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Natural Phenomena Evaluations of the K-25 Site UF_6 Cylinder Storage Yards

by

K. E. Fricke, Ph.D., P.E.
Center for Natural Phenomena Engineering
Central Engineering Services
Lockheed Martin Energy Systems, Inc.
Oak Ridge, Tennessee 37831

September 15, 1996

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Kenneth E. Fricke, Ph.D., P.E.
Center for Natural Phenomena Engineering
Central Engineering Services
Lockheed Martin Energy Systems, Inc.
Oak Ridge, Tennessee 37830

September 15, 1996

Prepared by
Oak Ridge K-25 Site
Oak Ridge, Tennessee 37831
Managed by
Lockheed Martin Energy Systems, Inc.
Oak Ridge, Tennessee 37831
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1. EXECUTIVE SUMMARY

1.1 INTRODUCTION

The K-25 Site, located in Oak Ridge, Tennessee, is owned by the U.S. Department of Energy (DOE). DOE owns an inventory of UF_6 at the K-25 Site that consists primarily of depleted UF_6 with assays of less than 0.711 wt % ^{235}U. The balance of DOE's uranium inventory at the K-25 Site includes small amounts of enrichment feed and "heel" quantities with assays ranging between 0.711 and 4.5%. The depleted and enriched inventories were collected during the course of the gaseous diffusion uranium enrichment operations while the plants were operated for DOE and its predecessors, the U. S. Atomic Energy Commission, and the Energy Research and Development Administration. During the development and operation of the enrichment process, containers, support equipment, and support facilities were designed, constructed, and used as a system to store, transport, and process the depleted UF_6. After a significant inventory was produced, outdoor storage facilities ("cylinder yards") evolved independently at the sites. Cylinder yards are constructed of either concrete, compacted gravel, or asphalt over gravel. The handling equipment used to stack these cylinders has also evolved, from mobile cranes to specially designed machines that grasp and lift the cylinders with hydraulically operated tines.

The K-25 Site UF_6 cylinder storage yards are used for the temporary storage of UF_6 normal assay cylinders and long-term storage of other UF_6 cylinders. In support of the operating gaseous diffusion plant at the K-25 Site these yards stored UF_6 cylinders filled with depleted assay UF_6, normal assay UF_6 feed material, and enriched assay UF_6 product material. Since enrichment operations were terminated in 1985, all of the filled UF_6 product cylinders and most of the feed UF_6 cylinders have been shipped off-site to the operating gaseous diffusion plants.

The K-25 Site UF_6 cylinder storage yards consist of six on-site areas: K-1066-B, K-1066-E, K-1066-F, K-1066-J, K-1066-K, and K-1066-L. There are no permanent structures erected on the cylinder yards, except for five portable buildings, which were not included in the natural phenomena evaluations. The yards are located in the lightly populated western and northern portion of the site in areas surrounding the inactive uranium separation facilities. The western yards are K-1066-E and K-1066-K, while the northern yards are K-1066-B, K-1066-F, K-1066-J, and K-1066-L. The locations of these yards in the K-25 Site are shown in Figure 2.1.

1.2 PURPOSE

At the request of the DOE, and in accordance with the requirements of DOE Order 5480.23, *Nuclear Safety Analysis Reports* (DOE 1992), Lockheed Martin Energy Systems, the operating contractor for the K-25 Site, is preparing a Safety Analysis Report (SAR) to examine the safety related aspects of the K-25 Site UF_6 cylinder storage yards. The SAR preparation encompasses many tasks terminating in consequence analysis for the release of gaseous and liquid UF_6, one of which is the evaluation of natural phenomena threats, such as earthquakes, floods, and winds, in accordance with DOE Order 5480.28, *Natural Phenomena Hazards Mitigation* (DOE 1993a). DOE Order 5480.28 defines performance categories (PCS) and establishes corresponding performance goals for the application of a graded approach in designing and evaluating facilities with regard to NPH threats. In support of the SAR, the six active cylinder storage yards were

evaluated for vulnerabilities to natural phenomena, earthquakes, high winds and tornados, tornado-generated missiles, floods (local and regional), and lightning. This report summarizes those studies.

1.3 FACILITY HAZARD CLASSIFICATION

The five storage yards (K-1066-B, K-1066-E, K-1066-J, K-1066-K, and K-1066-L) are Hazard Category 2 facilities based on their very large depleted UF_6 inventories, even though depleted uranium has no possibility of nuclear criticality and represents only a minimal radiological hazard. The one staging yard, K-1066-F, is administratively controlled to below Category 2, and is therefore a Category 3 facility. All six cylinder yards have been classified as "Moderate" hazard facilities with regard to non-nuclear hazards because of the potential for HF releases.

At the time of this writing, the final natural phenomena hazard performance categorization of the cylinders and the cylinder yards had not been made, but they most likely would be classified as either PC-2 or PC-3. For purposes of this study, the analysis assumed a PC-3 classification, but considered the effects of PC-2 if they were not satisfactory for the higher category.

1.4 NATURAL PHENOMENA HAZARDS

The natural phenomena (NP) hazards considered for the cylinder yards are earthquake, high winds/tornados, flood and lightning. The NP hazards were evaluated to determine the evaluation basis levels in accordance with the several Department of Energy (DOE) documents. The NP hazard evaluations and evaluation basis levels are described in detail in Section 3.

1.4.1 Earthquake Hazard

The earthquake hazard was evaluated by performing site specific studies. The site specific studies included performing probabilistic and deterministic seismic hazard analyses to define rock outcrop motions and soil amplification analyses to determine the Evaluation Basis Earthquake (EBE) ground surface motions. The seismic hazard analyses (top of rock motions) are described and documented in ES/CNPE-95/2, *Seismic Hazard Criteria for the Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth Ohio U.S. Department of Energy Reservations* (Beavers, 1995). The Department of Energy has approved the rock accelerations for the Oak Ridge sites.

Based on the rock outcrop motions defined in the seismic hazard analyses, soil amplification and liquefaction evaluations were performed and are documented in K/D-6566, *K-25 Site, Site-Specific Earthquake Response Analysis and Soil Liquefaction Assessment*, (Ahmed, 1996). The soil amplification analyses were performed to calculate a range of expected site specific, free-field earthquake responses to the rock outcrop motions of three hazard level earthquakes, a 500-year, a 1000-year and a 2000-year event. From the geotechnical and geophysical investigations, four soil columns (which covered a wide range of subsurface profiles) were derived for use in the amplification analyses. The geotechnical information from past site studies defining the soil stratigraphy and shear wave velocities was used. The lower bound, upper bound, and mean values of shear wave velocities were used in the analysis. The lower and upper bound shear wave velocities were computed in accordance with the recommendations given in the NRC Standard Review Plan (NRC, 1989). The variation of shear modulus and damping ratio with shear strain was used with standard relationships

developed for similar materials by others. The computer program SHAKE 91 was used to perform the soil amplification analyses and calculate the free-field ground motions for the representative soil columns. The motions calculated at the ground surface of free-field (soil over rock) were amplified over rock outcrop motions for all cases. The individual responses from the soil columns were used to determine the free-field ground surface motions.

1.4.2 Flood Hazard

The K-25 Site cylinder storage yards are potentially subject to flooding from two principal sources, (1) regional flooding conditions on Poplar Creek, and (2) the effects of intense local rainfall centered over the site.

Flood conditions on Poplar Creek can result either from large rainfall events occurring in the Poplar Creek watershed, or from flooding conditions on the Clinch River (into which Poplar Creek drains) or the Tennessee River (into which the Clinch River drains). A large storm centered over the Poplar Creek watershed would be characterized by higher than normal Poplar Creek elevations accompanied by relatively high velocities. Flooding on the Clinch or Tennessee rivers can potentially cause backwater flooding on the Poplar Creek, which would be characterized by higher than normal Poplar Creek elevations accompanied by relatively low velocities. The regional flooding hazard study was performed by TVA and is documented in ES/CNPE-95/1, *Flood Analysis for Department of Energy Y-12, ORNL, and K-25 Plants* (LMES, 1995).

A local drainage analysis was also performed for the cylinder yards and described in K/D-6565, *Flood Potential for K-25 Cylinder Storage Yards* (ECE, 1996). The intent of this study was to determine whether local flooding from creeks, ditches, storm sewers, culverts, and roof drainage systems during an extreme storm having approximate recurrence intervals of 2,000 years, 5,000 years, and 10,000 years posed a serious concern. The task was accomplished by performing hydraulic and hydrologic analyses of creeks, ditches, storm sewers, culverts, and roof drainage systems using standard methods to determine the effects of the influx of rainwater that occurs during an extreme storm on the cylinder yards. ECE used a computer model simulation to perform the local precipitation analysis. The study resulted in grid maps showing the water elevations and velocities in two orthogonal directions for each of the three recurrence intervals.

1.4.3 Wind and Tornado Hazards

The wind hazard was evaluated by performing a site-specific analysis. Lawrence Livermore National Laboratory (LLNL) has developed wind hazard models for DOE sites using experts in wind hazards. The results of these hazard model studies are defined DOE-STD-1020-94, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards* (DOE, 1994), and UCRL-53526, *Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazard Models for Department of Energy Sites* (Coats and Murray, 1985). The wind hazard curve for the Oak Ridge sites is shown in Figure 3.2.

1.4.4 Lightning Hazard

There is no specific guidance in DOE-STD-1020-94 (DOE, 1994b) on design or evaluation for the effects of lightning. DOE Order 6430.1A, *United States Department of Energy General Design Criteria*, (DOE, 1989) does imply that the effects of lightning should be considered with the design basis tornado (Section

0111-99.0.2). The only lightning specific document referenced in DOE Order 6430.1A is NFPA 78 (now 780), *Lightning Protection Code* (NFPA, 1992).

1.5 EVALUATION RESULTS

The Department of Energy has specific guidelines to be used in evaluating new and existing facilities for natural phenomena. The primary technical guiding document is DOE-STD-1020-94, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards* (DOE, 1994b). The DOE-STD-1020-94 document is invoked by DOE Order 420.1, *Facility Safety* (DOE, 1995b), and more specifically in the DOE Implementation Guide 420.1.4 (Draft for interim use), *Interim Guidelines for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-Nuclear Facilities* (DOE, 1995c), which provides guidance in implementing the natural phenomena hazard mitigation requirements in DOE Order 420.1.

Although the DOE-STD-1020-94 does not require the evaluation of a 100-year natural phenomena event, the FSAR for the UF_6 cylinder storage yards needed to determine whether an occurrence should be classified as either an "anticipated event" ($1 >$ annual frequency $\geq 10^{-2}$) or as an "Evaluation Basis Event" ($10^{-2} >$ annual frequency $\geq 10^{-6}$). Therefore, 100-year evaluations were performed for the seismic, wind, and flood events.

The calculations are given in DAC-NP-710660-A001, *Natural Phenomena Evaluation of K-25 UF_6 Cylinder Storage Yards* (LMES, 1996).

1.5.1 Earthquake

The K-25 Site UF_6 cylinder storage yards were evaluated for slope stability and seismic liquefaction in accordance with DOE-STD-1020-94 (DOE, 1994b) and DOE-STD-1022-94 (DOE, 1994a). The soil liquefaction evaluation is documented in the K/D-6566 (Ahmed, 1996). The liquefaction evaluation demonstrated that liquefaction was not a concern for the EBE at the site. Slope stability of the cylinder yards located in the vicinity of Poplar Creek (E-Yard and J-Yard) and Beaver Pond (K-Yard) was also evaluated for static and seismic events. Results of the stability analysis (Ahmed, 1996) led to the conclusion that the slopes of the cylinder yards are safe and stable for the static and seismic events.

The UF_6 cylinders in the yards were evaluated for the following possible seismic scenarios:

1. rocking of single cylinders sitting in saddles,
2. rocking of stacked cylinders sitting in saddles,
3. rolling of cylinders sitting on a concrete or gravel surface,
4. sliding of the cylinders and saddles as a unit, sitting on a concrete or gravel surface, and
5. damage of a cylinder shell due to upper row cylinders falling from a stacked stiffener-to-stiffener configuration onto a lower cylinder.

Static equivalent analyses were performed considering the cylinders to act individually as rigid bodies. Items #1 through #4 are scenarios that require the resistance to rolling, rocking, or sliding motion to be determined and then compared to the seismically imposed cylinder loads at the point where motion is expected to begin, usually the lower leading point of contact between the cylinder and ground in the direction of motion. For sliding of a cylinder-saddle system to not occur, the normal force (the weight of the cylinder and the saddle)

times the coefficient of friction must be equal to or greater than the seismically imposed horizontal inertial force. The rolling calculations assumed that the cylinder in question was resting directly on a flat concrete or gravel surface. A simple rolling resistance calculation was then performed assuming a very small ground indentation (thus making a "mini" saddle) and the threshold ground acceleration which would produce motion was determined. Single and multiple cylinder configurations were considered as applicable. Item #5 simply assumed that the upper cylinders would fall and the impact stresses in the shells of the two cylinders involved were evaluated and compared to a code allowable value.

The findings of the seismic analysis for the cylinder yards and the storage cylinders are as follows:

1. Slope stability and liquefaction of the yards is not a problem.
2. Rocking or rolling-out of saddles will not occur for single or multiple stacked cylinders.
3. Cylinders resting on a concrete pad will roll at fairly low ground motions, even below the 100-year event (about 0.05g), though, in general, only the smaller cylinders (12-in. diameter or less) are so resting. Cylinders with lifting lugs will only roll until the lugs contact the ground. Due to the cyclic nature of the earthquake motion, it is not expected that cylinders will displace very far unless they happen to be resting on a sloped surface. Damage to cylinders that roll will probably be limited to small dents and maybe shearing off the protruding end valves at the threads if they are directly impacted (the opening is expected to be less than an inch in diameter).
4. Cylinders resting on a gravel surface are less likely to start rolling. The larger 30 and 48-in. cylinders will roll at pga levels of about 0.10g, while the small 5 and 8-in. ones will not roll with a PC-3 0.30g level earthquake. The 12-in. cylinders will roll at 0.24g, below the PC-3 level, but above the PC-2 level. The 100-year event will not cause these cylinders to roll.
5. While the calculation indicates that sliding of a cylinder resting in a saddle may occur for PC-3 ground accelerations in wet conditions, it does not seem likely that this situation will lead to any damage to the cylinders due to the short duration of the event and the short distance which any given cylinder will move. Stacked groups of cylinders will not slide.
6. Given a seismic event (even the 100-year event), top tier cylinders stacked "narrow/plate stiffener to narrow/plate stiffener" could slide, fall about 2½-in., and be damaged (dented or, maybe, punctured), and also cause damage to an equal number of bottom tier cylinders. The damage, if any, to the **top tier cylinders** will occur near the bottom of the cylinder at the impact point with the narrow/plate stiffener from the bottom cylinder. The puncture would be in a location where the solid UF_6 exists. The damage, if any, to the **bottom tier cylinders** can occur in two locations, (i) at the top of the cylinder near the impact point of the falling cylinder, and (ii) near bottom of the cylinder adjacent to the saddle support. The damage at the top of the cylinder is in the ullage area (no solid material, just gases or vapors), while the damage near the saddle support would be in a location where solid UF_6 exists. Since the impact stresses that occur near the saddle support are lower than those that occur at the top of the cylinder, only cylinders with substantial amounts of corrosion in this area will be damaged. Data indicate that only about one cylinder in six may have enough corrosion in the saddle area to have a sufficiently reduced wall thickness to actually allow this type of damage.

1.5.2 Flood

The K-25 Site cylinder storage yards are potentially subject to flooding from two principal sources, (1) regional flooding conditions on Poplar Creek, and (2) the effects of intense local rainfall centered over the site. The flood evaluation considered three elements, these being

1. the floating characteristics of the individual and stacked cylinders,
2. the effects of local flooding (precipitation) for the 10,000 year (PC-3); 5,000 year (twice the PC-3 hazard probability); 2,000 year (PC-2) criteria, and
3. the effects of regional flooding for the same criteria.

The regional flood vulnerabilities were determined by comparing the cylinder yard elevations with the regional flood hazard elevations documented in ES/CNPE-95/1, *Flood Analysis for Department of Energy Y-12, ORNL, and K-25 Plants* (CNPE; 1995). The local flood (precipitation) standing water depths for the different criteria rainfall are described in K/D-6565, *Flood Potential for K-25 Cylinder Storage Yards* (ECE, 1996). Where flood vulnerabilities existed, further evaluations were performed in order to determine if cylinders would float in the vulnerable yards. The flood evaluation performed herein started with the PC-3 10,000 year criteria and if it was met, did not consider any other criteria, otherwise the 5,000 year and 2,000 year criteria were evaluated.

The flood studies for the K-25 UF_6 cylinder and cylinder yards obtained the following conclusions:

Floating of cylinders

1. All empty cylinders (including those with heel quantities of UF_6) larger than 12-in. in diameter will float. The 5-in., 8-in., and 12-in. diameter empty cylinders will not float. The weight of UF_6 needed to keep the 30-in. and 48-in. cylinders from floating varies considerably (from 300 lb to over 6,000 lb), depending on the specific cylinder.
2. Full cylinders will not float.
3. Stacked groups of empty cylinders will also float, though the water levels to do so are somehat higher than for single cylinders. Of course, once a stacked cylinder starts to float it will leave the stacked configuration and behave as a single cylinder.

Local Flooding

1. Local flooding is not a problem in any of the cylinder yards, with the exception of the depressed area in K-1066-F. In this region, an empty cylinder will float, but only within the general boundary of the depressed region.
2. The 100-year rainfall event will also cause cylinders to float in the K-1066-F yard depression region.

Regional Flooding

1. Regional flooding is not a problem in yards K-1066-B and K-1066-K.
2. For the PC-3 (10,000 year) flood, all the floatable cylinders will float in the remaining yards.
3. For the PC-3 increased hazard level (5,000 year) and the PC-2 (2,000 year) flood, some of the cylinders will float, depending on size.
4. The 100-year regional flooding event will not cause any problems.

Damage to floating cylinders from other floating cylinders is considered negligible, except for possible damage to the fill-valves, which might shear off at the threads, creating a small opening for material of vapors to exit.

1.5.3 High Wind and Tornado Missiles

Wind loads were applied in accordance with ASCE 7-93, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 1993), as recommended by DOE-STD-1020-94. For Oak Ridge the PC-2 wind speed is

70 mph with no tornado or missile requirements; for PC-3 the wind speed is governed by tornado requirements: 113 mph (straight wind analysis) plus two tornado-generated missiles: (i) a 2x4 timber plank, weighing 15 lb traveling at 100 mph (horizontally), having a maximum height of 150 ft; or traveling vertically at 70 mph, and (ii) a 3-in. diameter standard steel pipe, weighing 75 lb, traveling at 50 mph (horizontally), at a maximum height of 75 ft; or traveling vertically at 35 mph.

The wind/tornado evaluation of the UF_6 storage cylinders located in six yards at the K-25 Site included evaluation for the following:

1. instability of single cylinders sitting in saddles,
2. instability of stacked cylinders,
3. rolling of cylinders sitting on concrete or gravel surfaces,
4. sliding of cylinders resting in a saddle, and
5. effects of tornado generated missiles on cylinders.

The wind/tornado results of the UF_6 storage cylinders located in six yards at the K-25 Site determined the following:

1. Instability of single cylinders sitting in saddles and instability of stacked cylinders is not a problem for the 113 mph PC-3 wind speeds. Cylinders will remain in saddles and stacked cylinders will remain in the stacked configuration.

2. All sizes and configurations (empty or full) of cylinders sitting on a concrete pad are susceptible to rolling at wind speeds below the 70 mph, PC-2, criteria. Also, unrestrained cylinders subjected to the 100-year wind will also roll, since that wind speed is also 70 mph.

3. All of the empty cylinders (except the 5-in. cylinders) sitting on a gravel surface are susceptible to rolling at wind speeds below the 113 mph, PC-3, criteria. The empty 2.5-ton (30A/30B) and 48-in. thin-walled cylinders (48G and 48T) will roll on a gravel surface at speeds below the PC-2 criteria.

4. Sliding of cylinders plus saddle is not a problem.

5. Tornado generated missiles. Two missile types were considered: (i) a 2x4 timber plank, weighing 15 lb traveling 100 mph horizontally, and (ii) a 3-in. diameter standard steel pipe, weighing 75 lb, traveling 50 mph horizontally. A 3/16-in. shell thickness is required in order to prevent perforation by the timber plank, and 5/32-in. in order to prevent perforation by the steel pipe. All the cylinders included in this study, with the exception of the 8-in. cylinders, have a nominal wall thickness greater than the 3/16-in. value; the 8-in. cylinder has a nominal thickness equal to 3/16-in. Corrosion studies have clearly shown that the most "significant wall thinning of cylinders has been found in only a few locations, the most significant of these being (a) the underside due to ground contact or poor yard drainage, (b) the underside at or near the saddle/body contact interface, and (c) in skirt/head crevices. The corrosion study also has clearly shown that the most vulnerable and exposed area of a cylinder for a missile strike, the centerline and about ±45° from the centerline, is about the least corroded area, and the shell thickness exceeds the minimum required to prevent perforation. Although a missile might impact a cylinder in the corroded regions, the missile will glance off due to the angle of impact. Finally, the 8-in. cylinders are not at risk because it is considered incredible that a missile will exist at the very

low altitudes (3 to 5-in.) required to impact the 8-in. cylinder. However, a missile striking a protruding fill-valve could damage the valve, cause it to shear off at the threads, thus leaving a small opening hole.

1.5.4 Lightning

The purpose of the lightning evaluation was to determine what damage, if any, lightning might cause to the storage cylinders located outside in the K-25 Site cylinder yards. The evaluation considered the probability (based on lightning flash ground density data for the Knoxville-Oak Ridge area) that a lightning strike would occur in or near the yards, the consequences of a strike hitting a cylinder directly, and compared the NFPA 780 and DOT/FAA (1992) requirements for sheet metal thickness in order to prevent melt-through of holes. It was concluded that the shell thickness of the cylinders was more than sufficient to prevent lightning from penetrating a cylinder, and that the lightning effects would be dissipated long before the effects could produce a heating of the contents which might lead to an explosion/rupture of the cylinder. In addition, no documented occurrence of lightning strikes on cylinders was found. A number of persons having a long history of involvement with the cylinder program at the K-25, Paducah, and Portsmouth plants were contacted and none ever recalled any incident where a cylinder or yard had been struck by lightning. Since a few strikes would seem likely to have taken place in the past forty plus years, and since no incidents have ever been reported due to lightning strikes, it would appear that the consequences of a lightning strike on a cylinder, if it has occurred, has been minimal.

2. INTRODUCTION

2.1 SCOPE

The K-25 Site, located in Oak Ridge, Tennessee, is owned by the U.S. Department of Energy (DOE). DOE owns an inventory of UF_6 at the K-25 Site that consists primarily of depleted UF_6 with assays of less than 0.711 wt % ^{235}U. The balance of DOE's uranium inventory at the K-25 Site includes small amounts of enrichment feed and "heel" quantities with assays ranging between 0.711 and 4.5%. In addition to the DOE uranium inventory stored at the K-25 Site, there are about 150 UF_6 feed cylinders with normal assays of 0.711 wt % in the K-25 cylinder yards. The depleted and enriched inventories collected during the course of the gaseous diffusion uranium enrichment operations while the plants were operated for DOE and its predecessors, the U. S. Atomic Energy Commission, and the Energy Research and Development Administration.

During the development and operation of the enrichment process, containers, support equipment, and support facilities were designed, constructed, and used as a system to store, transport, and process the depleted UF_6. After a significant inventory was produced, outdoor storage facilities ("cylinder yards") evolved independently at the sites. Cylinder yards are constructed of either concrete, compacted gravel, or asphalt over gravel. The handling equipment used to stack these cylinders has also evolved, from mobile cranes to specially designed machines that grasp and lift the cylinders with hydraulically operated tines.

The K-25 Site UF_6 cylinder storage yards are used for the temporary storage of UF_6 normal assay cylinders and long-term storage of other UF_6 cylinders. The K-25 Site UF_6 cylinder storage yards consist of six active on-site areas: K-1066-B, K-1066-E, K-1066-F, K-1066-J, K-1066-K, and K-1066-L (shown in Figure 2.1). In support of the operating gaseous diffusion plant at the K-25 Site these yards stored UF_6 cylinders filled with depleted assay UF_6, normal assay UF_6 feed material, and enriched assay UF_6 product material. Since enrichment operations were terminated in 1985, all of the filled UF_6 product cylinders and most of the feed UF_6 cylinders have been shipped off-site to the operating gaseous diffusion plants. Current and future operations will consist of shipping the remaining feed cylinders to the operating diffusion plants and storing depleted assay UF_6 cylinders, empty cylinders and nearly empty cylinders containing residual quantities of UF_6. Storage will continue until plans for ultimate disposition of these cylinders are developed and implemented.

The six active cylinder storage yards were evaluated for vulnerabilities to natural phenomena, earthquakes, high winds and tornados, tornado-generated missiles, floods, and lightning.

2.2 PURPOSE

At the request of the DOE, and in accordance with the requirements of DOE Order 5480.23, *Nuclear Safety Analysis Reports* (DOE 1992), Lockheed Martin Energy Systems, the operating contractor for the K-25 Site, is preparing a Safety Analysis Report (SAR) to examine the safety related aspects of the K-25 Site UF_6 cylinder storage yards. The SAR preparation encompasses many tasks terminating in consequence analysis for the release of gaseous and liquid UF_6, one of which is the evaluation of natural phenomena threats, such as earthquakes, floods, and winds, in accordance with DOE Order 5480.28, *Natural Phenomena Hazards Mitigation* (DOE 1993a). DOE Order 5480.28 defines performance categories (PC) and establishes

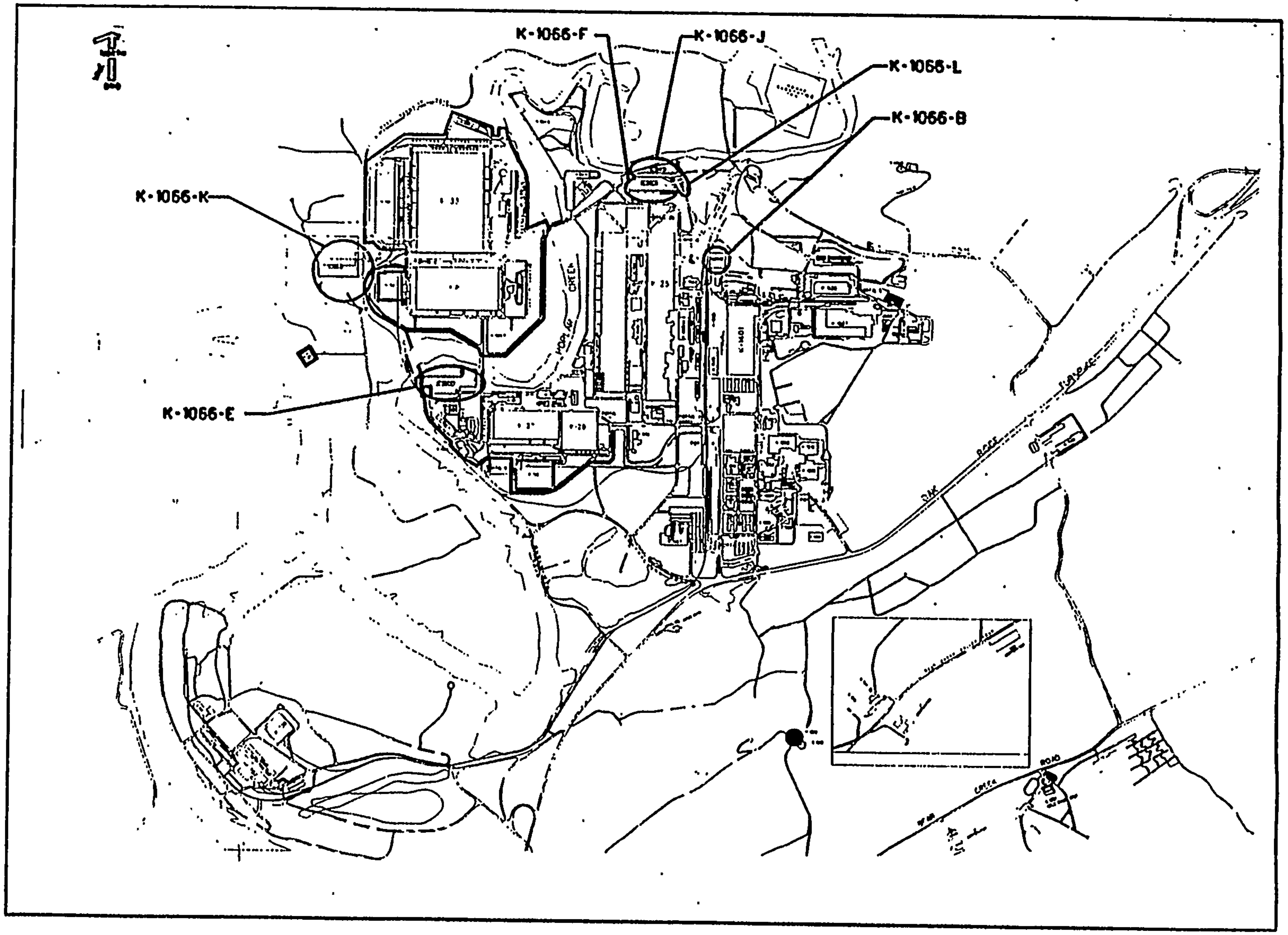

Figure 2.1. K-25 Site site plan showing location of UF_6 cylinder storage yards

corresponding performance goals for the application of a graded approach in designing and evaluating facilities with regard to NPH threats. This report summarizes the seismic, wind/tornado, flood, and lightning analyses for these sites.

2.3 GENERAL CYLINDER YARD DESCRIPTIONS

The K-25 Site UF_6 cylinder storage yards consist of six on-site areas: K-1066-B, K-1066-E, K-1066-F, K-1066-J, K-1066-K, and K-1066-L on the K-25 Site. There are no permanent structures erected on the cylinder yards, except for five portable buildings, which were not included in the natural phenomena evaluations. The yards are located in the lightly populated western and northern portion of the site in areas surrounding the inactive uranium separation facilities. The western yards are K-1066-E and K-1066-K, while the northern yards are K-1066-B, K-1066-F, K-1066-J, and K-1066-L. Site descriptive data pertinent to these yards are discussed in the sections that follow.

2.3.1 K-1066-B Yard

The K-1066-B cylinder storage yard is located approximately 530 ft east of the northern end of the K-25 building approximately 1400 ft (0.3 mi.) south of Poplar Creek mile marker 4.5. The yard is paved with a concrete pad measuring 220-ft x 230-ft (area 50,600 ft²). The pad is essentially level, sited between elevations 777.8 and 778.0 ft above sea level, sloped only to drain to two storm sewer catch basins located down the center of the yard. Storm water runoff drains through the catch basins and connecting storm sewer to an outfall on the Mitchell Branch of Poplar Creek to the northeast.

2.3.2 K-1066-E Yard

This yard is located due south of the K-31 building on the south side of Poplar Creek on a bend in the river between mile markers 2 and 2.5. The yard provides a storage area of 159,000 ft². The west end of this yard consists of a concrete pad covering 113,175 ft² (about 2.6 acres). The east end area of the yard consists of an existing 10,175 ft² strip of concrete that extends 235 ft to the east boundary of the yard plus a new concrete pad area of about 35,450 ft². The west end of the yard (which currently contains the vast majority of the stored cylinders in this yard) is quite level, its elevation varying between 750 ft and 751 ft. The east end of the yard has considerable more variation, ranging from 750.9 ft to 756.3 ft elevation (the median elevation is about 753 ft). Storm water runoff from the western yard flows predominantly to the southwest, collecting in a catch basin located at the western end of the yard, and discharging to Poplar Creek northwest of the yard. Runoff from the eastern yard drains to the west in an area between the western and eastern yards and flows north to discharge to Poplar Creek north of the yard. The yard is situated at a curve in Poplar Creek such that the creek runs along the northern and western sides of the yard. At its closest point on the northern side, Poplar Creek is about 80 ft northeast of the eastern yard. At its closest point on the western side, the creek is about 220 ft northwest of the western yard. Site access roads run along the eastern and southern sides of the yard. Yard entry is from the access road on the southern side of the yard into either the southwest or the southeast corner of the western yard. A security patrol road encircles the yard on the western, northern, and eastern sides.

2.3.3 K-1066-K Yard

The K-1066-K cylinder storage yard is located across Perimeter Road approximately 860 ft west of the K-31 and K-33 buildings, and provides approximately 135,000 ft² of yard area. The yard is outside the site's main security fencing in a separately fenced area on the west side of Perimeter Road. The approximate southern half of the yard is paved with concrete, while the northern portion of the yard is gravel. The yard is relatively level, with a mean elevation above sea level of 775 ft. The yard drains predominantly to the north and east, with surface runoff channeling through a series of drainage ditches and storm sewers and discharging through a 42-in. storm sewer outfall into Beaver Pond (K-901-A), located west of the yard. The yard is also located about 700 ft east of the Clinch River at about the 11.5 mile point. Perimeter Road runs north and south approximately 80 ft from the eastern side of the yard, and an access drive provides entry from Perimeter Road to the southeast corner of the yard. A security patrol road runs outside the security fencing along the southern and western sides of the yard.

2.3.4 K-1066-F Yard

This yard is the K-25 Site cylinder staging area, where cylinders scheduled for off-site shipment are temporarily located. K-1066-F is located adjacent to yards K-1066-J and K-1066-L and about 255 ft north of the K-25 building. The yard is paved with asphalt. It is located about 150 ft south of Poplar Creek at about the 4.5 mile marker. The elevation of F-yard varies between a low of 758.9 ft to 762.9 ft above sea level. It has an area about 117,000 ft^2, comprised of both an asphalt and a concrete surface. The low point in the yard, 758.9 ft is the top of a catch basin which is located inside a depression having an estimated area of 5600 ft^2 (5% of the yard). Storm water runoff drains through this catch basin and the storm sewer to a Poplar Creek outfall to the northeast. At its closest point, Poplar Creek runs approximately 150 ft north of the yard. The outer edge of the depression is located at 760 ft, with the remainder of the yard being located above this level. The median elevation for the yard is approximately at 761 ft above sea level.

2.3.5 K-1066-J Yard

The K-1066-J cylinder storage yard is located approximately 510 ft north of the K-25 building, and provides approximately 80,000 ft^2 of yard area. The yard is located in the same area as the K-1066-F and K-1066-L yards and sits north of these other yard locations. The yard area is primarily compacted gravel, with a small portion having an asphalt surface. The site is relatively level, with a minimum elevation of 756 ft and a mean elevation of about 758 ft above sea level. Surface runoff drains toward the northeast and directly into Poplar Creek. Poplar Creek runs along the northern side of the yard and, at its closest point, is a located approximately 60 ft from the yard. The yard is normally entered from the site access road running along its southern side. A security patrol road encircles the yard on the northern and eastern sides.

2.3.6 K-1066-L Yard

The K-1066-L cylinder storage yard is located approximately 560 ft north of the K-25 building, and provides approximately 44,200 ft^2 of yard area. The yard is located in the same area as the K-1066-F and K-1066-J yards, and sits east of and between these other yard locations. The yard is paved with a concrete pad. The yard is sloped toward the northeast, with low-point and median elevations above sea level of 757.5 and 760 ft, respectively. The yard is well drained, with surface runoff draining primarily to the Mitchell Branch of Poplar Creek, located to the east of the yard. Poplar Creek is located approximately 270 ft to the north. Normal entry to the yard is from the site access road running along the western side of the yard.

3. EVALUATION HAZARDS AND CRITERIA

3.1 NATURAL PHENOMENA HAZARDS, GENERAL DISCUSSION

The natural phenomena (NP) hazards described in this section are earthquake, high winds/tornados, flood and lightning. The NP hazards were evaluated to determine the evaluation basis levels in accordance with the Department of Energy (DOE) requirement documents listed and discussed below. The NP hazard evaluations and evaluation basis levels are described in the following sections.

The Department of Energy has specific guidelines to be used in evaluating new and existing facilities for natural phenomena. The primary technical guiding document is DOE-STD-1020-94, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards* (DOE, 1994). The DOE-STD-1020-94 document is invoked by DOE Order 420.1, *Facility Safety*, and more specifically in the DOE Implementation Guide 420.1.4 (Draft for interim use), *Interim Guidelines for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-Nuclear Facilities* (DOE, 1995), which provides guidance in implementing the natural phenomena hazard mitigation requirements in DOE Order 420.1.

Prior to applying these criteria, structures, systems, and components (SSC's) will be placed in one of five Performance Categories, PC-0 to PC-4. Performance Category (PC) is a classification using a graded approach in which SSC's in the same category are designed to assure similar levels of protection (i.e., meet the same performance goal) during natural phenomena events (see Table 3.1, which comes from IG 420.1.4). DOE-STD-1021-93 (Change Notice #1, January 1996), *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*, provides guidance on establishing PC levels for SSC's, which are primarily based on the consequence of failure of the SSC.

Table 3.1 Target Performance Goals for each SSC Category

Performance Category	PC-0	PC-1	PC-2	PC-3	PC-4
Target Performance Goal (Probability per year of exceeding damage limits)	none	$1x10^{-3}$	$5x10^{-4}$	$1x10^{-4}$	$1x10^{-5}$

Traditionally the target performance goal is achieved by specifying a natural phenomena hazard that has a more frequent annual probability of exceedance (than the target goal) and then applying a conservative design or evaluation approach. DOE-STD-1020 follows this methodology for the earthquake, straight wind, and flood PC-1 evaluations. For the higher PC categories for flood the hazard annual probability of exceedance is set equal to the target performance goal. For tornado evaluations for PC-3 and PC-4, the hazard annual probability of exceedance is less than that of the target performance goal, thus the target performance goal is automatically satisfied. PC-0 requires no special consideration of natural phenomena. PC-1, PC-2, and PC-3 are the categories normally considered for the Oak Ridge sites. The hazard annual probabilities for each of the natural phenomena hazards are discussed in the corresponding sections that follow.

3.2 FACILITY HAZARD CLASSIFICATION

The five storage yards (K-1066-B, K-1066-E, K-1066-J, K-1066-K, and K-1066-L) are Hazard Category 2 facilities based on their very large depleted UF_6 inventories, even though depleted uranium has no possibility of nuclear criticality and represents only a minimal radiological hazard. The one staging yard, K-1066-F, is administratively controlled to below Category 2, and is therefore a Category 3 facility. All six cylinder yards are classified as "Moderate" hazard facilities with regard to non-nuclear hazards because of the potential for HF releases.

At the time of this writing, the final natural phenomena hazard performance categorization of the cylinders and the cylinder yards had not been made, but they most likely would be classified as either PC-2 or PC-3. For purposes of this study, the analysis assumed a PC-3, but considered the effects of PC-2 if they were not satisfactory for the higher category.

3.3 EARTHQUAKE HAZARD

The earthquake hazard was evaluated by performing site specific studies. The site specific studies included performing probabilistic and deterministic seismic hazard analyses to define rock outcrop motions and soil amplification analyses to determine the Evaluation Basis Earthquake (EBE) ground surface motions. The seismic hazard analyses (top of rock motions) are described and documented in ES/CNPE-95/2, *Seismic Hazard Criteria for the Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth Ohio U.S. Department of Energy Reservations* (Beavers, 1995). The Department of Energy has approved the rock accelerations for the Oak Ridge sites (Beavers, 1995). The probabilistic seismic hazard analyses were performed using the Lawrence Livermore National Laboratory (LLNL) and the Electric Power Research Institute (EPRI) seismic hazard methodologies. The LLNL and EPRI seismic hazard methodologies represent major efforts to characterize the seismic hazard for nuclear power plants in the central and eastern United States, and use the most recent, up-to-date understandings of seismicity and ground motion relations for the region. The results of these studies and the two methodologies were used to develop the seismic hazard for this site. Both the LLNL and EPRI studies utilize a point-source representation of earthquakes, thereby ignoring the non-zero dimensions of earthquake ruptures. This simplification is appropriate for this site, because earthquakes with large ruptures are highly unlikely to occur near the site (due to low values of maximum magnitude).

The probabilistic seismic hazard results from the LLNL and the EPRI methodologies were used in accordance with DOE-STD-1024-92, *Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites* (DOE, 1992), to develop site specific uniform hazard rock response spectra. DOE-STD-1024-92 provides a methodology for combining the seismic hazard results from LLNL and EPRI to obtain a mean uniform hazard response spectra. Additional evaluations were made to address the uncertainty in the low frequency range (2.5 Hz and less) of the response spectra and are documented in ES/CNPE-95/2.

The deterministic seismic hazard analyses was performed by obtaining actual earthquake records with magnitudes and site characteristics similar to the K-25 Site seismic environment. The response spectra obtained from the earthquake recordings were compared with the probabilistic site specific uniform hazard response spectra to illustrate the uniform hazard response spectra were appropriate for the K-25 Site.

Based on the rock outcrop motions defined in the seismic hazard analyses (Figure 3.1), soil amplification and liquefaction evaluations were performed. The soil amplification evaluation is documented in K/D-6566, *K-25*

Site Site-Specific Earthquake Response Analysis and Soil Liquefaction Assessment, (Ahmed, 1996). The soil amplification analyses were performed to calculate a range of expected site specific, free-field earthquake responses to the rock outcrop motions of three hazard level earthquakes, a 500-year, a 1000-year and a 2000-year event. From the geotechnical and geophysical investigations, four soil columns (which covered a wide range of subsurface profiles) were derived for use in the amplification analyses. The geotechnical information from past site studies defining the soil stratigraphy and shear wave velocities was used. The lower bound, upper bound, and mean values of shear wave velocities were used in the analysis. The lower and upper bound shear wave velocities were computed in accordance with the recommendations given in the NRC Standard Review Plan (NRC, 1989). The variation of shear modulus and damping ratio with shear strain was used with standard relationships developed for similar materials by others.

The computer program SHAKE 91 was used to perform the soil amplification analyses (Ahmed, 1996) and calculate the free-field ground motions for the representative soil columns. The motions calculated at the ground surface of free-field (soil over rock) were amplified over rock outcrop motions for all cases. The individual responses from the soil columns were used to determine the free-field ground surface motions. The soil liquefaction evaluation is documented in the K/D-6566 (Ahmed, 1996). The liquefaction evaluation demonstrated that liquefaction was not a concern for the EBE at the site. Slope stability of the cylinder yards located in the vicinity of Poplar Creek (E-Yard and J-Yard) and Beaver Pond (K-Yard) was also evaluated for static and seismic events. Results of the stability analysis (Ahmed, 1996) led to the conclusion that the slopes of the cylinder yards are safe and stable for the static and seismic events.

Based on the seismic hazard analyses and soil amplification evaluation, smooth top of ground response spectra curves were developed (Ahmed, 1996) for the 500, 1000, and 2000 year return periods for damping values ranging from 2 percent to 15 percent. As an example, the 2,000 year (PC-3) EBE horizontal ground response spectra for various levels of damping is shown in Figure 3.2. The vertical earthquake ground motion is two-thirds of the horizontal ground motion. The following table summarizes the seismic hazard annual exceedance probabilities for the PC-2 and PC-3 categories as given in DOE-STD-1020-94, the (DOE approved) mean peak ground rock accelerations, and the mean peak ground acceleration at the top-of-soil for the K-25 Site.

Table 3.2. UF_6 Cylinder Yards Seismic Hazard Evaluation Criteria

	Analysis Category		Reference
	PC-2	PC-3	
Hazard Exceedance Probability, P_H	$1x10^{-3}$	$5x10^{-4}$	DOE-STD-1020-94
Return Period, years	1,000	2,000	DOE-STD-1020-94
Rock acceleration, g's, horizontal	0.08	0.12	Beavers, 1995
Top-of-Soil acceleration, g's, horizontal *	0.20	0.30	Ahmed, 1996

* vertical accelerations = 2/3 of the horizontal accelerations for analysis

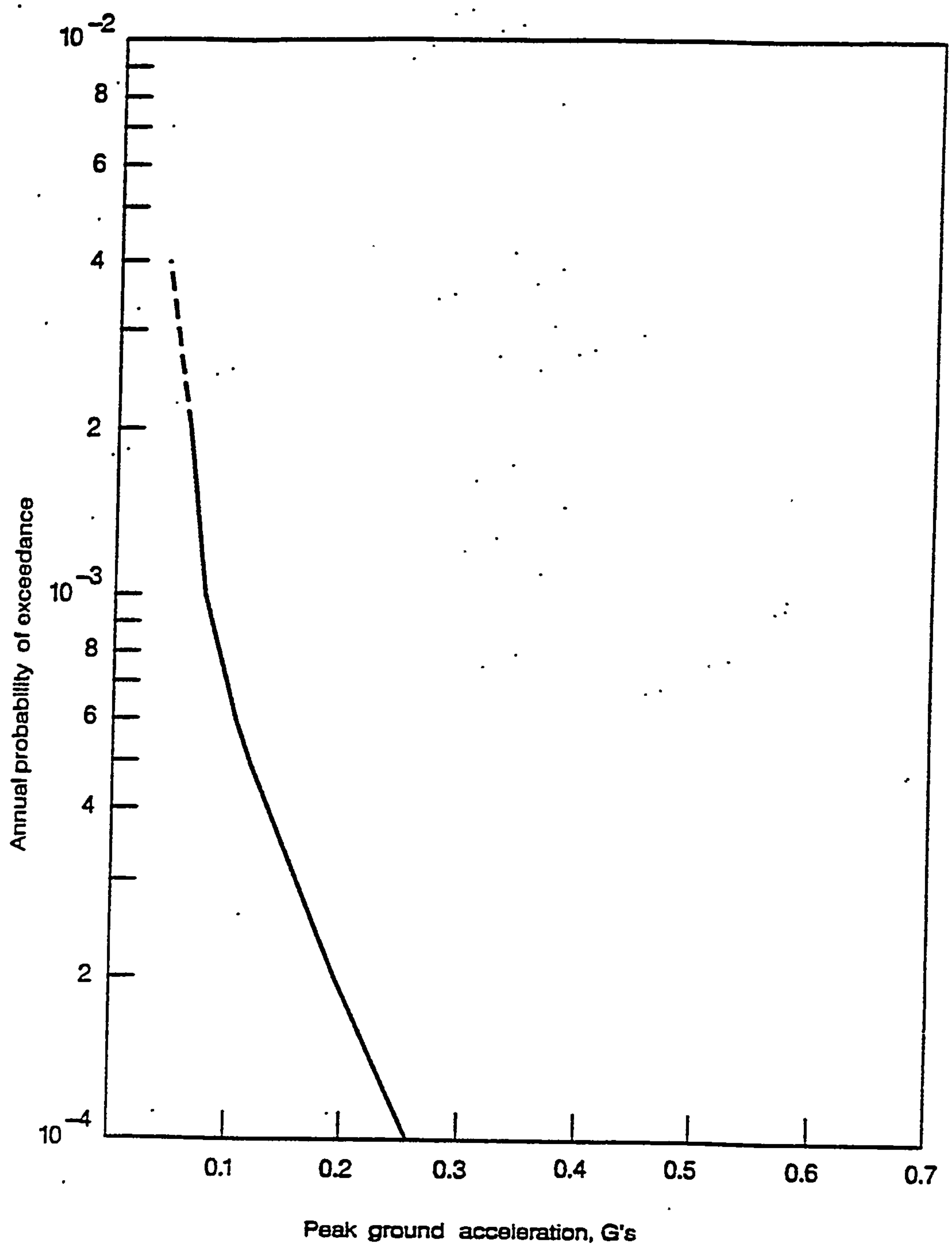

Figure 3.1. K-25 Site, PC-3 site specific hazard curve for peak rock acceleration for the Oak Ridge Reservation

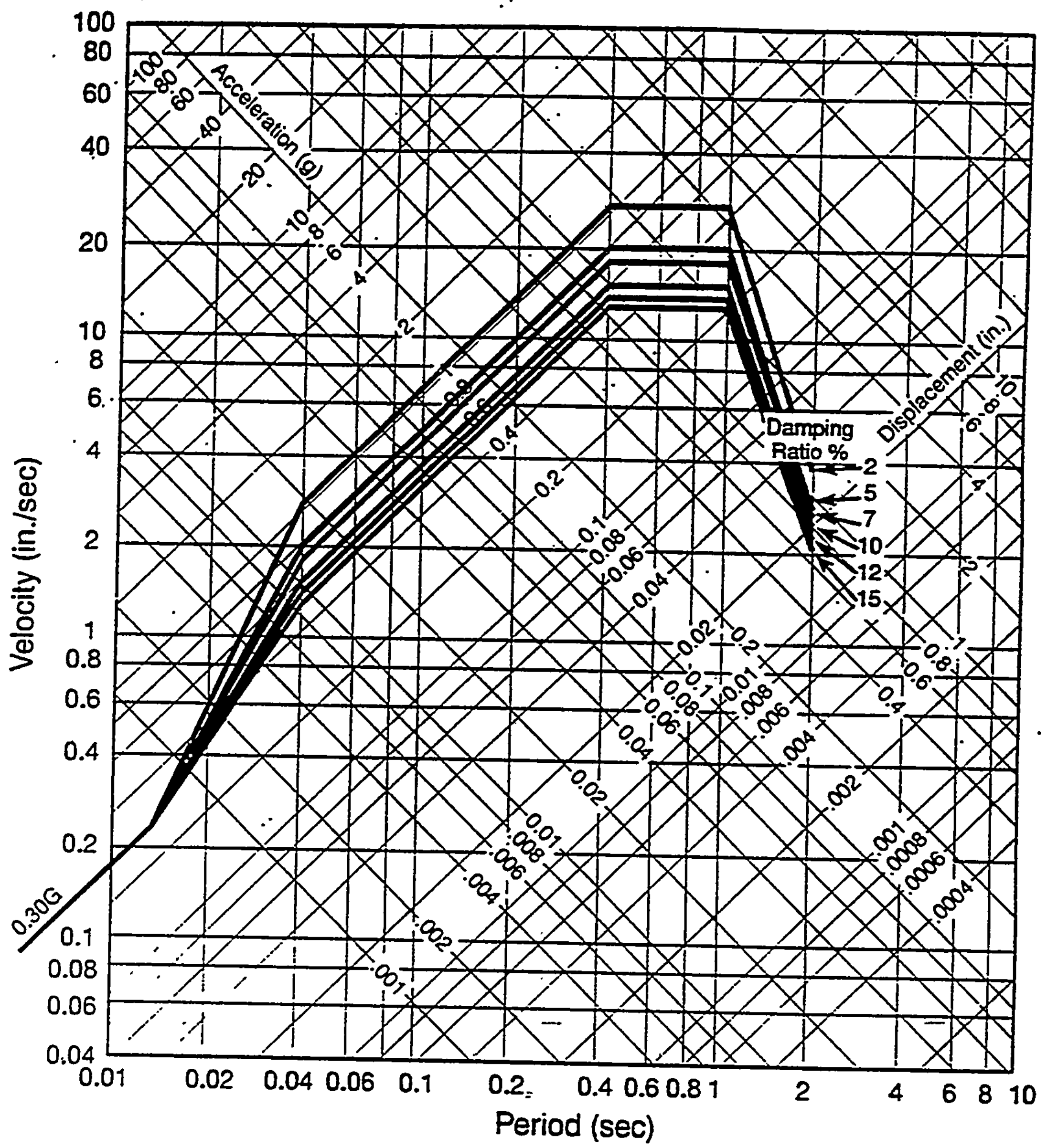

Figure 3.2. K-25 Site, site specific earthquake design response spectra for horizontal soil motion, PC-3, 2000 year return period, facilities supported on soil overburden

3.4 FLOOD HAZARD

The Department of Energy guidelines to be used in evaluating new and existing facilities for floods is given in DOE-STD-1020-94, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards* (DOE, 1994). The values of P_H associated with the PC-2 and PC-3 categories are $5x10^{-4}$ and $1x10^{-4}$ respectively, corresponding to return periods of 2000 and 10,000 years.

Poplar Creek winds it way through the western portion of the plant flowing roughly in a north to south direction and along the northern boundary of the plant flowing east to west. Only a very small portion of the K-25 site is located closer to the Clinch River than to Poplar Creek. Cylinder Yard K is probably located closer to the Clinch than to Poplar Creek. The plant site elevations range from 5 to 30 feet above the river banks. The cylinder yards flood study evaluated the potential for inundation during floods having recurrence intervals of 2,000 years (PC-2), 5,000 years, and 10,000 years (PC-3). PC-1 data was not included in this study. The 5,000 year value comes from the allowance that DOE makes for existing facilities (that do no meet the original criteria) in permitting evaluation at twice the hazard annual probability, which for PC-3 facilities this becomes 5,000 years.

The K-25 Site cylinder storage yards are potentially subject to flooding from two principal sources, (1) regional flooding conditions on Poplar Creek, and (2) the effects of intense local rainfall centered over the site.

Flood conditions on Poplar Creek can result either from large rainfall events occurring in the Poplar Creek watershed, or from flooding conditions on the Clinch River (into which Poplar Creek drains) or the Tennessee River (into which the Clinch River drains). A large storm centered over the Poplar Creek watershed would be characterized by higher than normal Poplar Creek elevations accompanied by relatively high velocities. Flooding on the Clinch or Tennessee rivers can potentially cause backwater flooding on the Poplar Creek, which would be characterized by higher than normal Poplar Creek elevations accompanied by relatively low velocities. The regional flooding hazard study was performed by TVA and is documented in ES/CNPE-95/1, *Flood Analysis for Department of Energy Y-12, ORNL, and K-25 Plants* (CNPE, 1995).

A local drainage analysis was also performed for the cylinder yards and described in K/D-6565, *Flood Potential for K-25 Cylinder Storage Yards* (ECE, 1996). The intent of this study was to determine whether local flooding from creeks, ditches, storm sewers, culverts, and roof drainage systems during an extreme storm having approximate recurrence intervals of 2,000 years, 5,000 years, and 10,000 years posed a serious concern. The task was accomplished by performing hydraulic and hydrologic analyses of creeks, ditches, storm sewers, culverts, and roof drainage systems using standard methods to determine the effects of the influx of rainwater that occurs during an extreme storm on the cylinder yards. ECE used a computer model simulation to perform the local precipitation analysis. The study resulted in grid maps showing the water elevations and velocities in two orthogonal directions for each of the three recurrence intervals.

3.4.1 Dam Failures

DOE-STD-1020-94 and DOE-STD-1023-95 indicate that probabilistic flood hazard analyses should be performed for sites with PC-3 and PC-4 SSC's, which should include consideration of dam failures from overtopping, seismically induced failure, and random failure. These studies have been performed through TVA and are documented in ES/CNPE-95/1 (LMES, 1995). TVA has shown that failure of Norris dam during a PMF will not occur, therefore overtopping is not a problem (plus the probability of the PMF occurrence is much greater than the performance goal of $1x10^{-4}$ for PC-3 SSC's). A seismic evaluation (Agbabian 1975) has been performed demonstrating that Norris Dam will withstand the 0.12g peak rock acceleration earthquake associated with the

PC-3, 2000 year return period event. Therefore seismic induced dam failure is not an issue. The probability of a random failure has been judged to be much less than the $1x10^{-4}$ performance goal, therefore a random dam failure is not an issue. The basis for this judgement is that TVA has a thorough inspection program which ensures random failures will not occur (LMES, 1995). Thus, it is concluded that dam failure for the K-25 Site cylinder yards is not a problem and no further evaluation is necessary.

3.5 WIND AND TORNADO HAZARDS

The wind hazard was evaluated by performing a site-specific analysis. Lawrence Livermore National Laboratory (LLNL) has developed wind hazard models for DOE sites using experts in wind hazards. The results of these hazard model studies are defined DOE-STD-1020-94, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards* (DOE, 1994), and UCRL-53526, *Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazard Models for Department of Energy Sites* (Coats and Murray, 1985). The wind hazard curve for the Oak Ridge sites is shown in Figure 3.3. A summary of the DOE-STD-1020 wind/tornado requirements are shown in Table 3.3. Note that using that wind hazard curve for the $2x10^{-5}$ one obtains approximately a wind speed of 130 mph. This is a tornado gust speed and must be converted to fastest mile wind speed ($V_{fm} = 0.958V_t - 11.34$) in order to use the DOE-STD-1020-94, which is consistent with the approach used in ASCE 7-93, *Minimum Design Loads for Buildings and Other Structures (ASCE, 1993)*. The conversion produces the 113 mph value given in DOE-STD-1020. While the hazard curve gives a value of 58 mph for the $2x10^{-2}$ annual probability, ASCE 7 requires that the minimum wind speed for evaluation and design be 70 mph.

Table 3.3. Wind/Tornado Hazard Evaluation Criteria

	Analysis Criteria	
	PC-2	PC-3
Wind Criteria		
Hazard Exceedance Probability, P_H	$2x10^{-2}$	$1x10^{-3}$
Return Period, years	50	1,000
Wind Speed, mph	70	----
Tornado Criteria		
Hazard Exceedance Probability, P_H	NA	$2x10^{-5}$
Return Period, years	----	50,000
Wind Speed, mph	----	113
Missile Criteria	----	2x4 timber plank, 15 lb @100 mph (horiz.), max height 150 ft; 70 mph (vert.) 3-in. dia. std. steel pipe, 75 lb @ 50 mph (horiz.), max. height 75 ft; 35 mph (vert.)

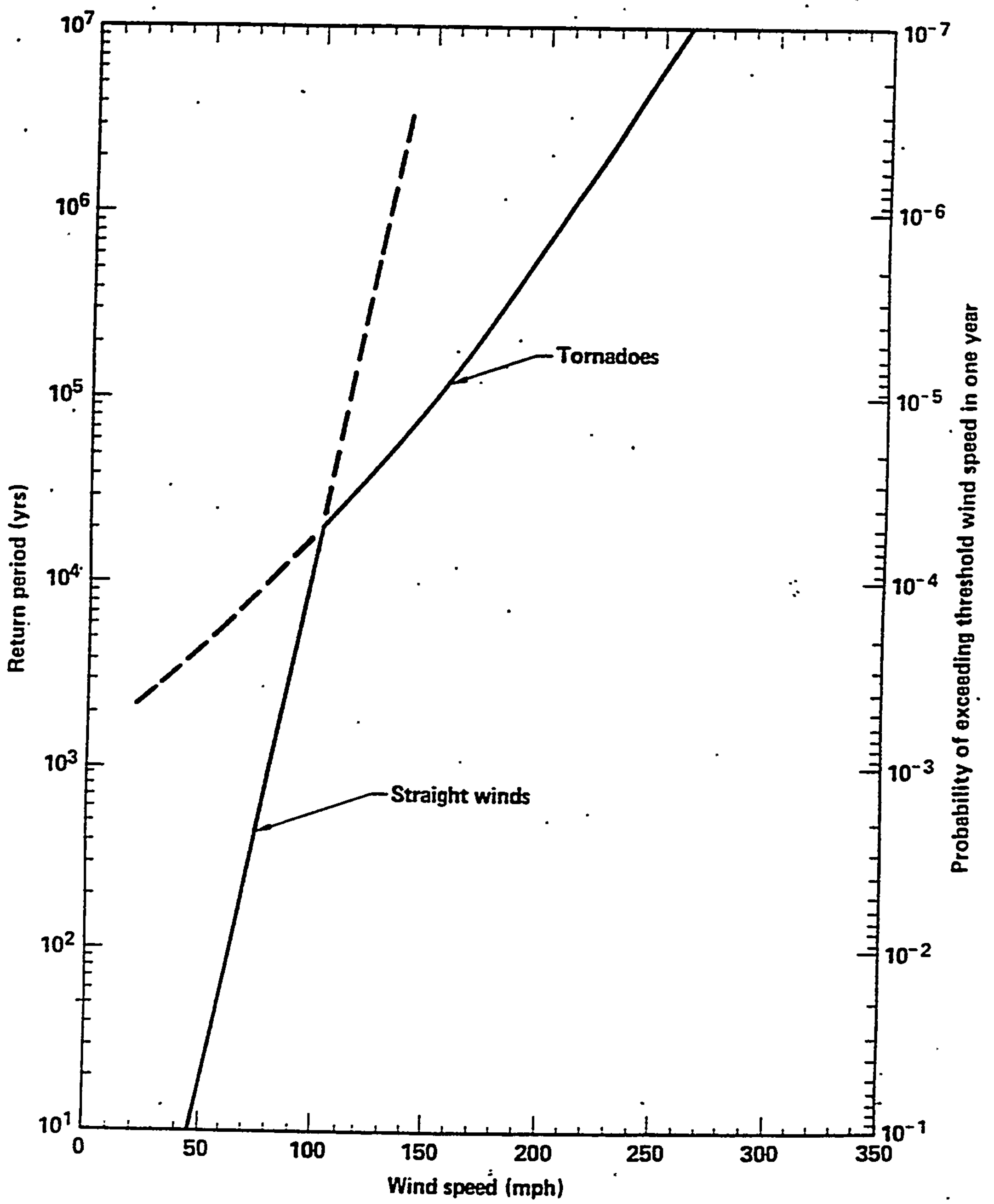

Figure 3.3. K-25 Site wind hazard curve

3.6 LIGHTNING HAZARD

There is no specific guidance in DOE-STD-1020-94 on design or evaluation for the effects of lightning. DOE Order 6430.1A, *United States Department of Energy General Design Criteria*, (DOE, 1989) does imply that the effects of lightning should be considered with the design basis tornado (Section 0111-99.0.2). The only lightning specific document referenced in DOE Order 6430.1A is NFPA 78 (now 780), *Lightning Protection Code* (NFPA, 1992).

The purpose of the lightning evaluation was to determine what damage, if any, lightning might cause to the storage cylinders located outside in the K-25 Site cylinder yards. The evaluation considered the probability (based on lightning flash ground density data for the Knoxville-Oak Ridge area) that a lightning strike would occur in or near the yards, the consequences of a strike hitting a cylinder directly, and compared the NFPA 780 and DOT/FAA (1992) requirements for sheet metal thickness in order to prevent melt-through of holes. No evidence exists that cylinders have ever been damaged due to a lightning strike.

4. SEISMIC EVALUATION

4.1 SEISMIC METHODOLOGY

The Department of Energy has specific guidelines to be used in evaluating new and existing facilities for seismic events. The primary technical guiding document is DOE-STD-1020-94, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards* (DOE, 1994). The values of P_H associated with the PC-2 and PC-3 categories are $1x10^{-3}$ and $5x10^{-4}$ respectively, corresponding to return periods of 1,000 and 2,000 years. DOE-STD-1020-94 allows some relief in the criteria for evaluation of existing facilities. For evaluation of existing facilities which are "close" to meeting the criteria, the evaluation may be performed using a natural phenomena hazard exceedance probability of twice the value specified for new design. Thus, a facility having a PC-3 classification may be evaluated for a 1,000 year earthquake instead of the 2,000 year return period earthquake, i.e., the hazard annual probability of exceedance may be increased from $5x10^{-4}$ to $1x10^{-3}$. This has the effect of reducing the natural phenomena loads by only about 10% to 20% (DOE, 1994) - it does not cut them in half.

Although the DOE-STD-1020-94 does not require the evaluation of a 100-year natural phenomena event, the FSAR needed to determine whether an occurrence should be classified as either an "anticipated event" ($1 >$ annual frequency $\geq 10^{-2}$) or as an "Evaluation Basis Event" ($10^{-2} >$ annual frequency $\geq 10^{-6}$). Therefore, 100-year evaluations were performed for the seismic, wind, and flood events.

The K-25 Site UF_6 cylinder storage yards were evaluated for

1. slope stability, and
2. seismic liquefaction

in accordance with DOE-STD-1020-94 and DOE-STD-1022-94. The soil liquefaction and slope stability studies are documented in the K/D-6566 (Ahmed, 1996) and are briefly discussed in the following section.

The UF_6 cylinders in the yards were evaluated for the following possible seismic scenarios:

1. rocking of single cylinders sitting in saddles,
2. rocking of stacked cylinders sitting in saddles,
3. rolling of cylinders sitting on a concrete or gravel surface,
4. sliding of the cylinders and saddles as a unit, sitting on a concrete or gravel surface, and
5. damage of a cylinder shell due to upper row cylinders falling from a stacked stiffener-to-stiffener configuration onto a lower cylinder.

Static-equivalent analyses were performed considering the cylinders to act individually as rigid bodies. Items #1 through #4 are scenarios that require the resistance to rolling, rocking, or sliding motion to be determined and then compared to the seismically imposed cylinder loads at the point where motion is expected to begin, usually the lower leading point of contact between the cylinder and ground in the direction of motion. For sliding of a cylinder-saddle system to not occur, the normal force due to the weight of the cylinder and the saddle must be equal to or greater than the seismically imposed horizontal inertial force. The rolling calculations assumed that the cylinder in question was resting directly on a flat concrete or gravel surface. A simple rolling resistance calculation was then performed assuming a very small ground indentation (thus making a "mini" saddle) and the threshold ground acceleration which would produce motion was determined. Single and multiple cylinder configuration were considered as applicable.

Item #5 simply assumed that the upper cylinders would fall and the impact stresses in the shells of the two cylinders involved were evaluated and compared to a code allowable value.

The calculations are given in DAC-NP-710660-A001, *Natural Phenomena Evaluation of K-25 UF_6 Cylinder Storage Yards* (LMES, 1996).

4.2 SOIL LIQUEFACTION AND SLOPE STABILITY EVALUATION

The soil liquefaction and slope stability studies are documented in the K/D-6566 (Ahmed, 1996) and are briefly discussed in the following section. The liquefaction evaluation showed that liquefaction was not a concern for the evaluation basis earthquake (PC-3) at the site. Slope stability of the cylinder yards located in the vicinity of Poplar Creek (E-Yard and J-Yard) and Beaver Pond (K-Yard) was also evaluated for static and seismic events, and the results led to the conclusion that the slopes of the cylinder yards are safe and stable for the static and seismic events. Slope stability of the remaining three cylinder yards was considered to not be a problem based on their location.

4.3 ROCKING OF SINGLE CYLINDERS SITTING IN SADDLES

The 30-in. and 48-in. cylinders (both thin and thick-wall) were evaluated for possible rocking and then rolling or jumping out of a saddle. For a cylinder, sitting in a saddle, to initially start to lift up and initiate rocking motion, the moment of the horizontal inertial force, F = ma (where "a", is the peak-ground acceleration) about the top edge of the saddle cavity must be greater than the restoring force due to the weight of the cylinder about the same point. It is fairly straight-forward to calculate the minimum value of acceleration (threshold level) needed to create this instability, which is called rocking (i.e., the cylinder is able to rock/roll back-and-forth in the saddle). If the calculated threshold acceleration is less than the peak ground acceleration due to the earthquake (0.3g for PC-3 and 0.2g for PC-2) then rocking will not start and the cylinder will remain essentially motionless in the saddle. Vertical earthquake accelerations (assumed to be equal to 2/3 of the horizontal acceleration), which reduce the restoring forces and hence make it easier for rocking to start, were included in these analyses. If rocking is possible, then an energy balance formulation is performed in order to determine if the cylinders can jump or roll out of the saddle. If it is determined that rocking does not initiate, then the second step is not performed. The general approach is given in Ishiyama (1982, 1984) for overturning of rigid bodies due to ground accelerations. The weight of the cylinders, and thus whether they are empty or full, does not enter into the analysis because the weight term, W, shows up on both sides of the equation and cancels out. Only the geometry is considered.

The rocking analysis resulted in threshold ground accelerations of 0.40g and 0.50g in order for rocking to start for the 30-in. and 48-in. cylinders, respectively. Since the PC-3 top-of-soil acceleration is 0.30g, it was determined that rocking would not take place.

The above calculations assumed that the saddle design was meant to reasonably fit the cylinder it was supporting. However, the case of setting the smaller cylinders (12-in., 8-in., and 5-in.) in the larger saddles (meant for the 30-in. and 48-in. cylinders) was also considered. The results indicate that, while the cylinders may roll back-and-forth inside the saddle depression, there is not sufficient energy in a PC-3 earthquake to cause the cylinders to eventually roll out of the saddle.

4.4 ROLLING OR ROCKING OF STACKED CYLINDERS

As was done for the single 30-in. and 48-in. cylinders resting in a saddle, groups of cylinders stacked either two or three high, were also evaluated for possible rocking and then rolling or jumping out of the stacked configuration. The analysis considered only the cylinders located at the ends of a row because cylinders located away from the ends of stacked rows have sufficient static forces on them from the cylinders above and on either side that an earthquake will not move them. Cylinders located at the ends of a row, however, are less confined and subject to loads from only one side, and, thus, would be the first cylinders to move in a stacked arrangement. The first step was to show that the upper cylinders would remain in place, and this was accomplished by noting that the "saddle" they sit in (between two cylinders) is deeper than the actual saddle considered in the previous section. The rocking analysis for the bottom row cylinders then combined the static forces due to half the weight of an upper cylinder plus the full (conservative) lateral seismic force from the upper cylinder and added these to the static and seismic forces from the bottom cylinder, summed moments about the point of expected rocking and solved for the minimum ground acceleration required to rock the stacked combination as a unit. The two-high stacked analysis showed that threshold ground accelerations equal to 0.39g and 0.54g were required in order for rocking to start for the 30-in. and 48-in. cylinders, respectively, higher than the PC-3 top-of-soil acceleration of 0.30g. A similar approach was used for the three-high stacked analysis, which showed that a minimum ground acceleration equal to 0.38g was required in order for rocking to start for the 30-in. cylinders (the calculation for the 48-in. case was not performed as it obviously would also result in a threshold value greater than 0.30g). Thus, it was determined that rocking, and hence, roll-out, would not occur with end row cylinders stacked either two or three high, and thus, the stacked arrangement of cylinders was concluded to be stable against a PC-3 seismic event.

4.5 ROLLING OF CYLINDERS SITTING ON GROUND

The smaller cylinders sit directly on the ground surface, without any lateral restraint. For the case on an ideal cylinder (or wheel) on an ideal surface, there is a single point of contact, and there would theoretically be no resistance to rolling, and hence, a very light wind or tiny earthquake would provide sufficient force to move the object. In practice, however, neither the cylinder nor the ground is perfect, some resistance to motion exists, due to the fact that both the cylinder and the ground deform, and hence the contact between the cylinder and the ground takes place, not at a single point, but over some larger distance or area. The length of this indentation is a measure of the *coefficient of rolling resistance* (note that it is not dimensionless), and is commonly denoted with the letter "b". The coefficient of rolling resistance is discussed briefly in most basic mechanics of statics textbooks, but values of "b" are not given for many combination of materials. Values of "b" vary from about 0.01-in. for a steel wheel on a steel rail to 5.0-in. for the same wheel on soft ground (Beer and Johnston, 1962). These same values differ somewhat in other books. For the case of the cylinders rolling, there are two types of surface that need be evaluated: concrete and gravel. The results are briefly discussed in the following paragraphs for each type of ground surface.

<u>Concrete pad</u>: The coefficient of rolling resistance of for steel-on-concrete was estimated to be 0.17-in. The calculations then show that ***all*** sizes of cylinders, ***empty or full***, are subject to roll if they are resting, unrestrained, on a concrete pad, at ground accelerations less than 0.01g to 0.04g. Damage due to cylinders hitting other cylinders is expected to be limited to the valve attachment. Since, in general, only the smaller cylinders, 12-in. or less, are the ones likely to move as they are the ones that are most commonly unrestrained,

it would seem that damage would be restricted to the smaller diameter cylinders (a rolling 12-in. cylinder is not big enough to damage a 30-in. or larger cylinder), if at all. However, if the larger cylinders are so resting, they are will also be moved from their original position. Since the earthquake motion is cyclic, the total cylinder displacement from its initial location is expected to be fairly small, probably less than a few inches.

Gravel surface: The coefficient of rolling resistance of for steel-on-gravel was estimated to be between 1.1-in. and 1.7-in. for the cylinders 30-in. and smaller, and 3.5-in. for the 48-in. cylinders. As would be expected the results indicate that fewer of the cylinders are susceptible to movement when resting on a gravel surface than on a concrete surface. The results are presented in the following table:

Table 4.1. Summary of Cylinders Rolling on Gravel Due to Earthquake

Cylinder Type	$a_{min\ roll}$ (g's)	PC-2 (0.20g) roll ?	PC-3 (0.30g) roll ?
5A/5B	0.34g	no	no
8A	0.30g	no	probably not
12A/12B	0.24g	no	yes
30A/30B	0.09g	yes	yes
48 all	0.13g	yes	yes

The total cylinder displacement from its initial location is expected to be smaller than when resting on a concrete pad.

4.6 SLIDING OF CYLINDERS

The possibility of a cylinder plus a saddle sliding along the ground was considered. The coefficient of dry friction for stone-on-stone is given in various reference books as being between 0.40 and 0.70. The coefficient of wet friction would be somewhat less, maybe 0.30 to 0.60. The references do not give values for concrete or wood-on concrete, but due to the roughness of the surfaces, it would be expected to be no less than that given for stone-on-stone. Thus in wet weather the cylinders might start sliding at about 0.30g, while in dry weather, the initial ground acceleration would have to be higher, around 0.40g. Objects can have various modes of response due to ground motion: remain at rest, slide, rock, slide-rock, and free-flight. Once the object has started to slide, it could just stop (go to rest), start rocking if one end sinks or hits an uneven surface, go into a slide-rock motion, or even be bounced in the air, depending on the actual ground motion. Since only in the case of a wet surface would a cylinder be capable of sliding (PC-3 criteria motion is 0.3g), it does not seem likely that substantial damage would ensue due to sliding of a cylinder. More than likely, it would very quickly come to rest. The total displacement would probably be less than a couple inches.

4.7 DAMAGE FROM SEISMIC FALL FROM RING-TO-RING CONTACT

In K-25 jargon this case is commonly referred to as the "narrow/plate stiffener ring to narrow/plate stiffener ring" stacking arrangement. Battelle (Wilkowski et al., 1992) evaluated the case where stacked 48G type cylinders were resting with the stiffening rings at one end of a cylinder in contact with a ring or lug from an adjacent cylinder. An external force, presumably from a seismic event, perturbs the cylinder and the upper cylinder slips and drops onto the lower tier cylinders. During an inspection tour of the cylinder yards this specific case was not seen, but a very similar one was: the case where multiple sets of stiffeners are in contact at the same time between two adjoining stacked cylinders (however, the Battelle case is possible since we did not inspect every cylinder). Battelle calculated the dynamic impact factor (DIF) to be 9.5, while the present analysis determined a range for the DIF between 9.1 and 10.1, enveloping the Battelle result. Furthermore, the Battelle study evaluated the static stresses between two cylinders having two ring contact (there are three stiffening rings per cylinder, and because of differences in the fabrication tolerances of any two cylinders, it is possible that only two of the rings might be in contact with the shell of the other) and six ring contact, and also considered increased stresses in reduced sections due to corrosion of the cylinders. One-inch thick stiffeners were used in the Battelle analysis, although the latest design for the 48G cylinders calls for stiffening rings to be 7/8-in. thick (change occurred in 1984). The stresses were determined at the ring-shell contact points where the upper and bottom row cylinders touch, and also at the bottom cylinder contact point with the saddle. As expected, the two-ring contact scenario produced the highest stresses, 66 ksi at the toe of the stiffener weld (using a nominal shell thickness of 5/16-in.) and 38 ksi at the saddle points. For the case where the shell has corroded down to 0.200-in., these same stresses are 128 ksi and 55 ksi, respectively. It is very important to note that these stresses are based on a linear analysis per the ASME Boiler and Pressure Vessel Code (BPVC) which gives allowable stress values based such an analysis. Also note that if additional stiffeners come into contact between two rows, the stresses at the toe of the stiffeners will decrease linearly in proportion to the number of stiffeners in contact, but the stresses at the saddle should remain pretty much the same since there are still only two saddles supporting the bottom row cylinder.

The dynamic stress is simply the static stress times the DIF. Thus, the dynamic stress due to one cylinder falling on another is almost 630 ksi (DIF = 9.5), at the toe of the weld near the impact point, but only 380 ksi at the saddle. Battelle indicates that the BPVC Section III tolerates an elastic-calculated local stress, for not more than 10 cycles of load application, of 580 ksi for a material like SA516 Grade 70. Thus, the dynamic stress = 630 ksi exceeds the allowable stress = 580 ksi by about 8.5%. If three rings are in contact then the dynamic impact stress would be 420 ksi (2/3 x 66 x 9.5), about 75% of the allowable value. Cylinders having a shell thickness less than the original 5/16-in. would have even higher stresses; for the case of the 0.200-in. shell thickness occurring near the saddle only, the impact stress would be 520 ksi, very close to the allowable. Also, there exist cylinders that have stiffeners less than 1-in. thick, in which case the contact area would decrease and the stresses would increase. Battelle's (Wilkowski et al., 1992) conclusion for the seismic slip-fall case is that the stresses are marginal, but puncture could occur.

4.7.1 Number of Cylinders at Risk Due to Ring-to-Ring Contact Condition

As of June 26, 1996 there were 203 such upper row cylinders in K-1066E yard and 165 such upper row cylinders in K-1066K yard, for a total of 368 vulnerable upper row cylinders. For "n" upper row cylinders, there are between "n + 1" and "2n" bottom row cylinders in contact with these upper row cylinders, depending on the arrangement of the upper row cylinders. The more the upper row cylinders are "clustered" together the closer the number of bottom row cylinders approaches the smaller "n + 1" value. Thus, the total number of cylinders (upper row plus bottom row) is between "2n + 1" and "3n". From personal experience during walkthroughs around the K-1066-E yard, it was observed that quite often three or more adjacent upper row cylinders were stacked in this manner, and thus, a reasonable estimate for the total number of cylinders so stacked is about 2.33 total cylinders for each observed upper row cylinder. However, based on engineering judgement, it can be stated that an upper row cylinder will, at most, damage (i.e., puncture) only one bottom row cylinder. A falling cylinder will most likely fall and strike one cylinder initially, and it is that initial impact that will cause the worst damage. The energy, as the falling cylinder continues to bounce and hit the second cylinder should not be large enough to cause puncture of that second cylinder. If it were to fall and strike both bottom row cylinders simultaneously, puncture will probably not result to any of the cylinders. ***Thus, regardless of the number of cylinders touching, for each top tier cylinder that falls, there will be only one additional bottom tier cylinder at risk.***

There are three potential locations where damage (puncture) could occur:

a. adjacent to the saddle support of the bottom row cylinder,
b. at the top of the shell near the impact location for a bottom row cylinder, and
c. at the bottom of the shell near the impact location for an upper row cylinder.

The Bothell analysis of stacked cylinders, using a shell thickness of 5/16" (nominal new cylinder thickness), calculates that the static stress at the point of contact between cylinders is about twice as high as the stress at the saddle support location, 66 ksi vs. 38 ksi respectively. Corrosion of the cylinders tends to be more concentrated near the bottom of a cylinder, and is often more pronounced for the bottom row cylinders, so Battelle also calculated the stress at the saddle support assuming a wall thickness of 0.20-in., and found it to be 55 ksi. According to the cylinder wall thickness data taken in 1994 (which included the two known breached cylinders found in 1991 and 1992) (Lyon, 1995), it would be expected that about 15% of the cylinders in the yards might have a minimum wall thickness equal to 0.20 in. or less by the year 2002. Furthermore, Battelle considered the seismic fall case and concluded that there is enough energy in the falling cylinder to cause a puncture in the cylinders at the point of impact. They used a 0.28" average wall thickness for this analysis, which assumes approximately a 0.03" reduction in thickness from the original nominal value due to corrosion. However, puncture, using the original 5/16" wall thickness, would still be predicted to occur at the direct impact location between the cylinders, and also would be possible at the saddle support location if the wall thickness was 0.20 in.

The most likely damage would be a dent or a crack near the actual impact point for either the upper or lower row cylinder, or near the saddle support of the bottom row cylinder, maybe as much as 1/8-in. wide, and less than an inch long.

The following table summarizes the potential number of damaged cylinders due to the seismic fall case, and indicates the location of the damage. It should be clearly understood that these numbers are conservative estimates of the potential for damaged cylinders. The extent of damage will greatly depend on a number of factors, especially how many stiffeners actually are involved in the initial impact of any one falling cylinder. The higher the number of stiffeners that are involved in the initial impact, the lower the impact stresses will be, and hence, the lower the potential for damage and puncture of the shell of the cylinders.

Table 4.2. Summary of the Number of Cylinders Stacked Narrow/Plate Stiffener to Narrow/Plate Stiffener that can be Potentially Damaged from a Seismic Falling Cylinder

Yard Location	Top Row Cylinders	Bottom Row Cylinders		
	damage point at bottom	damage point at bottom near saddle	damage point at top	total number potentially damaged
K-1066K Yard	165	25	165	165
K-1066E Yard	203	30	203	203

4.8 SUMMARY AND CONCLUSIONS

The findings of the seismic analysis for the cylinder yards and the storage cylinders are as follows:

1. Slope stability and liquefaction of the yards is not a problem.
2. Rocking or rolling-out of saddles will not occur for single or multiple stacked cylinders. Smaller cylinders (5", 8", and 12") sitting in oversized saddles may begin rolling back-and-forth in the saddle, but there is insufficient energy to roll them out of the saddle indentation.
3. Any cylinder resting on a concrete pad is likely to start rolling at fairly low ground motions, though, in general, only the smaller cylinders (12-in. diameter or less) are so resting. Cylinders with lifting lugs will only roll until the lugs contact the ground. Due to back-and-forth nature of earthquake motion, it is not expected that cylinders will move very far unless they happen to be resting on a sloped surface.
4. Cylinder resting on a gravel surface are less likely to start rolling. The larger 30 and 48-in. cylinders will roll at pga levels of about 0.10, while the small 5 and 8-in. ones will not roll with a PC-3 0.30g level earthquake. The 12-in. cylinders will roll at 0.24g, below the PC-3 level, but above the PC-2 level.
5. While the calculation indicates that sliding of a cylinder resting in a saddle may occur for PC-3 ground accelerations in wet conditions, it does not seem likely that this situation will lead to any damage to the cylinders due to the short duration of the event and the short distance which any given cylinder will move. Stacked groups of cylinders will not slide.
6. For an evaluation basis seismic event, top tier cylinders stacked "narrow/plate stiffener to narrow/plate stiffener" could slide, fall about 2½-in., and be damaged (punctured), and also cause damage to an equal number of bottom tier cylinders. The damage, if any, to the **top tier cylinders** would occur near the bottom of the cylinder at the impact point with the narrow/plate stiffener from the bottom cylinder. The puncture would be in a location where the solid UF_6 exists. The damage, if any, to the **bottom tier cylinders** can occur in two locations, at the top of the cylinder near the impact point of the falling cylinder, and near bottom of the cylinder adjacent to the saddle support. The damage at the top of the cylinder is in the ullage area (no solid material, just gases), while the damage near the saddle support would be in a location where the solid UF_6 exists. Due to the magnitude of the stresses occurring near the saddle support, it is expected that only about one bottom row cylinder in six so impacted may actually have damage in this area.

5. FLOOD EVALUATION

5.1 FLOOD METHODOLOGY

The Department of Energy guidelines to be used in evaluating new and existing facilities for floods is given in DOE-STD-1020-94, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards* (DOE, 1994). The values of P_H associated with the PC-2 and PC-3 categories are $5x10^{-4}$ and $1x10^{-4}$ respectively, corresponding to return periods of 2000 and 10,000 years. DOE-STD-1020-94 allows some relief in the criteria for evaluation of existing facilities. For evaluation of existing facilities which are "close" to meeting the criteria, the evaluation may be performed using a natural phenomena hazard exceedance probability of twice the value specified for new design. Thus, a facility having a PC-3 classification may be evaluated for a 5,000 year flood instead of a 10,000 year return period flood, i.e., the hazard annual probability of exceedance may be increased from $1x10^{-4}$ to $2x10^{-4}$. This has the effect of reducing the natural phenomena loads by only about 10% to 20% (DOE, 1994) - it does not cut them in half.

The K-25 Site cylinder storage yards are potentially subject to flooding from two principal sources, (1) regional flooding conditions on Poplar Creek, and (2) the effects of intense local rainfall centered over the site. The flood evaluation considered three elements, these being

1. the floating characteristics of the individual and stacked cylinders,
2. the effects of local flooding (precipitation) for the 10,000 year (PC-3); 5,000 year (twice the PC-3 hazard probability); 2,000 year (PC-2) criteria, and
3. the effects of regional flooding for the same criteria.

The regional flood vulnerabilities were determined by comparing the cylinder yard elevations with the regional flood hazard elevations documented in ES/CNPE-95/1, *Flood Analysis for Department of Energy Y-12, ORNL, and K-25 Plants* (CNPE, 1995). The local flood (precipitation) standing water depths for the different criteria rainfall were given in K/D-6565, *Flood Potential for K-25 Cylinder Storage Yards* (ECE, 1996). Where flood vulnerabilities existed, further evaluations were performed in order to determine if cylinders would float in the vulnerable yards. The flood evaluation performed herein started with the PC-3 10,000 year criteria and if it was met, did not consider any other criteria, otherwise the 5,000 year and 2,000 year criteria were evaluated.

The calculations are given in DAC-NP-710660-A001, *Natural Phenomena Evaluation of K-25 UF_6 Cylinder Storage Yards* (LMES, 1996).

5.2 FLOTATION OF CYLINDERS

The evaluation of whether a cylinder would or would not float considered both full cylinders, partially full cylinders, and empty cylinders. The minimum amount of UF_6 needed to just keep a cylinder from floating was also determined. For a cylinder to float its specific weight has to be less than one, i.e., its unit weight (lb/ft^3) has to be less than that of water. The "calculated" unit weight of a cylinder is the weight of the cylinder, empty, partially-full, or full, divided by the external volume of the given cylinder. The specific weight of the given cylinder is then evaluated as the ratio of the unit weight of the cylinder to that of water ($62.4\ lb/ft^3$). Minimum internal volumes for the various cylinders were found in either the ORO-651, Rev. 5 (1987) or the USEC-651, Rev. 7 (1995) documents. These volumes were increased by a factor of 1.035 for the thin-wall cylinders and 1.065 for a thick-wall cylinder to obtain the external volume of each cylinder. The empty and full weights were also obtained from the same documents. Calculations were also performed to determine the water level required to float a given cylinder. To greatly simplify the arithmetic, the calculation assumed that the cylinders were right circular cylinders (i.e., had flat ends instead of hemispherical heads). Since using this assumption plus using the original length of the cylinders is unconservative, a pseudo-length was obtained in order that the calculated volume of the cylinder be correct. The water levels so obtained are probably within 10% to 20% of the actual answer.

The results indicate that a completely full cylinder, regardless of size, will not float. Empty 12-in. and smaller cylinders will also not float. Empty cylinders 30-in. (2.5-ton) in diameter or larger will float. Single empty cylinders require that the water height be between 1.3 ft and 2.4 ft in order to float. Stacking empty cylinders simply means that a higher water flood level is required before the stacked cylinders will float. Both the 10-ton thin cylinders and the 14-ton thin cylinders will float before the water level reaches the top of the bottom row for either a two-high or a three-high stacking arrangement. The cylinders on the end of a row are in the "critical" (to float) positions, supporting parts of either one or two cylinders; when the water level reaches the float level, the end cylinders simply float away (obviously will not remain in a stacked arrangement) and leave another set of row end cylinders. Thus, it can be concluded, that empty cylinders in a stacked arrangement will all eventually float given that the water levels remain high for a sufficient amount of time.

Table 5.1 presents the results of the evaluation for single cylinders. It indicates whether a given cylinder will float, the weight of UF_6 needed to just keep the cylinder from floating, and the depth of the water required to float a cylinder sitting on the ground or on a saddle. Note that the float levels for the 10-ton and 14-ton thin-walled cylinders are similar, as are those for the 10-ton and 14-ton thick-walled cylinders. Changes in weight due to corrosion were not considered in the analysis. Weight losses due to corrosion are considered to be quite small, unless the corrosion is completely widespread throughout a given cylinder, and this does not appear to be the case based on the available data (Pawel, 1996).

Table 5.1: Summary of Floating Evaluation of Single Cylinders

Cylinder Type	Description	Will Cylinder Float?		Empty Weight of Cylinder (lb)	Min. Wt. of UF_6 to Prevent Floating (lb)	Water Level to Float Empty Cylinder	
		Empty	Full			Ground (ft)	Saddle (ft)
5A/5B	5-inch	no	no	55	----	----	----
8A	8-inch	no	no	120	----	----	----
12A/12B	12-inch	no	no	185	----	----	----
30A/30B	2.5 ton	yes	no	1400	250/280	2.0	2.1
48T	10-ton, thin wall	yes	no	2250	4770	1.4	2.1
48X	10-ton, thick wall	yes	no	4500	2710	2.4	3.2
48G	14-ton, thin wall	yes	no	2600	6390	1.3	2.1
48Y	14-ton, thick wall	yes	no	5200	4090	2.2	3.0

Note: The distance from bottom of cylinder and bottom of the saddle is 2" for 30B and 9" for the others.

Table 5.2 summarizes the required water depth levels in order to float single, double, and triple stacked cylinders, sitting on the ground. Note that all of the 48" diameter cylinders will float when stacked 2 or 3-high with the water level at or below the height of the bottom row of cylinders. In order to float stacked 2.5-ton cylinders the water level must exceed the height of the bottom row.

Table 5.2. Summary of Required Water Levels to Float Stacked Empty Cylinders, Sitting on Ground

Cylinder Type	Description	Single Stacked	Double Stacked	Triple Stack-ed
30A/30B	2.5 ton	2.0	2.9	3.3
48T	thin wall, 10 ton	1.4	1.9	2.3
48X	thick wall, 10 ton	2.4	3.6	4.0
48G	thin wall, 14 ton	1.3	1.8	2.0
48Y	thick wall, 14 ton	2.2	3.2	3.9

5.3 LOCAL FLOODING

The local flooding analysis was performed by Environmental Consulting Engineers (ECE, 1996). ECE developed a computer simulation model for each of the cylinder yards, subdividing each yard into approximately 25-ft x 25-ft (the actual size varies somewhat from yard to yard) grids. They then calculated the maximum depth of water (in inches) at the center of each grid for each of the 2,000-yr, 5,000-yr, and 10,000-yr frequency storms assuming a 1 hour duration storm. The 10,000 year rainfall is 9.5-in. per hour while the 2,000 year rainfall is 6.8-in. per hour. The maximum velocities, in feet per second, in the x-direction (plant east-west) and the y-direction (plant north-south) were also calculated for each grid square. The ECE analysis took into consideration the local drainage of each yard and also the local topography which would impact a given yard. Table 5.3 summarizes the ECE findings for the local flooding for the six cylinder yards. It is clear that there is very little difference between the 2,000 year and the 10,000 year results. The maximum velocity is 1.2 ft/sec which is equivalent to 0.82 mph. Note that the 1.2 ft/sec is less than the 2.0 ft/sec given as the lowering velocity of cylinders during handling operations. At this velocity, there is enough dynamic pressure to roll an empty cylinder (all sizes) that is resting on a concrete pad (note that cylinders with lugs may roll some, but will eventually be stopped by those lugs). However, except in the depression region of the K-1066-F-yard (and maybe a small distance beyond), the depth of standing water is not deep enough to float a cylinder sitting on a saddle. In the depressed region of F-yard, the maximum standing water depth is 3.5 ft, while at the edge of the region (defined by a 760 ft elevation contour) the depth drops to 2.4 ft, still enough to float an empty cylinder. At an elevation approximately equal to 760.5 ft the standing water depth is less than 2 ft and empty cylinders sitting on saddles will not float. However, it should be noted that F-yard is sited such that the standing water depth is below about 0.6 ft for over 80 percent of its area, thus, cylinders that float in the depressed region will eventually be contained.

Table 5.3. Summary of K25 Cylinder Yards Local Flood Studies

Cylinder Yard	2,000 year		5,000 year		10,000 year	
	Maximum Water Depth (ft)	Water Velocity (fps)	Maximum Water Depth (ft)	Water Velocity (fps)	Maximum Water Depth (ft)	Water Velocity (fps)
K-1066-B	0.2	0.4	0.2	0.4	0.2	0.4
K-1066-J	0.5	1.0	0.6	1.1	0.6	1.2
K-1066-F	0.5 - 3.4	0.5	0.6 - 3.5	0.6	0.6 - 3.5	0.6
K-1066-L	0.4	0.9	0.4	1.0	0.5	1.0
K-1066-K	0.2	0.4	0.2	0.4	0.3	0.4
K-1066-E	0.7	0.4	0.8	0.4	0.8	0.5

5.4 REGIONAL FLOODING

The regional flooding analysis was based on the 1991 TVA flood analysis (LMES, 1995). The TVA report lists the water elevation at various mile markers along the Clinch River and Poplar Creek for various frequency floods. Table 5.4 gives the flood elevations for the three different frequency floods and also shows the minimum elevation in each yard.

Table 5.4. K25 Cylinder Yards Regional Flood Elevations

Cylinder Yard	Minimum Elevation (ft)	2,000 year	5,000 year	10,000 year
		Water Depth (ft)	Water Depth (ft)	Water Depth (ft)
K-1066-B	777.8	760.0	761.6	762.7
K-1066-J	756.0	760.0	761.6	762.7
K-1066-F	758.9	760.0	761.6	762.7
K-1066-L	757.5	760.2	761.6	762.7
K-1066-K	774.6	753.9	755.8	757.3
K-1066-E	750.0	753.9	755.8	757.3

Table 5.5 gives a summary of the flooding for the yards using the minimum elevation existing in the given yard. The negative numbers indicate the distance of the yard above the criteria flood level, thus K-1066-K is 20.6 ft above the 2,000 year flood elevation. The data in Table 5.5 does not consider the local topography, it simply compares the minimum elevation in the yard with the flood elevation from the TVA analysis. The

ECE (1996) report of these yards did try to account for local variations in topography, and for example, shows that for the 2,000 and 5,000 year regional floods, that F-yard will not be under water because there is a high local contour along most of the perimeter of that yard. However, it can also be pointed out that there is a drainage system between the river and F-yard, so, given sufficient time, the water will get into the yard through that drain line and flood it anyway. The analysis in Table 5.5 is, thus, conservative.

Table 5.5. Summary of K25 Cylinder Yards Regional Flood Studies - Based on Minimum Yard Elevation

Cylinder Yard	Minimum Elevation (ft)	2,000 year Water Depth (ft)	5,000 year Water Depth (ft)	10,000 year Water Depth (ft)
K-1066-B	777.8	-17.8	-16.2	-14.8
K-1066-J	756.0	4.0	5.6	7.0
K-1066-F	758.9	1.1	2.7	4.1
K-1066-L	757.5	2.5	4.1	5.5
K-1066-K	774.6	-20.6	-18.8	-17.3
K-1066-E west portion	750.0	4.0	5.8	7.3
K-1066-E east portion	750.9	3.1	4.9	6.4

Tables 5.6 to 5.8 present the results of the different types of cylinders for each of the yards using the minimum elevations. Only the cylinders capable of floating are included in the data (i.e., the 12-in. and smaller cylinders which will never float are not included). It is clear that K-1066-B and K-1066-K are well above the 10,000 year flood levels and the consequences of regional flooding is not a problem in those two yards. In the other four yards all the floatable cylinders, regardless of stacking, will float at the PC-3 (10,000 year) flood. In yards K-1066-E and K-1066-J, these cylinders will float for the three yearly frequencies under consideration. In K-1066-L, these five types of cylinders will float in the 10,000 year and 5,000 year return floods, while in the PC-2 (2,000 year) the two thick-walled cylinders will not float, while the rest will float. In K-1066-F, the thick-walled cylinders will not float in the 5,000 year flood and none of the cylinders in question will float during the 2,000 year flood.

Table 5.6. Regional Flooding Summary, PC-3 (10,000 yr) Hazard for Single Cylinders Sitting on Saddles Based on Yard Minimum Elevation

<table>
<tr><th rowspan="2">Cylinder Yard</th><th colspan="5">Cylinder Type</th></tr>
<tr><th>30B
2.5-ton</th><th>48X
10-ton
thick wall</th><th>48T
10-ton thin
wall</th><th>48G
14-ton thin
wall</th><th>48Y
14-ton
thick wall</th></tr>
<tr><td>K-1066-B</td><td colspan="5">cylinders will not float</td></tr>
<tr><td>K-1066-J</td><td colspan="5" rowspan="3">cylinders will float</td></tr>
<tr><td>K-1066-F</td></tr>
<tr><td>K-1066-L</td></tr>
<tr><td>K-1066-K</td><td colspan="5">cylinders will not float</td></tr>
<tr><td>K-1066-E entire yard</td><td colspan="5">cylinders will float</td></tr>
</table>

Table 5.7. Regional Flooding Summary, PC-3 Increased (5,000 yr) Hazard for Single Cylinders Sitting on Saddles Based on Yard Minimum Elevation

<table>
<tr><th rowspan="2">Cylinder Yard</th><th colspan="5">Cylinder Type</th></tr>
<tr><th>30B
2.5-ton</th><th>48X
10-ton
thick wall</th><th>48T
10-ton thin
wall</th><th>48G
14-ton thin
wall</th><th>48Y
14-ton
thick wall</th></tr>
<tr><td>K-1066-B</td><td colspan="5">cylinders will not float</td></tr>
<tr><td>K-1066-J</td><td colspan="5">cylinders will float</td></tr>
<tr><td>K-1066-F</td><td>float</td><td>not float</td><td>float</td><td>float</td><td>not float</td></tr>
<tr><td>K-1066-L</td><td colspan="5">cylinders will float</td></tr>
<tr><td>K-1066-K</td><td colspan="5">cylinders will not float</td></tr>
<tr><td>K-1066-E entire yard</td><td colspan="5">cylinders will float</td></tr>
</table>

Table 5.8. Regional Flooding Summary, PC-2 (2,000 yr) Hazard for Single Cylinders Sitting on Saddles Based on Yard Minimum Elevation

Cylinder Yard	Cylinder Type				
	30B 2.5-ton	48X 10-ton thick wall	48T 10-ton thin wall	48G 14-ton thin wall	48Y 14-ton thick wall
K-1066-B	cylinders will not float				
K-1066-J	cylinders will float				
K-1066-F	cylinders will not float				
K-1066-L	float	not float	float	float	not float
K-1066-K	cylinders will not float				
K-1066-E entire yard	cylinders will float				

Table 5.9 gives a summary of the flooding for the yards using the median elevation existing in the given yard. The median elevation - that elevation where approximately half the yard area lies below and half the area lies above - is only an estimate based on survey drawings that show the elevation contours of the yards.

Table 5.9. Summary of K25 Cylinder Yards Regional Flood Studies - Based on Median Yard Elevation

Cylinder Yard	Median Elevation (ft)	2,000 year	5,000 year	10,000 year
		Water Depth (ft)	Water Depth (ft)	Water Depth (ft)
K-1066-B	778.0	-18.0	-16.4	-15.0
K-1066-J	758.0	2.0	3.6	5.0
K-1066-F	761.0	-1.0	0.6	2.0
K-1066-L	760.0	-1.0	0.6	2.0
K-1066-K	775.0	-21.0	-19.2	-17.7
K-1066-E west portion	750.0	4.0	5.8	7.3
K-1066-E east portion	753.0	1.0	2.8	4.3

Tables 5.10 to 5.12 present the results of the different types of cylinders for each of the yards using the median regional flood elevations. Only the cylinders capable of floating are included in the data (i.e., the 12-in. and smaller cylinders which will never float are not included).

Table 5.10. Regional Flooding Summary, PC-3 (10,000 yr) Hazard for Single Cylinders Sitting on Saddles Based on Yard Median Elevation

Cylinder Yard	Cylinder Type				
	30B 2.5-ton	48X 10-ton thick wall	48T 10-ton thin wall	48G 14-ton thin wall	48Y 14-ton thick wall
K-1066-B	cylinders will not float				
K-1066-J	cylinders will float				
K-1066-F	cylinders will not float				
K-1066-L					
K-1066-K	cylinders will not float				
K-1066-E entire yard	cylinders will float				

Table 5.11. Regional Flooding Summary, PC-3 Increased (5,000 yr) Hazard for Single Cylinders Sitting on Saddles Based on Yard Median Elevation

Cylinder Yard	Cylinder Type				
	30B 2.5-ton	48X 10-ton thick wall	48T 10-ton thin wall	48G 14-ton thin wall	48Y 14-ton thick wall
K-1066-B	cylinders will not float				
K-1066-J	cylinders will float				
K-1066-F	cylinders will not float				
K-1066-L					
K-1066-K	cylinders will not float				
K-1066-E entire yard	cylinders will float				

Table 5.12. Regional Flooding Summary, PC-2 (2,000 yr)
Hazard for Single Cylinders Sitting on Saddles
Based on Yard Median Elevation

Cylinder Yard	Cylinder Type				
	30B 2.5-ton	48X 10-ton thick wall	48T 10-ton thin wall	48G 14-ton thin wall	48Y 14-ton thick wall
K-1066-B	cylinders will not float				
K-1066-J	cylinders will not float				
K-1066-F					
K-1066-L					
K-1066-K	cylinders will not float				
K-1066-E west portion	cylinders will float				
K-1066-E east portion	cylinders will not float				

Thus, based on using the median elevation for the cylinder storage yards, only empty or near empty cylinders located in J- and E-yards will float given a 10,000 or 5,000 year regional flood event, and only those cylinders located in the west portion of E-yard will float in the 2,000 year event.

5.4.1 Movement and Damage due to Water Velocity

As part of the flood studies, ECE also developed water velocities at the four yards affected by the regionial flooding (ECE, 1996). The velocity of the water in the K-1066-F, -J, and -L yards for all three floods ranges from 0.8 (0.55 mph) to 1.4 ft/sec (0.96 mph), and ECE suggested that a single velocity of 1.0 ft/sec was appropriate. The velocity of the water in K-1066-E yard is essentially zero (ECE, 1996), because the flooding is due to Poplar Creek backwater.

The maximum velocity of the water during a regional flood is 1.4 ft/sec which is equal to 0.95 mph (and 1.0 ft/sec = 0.68 mph). These velocities are less than the handling velocity of 2.0 ft/sec used to lower a cylinder either to ground or into position on top of another. At this velocity, there is enough fluid dynamic pressure to roll an empty cylinder (all sizes) that is resting on a concrete pad (note that cylinders with lugs will be stopped by those lugs). Based on engineering judgement, it does not seem likely that an empty cylinder moving at 1.4 ft/sec will cause damage to either another floating cylinder or to a full cylinder, the only exception being if the impact were to occur on the protruding valve. The impact force is given by $F = ma = m(dv/dt) = m(\Delta v/\Delta t)$. m and Δv are known, but the Δt term must be estimated. If we use the heaviest empty cylinder which floats, 5200 lb, and consider it to be a "missile" moving at 1.4 ft/sec, and assume a value of $\Delta t = 0.05$ sec, then the force on the valve is 377 lb. This is probably large enough to cause some damage to the cylinder valve. The valve is attached to a coupling which is welded to the cylinder head. Damage to the valve would likely consist of shearing the valve threads at the coupling, but the coupling would remain as would the internal threaded portion of the valve. Thus the access hole would be the inside diameter of the valve itself.

Main River Channel Velocities: ECE estimated that the water velocity existing in the main river channel near the K-1066-F, -J, and -L yards, during a 2,000 year to 10,000 year flood, would be approximately 8.0 ft/sec (ECE, 1996, Appendix C). Thus, cylinders that find their way to the main river channel could receive higher levels of damage than those that remain in or near the cylinder yards. The water velocity existing in the main river channel near the K-1066-E yard were determined to be negligible.

5.5 100-YEAR CRITERIA EVALUATION

Although the DOE-STD-1020-94 does not require the evaluation of a 100-year natural phenomena event, the FSAR needed to determine whether an occurrence should be classified as either an "anticipated event" ($1 >$ annual frequency $\geq 10^{-2}$) or as an "Evaluation Basis Event" ($10^{-2} >$ annual frequency $\geq 10^{-6}$). Therefore, 100-year evaluations were performed for the seismic, wind, and flood events.

5.5.1 Regional Flooding

All the UF_6 cylinder yards are above the 100-year flood plain due to river flooding. E-Yard, with the lowest elevation, is still about 1.1-ft above the water level for the 100-year flood. Thus, it can be concluded that the 100-year regional flood will not cause any flooding problems in any of the cylinder yards.

5.5.2 Local Flood (Precipitation)

The local rainfall 100-year event will not cause a problem at any of the six UF_6 cylinder yards, with the possible exception of the local depression area in K-1066-F yard (a region having about 5800 sq. ft with a lowest elevation equal to 758.9 ft). Data from the ECE report indicted that the 2000-year rainfall event would not be a problem at the K-1066-B, -E, -J, -K, and -L yards, therefore the same conclusion follows for the 100-year event. Table 5.13 shows the maximum water depth inside the K-1066-F yard depression region and far away from the same area (but still in the yard) as predicted by ECE for the 10,000, 5,000, and 2,000 year events. The hourly rainfall rate is taken from the TVA report (LMES, 1995)

Table 5.13. Local Precipitation Data for K-1066-F Yard

Event (return yrs)	Rainfall Rate (in./1 hr)	Standing Water Depth (in.) Depressed Area	Standing Water Depth (in.) Distant Area
10,000	9.5	42.3	5.5
5,000	8.2	41.9	5.0
2,000	6.8	41.3	4.5

These data points plot as a straight line. However, using the resulting straight line and extrapolating data would indicate that flooding occurs when there is zero rainfall, which is obviously nonsense. The hazard curve is bound to be s-shaped, i.e., stays near zero standing water level up to some rainfall hourly rate value, then the curve rises sharply, and eventually levels off at the top. The difficult question that arises is "what is the shape of the s-shaped curve, where are the inflection points?" Depending on the shape that is assumed for the curve between zero rainfall and the 2,000 year rainfall, the maximum water depth in the depression region for the 100-year rainfall event could be as little as 6-in. (in which case there is no flooding concern) to as much as 39-in. (in which case floating of empty or near empty cylinders will occur). The ECE cylinder yards report (ECE, 1996) states that an earlier study of the K-25 Site done in 1994 showed that the K-25 storm drainage system would become surcharged in the event of the 25-year, 24 hour duration rainfall (about 5.5-in. of rainfall). The 100-year, 24-hour event would produce about 6.6-in. of rainfall and should lead to the same conclusion. If the 25-year rainfall is producing strain on the K-25 storm drainage system, it is engineering judgement that the 100-year, 1-hour rainfall (3.2"/1 hour) would also do so, and would likely produce a maximum water level in the F-yard depressed region of about 28-in. This level of water is enough to float empty or near empty 2.5-ton cylinders, and empty or near empty thin-wall 10-ton and 14-ton cylinders (all assumed sitting on saddles). The edge of the depression is at elevation 760-ft, and none of the cylinders will be able to float past this point, in fact none of the cylinders will float beyond the 759.5" elevation. The area within the depression region where cylinders could float is probably limited to less than 2500 sq. ft (an area about 50 ft by 50 ft).

5.6 SUMMARY AND CONCLUSIONS

The flood studies for the K-25 UF_6 cylinder and cylinder yards found the following:

Floating of cylinders

1. All empty cylinders (including those with heel quantities of UF_6) larger than 12-in. in diameter will float. The 5-in., 8-in., and 12-in. diameter empty cylinders will not float. The nominal weight of UF_6 needed to keep the larger cylinders from floating varies considerably (from 300 lb for the 30A to over 6,000 lb for the 48G), depending on the specific cylinder.
2. Stacked groups of empty cylinders will also float, though the water levels to do so are somehat higher than for single cylinders. Of course, once a stacked cylinder starts to float it will leave the stacked configuration and behave as a single cylinder.
3. Full cylinders will not float.

Local Flooding

1. Local flooding is not a problem in any of the cylinder yards, with the exception of the depressed area in K-1066-F. In this region, an empty cylinder will float, but only within the general boundary of the depressed region.
2. The 100-year rainfall event will also cause cylinders to float in the K-1066-F yard depression region.

Regional Flooding

1. Regional flooding is not a problem in yards K-1066-B and K-1066-K.
2. For the PC-3 (10,000 year) flood, all the floatable cylinders will float in the remaining yards.
3. For the PC-3 increased hazard level (5,000 year) and the PC-2 (2,000 year) flood, some of the cylinders will float, depending on size.
4. The 100-year regional flooding event will not cause any problems.

Damage to cylinders from other moving cylinders is considered negligible, except for possible damage to the fill-valves, which might shear off at the threads and leave a small opening which would allow some material or vapors to escape the cylinder.

6. WIND/TORNADO EVALUATION

6.1 WIND METHODOLOGY

Wind loads were applied in accordance with ASCE 7-93, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 1993), as recommended by DOE-STD-1020-94. Table 3.3 gives the wind requirements for the PC-2 and PC-3 wind criteria. For Oak Ridge the PC-2 wind speed is 70 mph with no tornado or missile requirements; for PC-3 the wind speed is governed by tornado requirements, 113 mph (straight wind analysis) plus two tornado-generated missiles: (i) a 2x4 timber plank, weighing 15 lb travelling at 100 mph (horizontally), having a maximum height of 150 ft; or travelling vertically at 70 mph, and (ii) the 3-in. diameter standard steel pipe, weighing 75 lb, travelling at 50 mph (horizontally), at a maximum height of 75 ft; or travelling vertically at 35 mph.

Although the DOE-STD-1020-94 does not require the evaluation of a 100-year natural phenomena event, the FSAR needed to determine whether an occurrence should be classified as either an "anticipated event" ($1 >$ annual frequency $\geq 10^{-2}$) or as an "Evaluation Basis Event" ($10^{-2} >$ annual frequency $\geq 10^{-6}$). Therefore, 100-year evaluations were performed for the seismic, wind, and flood events. However, from the Oak Ridge wind hazard curve (Figure 3.3), the 100-year wind speed would be 65 mph, which is less than the 70 mph minimum allowed by standards and codes, so the 100-year requirement for wind is the same as the PC-2 requirements.

6.2 EVALUATION RESULTS

The wind/tornado evaluation of the UF_6 storage cylinders located in six yards at the K-25 Site included evaluation for the following:

1. instability of single cylinders sitting in saddles,
2. instability of stacked cylinders,
3. rolling of cylinders sitting on concrete or gravel surfaces,,
4. sliding of cylinders resting in a saddle, and
5. efffects of tornado generated missiles on cylinders.

The calculations are given in DAC-NP-710660-A001, *Natural Phenomena Evaluation of K-25 UF_6 Cylinder Storage Yards* (LMES, 1996).

6.2.1 Instability of Single Cylinders Sitting in Saddles

The 30-in. and 48-in. cylinders (both thin and thick-wall, 10-ton and 14-ton) were evaluated for possible rocking and then rolling or jumping out of a saddle due to the 113 mph wind. The wind produces a lateral force on the cylinder which is resisted by the weight of the cylinder. Empty cylinders were considered first.

For a cylinder, sitting in a saddle, to initially start to lift up off the saddle, the moment due to the side wind force about the top edge of the saddle cavity must be greater than the restoring force due to the weight of the cylinder about the same point. It is fairly straight-forward, knowing the weight of the cylinder, to calculate the minimum lateral force (and hence, wind speed) needed to create this instability. If the calculated threshold wind speed is greater than the criteria wind speed (70 mph for PC-2 and 113 mph for PC-3) then lift off will not occur and the cylinder will remain in the saddle. The analysis showed that the 10 and 14-ton cylinders have a safety factor (lateral force) ranging between 1.6 and 3.5 against lift off, while the 2.5-ton (30A/30B cylinders) have a safety margin of 1.8. Since the wind pressure is proportional to the square of the velocity, that means that the wind velocities required in order to initiate motion of the cylinders resting in a saddle is 145 mph (type 48G/48T) to 210 mph (type 48X/48Y), and 150 mph for the 30-in. cylinders. Full cylinders would require much greater wind speeds to dislocate.

6.2.2 Instability of Stacked Cylinders

Based on the findings of the single cylinders on saddles it was concluded that stacked cylinders will not move out of saddles, or their location in a stacked configuration, due to a 113 mph PC-3 wind event.

6.2.3 Rolling of Cylinders Sitting Unrestrained on Concrete or Gravel Surfaces

This case is similar to rolling of cylinders resting directly on a concrete pad during an earthquake event, and was analyzed in generally the same manner. Some of the smaller cylinders sit directly on the ground surface, without being restrained by a saddle or other device. The coefficient of rolling resistance of for steel-on-concrete was estimated to be 0.17-in., that for steel-on-gravel varied from 1.1-in. to 3.5-in. (see seismic section 3.5).

Concrete pad: The calculations show that *all sizes of cylinders, empty or full, are subject to roll if they are sitting, unrestrained, on a concrete pad, at wind speeds lower than the 70 mph wind speed for the PC-2 criteria.* The distance moved would, of course depend on the duration of the wind, so there is no simple calculation that can be used to estimate the travel distance. The maximum velocity reached by one of the moving cylinders is also not easy to calculate due to a number of possible parameters. The smaller cylinders (8A and 12A), empty , weigh two to three times as much as the maximum tornado missile that needs to be considered by a PC-3 analysis, so the small cylinders are not credible tornado missiles of themselves. Thus, it is not credible that these smaller cylinders will become airborne, but they could roll some distance. They probably would do nothing more than wedge themselves somewhere, maybe underneath a larger cylinder in the area. Since 70 mph is the minimum wind speed allowed by the codes, it is concluded that unrestrained cylinders subjected to the 100-year wind would also roll.

Gravel surface: The coefficient of rolling resistance of for steel-on-gravel was estimated to be between 1.1-in. and 1.7-in. for the cylinders 30-in. and smaller, and 3.5-in. for the 48-in. cylinders. As would be expected the results indicate that fewer of the cylinders are susceptible to movement when resting on a gravel surface than on a concrete surface. The results are presented in Table 6.1:

In general, the same statements that were made for the cylinders moving on the concrete pad are equally valid for movement on the gravel surface, except that the travel distance and maximum speed would be expected to be smaller.

6.2.4 Sliding of Cylinders Resting in a Saddle

The possibility of a cylinder plus a saddle sliding along the ground was considered. The coefficient of dry friction for stone-on-stone is given in various reference books as being between 0.40 and 0.70. The coefficient of wet friction would be somewhat less, maybe 0.30 to 0.60. The references do not give values for concrete or wood-on concrete, but due to the roughness of the surfaces, it would be expected to be no less than that given for stone-on-stone. Thus, in wet weather empty 48G/48T cylinders plus saddles might start sliding around 105 mph (4 x 10^{-5} annual probability of exceedance), while in dry weather they would not slide until the wind speeds reached 130 mph, greater than the 113 mph PC-3 criteria. None of the other empty (or

Table 6.1. Summary of Cylinders Rolling on Gravel Due to Wind

Cylinder Type	Cylinders roll? (@ PC-2 70 mph wind speed)		Cylinders roll? (@ PC-3 113 mph wind speed)	
	empty	full	empty	full
5A/5B	no	no	no	no
8A	no	no	yes	no
12A/12B	no	no	yes	no
30A/30B	yes	no	yes	no
48X/48Y	no	no	yes	no
48G/48T	yes	no	yes	no

full) cylinders will slide in the PC-3 wind. However, DOE-STD-1020-94 allows, for the evaluation of existing facilities which are "close" to meeting the criteria, some relief in the phenomena hazard exceedance probability to twice the value specified for new design. Thus, an existing facility having a PC-3 classification may be evaluated for a 25,000 year tornado wind speed instead of a 50,000 year tornado wind speed, i.e., the hazard annual probability of exceedance may be increased from $2x10^{-5}$ to $4x10^{-5}$. Based on this relief, all the cylinder plus saddle configurations meet the PC-3 guidelines against sliding.

6.2.5 Efffects of Tornado Generated Missiles on Cylinders

The two criteria tornado generated missiles, (i) a 2x4 timber plank, weighing 15 lb travelling at 100 mph horizontally, and (ii) the 3-in. diameter standard steel pipe, weighing 75 lb, travelling at 50 mph horizontally, were evaluated for potentially damaging the cylinders standing in the yards.

Testing has been performed by Nevin and McDonald at Texas Tech University in Lubbock, Texas to study the resistance of different types of wall barriers for buildings subjected specifically to the DOE design tornado-generated missiles. Unfortunately, the barriers studied were for the most common wall materials, concrete and masonry, both reinforced and unreinforced. No testing was done on steel plate barriers, and very little applicable testing is available. Several empirical equations for estimating the impact and penetration resistance of steel barriers to missiles exist, the most common being the Ballistic Research Laboratories (BRL) formula and the Stanford Research Institute (SRI) formula (Singhal and Walls, 1993). There is one formula specifically developed by the Southwest Research Institute (SwRI) for penetration of wooden industrial type projectiles into metal targets (Baker, 1984). Much of the test data originated with military ballistics applications, for hypervelocities, which are much greater than the velocities proposed for the DOE criteria. All of these formulas have some range limits for the parameters in order to be "valid". Threshold thicknesses were calculated using each of the applicable formulae, and in the BRL formula proved to be the most conservative.

The calculation shows that in order to prevent the timber plank from perforating the cylinders, the steel shell thickness at the point of contact (and normal to the direction of motion) needs to be at least 3/16-in. (0.1875-in.), while to contain the steel pipe a wall thickness of 5/32-in. (0.156-in.) is required. All of the cylinders included in this study, with the exception of the 8-in. cylinders, have a nominal wall thickness greater than the 3/16-in. value; the 8-in. cylinders' nominal thickness is equal to 3/16-in.

Due to the curved shape of the cylinder, the higher (or lower) the hit is above (or below) the cylinder centerline, the more oblique the angle of impact becomes, and hence, the smaller the impact force normal to the shell, which means that the required shell thickness becomes smaller. If the angle of attack is greater than 45°, the required wall thickness to contain the steel missile is reduced to 3/32-in., or 1/16-in. less than required to prevent perforation at the center of the cylinder. In general, a missile striking at an angle greater than 45° will probably just glance off the cylinder.

Effects of corrosion: The effect of corrosion on the vulnerability of the cylinders to a tornado-generated missile was also considered, and determined to be minimal. Corrosion studies (Pawel, 1996) have clearly shown that the most "significant wall thinning of cylinders has been found in only a few locations, each where water is allowed or encouraged to accumulate for long periods of time. The most significant of these, in numbers and magnitude, are:

1) underside due to ground contact or poor yard drainage,
2) underside at/near chock/body contact interface, and
3) in skirt/head crevices.

The underside surface of cylinders generically means the bottom sixth or so of the surface (clock positions 5-7 along the bottom). That the most corrosion occurs here is very predictable in that this is the portion of the cylinder that can settle into ground or standing water contact, and the portion closest to the ground is expected to wick and hold water (condensate or collected rain) most efficiently along the chocks near the 6 o'clock position." Pawel also suggests that the corrosion rate for the large majority of the cylinder surface, in the absence of a protective coating, is in the range of 0.5 - 2.0 mils/yr. The smoother and drier the surface (generally toward the top), the lower the rate inside this range. He feels that most of top row cylinder surfaces fall in this low range and 80-90% of bottom row surfaces do, too. Very rough surfaces (toward the bottom of a cylinder already roughened by significant accelerated weathering) might be a little higher (1 to 3 or 4 mils/yr) due to collection of condensate in this area. It should also be pointed out (Pawel, 1996) that much of the thickness data so far available for the K-25 Site cylinders (Lyons, 1995) was collected from cylinders ***visually appearing to be the worst of a particular group*** (which is why these were being monitoring early in the ultrasonic thickness data program). This has the obvious influence of tending to "skew" the data toward worst case, at least in terms of the numbers of cylinders predicted to be similarly effected. Even assuming a value for the corrosion rate close to the high end (2.0 mils/yr) for the mid-side of the cylinder, a 50 year old cylinder should still have a minimum side wall thickness equal to 5/16 - 50(.002) = 0.2125-in., which is greater than the 3/16-in. thickness required to prevent perforation by the timber plank missile. While the amount of corrosion may be more pronounced near the bottom surface of the cylinder, this is not a likely position for an missile strike to successfully hit and penetrate - the missile will likely glance off. Thus, due to their location near the top or the bottom of the cylinders, it is not considered likely that a missile will damage a cylinder in the corroded zones. However, a tornado-generated missile striking an end cylinder valve could damage the valve, even cause it to break off, and leave a small access hole near the top of the cylinder.

One additional argument that will eliminate damage to the 8-in. cylinders from a tornado-generated missile strike is the very low height above ground (about 3-in. to 5-in.) at which the strike will, of necessity, occur. For an object to be injected into a tornado wind-field, three initial conditions are required (Malaeb, 1980): initial height, location relative to the tornado path, and missile release velocity. Given that the location exists, then only the initial height and the missile release velocity enter into the equation. Observations of post-storm damage indicate that non-airfoil objects lying loose on the ground or even near the ground are rarely, if ever, picked up (Malaeb, 1980), primarily because the wind velocity at ground level is zero. It has also been noted that while the upper elements of unrestrained stacked lumber have been picked up and transported some distance, as the stack height decreased, the lower pieces were not disturbed. In the case of the 8-in. cylinders, it would appear to be incredible (considering that the annual probability of a PC-3 tornado missile is $2x10^{-5}$) that a missile could be generated travelling at full velocity and remain only inches above ground. It can be concluded that the 8-in. cylinders will not be damaged due to the PC-3 tornado-generated missile.

6.3 SUMMARY OF WIND/TORNADO EVALUATION

The wind/tornado results of the UF_6 storage cylinders located in six yards at the K-25 Site determined the following:

1. Instability of single cylinders sitting in saddles and instability of stacked cylinders is not a problem for the 113 mph PC-3 wind speeds. Cylinders will remain in saddles and stacked cylinders will remain in the stacked configuration.

2. All sizes and configurations (empty or full) of cylinders sitting on a concrete pad are susceptible to rolling at wind speeds below the 70 mph, PC-2, criteria. Also, unrestrained cylinders subjected to the 100-year wind will also roll, since that wind speed is also 70 mph.

3. All of the empty cylinders (except the 5-in. cylinders) sitting on a gravel surface are susceptible to rolling at wind speeds below the 113 mph, PC-3, criteria. The empty 2.5-ton (30A/30B) and 48-in. thin-walled cylinders (48G and 48T) will roll on a gravel surface at speeds below the PC-2 criteria.

4. Sliding of cylinders plus saddle is not a problem.

5. Tornado generated missiles. Two missile types were considered: (i) a 2x4 timber plank, weighing 15 lb traveling 100 mph horizontally, and (ii) a 3-in. diameter standard steel pipe, weighing 75 lb, traveling 50 mph horizontally. A 3/16-in. shell thickness is required in order to prevent perforation by the timber plank, and 5/32-in. in order to prevent perforation by the steel pipe. All the cylinders included in this study, with the exception of the 8-in. cylinders, have a nominal wall thickness greater than the 3/16-in. value; the 8-in. cylinder has a nominal thickness equal to 3/16-in. Corrosion studies have clearly shown that the most "significant wall thinning of cylinders has been found in only a few locations, the most significant of these being (a) the underside due to ground contact or poor yard drainage, (b) the underside at or near the saddle/body contact interface, and (c) in skirt/head crevices. The corrosion study also has clearly shown that the most vulnerable and exposed area of a cylinder for a missile strike, the centerline and about ±45° from the centerline, is about the least corroded area, and the shell thickness exceeds the minimum required to prevent perforation. Although a missile might

impact a cylinder in the corroded regions, the missile will glance off due to the angle of impact. Finally, the 8-in. cylinders are not at risk because it is considered incredible that a missile will exist at the very low altitudes (3 to 5-in.) required to impact the 8-in. cylinder. However, a missile striking a protruding fill-valve could damage the valve, cause it to shear off at the threads, thus leaving a small opening hole.

7. LIGHTNING EVALUATION

The effects of lightning strikes are well documented in the literature (Hasbrouck, 1989). The writeup that follows was primarily taken from a telephone discussion with Hasbrouck (Hasbrouck, 1996). If a cylinder were to take a direct hit, the peak value of the return-stroke current pulse could be as high as 200kA (this is a 1 percentile value, i.e., 99% of all negative lightning is less than this value), but its duration would only be 50 - 100μsec. Fifty percent of all lightning exhibits peak less than 20 - 30kA. Most direct damage results from the heavy return stroke current that produces very large temperature rises in high resistance paths or from arcing. When lightning attaches to a reasonably smooth metallic surface, the damage depends on the magnitude of the charge, how quickly it is transferred, and the electrical and thermal conductivities of the surface. Damage can range from superficial pitting to holes approximately ½-inch in diameter. Additional locations for lightning to strike are sharp edges (these accumulate charge which attract the lightning), such as the ends of the cylinder skirts (though these are not really very sharp), or possibly the fill valve located at the upper portion of the hemispherical head of the cylinder. Fire, as a direct result of a lightning strike, is caused by *continuing current*, hundreds of amperes flowing for hundreds of milliseconds after the high-current return stroke. When this current flows through a resistive path, enough heating can take place to ignite flammable materials.

Hasbrouck indicated that a welded cylinder, such as the UF_6 cylinders, would make a good Faraday Cage (a topologically closed metallic barrier, which protects the contents from external electric fields) and would probably only see minuscule levels of pitting. The only danger in a lightning strike would be if an aperture existed, providing a direct path between the exterior of the cylinder and some flammable gas or vapor inside the cylinder.

It is known that lightning strikes on "thin metal sheets" can burn holes, but the 5/16-in. thick metal is not a thin sheet metal. Lightning strikes on heavier steel structures produce negligible damage, such as superficial pitting or blow-off of some surface paint. The most direct way to prevent melt-through of holes is to use sufficient thickness. One reference (FAA, 1989) suggests having a minimum thickness of 2.0 - 3.0 mm (0.080-in. - 0.120-in.) in order to prevent holes from forming on aluminum skins that are painted. The Lightning Protection Code (NFPA, 1992) states that "sheet steel less than 3/16-in. (4.8 mm) may be punctured by severe strokes ..." The minimum nominal wall thickness of the cylinders is 5/16-in. Although corrosion reduces this value, the worst corrosion appears to be near the very bottom of the cylinders (Pawel, 1996) and the wall thickness where the lightning would strike, the upper portions of the cylinders, is in general, greater than the 3/16-in. suggested value.

Studies and limited tests have been made of the effects of fire on cylinders containing UF_6. Williams (1988 and 1995) concluded that all sizes of UF_6 cylinders will rupture within 30 minutes when totally immersed in a fire having 1475°F temperatures, but were less likely to rupture if they are only adjacent to the fire. For cylinders totally immersed in a fire at 1700°F, Luk and Webb (1996) found that rupture would occur within 7 minutes for the thin-walled 10-ton and 14-ton cylinders, and in 11 to 15 minutes for the 2½ -ton and thick-walled 10-ton and 14-ton cylinders. Williams (1996) also concluded that the larger cylinders are less likely to rupture if they contain only small amounts of heel quantities even when immersed in a fire. Basically, these studies indicate that for a cylinder to rupture due to direct heat it takes both significant time and heat flux to convert the solid UF_6 (which is not flammable) to liquid UF_6 phase at 300-400°F, the calculated (conservatively) point of rupture for the larger cylinders. It seems implausible that a direct lightning strike could accomplish the same result. The energy required for the phase transformation simply does not remain in the cylinder shell long enough. It does not even seem likely that a direct strike on the fill-valve will do more damage than either scar the valve or, in the worst case, possibly "blow it off." In the latter case, the plug in the cylinder head would probably still remain in place, so the exposed area would be quite small. Since the fill-valve is not the highest point on a cylinder, it is less likely to be hit than the much larger body of the cylinder.

The Oak Ridge area averages about 19 lightning flashes to ground/mi.^{2}/year (Hasbrouck, 1996). The total area of the six cylinder yards at the K-25 Site is approximately 591,000 square feet, or about 0.021 mi.^{2}. Thus, it might be expected that in the past fifty years an area this size would be struck about twenty times ($0.021 \times 19 \times 50 = 20$), or about one every two and a half years, ***all other things being equal.*** The yards are generally not the highest point in the area, there are a number of structures in or very near the yards, such as large buildings and telephone and light poles, all which provide some shielding, so the number of strikes is probably less than that calculated above. It would, however, seem likely, due to the location of the cylinder yards - out in the open - and the number of years involved in storage of cylinders in the yards, that at some time in the history of the storage cylinders program that lightning has struck either a cylinder yard or in the vicinity of one.

However, there is no documented occurrence of lightning strikes on cylinders, or more to the point, lightning strike damage to a cylinder. A number of persons having a long history of involvement with the cylinder program at the K-25, Paducah, and Portsmouth plants were contacted as part of this exercise and none ever recalled any incident where a cylinder or yard had been struck by lightning. Since a few strikes would seem likely to have taken place, and since no incidents have ever been reported due to lightning strikes, it would appear that the consequences of a lightning strike on a cylinder, if it has occurred, has been minimal.

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