MANAGING TUBE METAL WASTAGE IN RDF-FIRED BOILERS AT ELK RIVER STATION

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NOMENCLATURE

RDF = refuse derived fuel
MSW = municipal solid waste
UT = ultrasonic thickness
esf = extended square feet (exposed tube surface area)

ABSTRACT

United Power Association's (UPA) three boilers at the Elk River Station were modified in 1988–1989 to fire RDF. In the first 2 years of RDF operation, excessive water wall tube wastage was experienced, causing forced outages and necessitating extensive maintenance on the boilers.

This paper discusses the phenomena of accelerated tube metal wastage when firing RDF and the Elk River Station's efforts to monitor and control it.

BACKGROUND

United Power Association's Elk River Station consists of Units 1 and 2 built in 1951 and Unit 3 built in 1959. Units 1 and 2 were originally built to fire coal on a stoker grate or natural gas. Unit 3 was designed to fire pulverized coal or natural gas. The Station was converted to also fire fuel oil in all three units in the mid-1970s.

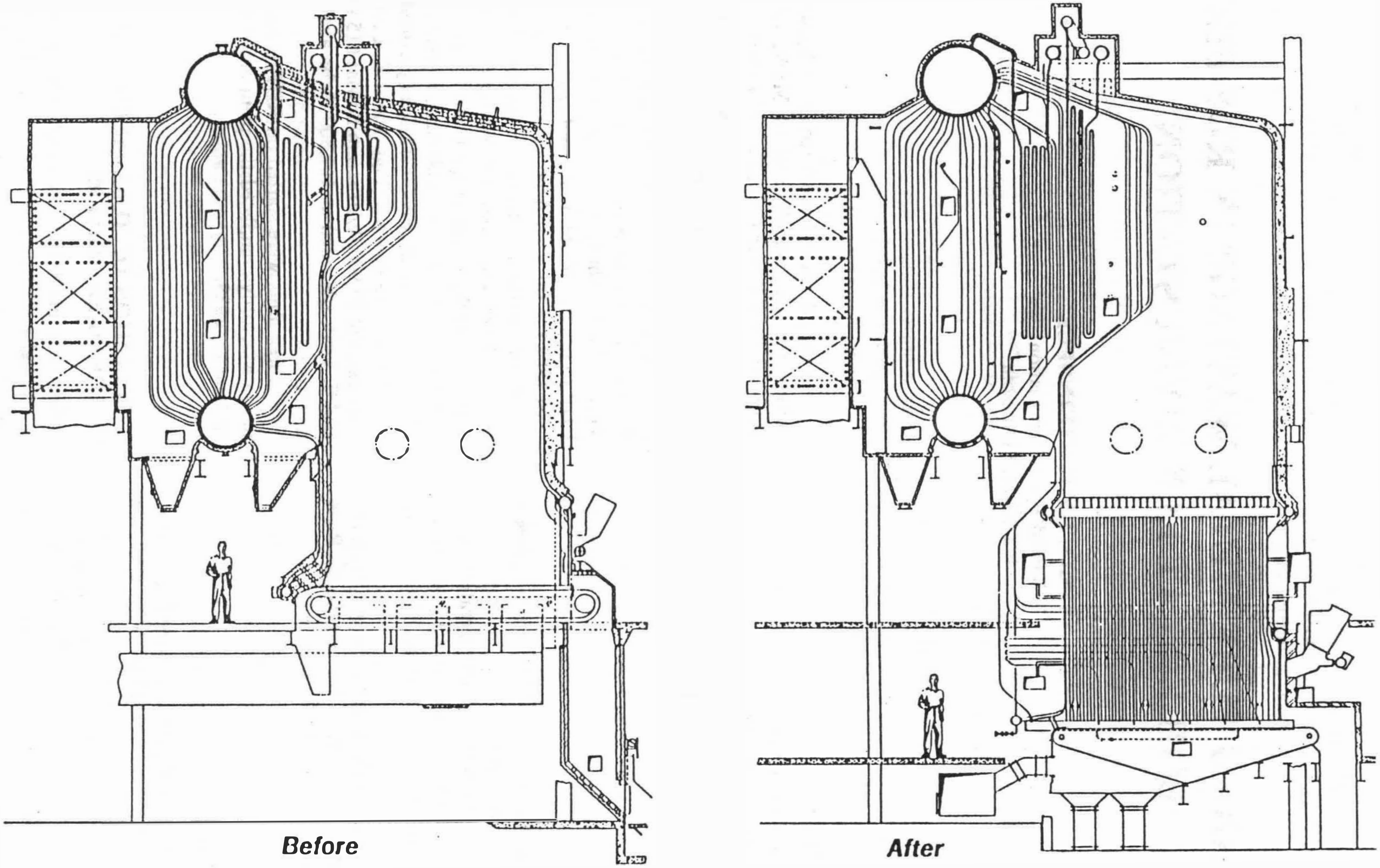
With the advent of landfill reduction legislation requiring the alternate disposal of MSW, UPA and Northern State Power Company (NSP) formed a joint venture to process, burn and generate electricity from the waste. NSP constructed and operates the RDF processing facility where the MSW is received and RDF produced. UPA modified and operates the Elk River Station. The project is designed to receive 1500 tons daily of MSW which is processed into 1050 tons of RDF to produce about 31 MW of electricity.

In 1988 the three UPA boilers, as well as much of the rest of the plant, underwent major modifications to burn the RDF. Each unit was redesigned by Babcock & Wilcox (B&W) and new superheaters, stokers, Unit 3 economizer, air ducts and baffle changes were installed. The furnaces volumes were increased by extending the lower furnace water walls (Figs. 1 and 2). Units 1 and 2 are rated at 87,900 lb/hr steam flow at 615 psig and 750° F. Unit 3 is rated at 167,800 lb/hr at the same conditions.

All three units were started on RDF in early 1989 and satisfactorily completed the plant acceptance test on June 27, 1989.

DESCRIPTION OF TUBE METAL WASTAGE IN RDF-FIRED BOILERS

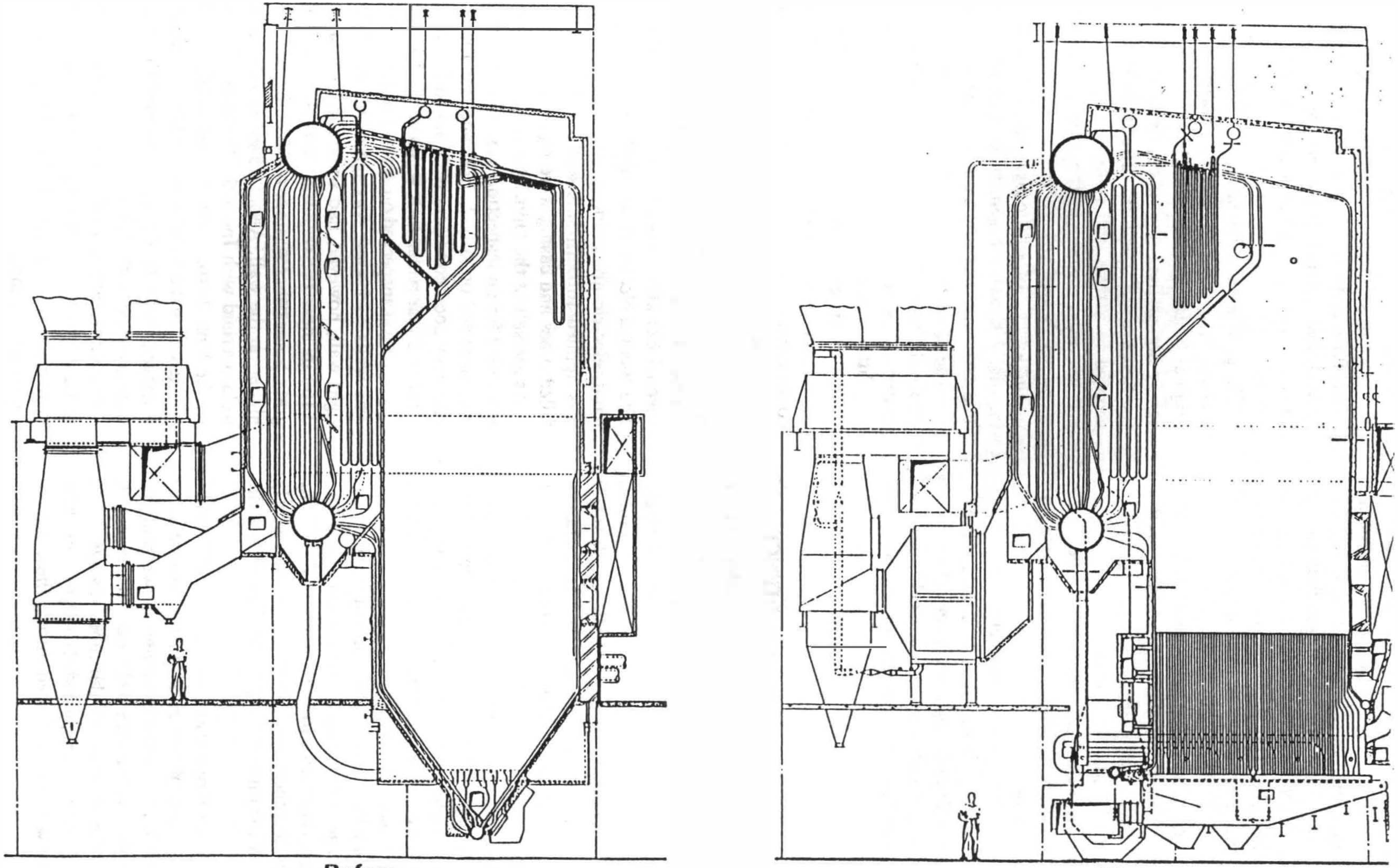
While burning RDF is a relatively new concept, there was enough industry experience to realize that the combustion of refuse fuels can cause corrosion of pressure



Before

After

FIG. 1 UNITS 1 AND 2 BEFORE AND AFTER MODIFICATION



Before

After

FIG. 2 UNIT 3 BEFORE AND AFTER MODIFICATION parts. The exact mechanism of this corrosion seems to be very random and plant specific but contributing factors are the quantities of sulfur, chlorine and molten salts (zinc chloride/lead chloride) in the fuel; the operating pressure and temperature; the combustion zone temperature; the boiler and feedwater quality; and localized reducing or oxidizing atmospheres in the furnace.

To manage the tube metal wastage in refuse-fired boilers many different alternatives have been used in the industry. Some of them are:

(a) Retubing with identical tubes.

(b) Retubing with thicker, single-metal tubes.

(c) Retubing with bimetallic tubes (carbon steel with nickel alloy cladding).

(d) Ceramic coating on carbon steel tubes.

(e) Thermal spray coating on carbon steel tubes.

(f) Studs and refractory installed over tubes.

(g) Carbon steel overlay on carbon steel tubes.

(h) Chrome/nickel alloy overlay on carbon steel tubes.

UPA–ELK RIVER STATION EXPERIENCE

To optimize the design of the UPA boilers, many different alternatives for the new tubes were evaluated. This led to the selection of carbon steel membraned water wall tube panels with additional tube wall thickness. On Units 1 and 2, 0.220 in. tubes were installed, and on Unit 3, 0.240 in. tubes were installed. Only 0.100 in. is required to meet the pressure and temperature requirements. The original tubes above the cut line for the new furnace extensions were 0.180 in. on all three units. Since the pattern and rate of potential corrosion was unknown, this additional thickness would allow the boilers to operate for some period of time while the extent of the corrosion was monitored and various repair methods were evaluated.

To have a baseline from which to monitor the potential tube wastage, a UT map of each furnace (old and new tubes) was done prior to starting up on RDF. The intention was to repeat the complete UT map yearly and spot check the tubes when possible throughout the year.

In the first year of operation, several spot UT checks were made in each of the units during maintenance outages. Since B&W's experience has shown that the lower rear wall and the side walls near the rear wall tend to have the majority of the tube wastage, these were the areas initially inspected. No significant tube metal wastage was ever indicated during these inspections.

On June 10, 1990 Unit 3 boiler experienced a simultaneous failure of six water wall tubes (Fig. 3). The subsequent furnace pressurization caused the boiler casing to buckle and bulge and several buckstay supports to bend. Fortunately, no personnel were injured in the incident.

The tube leaks occurred on the right side wall 13–19 ft above the grate elevation. This was in the area of the original boiler wall tubes (0.180 in.) and was significantly higher than any of the areas inspected during the first year of operation. The tubes that failed were thinned to a tube wall thickness of 0.040 in. due to extreme tube wastage in the area. Visual and UT inspections showed that there was general tube wastage on the lower 24 ft of the right side wall of up to 0.150 in. Fig. 4 shows the general pattern of this wastage. The left wall was not as severe but had some tube wastage of up to 0.100 in. The worst wastage on both side walls was 12–15 ft above the grate and near the center of the wall. The front and rear walls showed very little wastage.

Due to the extreme rate of corrosion (+0.010 in./month) on the side walls, it was decided that the boiler could not return to service unless the thinnest areas were repaired. The repair options were evaluated and it was decided that padwelding over the existing tubes with a chrome/nickel alloy would be the best immediate fix. Due to the positive reports from the industry, Inconel 625 alloy was chosen as the overlay material. The Inconel electrode was applied manually by downhand, electric arc welding. About 840 esf of overlay was applied to both side walls in 17 days while the failed tubes and casing were replaced.

As a result of the Unit 3 failure, Units 1 and 2 were scheduled for an inspection as soon as possible. Unit 1 was inspected on July 2, 1990 and was found to be in relatively good condition with only a few tubes on the right and rear walls with wastage of 0.025–0.040 in.

Unit 2 was inspected on August 6, 1990. The left and rear walls had some wastage of up to 0.040 in. The right wall, however, had some local wastage of up to 0.160 in. near the rear wall and about 5 ft above the grate. Some other wastage of 0.050–0.060 in. was found higher on the wall. About 15 esf of tube area was arc weld overlaid with Inconel 625 during this shutdown.

The Unit 2 front wall bottom bend, just above the chutes where the RDF comes in to the boiler, had some wastage of up to 0.100 in. About 40 of these tube bends were overlaid with Inconel.

On September 4, 1990 the front wall bottom bends of Unit 1 were UT inspected and were also found to have wastage of up to 0.100 in. Thirty tube bends were overlaid with Inconel.

FIG. 3 UNIT 3 TUBE FAILURES, JUNE 1990

In November 1990 the Elk River Station was shutdown for a scheduled plant maintenance outage. At that time all three boiler furnaces were UT and visually inspected again. The tube wastage rates since the summer 1990 inspections were continuing in some areas at a rate of 0.010–0.015 in. per month. Unit 2 was the worst with more than 80% of the lower right wall having 0.050 in. wall loss and about 30% of that more than 0.075 in. wall loss. The left wall had lost 0.050 in. on about 20% of the wall. The rear wall and front wall were not significantly changed. The very worst of the tubes on the right wall were Inconel overlaid at this time.

Unit 1 was in better shape with about 25% of the right wall and 10% of the left wall having 0.050 in. or greater wall loss. The rear wall, however, was found to have about 25% area where wall losses of 0.025–0.050 in. were occurring.

Unit 3 continued to have wastage at a rate of 0.010–0.015 in. per month on the bare tubes that were not overlaid with Inconel in June 1990. The Inconel material was inspected in a few areas and generally looked good but it appeared that, where there was not a sufficient overlap in weld beads, the tube was continuing to lose metal, causing crevicing. However, the furnace walls were not sufficiently cleaned during this outage to adequately inspect the majority of the June 1990 overlay and determine the magnitude of the crevicing.

As a result of these inspections it became apparent that the corrosion wastage rates would continue and cause forced outages in the near future on all units. A repair method was necessary by about February 1991 if the boilers were to remain in operation. Again, the repair options were evaluated based on economics, time frame and the relative life of the repair. Massive tube replacements (carbon steel tubes or bimetallic) were eliminated due to cost, availability of material, time to install and the obvious fact that carbon steel tubes had a very limited life. Spray coatings were eliminated due to industry experience indicating a short life. Weld overlay with Inconel 625 material was the best available option. The experience in June 1990 with electric arc welding, however, was less than satisfactory due to the time required, the quality of the weld, the amount of personnel required and the heat generated by the process that caused the tube walls to warp. It was decided that a better way to apply the Inconel material should be investigated.

Vendors with experience in gas metal arc welding with Inconel were surveyed and requested to bid. Welding Services, Inc. (WSI) was selected to apply the Inconel overlay in all three boilers in February 1991. WSI utilizes an advanced pulse spray gas metal arc welding system with automated motion control that can automatically cover large areas with minimal personnel. The procedure applies about 0.100 in. of quality overlay on the tube with minimal heat distribution to the surrounding area, thus minimizing the tube panel warpage.

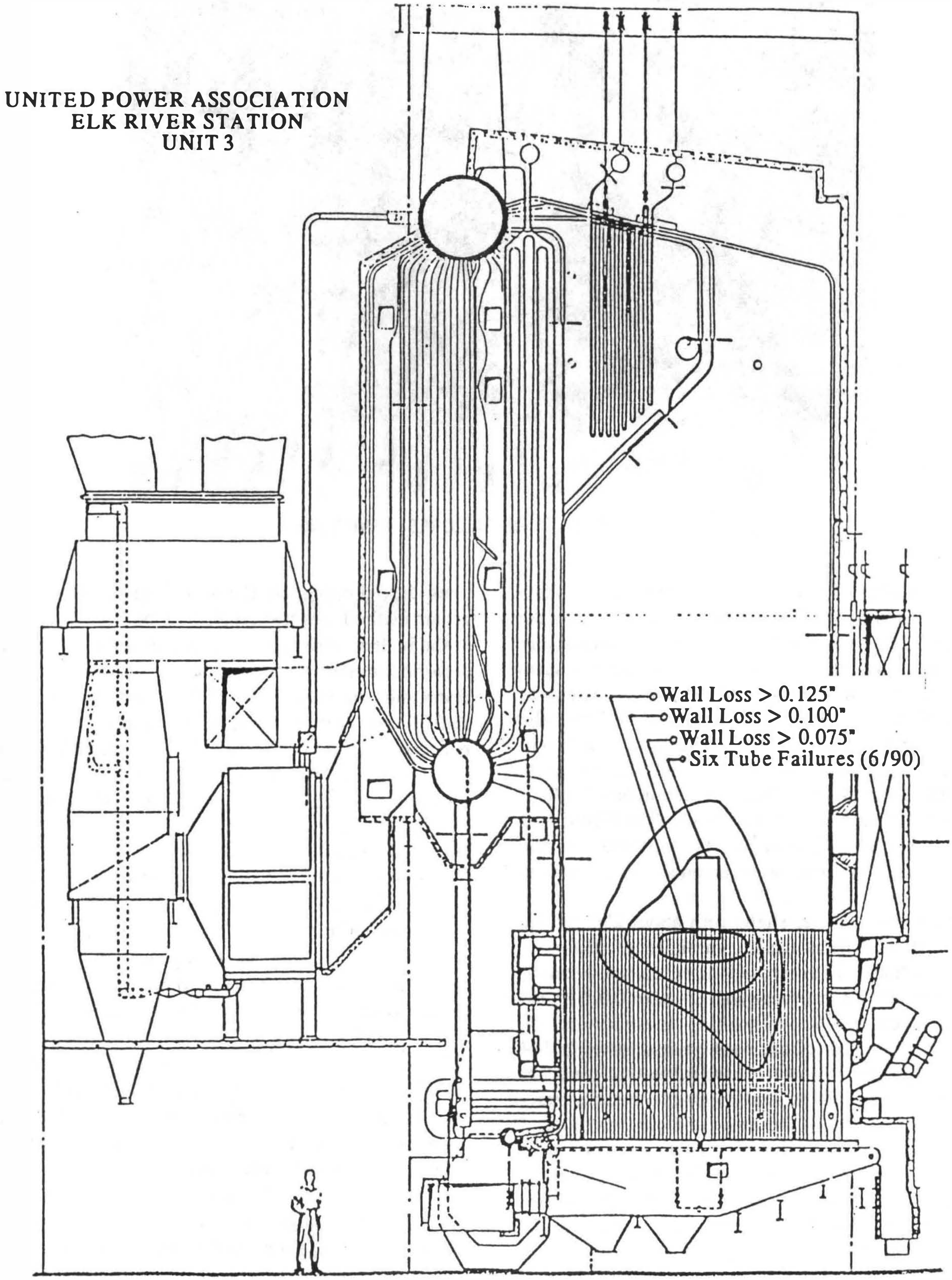


FIG. 4 UNIT 3 RIGHT SIDE WALL — PATTERN OF TUBE WASTAGE

TABLE 1 METALLURGIC ANALYSIS OF INCONEL 625 OVERLAYS
(Elk River Station — 02/21/91)

	Composition - Percent					
Description of Inconel Sample	Ni	Fe	Cr	Mo	Others	Total
Inconel 625 Wire	64	5	18	9	4	100
WSI Test Coupon	60	5	22	9	4	100
WSI Pulse Gas Metal Arc	58	7	22	9	4	100
Electric Arc Weld - 06/90 (Good Condition)	42	33	16	7	2	100
Electric Arc Weld - 06/90 (Worn Condition)	13	75	8	2	2	100

The overlay on Unit 2 began on February 3 and concluded February 12, 1991. When the unit was brought down, there were several tube leaks in the right wall due to tube wall thinning. A total of 799 esf of furnace wall tubes were overlaid, including all of the lower 15 ft of both side walls.

A total of 1883 esf were overlaid on Unit 3 from February 12 to February 28, 1991. The lower 30 ft of the right wall, 25 ft of the left wall, 24 ft of the rear wall and a small area of the front wall were covered. Of this area, 421 esf were areas that had been arc-weld overlaid in June 1990 and had severe pitting and loss of metal on the old overlay. There were also multiple small tube leaks in these areas when the boiler was shut down.

It was determined that the electric arc overlay procedure was very operator dependant and, where excessive heat was applied, the Inconel material was diluted with the carbon steel base metal. This dilution reduced the corrosion resistant properties (percent chrome nickel) of the overlay (Table 1). Some of the WSI applied overlay were also analyzed and show very little dilution at the surface of the weld. The balance of the old overlay was "spot" treated with new Inconel as necessary.

Unit 1 was overlaid from February 28 to March 8, 1991. A total of 819 esf was covered including all of the lower 15 ft of both side walls, and some of the front and rear walls.

This overlay protection is expected to be a long-term repair. A thorough UT survey was done in each unit including on the new overlay. Bench mark tags were installed at multiple elevations in the boiler so that UT inspections can be done to monitor the condition of the overlay and the remaining bare tube at exactly the same spot on the tubes. It is intended that a complete furnace UT will be completed yearly with periodic spot checks as possible and that additional overlay will be applied over small areas of the remaining carbon steel tubes in the future.

The first of these annual furnace UT inspections was done in October 1991 in Unit 2 boiler. The readings on the overlaid tubes were inconsistent and did not compare well to the post-overlay readings. Although visually the weld pattern was clearly defined and no obvious wastage had occurred, some of the readings were significantly thinner, while many were a lot thicker. Overall, however, the measured wall thicknesses were well above the original tube thickness, indicating a significant weld overlay still present. Future UT will continue to be done in an attempt to accurately measure the wall thicknesses.

Reasons for the different corrosion rates and the areas in which it occurred in the three boilers have not been positively identified. The right wall of all three units has consistently had the most wastage. This may be partially attributed to the fuel feed system. All three boilers share a common system that feeds the fuel in series from right to left. Each boiler has three fuel feeders and feed chutes and the first one (right) consistently has more fuel than the other two. At times these feeders cause clumps of fuel to pile on the grates and temporarily smolder (reducing atmosphere) until enough undergrate air can reach the fuel for good combustion. As these clumps burn off there is an abundance of undergrate air and a subsequent oxidizing atmosphere. It is theorized that these cycles of fuel/air swings contribute to the accelerated corrosion.

The internal surface of a few tubes from Unit 2 were found to have significant deposits. These tubes had experienced extensive metal wastage which was probably accelerated by the increased tube metal temperatures from the insulating internal deposit. Other tubes in the boiler were tested and significant deposits were not found. UPA feels that, although a major contributing factor in the corrosion wastage rate, internal cleanliness of the furnace walls is not a root cause of the corrosion wastage.

CONCLUSION

In the design of the boiler modifications to burn RDF at United Power Association's Elk River Station, furnace tube wastage due to corrosion was anticipated. The plant has been firing RDF for more than 2 years and has monitored wastage rates of up to 0.015 in. per month. The thick-wall carbon steel tubes have failed and the wastage has now been controlled by the extensive application of Inconel 625 weld overlay by an automated pulsed gas metal arc welding system. Annual UT surveys will monitor the overlay and attempt to detect additional tube wastage and areas that will need to be overlaid in the future.