SLAC-TN-64-11
G. C. Rogers
January 1964

ESTIMATION OF CORROSION ON ALUMINUM PIPE BELLOWS IN ACCELERATOR HOUSING FROM RADIATION-INDUCED REACTIONS IN THE HOUSING ATMOSPHERE

The operation of the accelerator will produce a variety of radiation products within the accelerator housing structure. Calculations of the effect of the radiation on the housing atmosphere and on the cooling water were presented by H. DeStaebler.[1] It is the purpose here to examine the chemical corrosion problem resulting from the action of the noxious chemicals formed on the aluminum bellows connecting the 40-foot lengths of aluminum support and alignment pipe. As the bellows is only 0.030-inch-thick, it would appear to be the most vulnerable single item inside the housing from the standpoint of chemical corrosion.

I. Operating Conditions Within the Accelerator Housing

Present plans are to operate the accelerator with no air circulation through the housing. This will eliminate the problem of dealing with the radioactive materials (chiefly 10-minute N^{13} and 2-minute O^{15}). The active chemicals produced by the radiation will consist essentially of ozone and a mixture of nitrogen oxides. With no air replacement, the active chemicals produced will build up to some maximum equilibrium level at which the decomposition and reaction rate will equal the rate of formation. At present the equilibrium level is unknown, and there is no good method of estimating what it will be; however, the rate of formation of chemically active molecules was estimated by DeStaebler to be 9.8×10^{23} molecules per day, and at equilibrium the total amount formed will react or decompose.

As there are no provisions for maintaining completely dry air in the housing, it is assumed that the dew point of the air will approximate the lowest surface temperature in the housing, that of the concrete walls. Assuming an air temperature of about 105°F and a wall temperature of about 90°F, the air will have a relative humidity of 55 to 60% and there will presumably be a thin film of moisture on the walls. As long as any significant number of water molecules is available, the nitrogen oxides formed will eventually convert to nitric acid[2,3] in the ratio of one molecule of HNO_3 per atom of nitrogen in the oxides. Therefore, in the housing as a whole, it can be expected that about 8×10^{23} molecules of HNO_3 per day will be formed. (This assumes that about 20% of the chemicals formed will be ozone and 80% nitrogen oxides.)

II. Corrosion Inside the Accelerator Housing

The HNO_3 and O_3 (ozone) formed in the housing will react with the housing walls and the accelerator components. It would appear that most of the HNO_3 formed would react with the concrete walls; they would be expected to have a thin film of water on the surface, and, being at a lower temperature, would tend to condense the HNO_3 vapor. However, the HNO_3 can also attack both copper and aluminum.

Consider the aluminum bellows, the thinnest material in the housing, as the item most likely to show any pitting failure. Ozone should not affect the aluminum, but dilute HNO_3 will react with aluminum to form aluminum ions and ammonium nitrate, as shown in the equation

$$8\ Al + 30\ H^+ + 6\ NO_3^- \rightarrow 8\ Al^{+++} + 3\ NH_4^+ + 3\ NO_3 + 9\ H_2O$$

An estimate of the time necessary for pits to be formed through the aluminum can be made by adopting the following simplifying assumptions: the HNO_3 is distributed uniformly throughout the housing; the attack of the HNO_3 will be in direct proportion to the total exposed area; and the pitting rate will be about ten times faster than the uniform surface attack rate.

Consider a 40-foot length of the housing:

Bellows surface $= 2\pi \times \frac{3}{12} = 1.57\ ft^2 = 1460\ cm^2$

Aluminum pipe surface $= 2\pi \times 40 = 251\ ft^2$

Tunnel walls surface $= 2 \times 40 \times 10 + 2 \times 40 \times 11 = 1680\ ft^2$

Other surfaces (mostly Cu) allow $\approx 67\ ft^2$

Total surface of 40-foot length $\approx 2000\ ft^2$

Total number of HNO_3 molecules available to react with each aluminum bellows:

$$\frac{(8 \times 10^{23})(1.6)(40)}{(2000)(10,000)} = 2.5 \times 10^{18} \text{ molecules } HNO_3\text{/day/bellows}$$

or

$$\frac{2.5 \times 10^{18}}{1460} = 1.7 \times 10^{15} \text{ molecules/day/cm}^2$$

Atoms of Al in 1 cm^2 of bellows:

Thickness = 0.030 inch; sp. gr. = 2.7

$$\text{Weight in grams} = (0.030)(2.54)(1)^2\,(2.7) = 0.206$$

$$\text{Atoms Al} = \frac{(0.206)}{(27)}\,6 \times 10^{23} = 4.6 \times 10^{21}$$

As a pit hole is assumed to form at the 10% reaction point and 8 atoms of Al react with 6 molecules of HNO_3, the time for a pit hole to form will be:

$$\frac{(4.6 \times 10^{21})(6)}{(10)(8)(1.7 \times 10^{15})} = 2 \times 10^5 \text{ days}$$

As this is roughly 550 years, it would appear that direct corrosion of the metal surfaces in the housing from radiation-formed chemicals will not be a pressing problem. It should be remembered, however, that any calculations of this nature are no better than the assumptions on which they are based, and other effects may be of great importance. It will be possible to make corrosion tests on copper and aluminum samples by installing in the "18th" (water return) penetration in one of the sectors a small test assembly, which could be withdrawn during operations for examinations. It is recommended that such corrosion tests be made.

LIST OF REFERENCES

1. H. DeStaebler, "Electron-photon flux in the tunnel when the machine is on: Applications to chemically active air and to active cooling water," TN-62-80, Stanford Linear Accelerator Center, Stanford University, Stanford, California (December 1962).

2. A. R. Jones, "Radiation-induced reactions in the H_2-O_2-H_2O system," Radiation Research 10, 655 (1959).

3. P. Harteck and S. Dondes, "The kinetic radiation equilibrium of air," J. Phys. Chem. 63, 956 (1959).