Monitoring of Corrosion in ORGDP Cylinder Yards

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INTRODUCTION

Uranium hexafluoride (UF_6) throughout the nuclear fuel cycle is handled and stored in cylinders which are designed, manufactured, and maintained in accordance with the ASME Boiler and Pressure Vessel Code for unfired pressure vessels (Section VIII). There are presently more than 40,000 of these cylinders within the DOE Oak Ridge Operations complex currently used for the storage of isotopically depleted material (process tailings).

These tails cylinders, in 10- and 14-ton sizes, are 48 inches in diameter and are constructed of mild steel. Most cylinder storage facilities are open areas adjacent to the enrichment plants where the cylinders are exposed to weather. Mild steel will corrode under these conditions, presenting the need for the monitoring of cylinders in storage to provide assurance that they have not deteriorated to the extent that they no longer meet wall thickness requirements for shipping and handling.

Cylinders used for transport of isotopically enriched materials are of heavier construction (5/8-inch wall construction rather than 5/16-inch) than these tails cylinders; they also see more activity than tails storage cylinders and are therefore subject to relatively frequent visual observation and cleaning, as well as periodic pressure testing during which potentially hazardous conditions may be detected and evaluated. Tails cylinders in storage are subjected routinely only to periodic inventory; no cylinder inspection is required until the cylinders are either emptied or transported (*ORO-651 1987*).

At one time, feed materials were transported exclusively in cylinders rated for 200 psi working pressure, the same design utilized for product (enriched) material. In frequent use in the fuel cycle, they too were subjected to periodic cleaning, inspection, and hydrostatic testing. Present practice, however, allows one-time use of a new 100 psi cylinder for UF_6 transport, after which it is used for tails storage at its destination. As a storage cylinder, it sees no further formal inspection. The cylinder yards are therefore occupied by three categories of storage cylinders:

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1. Obsolete feed cylinders rated at 200 psi working pressure with nominal 5/8-inch wall thickness.

2. Thin (5/16-inch) wall cylinders code-rated for 100 psi working pressure, designed and built as storage cylinders.

3. Thin wall cylinders built as one-time use feed cylinders, then diverted to tails storage at the receiving site. These cylinders were built to the same specifications as the storage cylinders in category 2.

Categories 2 and 3, the thin (5/16-inch) wall cylinders, are the initial focus of this corrosion work.

The mild steels used in UF_6 cylinder construction are pressure vessel grades of plate steel, covered originally by ASTM A285, then since 1978 by ASTM A516 standards. They undergo a general atmospheric corrosion attack; they are also subject to pitting or other localized damage under exposure conditions where moisture is maintained in contact with cylinder surfaces, and particularly where this moisture may be contaminated by chemical species which dissociate in solution to form high-conductivity electrolytes. These corrosion processes will eventually reduce wall thickness to the point where the cylinder contents cannot be safely removed by liquefaction but require sublimation emptying, a process both slow and costly. A cylinder with reduced wall strength due to corrosion would be more susceptible to handling damage during transport; damage to a cylinder during transport also involves potential environmental shock.

An extensive cylinder life study has been underway at the Paducah Gaseous Diffusion Plant to estimate the anticipated lifetime of storage cylinders (*Alderson*). Their data indicate that cylinders are generally expected to retain ASME Code qualification for at least another twenty years. The Oak Ridge work described in this paper supplements the Paducah study by examining conditions specific to the Oak Ridge cylinder yards and determining local differences in corrosion rate related to cylinder yard location and storage condition of individual cylinders.

A four-faceted program is underway in Oak Ridge. Initial objectives are to determine the current condition of cylinders in outside storage at ORGDP and mark those found to show marked deterioration. The program includes measuring corrosion rates to be anticipated in storage yards through preparation, deployment, and analysis of ASTM corrosion test coupons and commercial corrosion probes. It establishes and maintains a continuing inspection program of cylinders in storage, with statistically controlled measurements of wall thickness and records of corrosion activity. It further provides documentation through a complete data base to include cylinder manufacturing data, service history, corrosion observations, and location. Our work could be readily extended to any facility where cylinders are kept in storage for significant periods of time.

OAK RIDGE CYLINDER YARD CONDITIONS

Cylinder degradation is expected to take place primarily from exposure to the environment. Atmospheric corrosion of mild steel varies from 1 to 10 mils per year; UF_6 corrosion at the inside wall surface is expected to be less than 0.1 mil per year (*Fortune and Green 1965; Ritter; and Barger*).

Weathering attack depends on the presence of surface moisture; corrosion rate is therefore influenced markedly by relative humidity. Surface temperature will affect both the corrosion kinetics and the presence of surface moisture. Position of the cylinder yards with respect to plant emissions and plant operating parameters will influence attack rate. Air circulation and sunlight will also affect steel deterioration. Retention of moisture in contact with the steel surface, particularly where the moisture contains mineral salts, can promote localized attack or pitting corrosion where penetration rates can exceed general corrosion rates by a factor of 10 or more.

Oak Ridge rainfall varies in pH from about 3.7 to 5.2. The acidity of the rainfall has a highly localized character, even within an individual shower; however, not much rain is expected to fall outside the limits where significant acceleration of corrosion will occur (Fig. 1). Pitting due to particulate deposition is of more concern; scanning electron microscopy and energy-dispersive X-ray analysis have identified sulfur-bearing particles which have been deposited on the cylinder surfaces (Fig. 2).

Relative humidity in Oak Ridge is high; in the summer, exposed steel surfaces at ambient temperatures can be expected to be covered with a thin film of condensed moisture at least half the time. Lower cylinder walls where the metal is in contact with solid UF_6 retain this moisture film over longer periods of time and would be expected to suffer more corrosion damage.

Approximately 3,000 storage cylinders in the K-1066-G yard were moved to a new location, K-1066-K, in 1983-1984 (Fig. 3). Detailed observations were made on many of the cylinders at that time (*Kimmerly 1982; Ziehlke 1982*) revealing accelerated general attack and pitting in support areas shielded by wooden saddles on which the cylinders rested, and similarly accelerated corrosion in the head area of the skirted cylinders where the skirt accumulates moisture, rust, and dirt. Both of these areas showed pit depths of 60 mils superimposed on more general wall thinning that, in total, reduced wall thickness in several cases to below the minimum value required by ASME Code criteria for working pressure of 100 psi.

General wall thinning on the upper surfaces of those cylinders was estimated at the time of the move to be only about 35 mils, even though wind rose patterns measured at ORGDP (Fig. 3) indicate that for a significant fraction of time, cylinders located in the K-1006-G yard were downwind from the nearby steam plant. This amount of thinning is consistent with Paducah results (*Alderson*) which estimate less than 2 mils per year general attack rate.

Oak Ridge cylinder yard inspections are focused on areas which represent potential problem regions. Visual inspection of the storage cylinders is underway. Ultrasonic measurement equipment has been adapted for easy use in the yards, and field metallography techniques are being used to (a) determine the present status of stored cylinders, then (b) track the rate of deterioration. Cylinders identified as no longer conforming to code will be set aside for special handling. The wall thickness data, and any other pertinent observations (valve and plug conditions, damage) made during the projected periodic inspections, are being included in a computer data base.

A significant amount of data to be used as a guide for cylinder inspections is being obtained from the destructive evaluation (Fig. 4) of a Type P cylinder procured in 1951 from the Dallas Tank Company and fabricated of A285 steel. This cylinder was in continuous service from 1952 to 1985 when it was hydrostatically taken to failure as part of a cylinder rupture testing program (*Barlow and Ziehlke*). Ultrasonic measurements taken before cylinder sectioning showed a significant wall thinning in the lower region on the head area, as well as near the plug weld. The cylinder was then sectioned; examination of the head wall confirmed this thinning (Fig. 5). Figure 5 also compares the general appearance of the inner and outer wall surfaces, confirming that the major corrosion processes are exterior. Field metallography and ultrasonic measurements obtained from this cylinder before sectioning are being compared to laboratory characterization of the section cylinder. Similar data will be obtained from a Type 48Y cylinder bought in 1980 from Modern Welding Company and fabricated of A516 steel. These comparisons should confirm the validity of the field measurements to be taken in the cylinder.

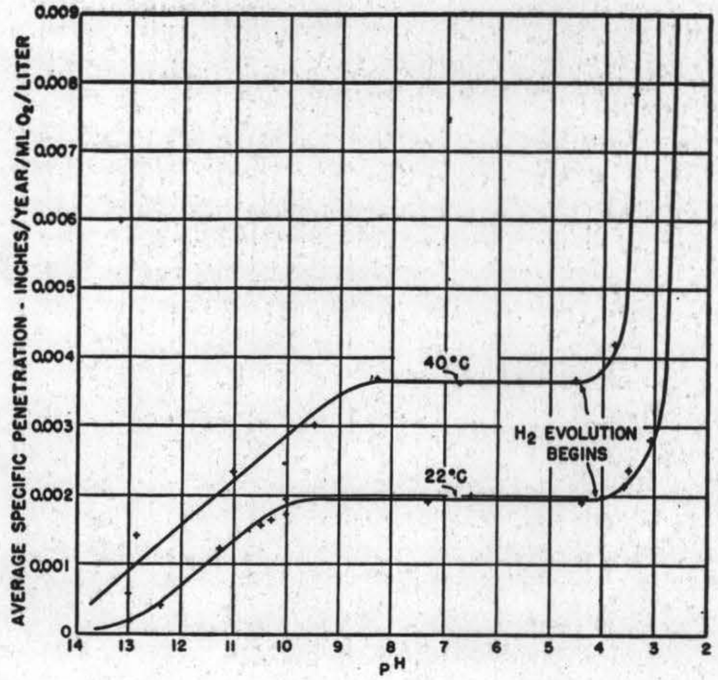


Fig. 1. Effect of pH on corrosion of mild steel (from Larrabee, C. P., "Atmospheric Corrosion of Iron," in *The Corrosion Handbook*, Uhlig, H. M., ed., John Wiley and Sons, Inc., New York, 1948). The pH of Oak Ridge rainfall varies from about 3.7 to 5.2, placing Oak Ridge corrosion rates in the plateau region of the curve.

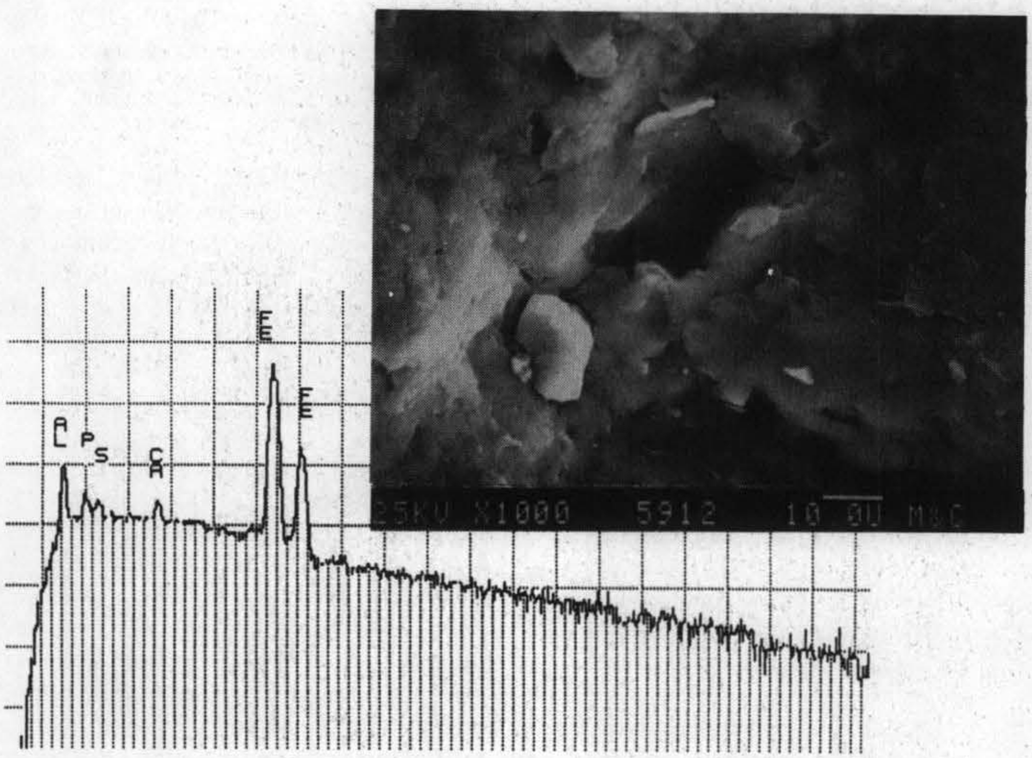


Fig. 2. Scanning electron microscopy and energy-dispersive X-ray analysis of tails cylinder surface particle. This particle contains sulfur; such particulates can initiate pitting corrosion.

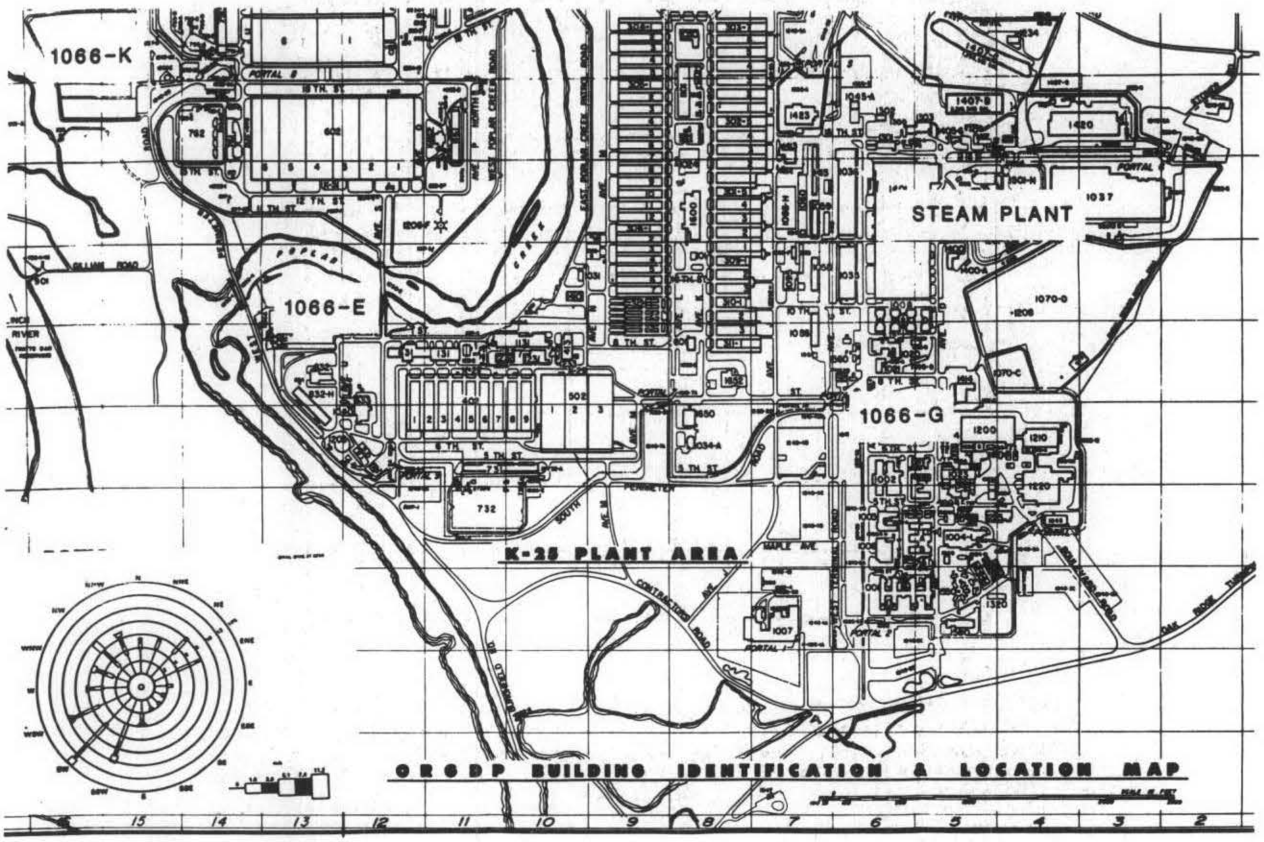


Fig. 3. Map of the Oak Ridge Gaseous Diffusion Plant, and wind rose data for the area. Approximately 3000 old tails cylinders were moved from the K-1066-G yard to the K-1066-K yard in 1983. Cylinders stored in the K-1066-E yard were fabricated after 1975. The most prominent wind in the area is from the southwest; however, night winds (second most prominent) are primarily from the northeast. The old K-1066-G cylinder yard was generally downwind from the steam plant during the evening hours.

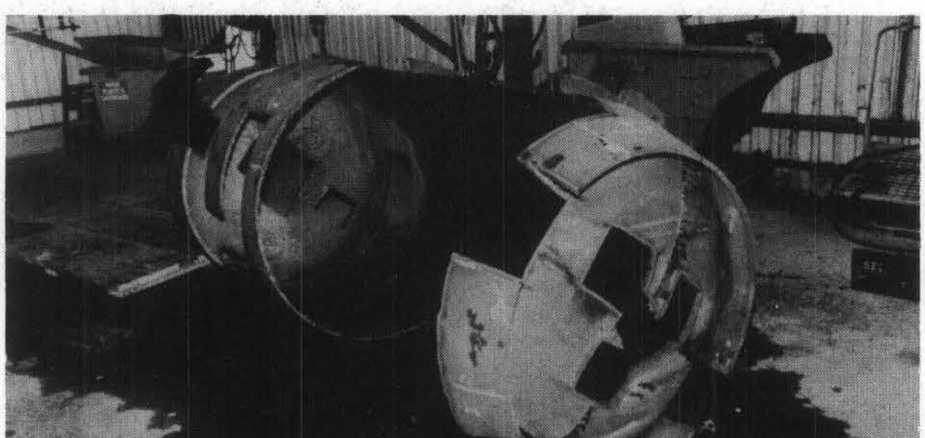
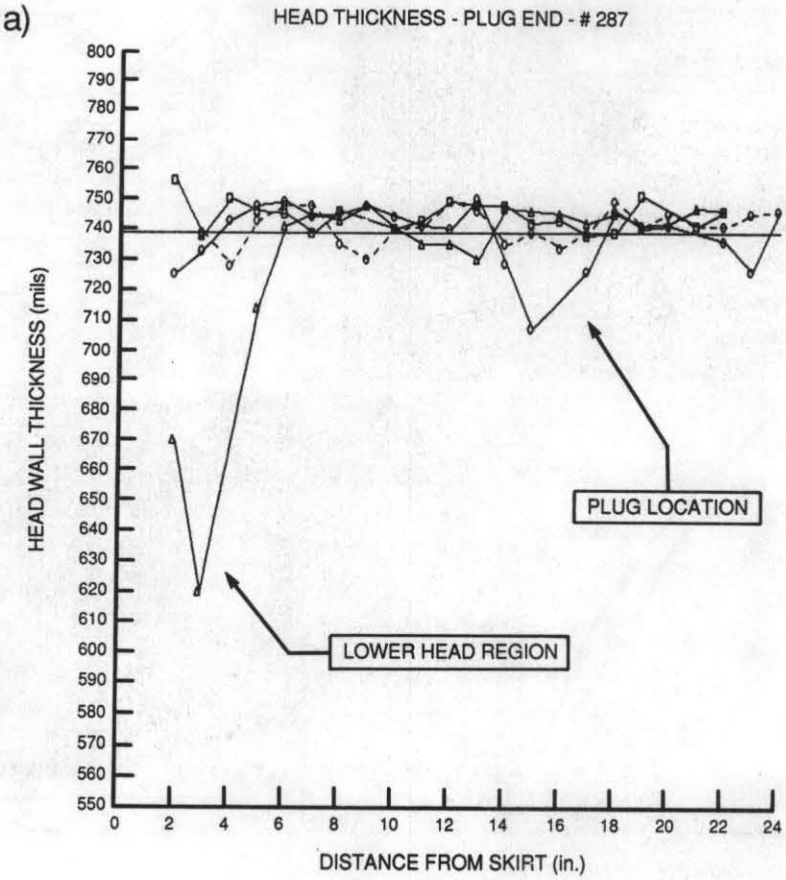


Fig. 4. Sectioning of cylinder 287. Field measurements were made on regions of this cylinder before sectioning; these will be confirmed through laboratory examination of samples cut from the same regions. Coupons cut from this cylinder will be placed in the cylinder yards.

a)



b)

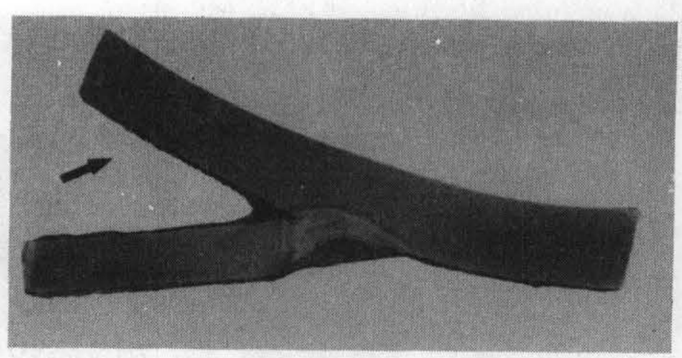


Fig. 5. (a) Field ultrasonic measurements taken across head region of cylinder 287. Considerable thinning is observed in the lower head region and near the plug weld. (b) Section cut from the lower head region of cylinder 287. Corrosion is proceeding primarily from the outside; the interior surface appears smooth and undamaged. The thinning seen in Fig. 5(a) is confirmed after sectioning; optical thickness measurements in this region range from 0.75 to 0.66 in. Original thickness of this cylinder head was approximately 3/4 in.

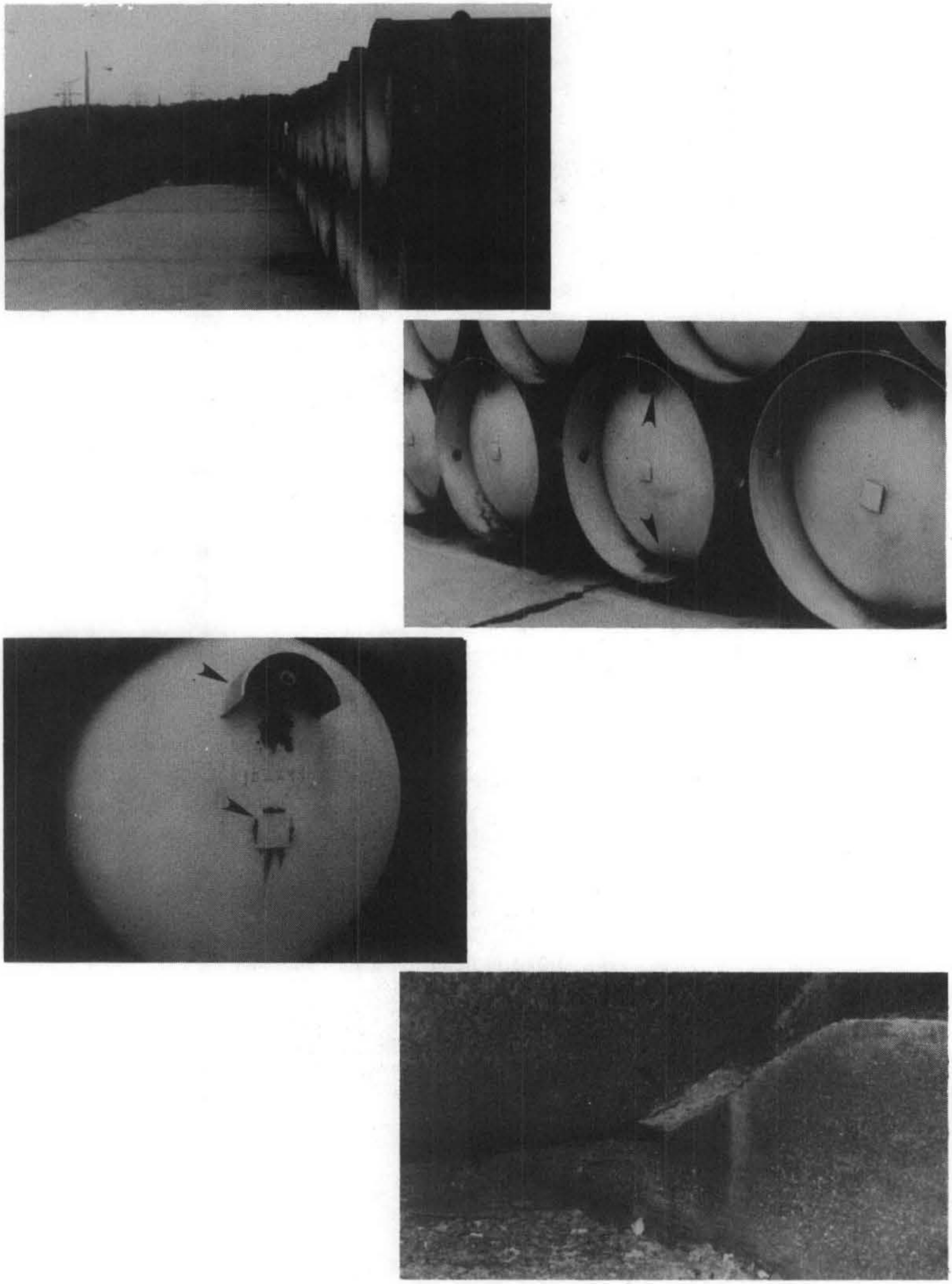


Fig. 6. Cylinders in storage at K-1066-K cylinder yard. Regions where accelerated corrosion attack might be anticipated are (a) lower head region, (b) areas in which dissimilar metals are in contract, (c) weld regions, and (d) areas where the cylinders rest on saddles. These regions are indicated with arrows.

DOCUMENTATION

A data base has been established following the guidelines set forth in ANSI/ASME NQA-1 *Basic Requirement No. 17 - Quality Assurance Records*. Data is entered in commercial dBase III spreadsheet format; and the data base is to be maintained using IBM-compatible personal computers. Cylinder manufacturing data, service history, and inspection records are included; records are flagged for cylinders identified through either inspection or history as requiring special handling.

SUMMARY

Tails cylinders in outside storage at ORGDP are corroding at rates which give a finite storage life as ASME code-qualified pressure vessels. General corrosion rates are estimated at less than 2 mils per year, yielding a service lifetime anticipated at more than 50 years; however, cylinder areas where accelerated attack might be expected have been identified through (a) cylinder yard history and (b) examination of cylinders which have seen extended service for special attention.

Field ultrasonic and metallography techniques have been developed for cylinder examination; periodic inspection (based on statistical sampling) of the cylinder yards at ORGDP is planned using these techniques. A corrosion monitoring program for the Oak Ridge yards, based on ASTM procedures and using environmental corrosion test coupons, is underway. Documentation of cylinder condition will be provided through an IBM PC-based records system, using commercial software, and conforming to ANSI/ASME NQA-1 standards. The program is intended to assure that corrosion of these cylinders at ORGDP never reaches the point where the cylinders cannot be safely transported or pressurized for transfer.

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