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**CORROSION OF EXHAUST AND FILTRATION EQUIPMENT  
IN A RADIOACTIVE WASTE INCINERATOR**

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**ABSTRACT**

Condensation in the exhaust gas system of an incinerator burning low activity radioactive wastes led to numerous corrosion developments and rapid failure of the discharge filters. The problem was traced to insufficient reheat of the exhaust gases following scrubbing. Rust particulate and moisture loaded the filters, leading to water accumulation, chloride cracking of the filter housings, and plugging and tearing of the filter media itself. To mitigate the problem, the exhaust gas temperature was increased, thermal insulation was installed on the ductwork, and the interiors of the ducts and new filter housings were lined with a protective coating.

Keywords: corrosive exhaust gases, chloride cracking, protective coatings

**BACKGROUND**

The off-gas system for the Consolidated Incinerator Facility (CIF) at the U.S. Department of Energy Savannah River Site consists of a quench and wash, separator, reheater, filters, and stack discharge (Figure 1). The cyclone separator and the ductwork upstream of the reheater are FRP. Approximately 45 m of carbon steel duct are downstream of the reheater and ahead of the high efficiency particulate air (HEPA) filters. Fans controlling the flow are downstream of the stainless steel filter housings.

Water accumulation occurred ahead of the filter housings, on the inlet end and within the housings. Wire wool prefilters were breaking up due to the exposure and the HEPA elements were failing due to the water load<sup>1</sup>. All the filter media were discolored as a result of fine rust

particulate being carried by the exhaust gases and possible degradation products from fiberglass and other composite components.

Failure analysis of the off gas prefilters (Figure 2) indicated that corrosion concerns probably existed throughout the system. After blow holes occurred in the HEPA elements, an expanded inspection of the entire system was performed to determine the overall extent of damage.

The wet discharge contained 6000 ppm chloride ion and 3000 ppm sulfate ion, both of which can be very destructive. Uniform corrosion of the carbon steel ductwork and pitting and stress cracking of stainless steel components were observed. The airborne rust particles and moisture caused rapid plugging of HEPA filter elements, thereby reducing efficiency of the entire operation and increasing maintenance requirements significantly.

The HEPA filter housings are assemblies of stainless steel boxes (Figure 3). Inlet and outlet ports and filter access doors have EPDM elastomer seals. The entire enclosure is insulated on the exterior and covered with a welded sheet metal skin - essentially a sealed metal wrap for protection against outdoor weather conditions. This may provide some measure of secondary containment as well, though the skin is not intended to be a pressure seal. The assembled housing is pressure tested at the factory.

Results of close inspections of the HEPA filter housings and other parts of the system are described. In addition, the types of repairs necessitated by the observed damage and recommendations for modifications in the design are discussed.

## OBSERVATIONS

### Filters

The prefilter material is a non-woven pad of fine stainless steel wire (0.1 mm) supported on a woven net-like structure of fiberglass cord. The HEPA filter is a non-woven paper material. A dark brown fine particle deposit was occurring on both media. The downstream side of the HEPA paper was relatively clean.

The filters failed or had been penetrated. Large holes occurred randomly in the wire pad of the prefilter. A large hole developed near the center of the area on the HEPA filter element, as a result of plugging and overloading of the membrane caused by exhaust fan suction.

### Prefilter

Pieces of metal wire from the prefilter were studied optically and in the scanning electron microscope (SEM). Only small remnants of the wire trapped within the woven fiberglass support structure were obtained. The pieces were short, < 0.3 to 5 cm., and the ends were corroded and broken. Chloride salts, silicates and rust were adhered to all surfaces (Figure 4). The deposits were easily dislodged, exposing clean metal. Some wire ends appeared to be cut, thus pre-existing the corrosion. However, the short lengths generally resulted from break-up of corroded, initially longer wire. Transverse chatter marks and long axial scratches associated

with original wire drawing were visible on the surfaces. Elemental x-ray analysis confirmed the wire was Type 304 stainless steel.

Pitting was the principal reason for failure of the prefilter. Pitting and possibly stress cracking of the wire would be expected based on the wet gas and high chloride content. Scattered large round bottom pits were seen. Wire break up resulted from pits growing across the wire or from fracturing through the reduced cross section due to the pits.

It was plausible that corrosion was occurring on the filter chamber walls, on the internal support structure for the filter, and everywhere else within the off-gas ductwork. The damage led to investigation of adequacy of the quench and scrubber systems, cyclone separator, reheater and general insulation.

#### HEPA Filter

The deposit on the HEPA filter was the same as on the prefilter, with about 5% iron oxide. A thick build up on the flat entry surface decreased porosity and movement through the filter, leading to eventual plugging. The accompanying increase in force at the entry face caused maximum deflection at center and breakthrough of the paper membrane.

#### Ductwork

Ultrasonic thickness measurements of the 30 in. (76 cm) carbon steel duct indicated that metal loss was uniform and not excessive. Thickness was 0.126 in. (3.2 mm) for the 10-gage (standard steel gage) material, nominally 3.4 mm thick. Mild flaky rust could be easily delaminated or separated at the inside wall, a result of exposure to the hot moist air environment.

The interior was studied with a video camera. Uniform surface rust, some loose scale, and scattered traces of a greenish/yellow residue were observed, the latter along the invert and at "high water marks" near the filter end. The water levels reached 7.5 cm above bottom. There was no evidence of non-uniform or localized attack or deterioration. The particulate oxides trapped at the filters had originated on these steel surfaces. Though only mild attack had occurred, the steel corrosion rate for the environment could exceed 25 mm/y. As a result, a protective coating (PLASITE<sup>®</sup> 4310<sup>(1)</sup> vinyl ester) was recommended to isolate the steel from the acid conditions. Abrasive blasting to white metal was specified for the interior and the duct was disassembled for this purpose (Figure 5). Several coats of the vinyl ester material were applied to develop a specified 40-mil (1 mm) final protective coating.

#### HEPA Housing - Interior

Dye penetrant examination of the interiors of the HEPA filter housings revealed large cracks on the prefilter access door seal area (Figure 6), and in heat affected zones of tack welds joining

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<sup>(1)</sup>PLASITE<sup>®</sup> is a registered trade name of Carboline Co.

interior walls to the floor (Figure 7). The cracks had the appearance expected for chloride stress corrosion. Metallurgical confirmation was not performed. All the cracks were at high residual stress locations, due to severe cold working or welding. The cracks were also at locations that effectively had been at times immersed in off-gas condensate.

#### HEPA Housing - Exterior

Individual pressure tests were conducted on each of the three HEPA filter housings. The tests revealed leaks in all three. Both the primary enclosures and the outside (secondary) skins were penetrated. One large leak was found beneath the floor at a location between the filter position and the adjacent upstream section.

To investigate the leak, a 30 cm. length of exterior support channel (outside the skin) at the leak location was removed, and a window was cut into the skin (total area ~900 cm<sup>2</sup>). Pressure retest confirmed leakage through the newly exposed floor at the window. A section of the framework for adjacent boxes in the primary container immediately above the cut channel was removed for study (Figure 8). The section had a T-configuration and included portions of structural and seal welds that join the boxes.

The portion of the external primary bottom area visible in the cut window had rust stains at several places. Penetrant testing revealed fine cracking at the stains. Several long linear indications were found on the floor along the main leg of the specimen T-section.

The interior floor in this vicinity was also penetrant tested. The fine cracks found on the exterior underside were matched with similar fine cracking on the inside floor of the chamber at this location. The long linear indications on the exterior bottom also penetrated fully to the inside floor and were identified as cracks.

#### HEPA Housing – Doors

During pressure testing, leaks were noted at several exterior tack welds on inlet port flanges. A full seal weld exists on the interior at this site, so pressure boundary failures had occurred. Cracks at the tack welds penetrated to the interior.

Cracks were also noted at the discharge port on one of the housings. An attempt to weld a patch over the affected area led to crack growth beyond the patch, a phenomenon often seen with chloride stress corrosion cracking. The extensive cracking precluded simple repair of the HEPA filter vessels.

#### Laboratory Results

The T-section from the bottom of the filter housing was examined metallographically. A photograph of the section is shown in Figure 9 (compare Figure 8). When in place, the two opposing legs of the T may be seal welded to the exterior skin. In this particular sample, one of the legs was only tack welded to the skin. One edge of the exterior channel at the location was seal welded to the skin but not to the leg of the T. In addition, the channel was only tacked to the

opposite leg, so an open path existed around the channel within the annular insulation space. Chloride stress cracking existed on the interior floor at the same general location, explaining the inability to hold pressure in the HEPA filter housing.

The crevice formed by the sides making the vertical leg of the T-section was opened by bending apart the contacting sides. Staining existed within the crevice, but no loss of material was evident.

## DISCUSSION

The exhaust gases are spray quenched and scrubbed, forced through mechanical solids and mist separators, and reheated before filtering. Halides and sulfates in the gas were not sufficiently eliminated before the reheat.

The long passage following reheat allowed the gases to cool in the duct. Misting developed, with acidic vapors leading to condensation and rusting of the steel. Rust dust and moisture loaded the filters and further aggravated the condensation process at the filter entry, leading to pitting of the steel and cracking of the stainless steel. It appeared that air in-leakage at door access sites on the housing led to localized cooling, condensation and corrosion under seals at these sites.

Note that incinerator operation is possible even with the penetrations in the pressure boundary. The off-gas system runs at negative pressure, and under normal operating conditions only in-leakage of air can occur upstream of the fans.

The low pH excursions at the scrubber and quench together with the chlorides are apparently responsible for the corrosion observed throughout the off-gas system. It was evident that cracking was very extensive and containment was breached at the filter housings. Because of the internal complexity of these structures, repair was not possible and replacement was directed. Improved resistance to chloride corrosion by use of different materials of construction or protective coatings was needed.

The new stainless steel HEPA filter housings have the interior lined with the same PLASITE<sup>®</sup> vinyl ester coating used on the ductwork. The coating provides the needed isolation from the chlorides. Alternate alloys that were considered for housing included AL6XN, 20Cb-3, C 276, and G 30. All are more resistant to chloride effects than Type 304L austenitic stainless steel, but fabrication costs are much higher, which precluded their use.

In practice, operation had been with two of the filters active and the third on standby. This allowed condensation to accumulate at the cold unused unit. Continuous draining of condensation is now provided at the housings, so a build up will no longer occur. However, it is desirable to eliminate the standby operation altogether. It was recommended that the three housings be run simultaneously and continuously. For changing filters, flow can be interrupted through one housing at a time, thus allowing the other two units to continue operating. The protective coating on the duct interior will eliminate steel corrosion and generation of rust particles which plagued earlier filter operations.

To further improve exhaust system operation, it was necessary to retain the higher gas temperature longer and to avoid water drop out ahead of the filters. For this purpose, the large duct was wrapped with fiberglass insulation for its entire length. The filter housings have 8-pound density mineral wool thermal insulation applied.

## RECOMMENDATIONS

After start up of the renovated incinerator exhaust system, it was suggested that the reheaters be set for maximum heat output and that fan speed be slowed to reduce the flow rate. It was anticipated that the rate could be controlled and this would eliminate misting and water formation, and lead to improvement in HEPA filter performance and life.

It was also recommended that the prefilter material be changed to an alloy having more resistance to chloride attack. Even if misting is eliminated, there will be a tendency to condense during maintenance shutdowns and standby periods, leading to exposure of the fine wire in the pads to corrosive solutions.

## ACKNOWLEDGEMENTS

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Figure 1. SRS Consolidated Incinerator Facility. The stack and portions of the off gas ducts are evident.

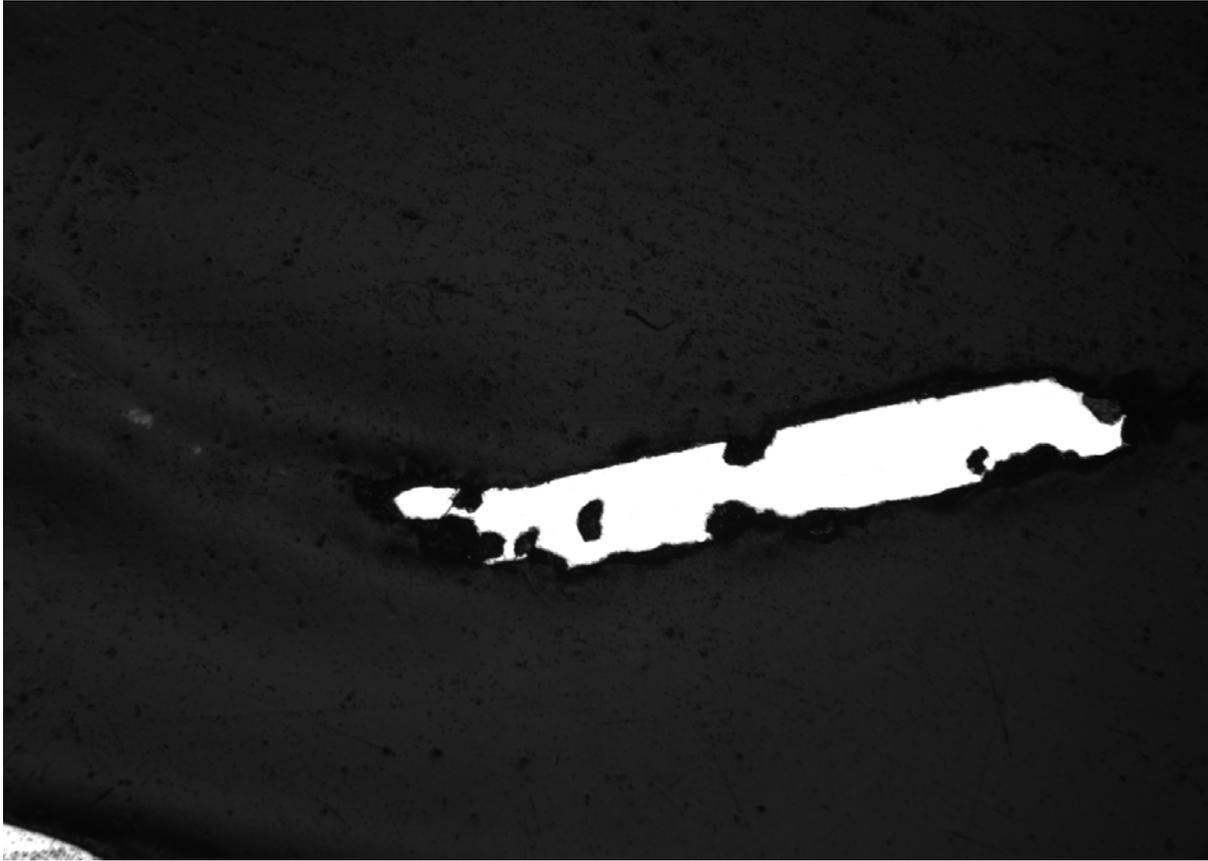


Figure 2. Piece of HEPA prefilter wire (0.1 mm). The stainless steel in the wire wool filter pitted and broke up as a result of the exposure. Magnification, ~160x.

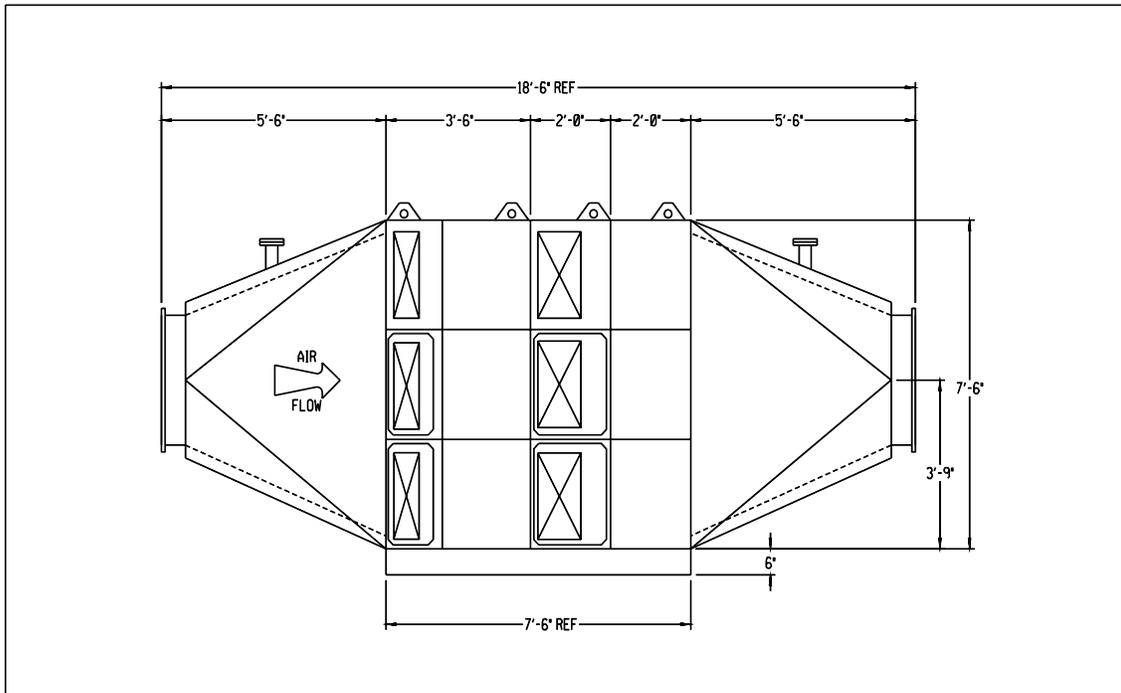


Figure 3. Sketch of a HEPA filter housing for the incinerator exhaust gas discharge system.

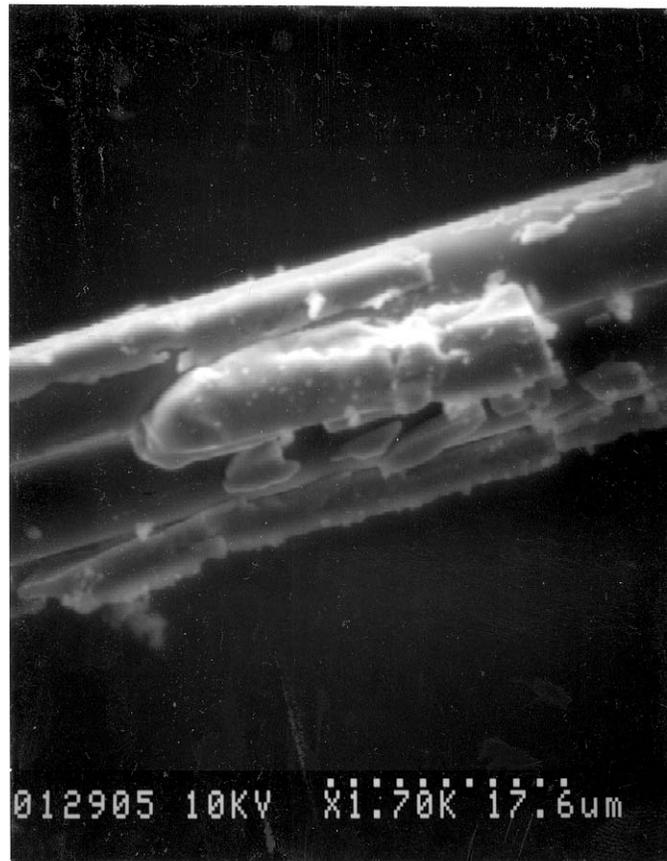


Figure 4. Deposits on pieces of three prefilter wires.  
Analysis of the deposits showed KCl, NaCl,  
Fe-O, and Na-Al-silicates.



Figure 5. Sections of steel exhaust duct being prepared for interior lining with a vinyl ester resin. HEPA filter housings in the background were replaced with similarly coated housings.



Figure 6. HEPA filter access port on housing, with major cracks on seal surfaces.<sup>1</sup>



Figure 7. Crack (arrow) on floor, inlet side of filter housing. Location is at a tack weld.<sup>1</sup>

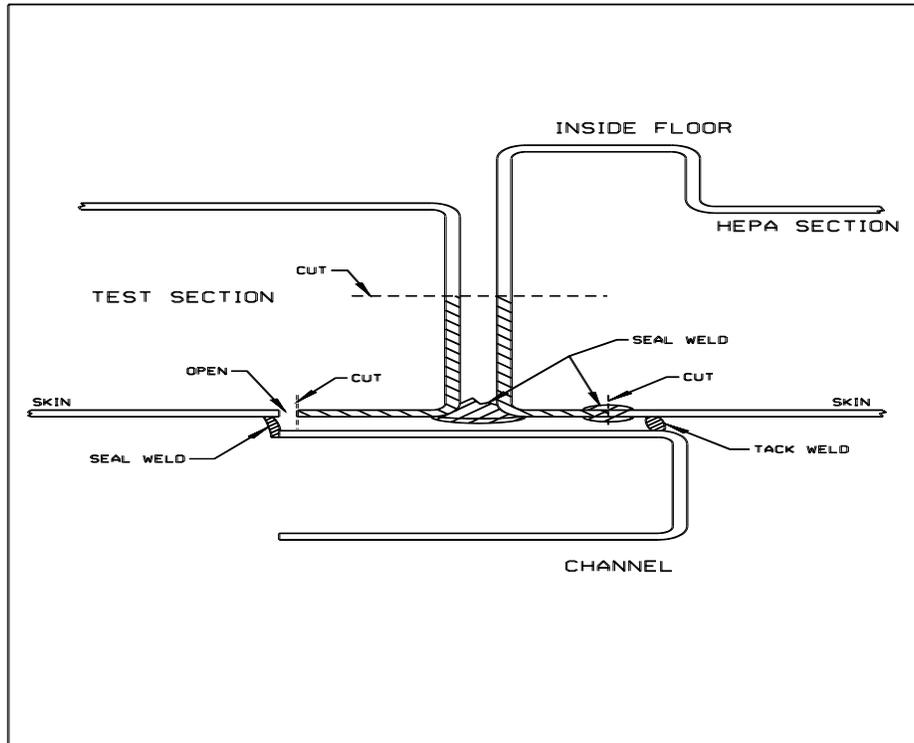


Figure 8. Sketch illustrating a junction between adjacent box sections in an assembled HEPA filter housing. The sample T-section removed for metallographic study is indicated. The open leak path shown is normally included closed by the “seal weld” to the outer supporting channel.

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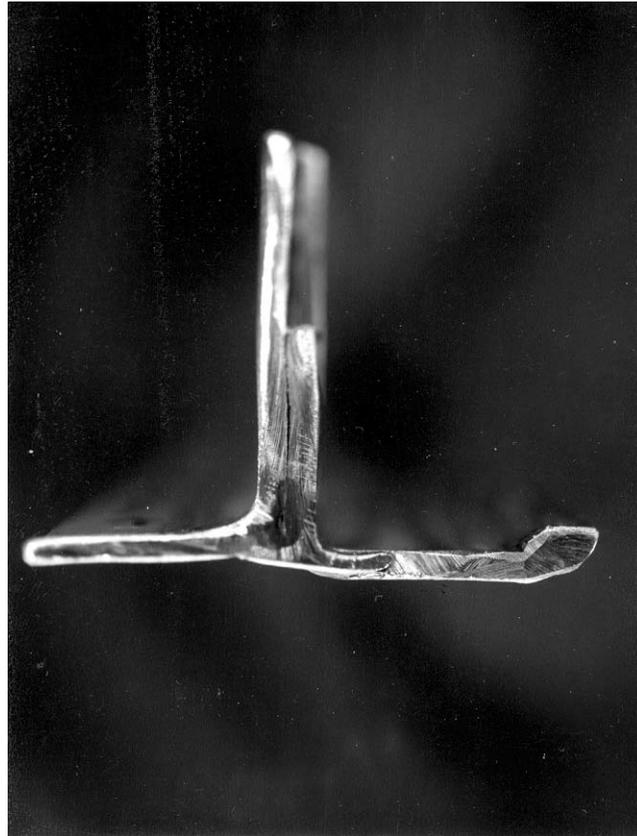


Figure 9. T-section removed from HEPA filter housing at a leak site. Absence of a seal weld between the outer skin and the angle on the left provided one part of the leak path. Magnification is ~ 2 X. The crack on the interior floor (Figure 7) penetrated the floor plate and was the other part of the leak path.

## LIST OF FIGURES

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