

Integrity of Uranium Hexafluoride Cylinders

Defense Nuclear Facilities Safety Board

Technical Report



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INTEGRITY OF URANIUM HEXAFLUORIDE CYLINDERS

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I. OVERVIEW

This report reviews the safety of depleted uranium hexafluoride (UF_6) presently stored in large cylinders at the K-25 Site in Oak Ridge, Tennessee, and the gaseous diffusion plants in Portsmouth, Ohio, and Paducah, Kentucky. Depleted uranium hexafluoride is referred to as the "tailings" of the gaseous diffusion process in uranium enrichment. Cylinders have been used in the uranium enrichment program since the late 1940s for transportation and storage of uranium hexafluoride. This report addresses the integrity of the cylinders as containment vessels.

Cylinder life is limited by exterior corrosion or mechanical damage. Defense Nuclear Facilities Safety Board (Board) staff reviews of Department of Energy (DOE) actions for remediation of breached cylinders and management of the UF_6 cylinder inventory indicate that DOE's present program is not adequate for long-term storage of depleted UF_6 . After discovering seven breached cylinders in 1990-1992, DOE increased its efforts to study the effects of corrosion, established an inspection program, revised handling procedures, and updated safety reports. However, it appears that:

- corrosion studies have not addressed sufficiently the effect of accelerated corrosion mechanisms on cylinder integrity, nor have they been used to predict future cylinder integrity;
- the inspection program does not adequately verify cylinder integrity, nor does it document actual current conditions of the cylinders;
- handling procedures do not compensate for possible fragility associated with degradation of cylinder integrity, nor do they incorporate lessons learned to prevent further occurrence of cylinder damage during handling; and
- safety analyses do not address the potential impact of a breach on the upper portion of the cylinder wall (around the vapor space), nor do they investigate degradation of cylinder integrity as a high-probability initiator of accident scenarios.

Management of the UF_6 cylinder inventory would benefit significantly from a systems engineering approach to integration of efforts. Martin Marietta Energy Systems (MMES) attempted a systems approach in its *UF₆ Long-Term Storage Cylinder Integrity Management Plan*¹. The plan does not, however, integrate aspects of the UF_6 program into a useful, problem-solving and decision-making process. In addition, the plan has never been formally approved for implementation by DOE and evidence suggests that many portions of it have never been implemented or closed out, though many of the due dates have passed.

A. Inventory

There are approximately 50,000 storage cylinders containing over 500,000 metric tons of UF_6 at the Oak Ridge K-25, Portsmouth, and Paducah Gaseous Diffusion Plants. UF_6 produced prior to July 1994 is legacy material from national defense programs and is the property of DOE; UF_6 produced since July 1994 is owned by the U. S. Enrichment Corporation (USEC), and under the regulatory purview of the Nuclear Regulatory Commission. DOE plans to store the depleted UF_6 inventory in these cylinders until the year 2020; as shown in Figure 1, the oldest cylinders have been in storage since 1956. Depleted UF_6 continues to be produced, filling approximately 2,000 cylinders per year; this material is tailings from the USEC enrichment processes and, therefore, not considered in this report.

The majority of the cylinders, made from low carbon steel, exhibit extensive areas of general corrosion. Outdoor storage in yards with poor drainage, however, gives rise to an even greater concern - accelerated corrosion. Numerous dents and gouges from improper stacking, ground contact, debris buildup on cylinders with skirts, and pitting at the interface area between the cylinder and storage saddles, all present potential sites for initiation of accelerated corrosion mechanisms. The discovery of seven breached cylinders between 1990 and 1992 gave rise to concern about the long-term, safe storage of depleted UF_6 in these cylinders.

B. Hazard Summary

UF_6 is highly reactive with water, forming soluble reaction products such as uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF), both of which are toxic. Aqueous HF is an extremely corrosive acid. Exposure to HF can be fatal; however, individuals can smell HF at concentrations two orders of magnitude below the lethal concentration specified in EPA's Integrated Risk Information System.

When released to the atmosphere, gaseous UF_6 reacts with water vapor to form a cloud of particulate UO_2F_2 and HF fumes. The reaction is fast, but is dependent on the availability of water. External contact with HF results in chemical burns of the skin, while exposure to airborne HF causes chemical burns/irritation of the eyes, nose, and throat. Because UF_6 reacts readily with water and organic materials, it must be handled in clean equipment and out of contact with moist air. A breach in a cylinder allows the external atmosphere to react slowly with the UF_6 . The solid reaction product tends to plug the breach; however, the HF formed releases slowly, attacks the metal cylinder, and enlarges the breach over time. The hole diameter is estimated to increase at a rate of approximately one inch per year. The reaction products, consisting of UF_4 , FeF_3 , and other iron oxides, fall to the ground or onto adjacent cylinders. The material released to the environment is HF and solvated uranyl fluoride $[H_3O]_2[U(OH)_4F_4]$, which is soluble in water. Figure 2. is a photograph of the largest breach discovered to-date.

"THINWALL" CYLINDER INVENTORY

TOTALS AS OF 1992

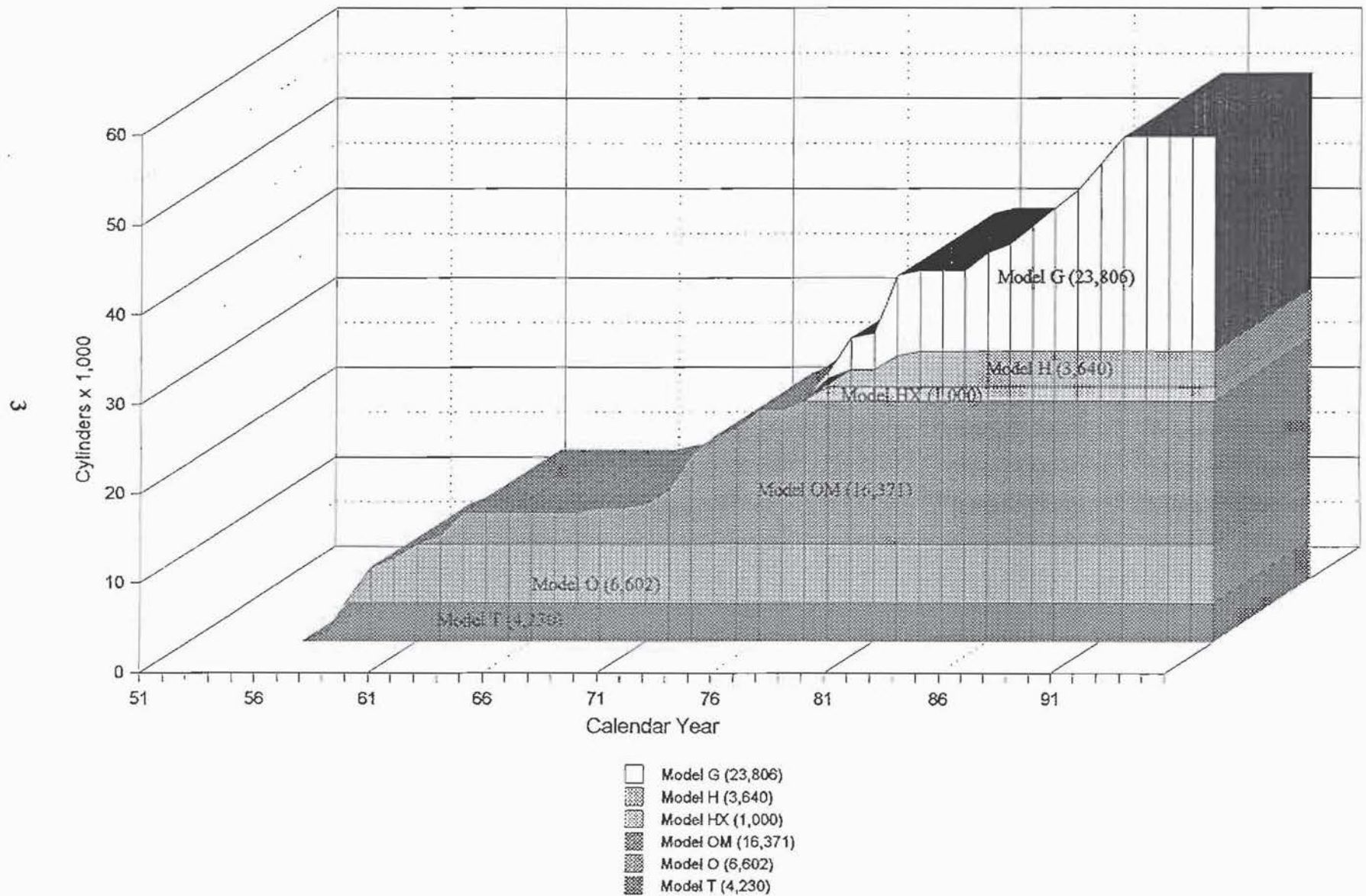


Figure 1

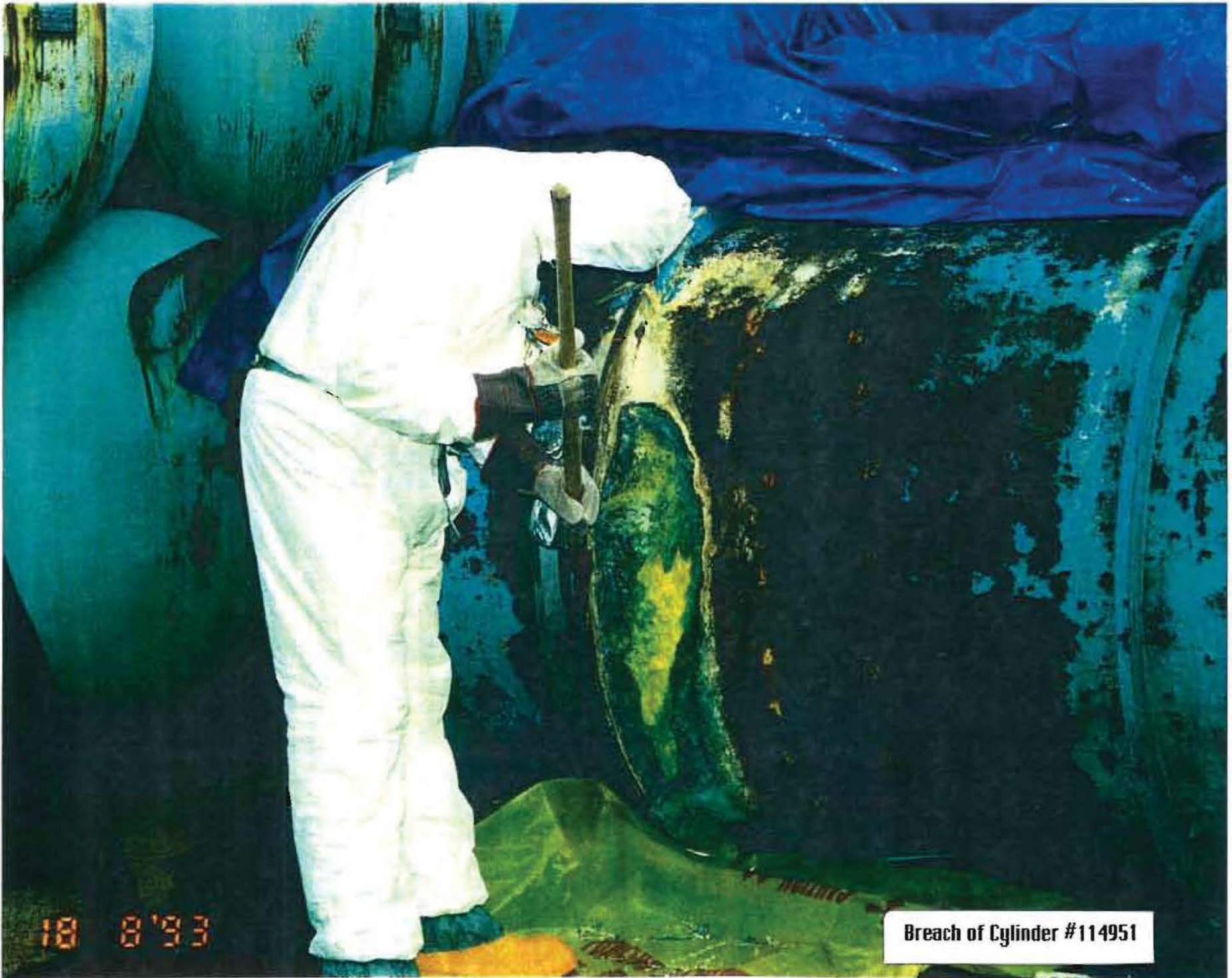


Figure 2 Breached Cylinder at Oak Ridge K-25 Site

As described in the *Draft Preliminary Report of the DOE Independent UF₆ Cylinder Assessment Team*², the radioactivity UF₆ material depends upon the assay, but is approximately three curies per cylinder. Martin Marietta Energy Systems (MMES), the maintenance and operating contractor at all three sites, calculated that the amount of material lost by the largest cylinder breach (in Portsmouth) was about 110 pounds of UF₆. Neither this amount nor the amounts of material estimated lost from the other smaller breaches was reportable per EPA standards.

C. Ultimate Disposition

In light of the fact that demand for depleted uranium had become quite small compared to quantities available, the DOE Office of Nuclear Energy directed a study in 1990 to review options and develop a comprehensive plan for inventory management and the ultimate disposition of depleted uranium accumulated at the three gaseous diffusion plants. The report, *The Ultimate Disposition of Depleted Uranium*³, concluded that "it is acceptable and desirable to maintain depleted uranium working inventories as UF₆ as long as they remain potential feed sources for the plants and as long as cylinders and storage facilities are adequately monitored and maintained." The report discussed possible options for ultimate disposition, such as transfer or sales to other government programs or to the private sector, but recognized that commercial and government sectors would use only a small fraction of the depleted uranium in the foreseeable future. The report recommended that: UF₆ cylinders be inspected on a semi-annual basis; cylinder maintenance and storage yards be upgraded; and depleted uranium be converted to U₃O₈ for long-term storage or disposal. Contrary to this last recommendation, the present plan established by DOE provides for long-term storage of the depleted, uranium stockpile as UF₆ until conversion to uranium oxide begins in fiscal year 2020.

No further decision has been made on the ultimate disposition of the depleted UF₆ material. However, DOE published two Federal Register notices in November 1994 concerning UF₆: a notice of request for recommendations for potential uses of the depleted UF₆ and technologies that could facilitate the long-term management of this material; and an advance notice of intent to prepare an environmental impact statement. An independent review team from Lawrence Livermore National Laboratory is currently reviewing forty-five written responses to the request for technologies. DOE continues to manage the depleted UF₆ resource as "source material" under the Atomic Energy Act of 1954, as amended. DOE has also received two unsolicited proposals for conversion of the depleted UF₆ to uranium oxide and metal.

D. Corrective Action

DOE and MMES have conducted corrosion studies and investigations of cylinder management to both determine the causes of breached cylinders and to recommend preventive measures against future breaches. These efforts have been undertaken by several different groups, including special investigation teams and one independent review team.

The review conducted by the DOE Independent UF₆ Cylinder Assessment Team was a comprehensive assessment of the entire cylinder program. The team reviewed the design, fabrication, transportation, filling, storage, handling, inspection, legal considerations, safety and health considerations, environmental considerations and ultimate disposition of the cylinders. Unfortunately, this report is still considered "draft" after three years. Other investigations, such as the *Cylinder Yard Inspection and Corrective Actions*⁴, and *Investigation of Breached Depleted UF₆ Cylinders at the K-25 Site*⁵, were focused on smaller segments of the cylinder program. Each report brought forth specific, technically supported recommendations which collectively cover nearly every aspect of UF₆ cylinder management.

In each report the findings were very similar and they each came to similar conclusions. These reports proposed solutions as basic as forcing contractor compliance with the manual, *Uranium Hexafluoride: A Manual of Good Handling Practices*⁶, and painting or coating the cylinders to arrest corrosive attack. While some of the recommendations have been incorporated into MMES plans, it appears that several feasible courses of remedial action, such as painting or coating the cylinders, or installing spacers between stacked cylinders, repeatedly proposed to DOE, have not been seriously considered as options.

II. DISCUSSION

A. Corrosion

1. Background

Cylinders used to contain and store depleted UF_6 are made of formed and welded ASTM A516 or A285 carbon steel plates. Nominal thickness is 312 mils; the minimum allowable thickness for safe transportation is 250 mils per the DOE Manual of Good Handling Practices. Coatings on the vast majority of cylinders have not been maintained, leaving them vulnerable to a variety of localized corrosion mechanisms. Two cylinder breaches have been attributed to localized external corrosion initiated by extended contact with the ground. Such external corrosion could weaken cylinders to the point that failure occurs during handling, shipping, or unloading operations. Cylinders could also become breached from the inside due to corrosion resulting from valve leakage and failure to identify and correct such leaks in a timely manner.

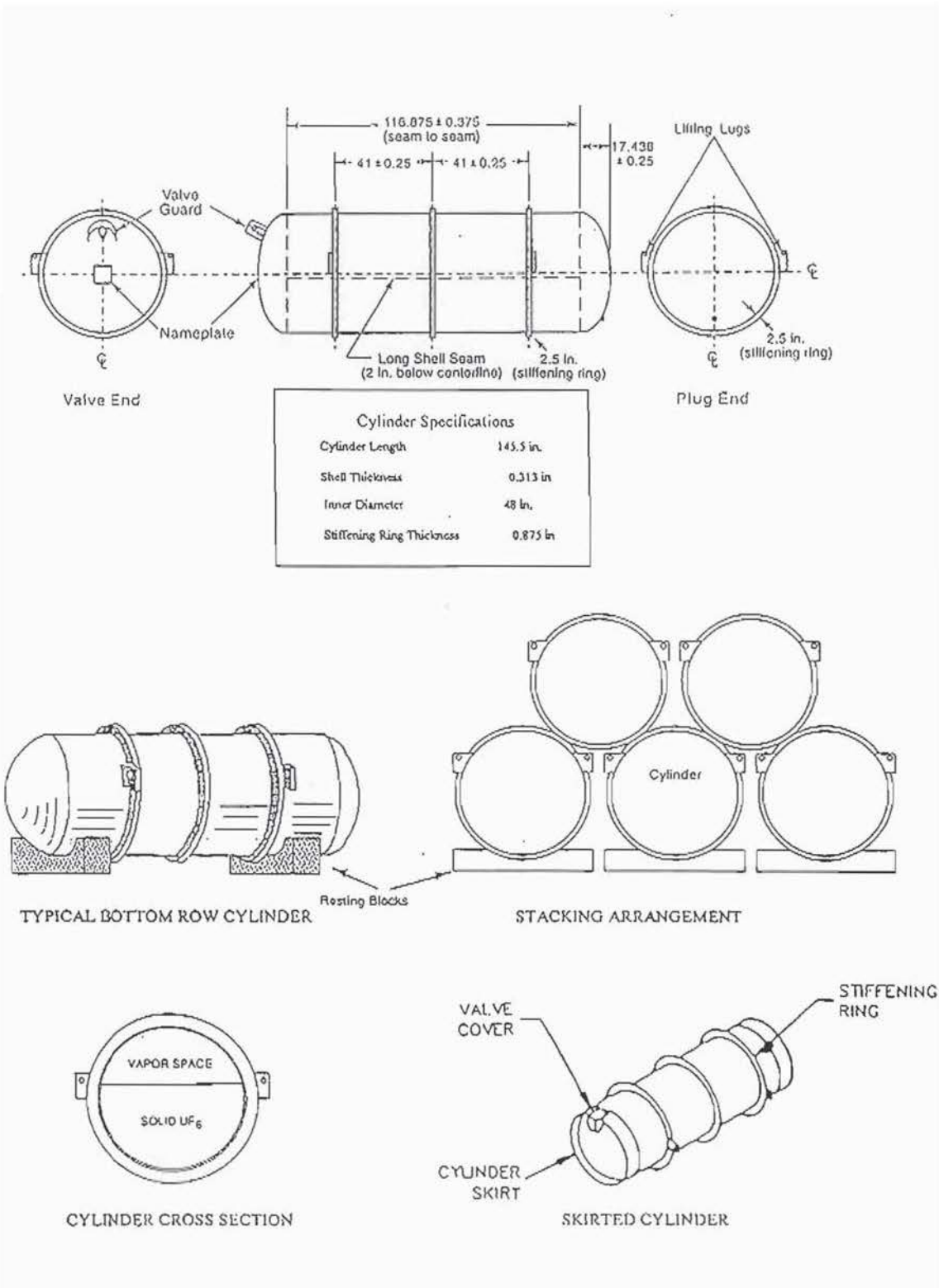
Visual inspections of the cylinders have shown abundant pitting and crevice corrosion (differential oxygenation corrosion) on the cylinders, as well as some apparent galvanic attack near bronze valves and plugs. Other than the failures, the deepest corrosion discovered thus far was slightly over halfway through the cylinder wall.

2. Summary

MMES corrosion studies have focused mainly on the variables affecting the general corrosion rate of carbon steel. The highest corrosion rate is estimated to be three mils per year. More work needs to be done to characterize the localized accelerated corrosion mechanisms that are occurring and to identify methods to ameliorate this accelerated corrosion.

It does not appear that inspection methods, such as ultrasonic thickness measurements, are consistently being used in a manner that will provide needed information about the extent and rate of cylinder corrosion. For example, thickness measurements made on cylinders at K-25 were not correlated with the actual storage history of the cylinders (e.g., ground contact versus non-ground contact, or surfaces formerly on resting blocks). Also, ultrasonic measurements of the cylinders at K-25 and the bottom row of cylinders at Paducah were typically limited to spots that visually appeared to be the most corroded. Views and stacking arrangements of typical cylinders are shown in Figure 3.

The discussion below is drawn from Board staff observations and several MMES and DOE reports (see references).



Various Cylinder Views
Figure 3

3. Corrosion mechanisms

INTERNAL CORROSION: Experimental testing and operating data on corrosion of ASTM 516 steel by UF_6 show that uniform corrosion of the internal surfaces of intact cylinders (i.e., corrosion of steel in contact with solid UF_6) occurs at a negligible rate. However, in the presence of moisture, UF_6 reacts to form HF which results in significant corrosion of the steel. Corrosion of cylinder walls by this mechanism have been estimated to enlarge an existing breach (in diameter) at a rate of one inch per year.

EXTERNAL CORROSION: Atmospheric corrosion of mild steel varies from zero (for those cylinders with paint intact) to about 1 to 10 mils per year (on bare cylinders or those with degraded paint, from *Monitoring of Corrosion in ORGDP Cylinder Yards*⁷). The life expectancy of many of the cylinders, however, has been greatly reduced by accelerated, localized corrosion mechanisms associated with several storage environments and design features. Types of localized corrosion that have been identified include ground contact corrosion, resting block corrosion, skirt corrosion, other types of crevice and differential oxidation corrosion, and galvanic corrosion at valves, plugs, and nameplates.

Ground contact corrosion occurs when the cylinders sink into the ground, or debris and water accumulate under the cylinder. In both scenarios, foreign material and moisture stay in almost continuous contact with the steel and accelerated corrosion and/or pitting result. Accelerated corrosion continues even after the cylinder is removed from ground contact, due to moisture retained in the oxide scale formed while on the ground.

Two of the cylinder failures at K-25 were attributed, at least partially, to the fact that the cylinders had spent several years in ground contact. A total of 29 cylinders in ground contact from two different storage yards at Paducah have been raised and inspected. Accelerated corrosion and pitting were found in the ground contact areas. Ultrasonic thickness measurements made at the deepest pit locations found that corrosion and pitting had reduced the wall thickness by one-third on average and by one-half for the worst cylinder inspected. However, this sample size is quite small and does not necessarily include the worst-case cylinders.

A total of 136 cylinders stored in what MMES termed "substandard conditions" at K-25 were also ultrasonically inspected. Wall thicknesses had been reduced to less than half the nominal thickness at the worst locations.

Resting block corrosion occurs at the interface between the cylinder and its resting block. Cylinders that have been inspected during movement have shown that a line of pits develops in the cylinder, immediately adjacent to the block at the cylinder-block interface. Ultrasonic measurements at Paducah have found wall thicknesses reduced to less than half their nominal thickness in pitted areas next to the resting blocks.

Skirt corrosion occurs on the heads of cylinders with skirts. The skirts are an extension of the cylinder body over the head ends to protect the heads from impact damage. About one-third of the cylinders have skirts where puddles form and piles of corrosion products (rust) collect. Puddles and debris in the skirts greatly accelerate cylinder head corrosion and pitting by trapping moisture and promoting differential oxidation. At Paducah, for example, ultrasonic wall thickness measurements were made on a sample of 50 skirted cylinders and correlated with the depth of the rust pile accumulated in the skirt. For rust depths of 1 to 1-1/2 inches, 10%-15% thinning occurred, and for rust depths greater than 1-1/2 inches, 10%-30% thinning occurred. Over 2,000 skirted cylinders still contain debris. However, not all of these are accessible for cleaning; other cylinders need to be moved to provide access.

Crevice corrosion occurs in crevices, cracks, surface defects, and where cylinders contact one another. Visual inspections have found numerous dents, gouges, and cracks in the cylinders at these points. Additionally, piles of corrosion products have accumulated on top of cylinders and on the line of contact between stacked cylinders without stiffeners. The extent of corrosion in such areas has not been evaluated by MMES.

Galvanic corrosion has occurred where bronze plugs and valves screw into the steel cylinders and where stainless steel nameplates are welded to the cylinder. If the joint between the plug or valve and the cylinder becomes moist, corrosion of the threads in the steel vessel could allow air to leak into the cylinder. Air and moisture entering through a failed valve will react with UF_6 to produce acids, which can eventually corrode through the cylinder wall. DOE and MMES have not performed analyses to quantify the damage expected by this mechanism.

Valves have failed in storage and allowed leakage of HF to the atmosphere. The cause of failure has been identified as stress corrosion cracking of packing nuts. This pathway could also permit air leakage into the cylinder.

Channel-type stiffeners on many cylinders have also shown accelerated corrosion. Some have become perforated allowing water to accumulate in close proximity to the cylinder shell. MMES believes that such channels are anodic relative to the shell and, thus, this phenomenon poses no threat to cylinder integrity. Limited examinations have tended to confirm this opinion, but a thorough investigation has not been performed by MMES.

B. Inspection Program

1. Background

Prior to 1990 there was no routine inspection program for cylinders in storage. In June 1990, inspection of valves on cylinders was initiated in response to several reports of leakage. During this inspection, a cylinder with a large hole was found at Portsmouth.

This discovery resulted in the immediate initiation of a new inspection program to identify holes and indications of degraded conditions (*Cylinder Yard Inspections and Corrective Actions*). A total of seven breached cylinders were found: five at K-25; two at Portsmouth; and one at Paducah.

To conduct this inspection, a special checklist with 52 defect criteria was developed. Examples of the defect criteria that indicate a degraded state include: heavy scale on cylinder (or ground); poor yard drainage; body in ground contact; and scale in the cylinder's protective skirt. The result of this aspect of the inspection program was that about half the cylinders were classified by MMES as potentially at risk, and were put on an annual reinspection cycle; the remainder were put on a four-year reinspection cycle.

Due to storage conditions, however, not all surfaces on all cylinders were inspectable. Thousands of cylinders were in contact with the ground, and a significant fraction of the rest were stacked so tightly that not all surfaces are accessible. The contact area between the saddle and the cylinder cannot be inspected until the cylinder is moved. Therefore, the potential exists for additional breached cylinders to be discovered.

2. Summary

The Board staff performed a detailed review of the inspection program and procedures. As it exists today, the program has a number of deficiencies that minimize its usefulness in evaluating cylinder integrity. The documentation required for defects is not adequately descriptive and, therefore, does not lend itself to analysis of cylinder integrity. The results and scheduling of the inspection program are not integrated with other portions cylinder management, such as corrosion studies and cylinder maintenance. For example, there is presently no cohesive plan to take advantage of scheduled cylinder movements to inspect previously inaccessible areas. The inspection program does not aggressively pursue full inspection of all cylinder surfaces; in fact, a one hundred percent inspection of all cylinder surfaces is not expected until around the year 2000 (plans are not yet definite). Finally, training provided to personnel performing the inspections is inconsistent and inadequate; this has led to widely varying quality in the inspection results.

3. Discussion

A logical starting point for the discussion of an inspection program are the criteria used for inspections. In MMES' program these criteria are embodied in the inspection checklist and accompanying procedure (*Inspection of UF₆ Cylinders In Storage*⁸). In accomplishing the inspection, inspectors are not required to record the size, type, number, locations nor a physical description of the defects they observe; they simply check very broad categories of defects. Without this type of information, the condition of the cylinder is not documented and it is impossible to compare follow-on inspections. In addition, it has been MMES practice to withhold the results of

previous inspections from inspectors in an attempt to judge the comparability of inspections. These practices make trending of cylinder condition very problematic.

Notwithstanding the limitations described above, the inspection program has developed some useful information. The program, however, is not being integrated with other efforts, further limiting its utility. The inspection data are not being used to design maintenance programs for specific cylinders; rather, it being lumped into broad categories that ignore the specific condition of a given cylinder. Personnel from the corrosion engineering effort have not yet been consulted as regards important parameters for their corrosion studies, thus this information is being gathered in a less than comprehensive manner.

Several thousand cylinders have extensive areas that are not accessible for visual inspection. This condition exists for a number of reasons, as discussed above. Since even the imperfect visual inspections performed to-date have identified important information, it would appear prudent to complete inspections of all surfaces on the cylinders. Present DOE plans do not complete the inspection of all surfaces of the cylinders in storage until somewhere around the year 2000 (plans are neither precise nor complete). Consistent with the need for further understanding of the risks involved in moving these cylinders, completing this inspection should be pursued in a timely manner.

Performance of the personnel conducting the inspections appears to have been inconsistent. The Board staff reviewed the inspection records of 56 cylinders chosen randomly at the three sites. The staff review indicates that inspection results from the initial inspection and subsequent reinspections are very dissimilar. Reviews performed by MMES have shown similar inconsistencies. This raises further questions concerning the efficacy of the inspection program and the need for more comprehensive and thorough training for personnel performing the inspections.

C. Cylinder Handling

1. Background/Summary

Poor handling of UF_6 cylinders has caused five of the seven identified cylinder breaches to date (*Investigation of Breached Depleted UF_6 Cylinders*⁹). It is typical at all three sites that cylinders are severely rusted, dented, and gouged. While some changes have been made in the procedures to minimize damage to new cylinders, the procedures still do not consider all potential consequences involved in moving deteriorated ones. Special procedures focused toward the task of relocating degraded cylinders from their current, substandard yards to new, engineered yards have yet to be developed. While procedural changes can limit new or additional damage to cylinders, some stacking improvements

previously rejected by MMES and DOE may need to be reconsidered to minimize future damage to cylinders.

3. Discussion

a. Handling Damage

Handling damage can be divided into two categories: surface coating and structural. While the most common damage is to the surface coating, damage resulting in a structural breach of the cylinder wall is of more immediate concern. The two major initiating events that have the potential to produce a structural breach are: (1) impacting cylinders against one another and (2) handling degraded cylinders.

The most common damage to the cylinders is the chipping of the surface coating. The coating is scraped off in the vicinity of the handling equipment and saddles. Corrosion initiates at these areas and can result in the large-scale blistering of paint currently seen in the storage yards.

The most probable cause of five of the seven breaches discovered is the lifting lug or stiffening ring of an adjacent cylinder impinging upon the breached cylinder. During testing at Paducah, it was determined that an impact adjacent to a welded stiffening ring may result in tearing of the cylinder wall (*Fracture Control of Steel UF₆ Cylinder*¹⁰). While only five cylinder breaches have been attributed to this mechanism, a large number of cylinders at all three facilities have such damage. Although modified handling procedures direct that the lugs be oriented to avoid impinging on adjacent cylinders, there will still be impact between the stiffening rings of one cylinder and the wall of another when an upper row cylinder is dropped into place. This situation has not been sufficiently examined as a potential cause of tearing of the cylinder wall, especially in older, deteriorated cylinders.

The cylinder handler itself removes paint on new cylinders as the claws scrape along the bottom until force is sufficient to support the weight (11 to 15 tons). Since the cylinder is supported only by the four tips of the claws, the potential to breach a deteriorated cylinder with this loading scheme warrants thorough structural analysis.

b. Handling Procedures and Practices

The current procedures are oriented toward the USEC processing of UF₆. Although they are labeled as critical lift procedures, they do not contain the elements of a critical lift as specified in the DOE *Hoisting and Rigging Manual*¹¹. This manual states that "a lift shall be designated a critical lift if collision, upset, or dropping could result in ... significant release of radioactive/other hazardous material or other undesirable conditions." Critical lift requirements include: the appointment of a

qualified person-in-charge of the lifting operation present at the lift site during the entire operation; a procedure which specifies equipment to be used by identification number and capacity; rigging sketches including lifting points on the cylinder, load vectors, and the method of attachment to the cylinder; and special instructions to operators including rigging precautions and safety measures. The procedures and rigging sketches are required to be approved by the responsible manager, and safety and quality assurance groups. A critical lift procedure also requires signers on the ground to prevent miscommunication with the stacker operator. The current procedures do not comply with the requirements in the DOE *Hoisting and Rigging Manual*.

The *Handling of UF₆ Cylinders*¹² procedure is being revised and was in draft form when reviewed by the Board staff. More precautions and limitations aimed at reducing cylinder damage are being incorporated. The precautions regarding lifting lug orientation reviewed, however, are contradictory. One instructs the operator to maintain the lugs horizontal, while a later precaution states "roll the cylinder until a lifting lug touches the side and chock the cylinder in place."

The current handling procedures are geared for production operations utilizing new cylinders. New procedures that would comply with the DOE *Hoisting and Rigging Manual* and cover the transfer of depleted UF₆ cylinders from current storage yards to the new engineered storage yards may need to be significantly different from past operations, due to the degraded condition of the cylinders. Safety analysis could determine whether these handling operations should be categorized as critical lifts.

The analysis required if UF₆ cylinder handling is designated a critical lift would have several benefits. Load vectors and lifting speeds would show the distribution of forces in the equipment so that rated capacities should not be exceeded. Typically, for this handling operation, a cylinder handler/stacker is used. The handler grabs the wall of the cylinder rather than pulling up from the lifting lugs. If designated a critical lift, the handler would be analyzed for cylinder stresses to ensure that a degraded cylinder would not be breached by the handler, or by incidental impacts during stacking. If the calculations determine that a cylinder handler operating normally may cause the postulated accident, the critical lift guidelines would require modifications such as alternate rigging operations, use of a crane, attachments, and new procedures.

The stacking operations observed did not comply fully with the instructions in the procedures. A distinct person in control of the handling operations could not be identified. The operator of the cylinder handler/stacker was seen to be performing actions contrary to the direction of the on ground spotter. In addition, comments from the handling supervisor regarding a misaligned saddle were overruled by the spotter. The lack of a clear person in charge increases the potential for an accident due to the lack of effective communication and control of the handling operation.

D. Safety Analyses

1. Summary

Safety analyses of the depleted UF₆ cylinders are incomplete and, therefore, do not provide DOE and its contractor reasonable assurance that operations can be accomplished without undue risk. A formal, systematic, and comprehensive examination of the facilities and processes, including storage, and on-site transportation, is not evident. Detailed evaluations of potential hazards and accidents associated with normal operation, deviations from normal processing, internally initiated events (e.g., fires), and externally initiated events (e.g., high winds, tornadoes, earthquakes) are missing.

Physical and administrative controls for hazards that could result in unacceptable consequences have, in some cases, been identified, but not implemented. In addition, the safety analyses do not incorporate results of corrosion studies or data collected during inspections, and do not address degradation of cylinder integrity over time.

2. Status of Safety Documentation

Safety documentation for the cylinder yards at K-25, Portsmouth, and Paducah are not in compliance with DOE Order 5480.23, *Nuclear Safety Analysis Reports*¹³. Implementation Plans were submitted to DOE Headquarters in January 1993, and the Portsmouth and Paducah plans were approved in June 1993. The K-25 implementation plan has yet to be approved by DOE and was one of several addressed in a memorandum from DOE Oak Ridge that caused MMES to stop efforts on Implementation Plans for DOE Orders 5480.21, 5480.22, and 5480.23. MMES has yet to produce the Bases for Interim Operation (BIOs) for K-25, Portsmouth, or Paducah. (Letter, K. Edwards to G. Draper¹⁴).

3. Adequacy of Safety Documentation

DOE Order 5480.23, *Nuclear Safety Analysis Reports*, defines safety analysis to be a documented process to: (a) provide systematic identification of hazards; (b) describe and analyze the adequacy of measures taken to eliminate, control, or mitigate identified hazards; and (c) analyze and evaluate potential accidents and their associated risks. It appears that the available safety and hazard analyses for the cylinders do not sufficiently address information considered necessary to adequately support an overall understanding of the facility operations as they pertain to safety.

Potentially hazardous environments and processes (such as open storage) and facility processes (such as handling or movement) that could have an effect on cylinder integrity, have not been evaluated as part of the safety analysis. For example, the impact and potential consequences of lifting a corrosion-degraded cylinder are not examined.

The accident analyses relating to UF_6 cylinder operations tend to disregard without rationale the need for detailed assessment by anticipating a low probability of occurrence of events such as: airplane crash/fire, fire in the cylinder yard, and earthquake and flood. A systematic identification and evaluation of hazards, and rationale for or against corrective actions are not identified. In addition, the existing safety analyses do not address the impact of the lack of capability to off-load breached cylinders at K-25. Assumptions of worst case cylinder conditions or incident scenarios have not considered localized accelerated corrosion effects.

A paper entitled *Investigation of Breached Depleted UF_6 Cylinders*¹⁵, presented at the Second International Conference on Uranium Hexafluoride Handling, proposed experimental effort directed at examining the effect of a hole near the top of the cylinder that remains undetected. Scenarios had been proposed that could lead to a steam-driven expulsion of contaminated liquid and HF from the cylinder due to accumulation of water in the vapor space (due to rain and condensation) and subsequent chemical reactions. Further examination of this potential accident would appear warranted, based on the information available to-date.

There are a number of other apparent inadequacies in of the safety analysis. There is no treatment of mechanical degradation caused by aging, brittle fracture, propagation of cracks, corrosion, or irradiation. Inspection criteria are not explicitly related to a safety analysis of cylinder integrity. Risks associated with cylinder movement are not analyzed, and environmental insult from uranium compounds exiting the cylinder yards has not yet been studied. Consequences of seismic events in the storage yards are not addressed. The use of preventive maintenance as a mitigative measure is not considered.

Oak Ridge National Laboratory (ORNL) has begun work (using previously collected data, risk assessment methods, and cylinder modeling techniques) to assess health risks related to release of UF_6 contaminants, gage the current corroded condition of the cylinders, and predict the probability of future breaches. The Board staff review of this preliminary work can be found in Appendices A and B.

E. Status of Breached Cylinders

Remediation of the four breached cylinders at K-25 is apparently being handled as a low priority task. Although the breached cylinders were discovered in late 1991 and early 1992, they still await shipment to Portsmouth or Paducah, where capability exists to off-load the contents. The *UF_6 Long-Term Cylinder Integrity Management Plan* originally scheduled obtaining Department of Transportation approval to transport one of the cylinders from K-25 by September of 1993, but the approval request has yet to be submitted by DOE. K-25 is therefore still, after four years, "maintaining" the hazards associated with storage of four incompletely patched cylinders.

The one breached cylinder at Paducah was off loaded in December 1994; the two at Portsmouth have been weld patched and are stored indoors pending completion of off load.

III. CONCLUSIONS

DOE has stored depleted UF_6 in transportation cylinders for more than 40 years and may continue to store them for an additional 30 years. The analysis of the adequacy of the existing cylinders for use as storage systems over this extended time period has not been systematic and has not addressed all the pertinent concerns. Specifically, the following areas need further assessment:

1. the potential for failure by accelerated corrosion mechanisms needs to be better characterized and then quantified;
2. the inspection program, used to characterize the condition of the cylinder population and monitor continued adequacy for storage, needs significant overhaul to achieve these purposes;
3. cylinder handling procedures need to be analyzed and then revised to incorporate precautions for handling potentially degraded cylinders; and
4. the safety analyses for the cylinder storage yards need to be upgraded to: include insights gained through the above reviews; investigate the unique problems presented by a breach in the vapor space; investigate the hazards associated with moving degraded cylinders; and incorporate structural analyses of the cylinders.

Appendices

Appendix A

Risk Assessment for UF₆ Cylinders in Storage

Background: Preliminary risk assessment performed and reported in ORNL *Risk Assessment*¹⁶ used EPA-approved risk assessment methodology.

Methodology: The contaminants of concern identified in the methodology are hydrogen fluoride (HF) and uranium compounds (the latter includes both toxicological and radiation effects). At the time of review, risks from uranium compounds had not been assessed. The dominant risk is toxicological in the case of low enriched UF₆. The potential receptors identified include the off-site population within a 50-mile radius, the on-site, non-involved workers, and the involved workers.

The release rates computed are 7.91×10^{-3} g/hr at Portsmouth and 9.06×10^{-3} g/hr at K-25 and Paducah, with the difference due to mean annual temperature differences between the sites. An estimate for the number of predicted cylinder breaches was made (see Appendix B) and incorporated into the release rates for each site from the present until the year 2020. The maximum release rate corresponds to a 30-year-old breach. ORNL computed worker risk, non-involved worker risk, and off-site population risk for UF₆ cylinder breaches.

Results: The results of the analysis indicate that the probable releases from cylinders based on the expected number of breaches and the expected growth of the holes have a significant margin of safety through the year 2020 with the worst case risk occurring in the G-yard at Paducah. The relative hazard was 0.287 (where 1.0 represents unacceptable risk).

Board Staff Observations: It does not appear that these estimates include larger breaches which may result from handling of cylinders with walls weakened by general or local corrosion. Similar calculations for the release of UF₆ in such cases have yet to be performed. These estimates also discount the more severe consequences of releases due to fire or seismic events.

A fire-induced release has been assumed to be very unlikely. Similarly, the probability of an aircraft crash has been estimated as incredible (2.8×10^{-7}) due to design and administrative constraints. The risk from earthquake damage to cylinders may be the least well-characterized, based on results of calculations by Battelle (*Structural Integrity Analysis of UF₆ Storage Cylinders*¹⁷). The case of a major solid UF₆ release during a heavy rain was evaluated with the following results: the concentration leaving the site is 1.2 mg-U/liter (where no health effects are expected below 5 mg-U/liter). In the analyzed event, the HF is assumed to dissolve in the rain as it is evolved.

Appendix B

Summary of Preliminary Structural Analyses for Uranium Hexafluoride Cylinders in Storage

In February 1995, ORNL briefed the Board staff on recent analyses involving UF₆ cylinders (Draft Report, *Prediction of External Corrosion for UF₆ Cylinders: Preliminary Results of an Empirical Method*⁸. ORNL is applying statistical and finite element methods to predict the number of cylinder failures that could be expected in the future. One analysis grouped existing data from ultrasonic tests and corrosion studies at the three sites, and used statistical methods in an attempt to estimate the number of breaches that could be expected in the yards in 1995, as well as by the year 2020. The results of these calculations predicted the number of cylinders that will fail the ANSI N14.1 specification for minimum wall thickness for normal processing and for transportation, as well as the number of breaches that could be expected. The preliminary indications from the analysis, which is still underway, is that 12 additional breached cylinders may currently exist elsewhere in the yards, and that the number could be as high as 200 additional breaches.

Other efforts briefed at the February 1995 meeting were structural analyses using finite element methods. The analyses attempt to determine stresses, due to corrosion or other damage-caused weaknesses, imparted on the cylinders during handling or as a result of patching breached cylinders. At the time of the February briefing, the ORNL personnel present were unable to provide clearly describe the assumptions and methods used in the analysis; additional information has since been provided in the October 1992 Battelle report entitled *Structural Integrity Analysis of UF₆ Cylinders*. This information is presently being evaluated.

These calculations of structural analysis of the ASTM A516 steel cylinders were performed by Battelle to determine the punching shear force requirements, the actual versus allowable stresses for normal stacking conditions, the minimum thickness for a 3-inch diameter thinned area, and the allowable loads for dynamic loading due to transport, lifting/stacking operations and seismic conditions. The analysis showed that, for the case of typical stacking conditions with the stiffening rings in contact with the cylinders, stresses are above the design stress, but below the allowable elastically-calculated local stress limit. For the case of lug-contact with a cylinder under static loading, the ASME allowable local stress would be exceeded for a thickness of 270 mils or less. Thus, lug-to-cylinder contact stresses would generally not be acceptable.

The Board staff is in the process of conducting a technical review of the analyses that have been provided to date, and have requested additional information, as it can be made available.

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