OPERATIONAL TESTING OF AN ELECTRICALLY FIRED Pu-238 WASTE INCINERATION PROCESS

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ABSTRACT

Combustible Pu-238 waste is generated as a result of normal operation and decommissioning activity at the Savannah River Plant and is being retrievably stored at the plant. An electrically fired, two-stage incineration process is being developed to study the feasibility of using incineration to process and recover plutonium from the waste. A prototype incinerator is being tested to assess its capability to be remotely operated and maintained. Technical development is focusing on the following six areas to determine the feasibility of placing the incinerator in radioactive service: continuous feeding, vacuum control, remote operability and mechanical integrity of the system, ash burnout, and life of the belt in the primary incinerator chamber.

BACKGROUND

Pu-238 is produced at the Savannah River Plant (SRP) for use primarily as satellite heat sources. Pu-238 contaminated waste is generated as a result of production, laboratory, and decommissioning activities and is being retrievably stored at SRP. To effectively process and dispose of Pu contaminated waste, SRP plans to design and build a Transuranic Waste Facility (TWF), which will retrieve and prepare TRU waste for shipment to the Waste Isolation Pilot Plant (WIPP). An alternative approach is to add the incinerator later to recover the Pu from the high activity fraction of the combustible Pu-238 waste. The Plutonium Waste Incinerator (PWI) will convert the combustible waste (60% of the total waste volume) into an ash compatible for recovery.

PROCESS

The PWI process consists of a continuous feed preparation system, a two-stage electrically fired incinerator, and a filtration off-gas system. Due to the radiological hazard of Pu-238, the feed preparation system was designed to remotely process combustible feed packaged in 55-gallon drums with no manual sorting or handling of the waste.

It shreds the contents of the drum (and the drum itself if necessary) and delivers the shredded material to the incinerator at a controlled rate of 20 lbs/hr. A woven wire belt moves the ash along the length of the primary chamber. After cooling, off-gases are filtered in sintered metal and HEPA filters. Vacuum is maintained in the process by an induced draft blower and butterfly control valve. Process control is provided by a programmable controller. Figure 1 is an isometric of the PWI process.

FEED SYSTEM TESTS

The feed preparation system was designed using a 45 hp shredder and a 15 hp shredder coupled with a "Paxpump" which is used as a metering device. Even though the feed chute design resulted in satisfactory tests conducted at the vendor's shop, shredder parameters and chute configurations were expected to undergo further development work to improve feed rate uniformity. Two minor feed chute modifications tested to improve solid flow. The modifications which were required for consistent feed rate were:

- Conversion of the chute between the "Paxpump" and the 15 hp shredder from a 90° angle chute to one with a 45° angle. This enhanced solid flow and prevented pluggage.
- Increasing the clearance between the incinerator final feed chute and the belt from 2" to 6" to prevent plugs in the incinerator.

Figure 2 is a schematic of the feed preparation system.

Feedrates

Consistent feed rates were found to depend on both the "Paxpump" and fine shredder. Coarse metering of the feed is achieved by the "Paxpump" and good uniformity is

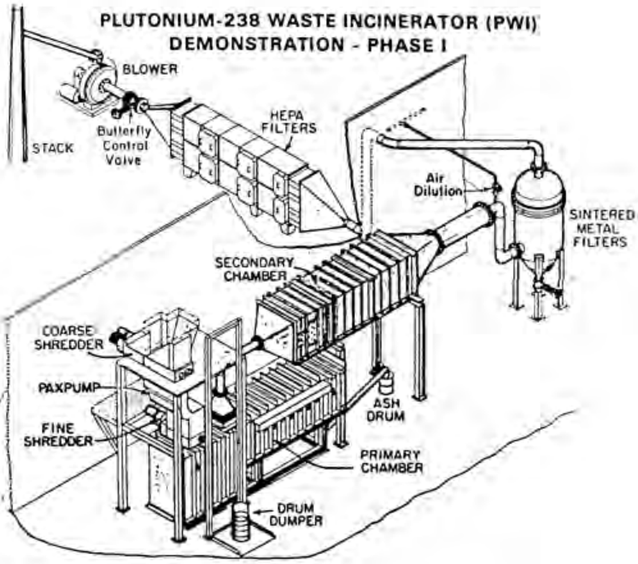

Fig. 1. PWI Incinerator.

achieved by cycling the fine shredder. If the cycling is not timed properly, an uneven feedrate or flood feeding of the feed chute will occur, which plugs the feed chute. Testing has been completed to adjust the parameters of the "Paxpump" and fine shredder to ensure a consistent feed rate and eliminate flood feeding. Figure 3 shows the feedrates at the various "Paxpump" and fine shredder settings. Based on this data, the "Paxpump" and fine shredder parameters have been set to achieve consistent 20 lbs/hr feedrate.

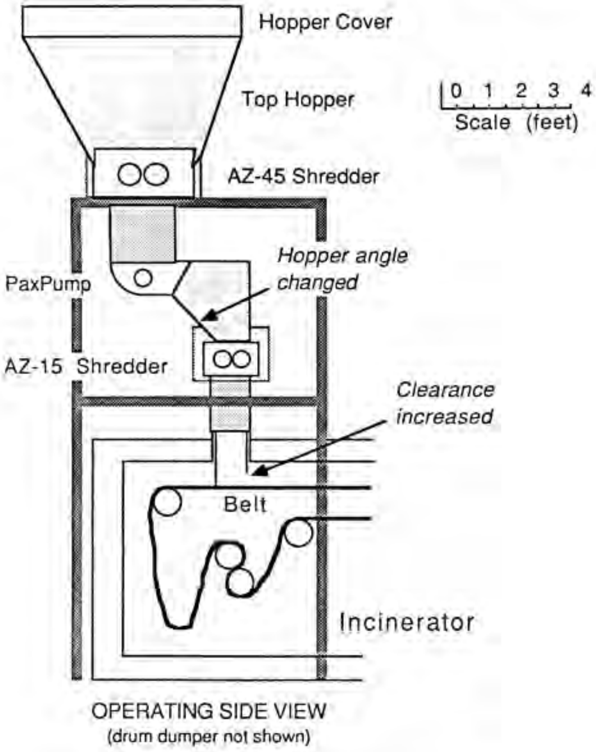

Fig. 2. PWI Feed Preparation.

Thickness of Material on the Belt

Tests were also conducted to determine the feed thickness which is an important consideration in carbon burn-out of the waste. The actual thickness did not compare with residence time increases. The motion of the belt and weight of piled feed cause it to settle. Figure 4 shows the actual thickness and the predicted data with the settling factor. Table I shows actual thickness data and calculated densities.

TABLE I

Measured and Calculated Thickness of Feed on Belt

% Belt *Drive*	Residence Time (min)	Measured Thickness (inches)			Calculated Thickness (inches)			Calc Density lbs/ft^3
		15 pph	20 pph	33 pph	15 pph	20 pph	33 pph	
100	9	0.25	0.28	0.40	0.31	0.41	0.68	3.7
90	10	0.28	0.38	0.50	0.33	0.44	0.72	3.8
80	11	0.30	0.40	0.75	0.35	0.47	0.77	3.9
70	12	0.35	0.45	0.80	0.37	0.49	0.81	4.1
60	14	0.40	0.55	0.90	0.40	0.54	0.88	4.4
50	17	0.45	0.63	0.97	0.44	0.59	0.98	4.8
40	22	0.50	0.75	1.10	0.50	0.67	1.10	5.5
30	29	0.60	0.85	1.25	0.56	0.75	1.23	6.5
20	40	0.68	0.93	1.38	0.63	0.83	1.38	8.0
10	85	0.75	1.00	1.50	0.74	0.99	1.63	14.3

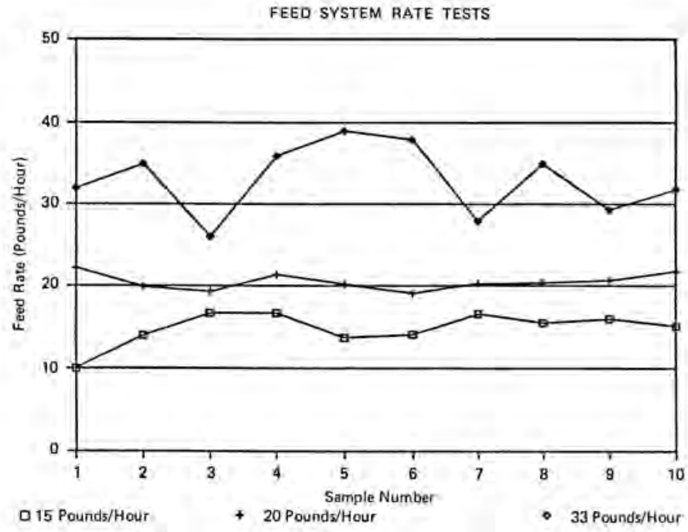

Fig. 3. Feed Rate Data.

INCINERATION TESTS

The incinerator is a two-stage, controlled air, electrically fired unit designed and manufactured by Shirco, Inc. in Dallas, Texas. The primary chamber of the incinerator is designed to pyrolyze the waste in substoichiometric air concentrations. Pyrolytic gases from the primary chamber are mixed with excess air and burned to complete combustion products in the secondary chamber. This mode of operation along with the electric heating design, minimizes carry-over of radioactive particulates into the secondary chamber and from there into the off-gas system.

Approximately 500 hours of incineration time have been completed, with three objectives:

- Assess the incinerator reliability and adaptability to remote maintenance.
- Assess the system performance under continuous feed conditions.
- Determine the optimum operating conditions of the incinerator (residence time, feed rate, temperatures and air flow) and the ash characteristics at the conditions.

A mix of cellulose, polyethylene, latex, and PVC was used in the tests. Various process parameters were tested, including residence time, temperature, and primary chamber air flows.

Incinerator Reliability and Utility

During 358 hours of the total incinerator operating time, the incinerator operated primarily at continuous intervals. During operation, the average utility was 72%. However, the utilities of two continuous runs with operating times of 72 and 67 hours were 90% and 95%, respectively. A summary of operating utility is shown in Table II.

The lower utilities during the first four tests were caused by feed chute plugs resulting from shredder malfunctions and mistimed cycling of the fine shredder and "Paxpump". The increased utilities of the remainder of the tests resulted after adjustment of the

TABLE II

Summary of Operating Utility

Test	*Hours of Operation*	*Cumulative*	*Utility*	*Type Operation*
Checkout	*51*	*51*		
1	*16*	*67*	*42*	*Continuous*
2	*28*	*95*	*70*	*Continuous*
3	*55*	*150*	*60*	*Continuous*
4	*54*	*204*	*80*	*Continuous*
5	*27*	*231*	*95*	*Daily*
6	*72*	*303*	*90*	*Continuous*
7	*19*	*322*	*30*	*Daily*
8	*67*	*389*	*95*	*Continuous*
9	*20*	*409*	*95*	*Daily*
10	*58*	*467*	*95*	*Continuous*
11	*15*	*482*	*95*	*Daily*

Vacuum Control

The PWI process operates under a vacuum, controlled at 0.05 to 0.10 inches of water, measured at the ash end of the primary chamber. During initial start-up the vacuum was a primary technical concern since the control loop interacted with the secondary combustion air control loop and the cooling/dilution air control loops. After replacing the vacuum control butterfly valve and tuning control parameters, a consistent vacuum could be maintained with a maximum oscillation of 0.005" wc. The response of the control system is now consistent both at ambient temperatures and at operating temperatures with or without waste burning. Figure 5 illustrates the system vacuum before and after the changes. The average vacuum before the changes was .11 inches water with a standard deviation of .07 while after change we were able to control at .07 inches water with a standard deviation of .01 inches.

Incinerator Operating Characteristics

The effects of primary chamber operating temperatures, feed rate, residence time, and primary chamber air flows were investigated. Measured variables included the remaining percent of carbon and volatiles in the ash. It is desirable to produce a carbon-free ash.

Table III is a summary of the conditions tested during the 500 hours of testing.

Analysis performed on the data indicates that the ability of the incinerator to produce carbon free ash increases with higher primary chamber air flows at lower feed rates, and higher temperatures. Modeling studies performed on the incinerator ash also indicate that the char-burning rate is transport limited. This study confirms that increased carbon burnout will occur at higher air flows and reduced feed rates, resulting in reduced ash thickness on the belt, as the reduced thickness on the belt allows increased air contact with the ash particles. Increased residence time is not a significant factor in the burn rate since a thicker layer on the belt results in less air/char contact.

A char-burning test conducted at four different conditions using cellulose confirmed that increased carbon burn out occurs at high temperatures and air flows. Reduced air flows resulted in the least carbon burnout and reduced temperatures and increased residence time did not significantly offset the burning rate. Table IV is a summary of the different test conditions.

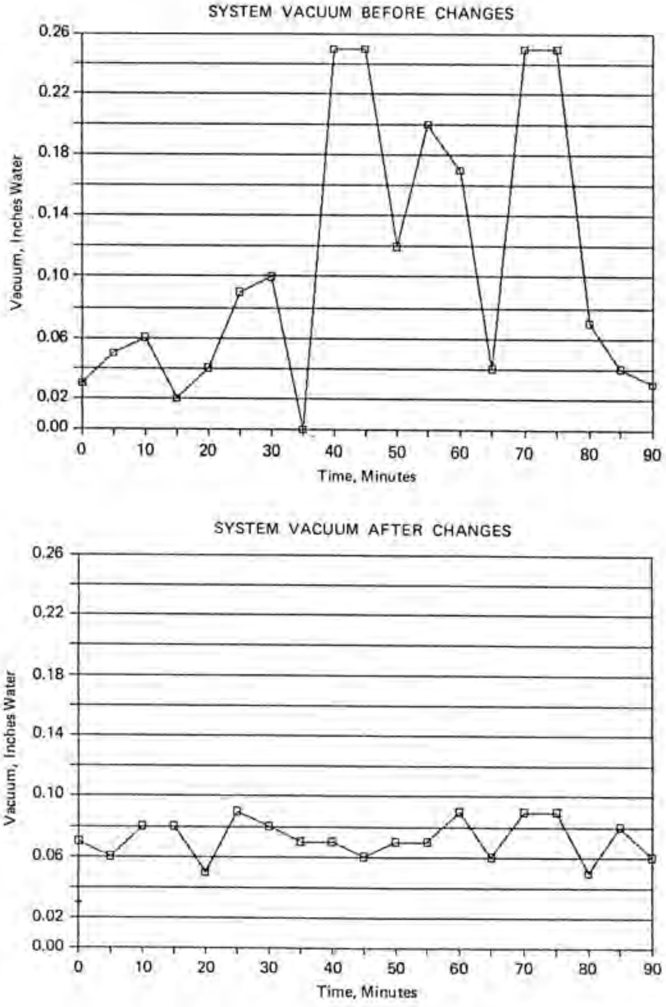

Fig. 5. Vacuum Control.

Incinerator Belt Life

The most critical aspect of maintenance of the unit is the life of the woven-wire belt that moves

TABLE III

Summary of Incinerator Operations

Mix	*PC Air (SCFH)*	*Feed Rates (lb/hr)*	*Temperatures (C) Zone A*	*Zone B*	*Residence Time (Min)*	*% Vol*	*% C*
1	*1000*	*<20*	*800*	*850*	*60*	*11.7*	*0.7*
2		*20*	*650*	*650*	*60*	*19.5*	*6.9*
3			*450*	*650*	*80*	*15.4*	*7.0*
4	*800*	*15.5*	*800*	*800*	*60*	*8.6*	*13.2*
5		*20*	*650*	*650*	*60*	*1.03*	*27.2*
6	*700*	*<20*	*800*	*850*	*60*	*14.1*	*1.2*
7			*650*	*700*	*60*	*13.8*	*4.6*
8	*600*	*<20*	*800*	*850*	*80*	*25.9*	*1.5*
9	*500*	*<20*	*800*	*850*	*80*	*13.2*	*.95*
10			*800*	*850*	*80*	*10.6*	*6.1*
11	*400*	*<20*	*800*	*850*	*45*	*19.7*	*10.7*
12			*800*	*850*	*45*	*19.6*	*53.9*
13	*0*	*<20*	*800*	*900*	*45*	*8.8*	*39.4*

TABLE IV

Char-Burning Test (Cellulose)

Test	*PC Air (SCFH)*	*Feed Rates (lb/hr)*	*Temperatures (C) Zone A*	*Zone B*	*Residence Time (Min)*	*Weight Reduction*
1	*800*	*12.5*	*800*	*800*	*45*	*1:47*
2	*400*	*14.3*	*800*	*800*	*45*	*1:12*
3	*800*	*14.3*	*800*	*800*	*80*	*1:43*
4	*800*	*14.3*	*650*	*650*	*45*	*1:35*

the length of the primary chamber. Corrosion of the belt is a key concern, as the belt is exposed to high temperatures and an alternating oxidizing/reducing atmosphere as it rotates through the incinerator. The belt was initially composed of seven different alloys to determine which alloy was the most corrosion resistant. Four of the seven alloys were chosen based on a 400-hour laboratory-scale test. Metallurgical testing was completed on the belt after it had operated for 250 hours. Four of the seven candidates had corroded to the point that embrittlement fractures were occurring. Three cobalt-based superalloys were the most corrosion resistant with no embrittlement breaks. Table V is a summary of the uncorroded metal diameter from the 250-hour belt test. Based on this test, a Haynes 188 belt and a Mar M-918 belt are projected to last 1500 and 2000 operating hours, respectively.

The corrosion rate of the belt as measured by the uncorroded wire diameter was faster in the PWI than in the laboratory scale unit as illustrated in Fig. 6. The difference in the corrosion rates is a result of higher operating temperatures and more startups and shutdowns (hence, thermal cycling) in the pilot unit.

The primary causes of belt corrosion are reduction in which carbon-oxygen reactions remove the protective oxide layer, and low melting eutectic formation due to impurities migrating into the grain boundaries of the alloy at high temperatures. To minimize the corrosion rate, air flows were increased and temperatures reduced in the primary chamber. Also, the operating run times were increased to reduce thermal cycling.

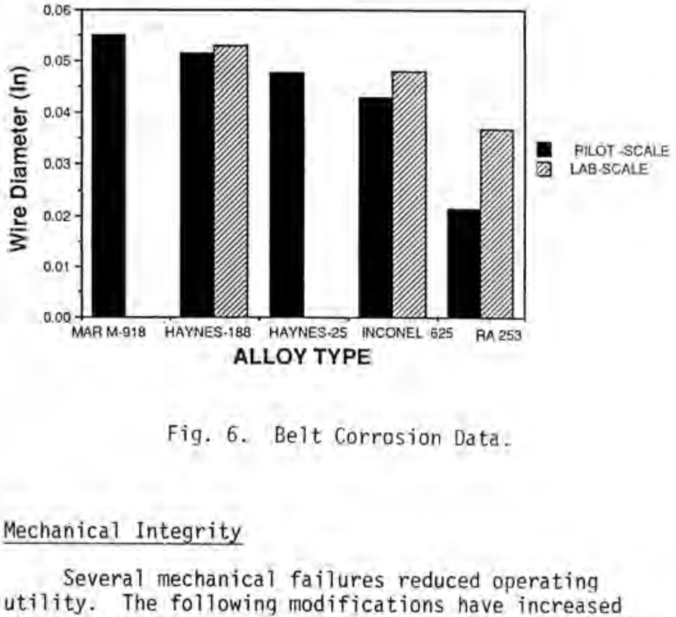

Fig. 6. Belt Corrosion Data.

Mechanical Integrity

Several mechanical failures reduced operating utility. The following modifications have increased the integrity of the system and prevent recurrence of failures.

- *Belt Positioners* - To prevent the belt from drifting gradually to one side, an automatic positioning device was added that pushes the belt to the center on a set time frequency. During initial startup, the positioner heads would loosen from the shaft resulting in belt drifting. The shaft-head connection was modified and aligned to prevent recurrence. The vendor has since developed a higher integrity belt positioner.

- *Heating Element Power Cables* - The power supply cables to the silicon carbide heating elements were found deteriorated inside the secondary chamber wire way. The failure was partially caused by heat and HCL attack, since $CuCl_2$ was found on the surface of the cables. Deterioration was most likely initiated by poor vacuum control during early runs, which allowed the hot volatile gases to escape into the wireway box. The deterioration exposed the cables, allowing a path for the current to go to ground and resulting in excessive amperage being carried by the cables. To prevent recurrence, a thermocouple was placed in the wireway to allow monitoring of the temperatures. Also, improved vacuum control prevents the release of corrosive HCL gases. No deterioration has occurred in the primary chamber wireway due to the installation of a wireway fan to circulate and purge the escaped gases.

Process Control System

The entire process is controlled by a Gould Modicon 584L process controller. The system includes over 150 inputs and outputs and 8 proportional-integral-derivative control loops. During its approximately 100 millisecond scan time, the Modicon monitors all its inputs, controls all its loops, and adjusts all its outputs. This nearly instantaneous control provides safe, steady incinerator operation. Software for the system includes not only operating logic but automatic sequences to start up the system or to shut it down correctly in a variety of situations. In a process upset, the correct action is taken immediately without the need for operator interaction.

Included in the control system is a process alarm system featuring an Automatic Technology "Microtie" process computer. The "Microtie" receives alarm messages from the modicon and transmits them to a series of CRT display screens. The "Microtie" has a diagnostics program that can pinpoint the cause of a series of alarms to the initial Modicon input that initiated the upset. Thus, the problem can immediately be traced to the individual device causing a chain of events.

Future Testing

Continued testing at different process parameters will allow modeling of the ash buring characteristics of the incinerator. Previous testing under pyrohydrolysis conditions indicates that greater carbon burnout occurs than testing under substoichiometric conditions without steam. The purpose of this testing will be to demonstrate producing a carbon-free ash at lower temperatures that could enhance plutonium recovery capability.

Pure pyrolysis produces a high carbon ash which is not suitable for plutonium recovery. Combustion is a highly exothermic reaction, and close temperature control is difficult. Incinerator operation in an air-starved steam environment (pyrohydrolysis) promotes endothermic hydrolysis reactions which strip carbon from the ash and make temperature control much easier. No combustion reactions occur, so localized hydrolysis is a slower process than pyrolysis followed by combustion, so processing rates are adversely affected. This tradeoff between plutonium recovery potential and incineration capacity will be studied thoroughly.

REFERENCES

1. D. L. Charlesworth, *Design of a Pu-238 Waste Incineration Process*, U. S. Department of Energy Report DP-MS-84-109, E. I. du Pont de Nemours & Company, Savannah River Laboratory, Aiken, SC 29808 (1984).