and costly, only a small portion of the entire inventory has been measured. To estimate the numbers of breaches expected during various time intervals, several recent attempts have been made to extrapolate the results from the sample of cylinders measured to the entire inventory (Lyon 1995, 1996a-b, 1997; Nichols 1995; Rosen and Glaser 1996a-b).

Uncertainties associated with accurately estimating the expected number of breaches include the following:

- The sample of cylinders with ultrasonic test data available is not a random sample from the entire inventory of cylinders. Generally, cylinders showing signs of accelerated corrosion were chosen for ultrasonic testing. Therefore, basing the corrosion rate for the entire cylinder inventory on the ultrasonic test data may result in overestimation of potential breaching.

- The initial thickness of the cylinders is not known. Although the manufacturer-specified thickness for the most prevalent cylinder type is 312.5 mil, many of the cylinders actually had greater initial wall thicknesses. One estimate of the maximum initial wall thickness for the 5/16-in. (0.79-cm) cylinders is 345.5 mil, based on the nominal 312.5-mil thickness plus an American Society for Testing and Materials mill tolerance of 33 mil; however, estimates of up to 400-mil initial thickness have been made for some 5/16-in. (0.79-cm) cylinders at the Portsmouth site (Nichols 1995).

- Currently, it is not possible to reliably address the effects of past storage history on different cylinder inventories. Previously, some cylinders were stored under substandard conditions in which they were in prolonged contact with moisture. Improved storage conditions have undoubtedly reduced the corrosion rates. However, these changes have not been accounted for in the modeling studies because not enough data are available on corrosion rates under the improved storage conditions to support the predictive models.

In a more recent method used to predict numbers of breached cylinders over time (Lyon 1996b, 1997), the available ultrasonic test data were modeled using one to three functional forms (i.e., statistical equations) for predicting corrosion. (Corrosion is also referred to as penetration depth in Lyon 1996b.) Each statistical form of corrosion was assumed to be either normally or lognormally distributed. The three forms represent statistical methods that assume (1) the distribution of corrosion rates is constant with time or (2) the corrosion rates level off with time. For the modeling, the initial thickness of the cylinders was assumed to have a triangular distribution between 302.5 and 345.5 mil, with a most likely value of 330 mil.

B.2 BREACHED CYLINDERS AND MATERIAL LOSS

Before 1998, seven breached cylinders had been identified at the three storage locations: four at the K-25 site, two at the Portsmouth site, and one at the Paducah site. The first breached cylinders to be identified were those at the Portsmouth site. Investigation of these breached cylinders indicated that the initial damage occurred during stacking because of impact with an adjacent cylinder at the weld joint of the stiffening ring and the cylinder wall (Barber et al. 1991). The hole sizes increased over time due to moist air migrating into the cylinder and reacting with the UF_6 and iron. This reaction resulted in a dense plug of uranium tetrafluoride (UF_4) hydrates and various iron fluoride hydrates that prevented rapid loss of material from the cylinders. One breached cylinder that had been in storage for 13 years had an approximate hole size of 9 in. × 18 in. (23 cm × 46 cm); the mass of UF_6 lost from this cylinder was estimated to be between 17 and 109 lb (7.7 and 49 kg). The other breached cylinder had a hole 2 in. (5.1 cm) in diameter and had been in storage only 4 years; the mass of uranium lost from this cylinder was estimated to be less than 4 lb (1.8 kg).

Of the four breached cylinders identified at the K-25 site, two were concluded to have been damaged during handling in a manner similar to the breached cylinders at the Portsmouth site. However, external corrosion due to prolonged ground contact was concluded to be the cause of the other two breaches (Barber et al. 1994). The hole sizes in the four breached cylinders were 2 in. (5.1 cm) in diameter (cylinder stored for about 16 years), 6 in. (15 cm) in diameter (cylinder stored for about 28 years), 10 in. (25 cm) in diameter (cylinder stored for about 33 years), and 17 in. × 12 in. (43 cm × 30 cm) (cylinder stored for about 17 years). Because equipment to weigh the cylinders was not available at the K-25 site, the extent of material loss from the cylinders could not be determined.

The hole size of the breached cylinder identified at the Paducah site in 1992 was approximately 1/16 in. × 2 in. (0.16 cm × 5.1 cm); the cause of the breach was concluded to be damage during handling. The contents of the cylinder have been transferred to another cylinder.

In 1998, one additional breached cylinder occurred at the K-25 site during the course of cylinder maintenance operations (i.e., cylinder painting). Previous corrosion modeling had predicted that some additional cylinder breaches would be detected during such activities; see Table B.1. The breach occurred during steel grit blasting of the cylinder surface in preparation for painting. An as-fabricated weld defect was opened by the blast process. The cylinder management program includes provisions for patching newly identified breached cylinders to eliminate releases of material.

B.3 ESTIMATED NUMBER OF CYLINDER BREACHES AND MATERIAL LOSS USED FOR ANALYSIS

One of the strategies being used to maintain the cylinders is a painting program to mitigate external corrosion. It is estimated that the paint system currently in use will be effective for 12 years before significant maintenance or repainting would be needed (Pawel 1997). The painting program is therefore designed to eliminate further reduction in wall thickness on painted cylinders during the effective life of the paint. Furthermore, once painted, no additional wall thinning would occur as long as the paint was maintained.

For the no action alternative, the impacts of indefinite continued storage at the three sites were analyzed by estimating the number of expected cylinder breaches through 2039, assuming that the maintenance and painting program would be effective in controlling corrosion of cylinder surfaces. This is considered to be representative of the actual conditions that will occur at the three sites. To address the uncertainty associated with the effectiveness of painting and with future painting schedules, an analysis was also conducted that assumed that cylinder corrosion continued at historical rates (i.e., that improved storage conditions and cylinder painting had no effect on corrosion).

For the no action alternative analyses, corrosion of the cylinders was assumed to continue until cylinders were painted (painting estimated to be complete by 2009). Corrosion estimates through 2009 were based on modeling of corrosion that has occurred to date (Lyon 1996b, 1997). The possibility of initiating breaches during handling of the cylinders was incorporated into the breach estimates by using historical data regarding the approximate rates of such handling-initiated breaches that have occurred to date. (The rate assumed was 0.00014 breach per cylinder move; this value was based on five breaches that were initiated by handling damage and the estimated number of 50,000-cylinder moves during storage to date, plus an additional factor of 0.00004 to account for the possibility of a cylinder breaching during handling because it had been weakened from previous corrosion.) The number of cylinder breaches in the inventory at each site through 2039 was estimated

TABLE B.1 Estimated Number of Breaches and Releases from DOE-Generated Cylinders at the Paducah, Portsmouth, and K-25 Sites from 1999 through 2039, Assuming Control of External Corrosion by Painting[a]

	Paducah Site				Portsmouth Site				K-25 Site			
Year of Breach	Cylinder Inventory	Number of Breaches[b]	Number of Active Breaches[c]	HF Emissions[d] (kg/yr)	Cylinder Inventory	Number of Breaches[b]	Number of Active Breaches[c]	HF Emissions[d] (kg/yr)	Cylinder Inventory	Number of Breaches[b]	Number of Active Breaches[c]	HF Emissions[d] (kg/yr)
1999	28,351	2	2	4	13,388	0	0	0	4,683	1	1	2
2000	28,351	1	3	6	13,388	2	2	4	4,683	1	2	4
2001	28,351	1	4	8	13,388	0	2	4	4,683	0	2	4
2002	28,351	1	5	10	13,388	1	3	6	4,683	0	2	4
2003	28,351	2	5	10	13,388	0	3	6	4,683	0	1	2
2004	28,351	1	5	10	13,388	0	1	2	4,683	0	0	0
2005	28,351	0	4	8	13,388	1	2	4	4,683	0	0	0
2006	28,351	1	4	8	13,388	0	1	2	4,683	0	0	0
2007	28,351	1	3	6	13,388	0	1	2	4,683	0	0	0
2008	28,351	1	3	6	13,388	1	2	4	4,683	1	1	2
2009	28,351	1	4	8	13,388	0	1	2	4,683	0	1	2
2010	28,351	1	4	8	13,388	1	2	4	4,683	0	1	2
2011	28,351	0	3	6	13,388	0	2	4	4,683	1	2	4
2012	28,351	1	3	6	13,388	0	1	2	4,683	0	1	2
2013	28,351	1	3	6	13,388	1	2	4	4,683	0	1	2
2014	28,351	1	3	6	13,388	0	1	2	4,683	0	1	2
2015	28,351	0	3	6	13,388	0	1	2	4,683	0	0	0
2016	28,351	1	3	6	13,388	1	2	4	4,683	0	0	0
2017	28,351	1	3	6	13,388	0	1	2	4,683	0	0	0
2018	28,351	1	3	6	13,388	1	2	4	4,683	0	0	0
2019	28,351	1	4	8	13,388	0	2	4	4,683	0	0	0
2020	28,351	1	4	8	13,388	0	1	2	4,683	1	1	2
2021	28,351	0	3	6	13,388	1	2	4	4,683	0	1	2
2022	28,351	1	3	6	13,388	0	1	2	4,683	0	1	2
2023	28,351	1	3	6	13,388	0	1	2	4,683	0	1	2
2024	28,351	1	3	6	13,388	1	2	4	4,683	0	0	0
2025	28,351	0	3	6	13,388	0	1	2	4,683	0	0	0

TABLE B.1 (Cont.)

	Paducah Site				Portsmouth Site				K-25 Site			
Year of Breach	Cylinder Inventory	Number of Breaches[b]	Number of Active Breaches[c]	HF Emissions[d] (kg/yr)	Cylinder Inventory	Number of Breaches[b]	Number of Active Breaches[c]	HF Emissions[d] (kg/yr)	Cylinder Inventory	Number of Breaches[b]	Number of Active Breaches[c]	HF Emissions[d] (kg/yr)
2026	28,351	1	3	6	13,388	1	2	4	4,683	0	0	0
2027	28,351	1	3	6	13,388	0	2	4	4,683	0	0	0
2028	28,351	1	3	6	13,388	0	1	2	4,683	0	0	0
2029	28,351	1	4	8	13,388	1	2	4	4,683	1	1	2
2030	28,351	0	3	6	13,388	0	1	2	4,683	0	1	2
2031	28,351	1	3	6	13,388	0	1	2	4,683	0	1	2
2032	28,351	1	3	6	13,388	1	2	4	4,683	0	1	2
2033	28,351	1	3	6	13,388	0	1	2	4,683	0	0	0
2034	28,351	1	4	8	13,388	1	2	4	4,683	0	0	0
2035	28,351	0	3	6	13,388	0	2	4	4,683	0	0	0
2036	28,351	1	3	6	13,388	0	1	2	4,683	0	0	0
2037	28,351	1	3	6	13,388	1	2	4	4,683	0	0	0
2038	28,351	1	3	6	13,388	0	1	2	4,683	1	1	2
2039	28,351	1	4	8	13,388	0	1	2	4,683	0	1	2
Total (1999-2039)		**36**				**16**				**7**		

[a] PEIS analyses conducted for the period 1999 through 2039. Existing models also predicted one possible breach at each site for 1998, because of either handling (Paducah and Portsmouth) or corrosion (K-25).

[b] Estimates based on the assumption that a painting program would be effective in eliminating external corrosion by the year 2009. Breaches prior to 2009 were calculated as the sum of corrosion-initiated breaches for the proportion left unpainted in each year (based on external corrosion statistical model [Lyon 1996b, 1997]) plus the handling-initiated breaches. For 2009-2039, only handling-initiated breaches were assumed. The breaches were assumed to go undetected for 4 years; in practice, improved storage conditions and maintenance and inspection procedures should prevent any breaches from occurring or going undetected for long periods.

[c] Number of active breaches = sum of current-year breaches and previous-3-year breaches, based on 4-year inspection intervals. Annual uranium emissions (lb/yr) = number of active breaches in that year (1 lb per active breach per year).

[d] Annual HF emissions (kg/yr) = number of active breaches × 0.0055 kg per breached cylinder per day × 365 days per year.

as the number of cylinder moves times the handling breach rate, added to the estimated number of corrosion breaches for unpainted cylinders through 2008. The number of cylinder moves through 2039 was estimated from the painting and relocation schedule given in Parks (1997), assuming two moves per painted cylinder. The annual numbers of breaches in DOE-generated cylinders estimated for the three sites on the basis of these assumptions are given in Table B.1.

The potential impacts that would occur using more conservative (i.e., higher) breach assumptions were estimated by assuming that the historical corrosion rates would continue through the year 2039. This assumption could be applicable if it was found that the effectiveness of the paint was significantly less than 12 years. For this analysis, the method of Lyon (1996b, 1997) for predicting numbers of cylinder breaches due to external corrosion was used to estimate the number of breaches expected through the year 2039 for the three sites, assuming that the entire inventory would remain in storage at the current sites. The values used were the maximums of the predicted ranges for each year, as summarized by Parks (1997). Separate breach rates were estimated for the Paducah site C-745-G-yard and the K-25 site K-1006-K-yard because the worst historical storage conditions have occurred in these yards. This method is subject to the uncertainties discussed in Section B.1. By using the maximum result of the range for a number of assumptions regarding the form of distribution of the penetration depth, this method probably overestimates the actual number of cylinder breaches that would occur at each site through the year 2039.

The estimated number of cylinder breaches among DOE-generated cylinders from 1999 through 2039, based on the method of Lyon (1996b, 1997), is listed in Tables B.2 through B.4 for the three sites. No adjustment was made to the breach estimates given in these tables to account for handling-initiated breaches. Handling-initiated breaches were considered less likely for these cylinders because no credit was taken for corrosion protection from painting (i.e., it is likely that much less painting and maintenance would be taking place). In any case, the number of handling-initiated breaches would be minor in comparison with the predicted corrosion-initiated breaches.

The potential impacts of continued DOE-generated cylinder storage through 2028 for the action alternatives considered in this PEIS were estimated on the basis of the conservative corrosion-initiated breaches predicted with Lyon's method (Lyon 1996b, 1997). However, for the period 2009 through 2028, the estimated number of breaches was reduced by the proportion of inventory reduction occurring in each year.

The estimated "active" breaches in specific years at the three sites are also shown in Tables B.1 through B.4. These values take into account that under the given assumptions for the continued storage period, the minimum required inspection frequency is once every 4 years, although some cylinders are inspected more frequently (i.e., suspect cylinders with signs of extensive exterior corrosion are inspected annually). Therefore, to calculate active breaches, it was assumed that all breaches would go undetected for 4 years. The number of active breaches is the sum of the current-year breaches and the previous-3-year breaches.

TABLE B.2 Estimated Number of Breaches and Releases from DOE-Generated Cylinders at the Paducah Site from 1999 through 2039, Assuming Historical Corrosion Rates

	Breaches and Releases at G-Yard				Breaches and Releases at All Other Yards			
Year of Breach	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)
1999	5,733	1	1	2	22,618	0	0	0
2000	5,733	0	1	2	22,618	0	0	0
2001	5,733	1	2	4	22,618	0	0	0
2002	5,733	0	2	4	22,618	0	0	0
2003	5,733	1	2	4	22,618	1	1	2
2004	5,733	1	3	6	22,618	0	1	2
2005	5,733	1	3	6	22,618	0	1	2
2006	5,733	1	4	8	22,618	1	2	4
2007	5,733	2	5	10	22,618	1	2	4
2008	5,733	2	6	12	22,618	1	3	6
2009	5,733	2	7	14	22,618	1	4	8
2010	5,733	2	8	16	22,618	1	4	8
2011	5,733	3	9	18	22,618	1	4	8
2012	5,733	3	10	20	22,618	1	4	8
2013	5,733	3	11	22	22,618	1	4	8
2014	5,733	4	13	26	22,618	1	4	8
2015	5,733	4	14	28	22,618	1	4	8
2016	5,733	5	16	32	22,618	1	4	8
2017	5,733	5	18	36	22,618	2	5	10
2018	5,733	5	19	38	22,618	1	5	10
2019	5,733	6	21	42	22,618	2	6	12
2020	5,733	7	23	46	22,618	1	6	12
2021	5,733	7	25	50	22,618	2	6	12
2022	5,733	8	28	56	22,618	2	7	14
2023	5,733	8	30	60	22,618	3	8	16
2024	5,733	9	32	64	22,618	2	9	18
2025	5,733	10	35	70	22,618	3	10	20
2026	5,733	10	37	74	22,618	2	10	20
2027	5,733	11	40	80	22,618	3	10	20
2028	5,733	13	44	88	22,618	4	12	24
2029	5,733	13	47	94	22,618	3	12	24
2030	5,733	15	52	104	22,618	4	14	28
2031	5,733	17	58	116	22,618	4	15	30
2032	5,733	17	62	124	22,618	5	16	32
2033	5,733	19	68	137	22,618	4	17	34
2034	5,733	20	73	147	22,618	5	18	36

TABLE B.2 (Cont.)

	Breaches and Releases at G-Yard				Breaches and Releases at All Other Yards			
Year of Breach	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)
2035	5,733	21	77	155	22,618	5	19	38
2036	5,733	22	82	165	22,618	6	20	40
2037	5,733	23	86	173	22,618	6	22	44
2038	5,733	24	90	181	22,618	6	23	46
2039	5,733	25	94	189	22,618	6	24	48
Total (1999-2039)		**351**				**93**		
Total Breaches at Site				**444**				

[a] These estimates are conservative estimates used for assessing potential impacts based on an external corrosion statistical model (Lyon 1996b, 1997). The estimates were based on the assumption that historical corrosion rates would continue through 2039 (i.e., that corrosion would not have been eliminated by painting and maintenance). In practice, painting of cylinders, improved storage conditions, and maintenance and inspection procedures should prevent any breaches from occurring or from going undetected for long periods.

[b] Number of active breaches = sum of current-year breaches and previous-3-year breaches, based on 4-year inspection intervals. Annual uranium emissions (lb/yr) = number of active breaches in that year (1 lb per active breach per year).

[c] Annual HF emissions (kg/yr) = number of active breaches × 0.0055 kg per breached cylinder per day × 365 days per year.

TABLE B.3 Estimated Number of Breaches and Releases from DOE-Generated Cylinders at the Portsmouth Site from 1999 through 2039, Assuming Historical Corrosion Rates

Year of Breach	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)
1999	13,388	0	0	0
2000	13,388	1	1	2
2001	13,388	1	2	4
2002	13,388	0	2	4
2003	13,388	0	2	4
2004	13,388	1	2	4
2005	13,388	1	2	4
2006	13,388	1	3	6
2007	13,388	1	4	8
2008	13,388	1	4	8
2009	13,388	0	3	6
2010	13,388	1	3	6
2011	13,388	1	3	6
2012	13,388	0	2	4

TABLE B.3 (Cont.)

Year of Breach	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)
2013	13,388	1	3	6
2014	13,388	1	3	6
2015	13,388	1	3	6
2016	13,388	1	4	8
2017	13,388	2	5	10
2018	13,388	1	5	10
2019	13,388	1	5	10
2020	13,388	2	6	12
2021	13,388	1	5	10
2022	13,388	2	6	12
2023	13,388	2	7	14
2024	13,388	2	7	14
2025	13,388	2	8	16
2026	13,388	2	8	16
2027	13,388	2	8	16
2028	13,388	3	9	18
2029	13,388	3	10	20
2030	13,388	2	10	20
2031	13,388	3	11	22
2032	13,388	4	12	24
2033	13,388	3	12	24
2034	13,388	3	13	26
2035	13,388	4	14	28
2036	13,388	4	14	28
2037	13,388	4	15	30
2038	13,388	4	16	32
2039	13,388	5	17	34
Total (1999-2039)		**74**		
Total Breaches at Site		**74**		

[a] These estimates are conservative estimates used for assessing potential impacts based on an external corrosion statistical model (Lyon 1996b, 1997). The estimates were based on the assumption that historical corrosion rates would continue through 2039 (i.e., that corrosion would not have been eliminated by painting and maintenance). In practice, painting of cylinders, improved storage conditions, and maintenance and inspection procedures should prevent any breaches from occurring or from going undetected for long periods.

[b] Number of active breaches = sum of current-year breaches and previous-3-year breaches, based on 4-year inspection intervals. Annual uranium emissions (lb/yr) = number of active breaches in that year (1 lb per active breach per year).

[c] Annual HF emissions (kg/yr) = number of active breaches × 0.0055 kg per breached cylinder per day × 365 days per year.

TABLE B.4 Estimated Number of Breaches and Releases from DOE-Generated Cylinders at the K-25 Site from 1999 through 2039, Assuming Historical Corrosion Rates

	Breaches and Releases at K-Yard				Breaches and Releases at E-Yard and L-Yard			
Year of Breach	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)
1999	2,945	1	1	2	1,738	0	0	0
2000	2,945	0	1	2	1,738	0	0	0
2001	2,945	0	1	2	1,738	0	0	0
2002	2,945	0	1	2	1,738	0	0	0
2003	2,945	0	0	0	1,738	0	0	0
2004	2,945	0	0	0	1,738	0	0	0
2005	2,945	2	2	4	1,738	1	1	2
2006	2,945	1	3	6	1,738	1	2	4
2007	2,945	0	3	6	1,738	0	2	4
2008	2,945	2	5	10	1,738	0	2	4
2009	2,945	0	3	6	1,738	0	1	2
2010	2,945	1	3	6	1,738	0	0	0
2011	2,945	2	5	10	1,738	0	0	0
2012	2,945	2	5	10	1,738	0	0	0
2013	2,945	2	7	14	1,738	0	0	0
2014	2,945	2	8	16	1,738	1	1	2
2015	2,945	2	8	16	1,738	0	1	2
2016	2,945	2	8	16	1,738	1	2	4
2017	2,945	2	8	16	1,738	0	2	4
2018	2,945	3	9	18	1,738	0	1	2
2019	2,945	3	10	20	1,738	1	2	4
2020	2,945	4	12	24	1,738	1	2	4
2021	2,945	4	14	28	1,738	1	3	6
2022	2,945	4	15	30	1,738	1	4	8
2023	2,945	5	17	34	1,738	0	3	6
2024	2,945	6	19	38	1,738	1	3	6
2025	2,945	6	21	42	1,738	0	2	4
2026	2,945	7	24	48	1,738	0	1	2
2027	2,945	6	25	50	1,738	1	2	4
2028	2,945	7	26	52	1,738	1	2	4
2029	2,945	8	28	56	1,738	0	2	4
2030	2,945	9	30	60	1,738	1	3	6
2031	2,945	10	34	68	1,738	1	3	6
2032	2,945	8	35	70	1,738	1	3	6
2033	2,945	11	38	76	1,738	1	4	8
2034	2,945	11	40	80	1,738	1	4	8

TABLE B.4 (Cont.)

	Breaches and Releases at K-Yard				Breaches and Releases at E-Yard and L-Yard			
Year of Breach	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)	Cylinder Inventory	Number of Breaches[a]	Number of Active Breaches[b]	HF Emissions[c] (kg/yr)
2035	2,945	11	41	82	1,738	1	4	8
2036	2,945	12	45	90	1,738	1	4	8
2037	2,945	12	46	92	1,738	1	4	8
2038	2,945	12	47	94	1,738	1	4	8
2039	2,945	12	48	96	1,738	1	4	8
Total (1999-2039)		**192**				**21**		
Total Breaches at Site				**213**				

[a] These estimates are conservative estimates used for assessing potential impacts based on an external corrosion statistical model (Lyon 1996b, 1997). The estimates were based on the assumption that historical corrosion rates would continue through 2039 (i.e., that corrosion would not have been eliminated by painting and maintenance). In practice, painting of cylinders, improved storage conditions, and maintenance and inspection procedures should prevent any breaches from occurring or from going undetected for long periods.

[b] Number of active breaches = sum of current-year breaches and previous-3-year breaches, based on 4-year inspection intervals. Annual uranium emissions (lb/yr) = number of active breaches in that year (1 lb per active breach per year).

[c] Annual HF emissions (kg/yr) = number of active breaches × 0.0055 kg per breached cylinder per day × 365 days per year.

A reasonable estimate of material loss from breached cylinders was required to analyze the impacts of breached cylinders for the continued cylinder storage component of each alternative considered in this PEIS. For uranium, it was assumed that the amount lost would be similar to the amount lost from the cylinder at Portsmouth that had been in storage for 4 years at the time of breach identification. Therefore, the amount of uranium lost was assumed to be 4 lb (1.8 kg) per breached cylinder: 1 lb/yr (0.45 kg/yr) uranium per breached cylinder. It was assumed that uranium would be released as solid uranyl fluoride (UO_2F_2), which would be deposited on the ground, from where it could be transported as runoff to soil or surface water or infiltrate to groundwater.

The rate of HF loss from breached cylinders increases over time as the hole size increases. The time-dependent rate provided in Barber et al. (1994) was used to estimate the average daily HF emission rate that would be applicable over the assumed 4-year period that a breach could go undiscovered. An exponential equation for HF loss was used to estimate a value of 0.0055 kg per day HF emission per breached cylinder (Folga 1996a-b). Potential uranium and HF emissions from breached cylinders are summarized in Tables B.1 through B.4 for the Paducah, Portsmouth, and K-25 sites.

For analysis of continued storage (Appendix D), it was assumed that welded patches would be applied within about 1 week of any breach discovery and that no further uranium or HF leakage would occur after patch application.

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