

DESIGN OF A 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. As part of the long-term plan to process the stored waste and current waste in preparation for future disposition, a Pu-238 incineration process is being cold-tested at SRL. The incineration process consists of a continuous-feed preparation system, a two-stage, electrically fired incinerator, and a filtration off-gas system. Process equipment has been designed, fabricated, and installed for nonradioactive testing and cold run-in. Design features to maximize the ability to remotely maintain the equipment were incorporated into the process. Interlock, alarm, and control functions are provided by a programmable controller. Cold testing is scheduled to be completed in 1986.

BACKGROUND

Pu-238 is produced at the Savannah River Plant (SRP) for use primarily as a satellite heat source. Pu-238 is over 200 times more active than Pu-239 produced for national defense. Criticality is not as major a concern with Pu-238 as it is with Pu-239; however, Pu-238 is more toxic than Pu-239. As the only large scale producer of Pu-238 in the United States, SRP faces a unique problem - that of safely disposing of a large volume of highly radioactive Pu-238 contaminated waste.

Pu-238 contaminated waste is generated at SRP as a result of heat source production, laboratory work, and decommissioning activities. Most of this waste has been retrievably stored in the plant burial ground since 1965. To effectively process and dispose of this waste, the plant proposes to design and build a Transuranic Waste Facility in the late 1980's. Figure 1 is a schematic of the SRP TRU Waste Management Plan.

The Transuranic Waste Facility will consist of a retrieved waste processing facility (RWPF) to prepare stored waste for further processing, a disassembly and decontamination facility to process noncombustible transuranic waste, and a Pu-238 waste incinerator (PWI) to process combustible transuranic waste. The PWI will convert the combustible waste (60% of the total waste volume) into an ash compatible with the Defense Waste Processing Facility (DWPF) for ultimate disposal in glass.

PROCESS THEORY

The reference design for a transuranic waste incinerator consists of three sections: a feed preparation system, the incinerator, and an off-gas system. The three sections process the waste as received to produce a noncombustible, low-carbon ash and nonradioactive, nonhazardous off-gas. Figure 2 is a block diagram of the PWI process.

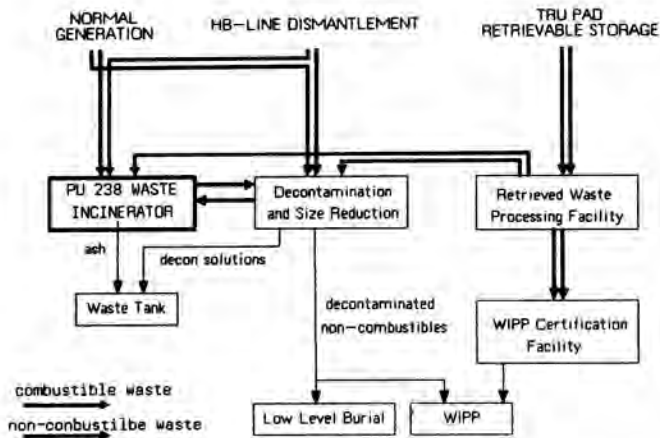


Fig. 1. Savannah River Plant Transuranic Waste Management Plan.

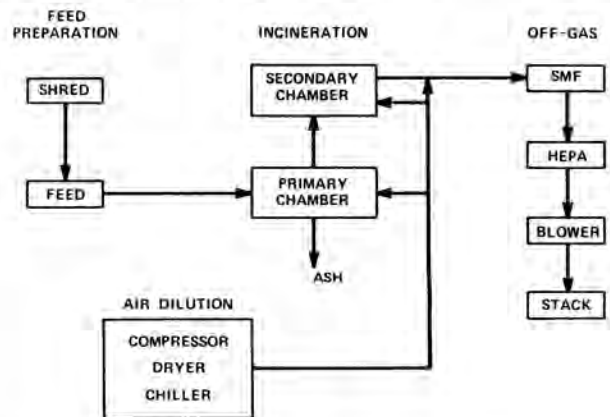


Fig. 2. Pu-238 Waste Incinerator Process Flowsheet.

At SRP, transuranic waste is packaged in zinc galvanized 55-gallon drums with 90 mil polyethylene liners. The PWI feed preparation system shreds the liner and its contents (and the drum if the liner cannot be removed) and delivers the shredded material to the incinerator at a controlled rate.

The incinerator is a two-stage, controlled air, electrically fired incinerator. The primary chamber of the incinerator is designed to pyrolyze the waste in substoichiometric air concentrations. Pyrolysis 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 carryover of radioactive particulates into the secondary chamber and from there into the off-gas system. The radioactive ash from the primary chamber will be slurried and pumped to the high level waste tanks at SRP for ultimate disposal in DWPF.

The off-gas system does not include a scrubber, and hence produces no liquid effluent. Dry instrument-quality air is used for dilution and cooling. This design minimizes the potential corrosion from burning polyvinylchloride. After cooling by air dilution, the off-gas from the secondary chamber passes through sintered metal filters (SMF), high efficiency particulate air (HEPA) filters, and a sand filter before being stacked to the atmosphere. The gas released meets all South Carolina Department of Health and Environmental Control standards.

The sintered metal filters include a silica powder precoat system. The silica is used to prevent blinding of the filter tubes by tar-like residues from incineration of plastics. The silica will be blown off the filters based on pressure drop through the SMF. This silica is also compatible with DWPF, hence it will be slurried with the ash and pumped to the SRP high level waste tanks. As HEPA filters become plugged, they will be changed out and the old filters shredded and processed in the PWI.

TESTS AND DESIGN - FEED PREPARATION SYSTEM

Due to the high toxicity of Pu-238, the feed preparation system must:

- o Avoid manual handling or sorting of the waste, as it may contain tramp metal or glass which could present a hazard to personnel.
- o Avoid air classification of the waste, as the Pu-238 in the waste is too active to convey or separate this way.
- o Be totally enclosed and purged with nitrogen to eliminate the possibility of fire in the system.
- o Be remotely operable and capable of processing materials made of wood, plastic (PVC, polyethylene), rubber, lead-lined gloves, paper, and tramp glass and metal.

To satisfy these constraints, low-speed electric shredders manufactured by Shred Pax Corporation were selected to size reduce the waste, based on shredder tests completed at Idaho Falls¹. Two shredders in series are used to size reduce the waste. Each shredder has two sets of counter-rotating blades. One shaft turns at 45 rpm and the other turns at 60 rpm. The shredders are designed to stop and reverse whenever significant resistance is encountered. When coupled with the relatively slow operating speed, this allows the shredder to gradually process almost any material without damaging itself.

To provide design data, several hundred pounds of simulated combustible waste were shredded at the vendor's shop, first through a coarse, 80 hp shredder, and then through a fine, 15 hp shredder.

Table I shows shredding times for individual components of the mix and for the simulated waste mix.

TABLE I
Shredding of Simulated Waste

	Percent in Mix	Component Average Shredding Time ^(a)	
		80 hp	15 hp
Cellulose	33	60 sec	10 min
Polyethylene	7	90 sec	20 min
PVC	12	90 sec	6 min
Rubber	18	40 sec	5 min
Lead-lined Gloves	10	30 sec	3 min
HEPA Filters	2	180 sec	8 min
metal	7		
glass	10		
Mix		1 min	30 min

(a) per 50 lb drum of material, including 90 mil polyethylene liner

Nominal 4" by 4" to 2' particles were observed exiting the large shredder. Nominal 1/2" by 1/2" to 3" particles were observed exiting the small shredder.

Based on these data, the feed preparation system was designed using a 45 hp shredder and a 15 hp shredder coupled with a "PaxPump"®. A "PaxPump" is normally used to compress and convey shredded materials, but it can be used as a metering device when coupled with a variable speed drive. Belt conveyers are normally used to meter incinerator feed; however, the "PaxPump" offers advantages, as it:

- o Is simpler and more rugged than a belt conveyer and requires less maintenance.
- o Is totally enclosed.
- o Does not plug due to its positive displacement pumping characteristics.

The two shredders, "PaxPump", and associated hoppers were assembled and tested. Satisfactory shredding was demonstrated; however, as of this writing, shredder parameters and chute configurations are still being developed to improve feed rate uniformity. Particle sizes of 1/2" by 2" exiting the 15 hp fine shredder have been achieved. Figure 3 is a schematic of the feed preparation system, Fig. 4 is a photograph of the completed unit, and Fig. 5 is a photo of the "PaxPump."

TESTS - INCINERATOR SYSTEM

The incinerator is a two-stage, controlled air, electrically fired unit. It is patented and manufactured by Shirco, Inc. in Dallas, TX. The primary chamber uses a slowly moving woven wire mesh belt conveyor to slowly move material through the incinerator. Both the primary and secondary chambers are constructed of internal insulation and steel shells. Figure 6 is a schematic of the Shirco incineration system.

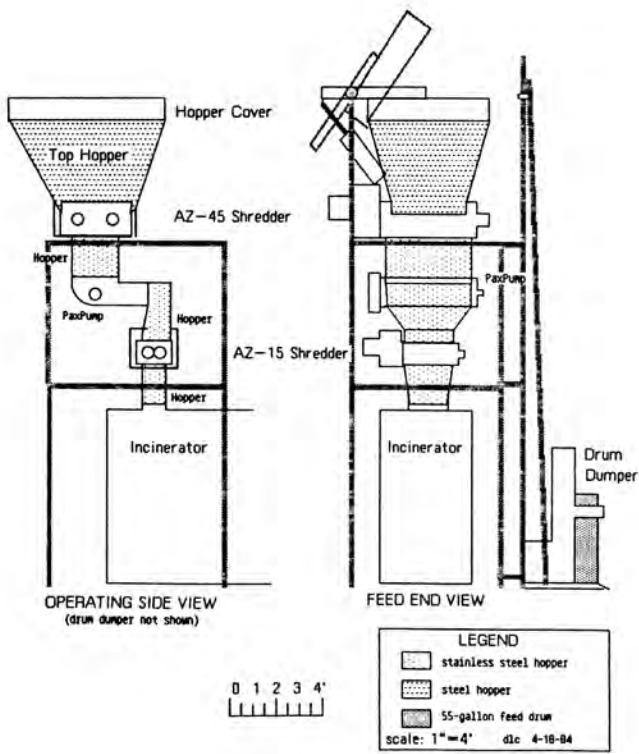


Fig. 3. Feed Preparation System.



Fig. 5. "PaxPump" Installed in Feed Preparation System.



Fig. 4. Photograph of Assembled Feed Preparation System.

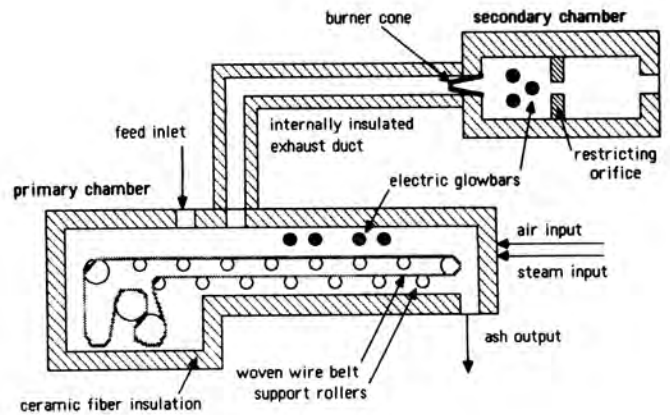


Fig. 6. Shirco Incineration System.

The incinerator system was tested for two weeks at the vendor's pilot facility. There were four test objectives:

- o Assess incinerator reliability and adaptability to remote maintenance.
- o Determine if off-gas emission requirements could be met.
- o Scout operating characteristics of the incinerator (residence time, feed rate, temperature) and determine the effects on ash quality and operation.
- o Test the incinerator on each of the separate categories of feed materials (cellulose, PVC, polyethylene, HEPA filters, and rubber) to simulate worst-case feed mixtures.

Individual waste components and mixes were tested. Off-gas measurements were made and the ash was characterized. Various process parameters were tested, including residence time, temperature, and combustion air flow. Results of the test relative to the test objectives are discussed in the following paragraphs.

1. Incinerator reliability - The process was operated continuously for 92 hours during the first week of testing and intermittently for 25 hours during the second week of testing. Operating utility was 84%; the unit was down for maintenance the other 16% of the time. Of the downtime, 12 hours were due to belt stoppages, 5 hours were due to problems with the primary chamber exhaust duct, and 2 hours were due to other reasons.

About 11 of the 12 hours of downtime due to belt stoppages occurred while the incinerator was being operated at 900°C. The tramp glass added to the simulated waste mix melted slightly and stuck to the belt and eventually jammed the pinch

rollers. This problem will be avoided in the future by operating the primary chamber at 850°C or less. Also, the incinerator was modified to address this potential problem.

The vendor's pilot unit had an externally insulated steel off-gas pipe between the primary and secondary chambers. A small leak developed in this pipe, and during the first two days of testing the flame from the secondary chamber moved back into the pipe on occasion. Downtime associated with this was about 5 hours. No effect on off-gas was observed as a result of the leak.

2. Off-gas test results - Table II summarizes data from off-gas sampling. Based on these data, the incinerator will produce acceptable off-gas while processing either the mix of waste or the individual components.
3. Incinerator operating characteristics - The effects of primary chamber operating temperature, feed rate, residence time, and steam addition were investigated. Measured variables included the remaining percent of carbon in the ash and power consumption. It is desirable to produce a carbon-free ash, as ultimately the ash will be disposed of via vitrification in the Defense Waste Processing Facility, and significant quantities of carbon could affect glass melter performance.

Table III is a summary of the conditions tested during the 118 hours of testing and also shows three states (s1, s2, and s3) from a pyrohydrolysis test discussed later. Regression analysis performed on the data indicates that the ability of the incinerator to produce carbon-free ash increases with temperature, residence time, and steam addition and decreases with increased feed rate, which is consistent with expectations. Also, acceptable ash can be produced at several operating conditions without exceeding 850°C, thus avoiding the range of operation where the tramp glass sticks to the belt.

TABLE II
Off-Gas Data from Shirco Test

	Total kg fed	Off-Gas Air Quality				
		SO ₂ (a)	NO _x	HCl	CO	Particulate
Waste mix	46	0.35	0.05	0.48	3.40	0.57
Component tests						
Cellulose	12	0.06	0.02	0.25	0.23	0.04
HEPA filters	16	0.03	0.04	0.83	1.00	0.18
Polyethylene	8	0.09	0.03	0.18	0.60	0.09
PVC	15	0.17	0.01	1.56	0.80	0.50
Rubber	14	2.10	0.07	0.24	1.10	0.06
State standard		1300	100	n/a	40000	60

(a) All concentrations are micrograms/cubic meter.

TABLE III

Summary of Incinerator Operation

State	Temperature (degrees C)		Feed Rate, kg/hr	Res Time, min	Steam Rate, kg/hr	Percent Carbon in Ash	Power (ave kw)	
	Zone 1	Zone 2					Pri	Sec
Mix-Base	750	800	5	20	0	8.1	13.8	21.0
mix- 1	650	650	5	20	0	8.4	9.5	18.0
mix- 2	650	650	5	20	5	5.2	5.0	17.0
mix- 3	650	650	5	30	0	10.1	9.1	23.8
mix- 4	800	750	5	30	0	2.7	7.0	21.3
mix- 5	800	900	10	30	0	0.1	11.0	20.5
mix- 6	800	900	10	20	0	10.1	13.0	12.5
mix- 7	750	900	10	20	0	19.6	5.0	9.0
mix- 8	750	650	10	20	5	4.1	1.5	10.0
mix- 11	750	900	5	20	0	0.0	13.3	13.3
mix- 12	750	900	5	20	5	0.1	13.5	13.5
mix- 13	750	900	5	20	0	0.6	16.5	16.3
mix- 14	750	900	5	30	0	0.5	15.6	17.3
Cellulose	750	900	5	30	0	1.7	16.9	14.7
HEPA's	750	900	5	30	0	6.8	13.2	13.3
Polyethyl	700	900	5	30	0	15.5	14.4	8.5
PVC	700	900	5	30	0	3.2	11.9	11.8
rubber	750	900	5	30	0	57.0	11.9	6.7
mix- s1	650	800	2	60	7	71.4	15.0	13.3
mix- s2	750	800	2	90	5	56.2	14.0	13.0
mix- s3	750	800	1	120	3	6.5	15.0	14.2

As can be seen from the data in Table III, with the exception of rubber, most of the carbon was removed from the ash from burning the individual waste component materials. A longer residence time would be needed for rubber, probably because shredding of latex gloves compressed the rubber into hard particles which burned more slowly.

TESTS - INCINERATOR BELT

The most critical aspect of maintenance of the unit is the life of the woven-wire belt. Corrosion of the belt is a key concern, as the belt is exposed to high temperatures and an alternating oxidizing/reducing atmosphere as it moves through the incinerator. To obtain corrosion data, a 400-hour belt test on a laboratory scale unit was completed at Shirco's laboratory. This unit was operated with counter-current air and simulated waste mix to expose the belt to alternating oxidation/reduction conditions.

Eight sections of the continuous belt were each made of a different alloy. Metallurgical testing was completed on the belt after it was operated for 400 hours. Four of the eight candidates corroded less than the others. One candidate, a cobalt-based superalloy (Haynes 188) appears to be most resistant, although the other materials cannot be ruled out as candidates. Table IV is a summary of results from the 400-hour belt test. Diameters of uncorroded metal were metallographically measured from polished cross-sections and tensile strengths were measured at the operating temperature of the incinerator. Initial tensile strengths shown are literature values.

PLUTONIUM RECOVERY POTENTIAL

Incinerator operation at the proper process conditions produces an ash compatible with plutonium recovery processes. For plutonium recovery from incinerator ash to be feasible, a primary chamber operating temperature of 600-800°C must be maintained and localized combustion must be avoided. Plutonium recovery generally involves dissolution of plutonium oxide in nitric acid and hydrofluoric acid. Oxides produced at temperatures less than 600°C are considered relatively easy to dissolve, while it becomes increasingly difficult with higher processing temperatures. Thus, incinerator operation is a key variable.

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 (pyro-hydrolysis) promotes endothermic hydrolysis reactions which strip carbon from the ash and make temperature control much easier. No combustion reactions occur, so localized hot spots are not a problem. However, pyro-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 must be examined on an individual basis.

A two-day pyro-hydrolysis test was performed in August 1983 on a pilot incinerator at Shirco, Inc.² The two major goals of the test were to demonstrate the ability of pyro-hydrolysis to maintain a constant temperature in the primary chamber and to produce a low carbon ash. Simulated waste used in the test consisted of polyethylene (14%), polyvinylchloride (14%), cellulose (44%), and latex gloves (14%). The waste mix was shredded to a nominal 2 inch square particle size.

Test burns were conducted at a primary chamber temperature of 800°C and waste/ash residence times of 60, 90, and 120 minutes (vs. 30-45 minutes under normal conditions). A steam injection rate of 1.8 kg of steam per kg of waste was used based on data obtained in a literature search.

Experimental data indicate very steady primary chamber temperature control at 800°C and complete carbon removal at a 120-minute residence time. A residence time of 120 minutes is equivalent to a processing rate of 2 kg/hr in the pilot furnace.

DESIGN - INCINERATION SYSTEM

Data obtained during the pilot runs were used to identify modifications to adapt the unit to alpha service. Specifications and design parameters were developed and a full-scale unit was built. Figure 7 is a photograph of the completed unit.

The unit and associated off-gas piping were designed to a 10 psi ASME design specification to contain any unplanned detonation of pyrolytic gases. Measures specified to adapt the unit to alpha service are discussed in the following paragraphs.

1. Belt drive system - The largest utility loss during the pilot testing was due to belt stoppages. The full-scale unit was built with a different angle on the pinch roll to provide a more positive hold on the belt, and a ratchet was added to turn the second pinch roll drum if the belt stops. This second drum can be electrically powered if necessary. A pneumatic (rather than spring) belt tensioner was installed, and a sensor alarms immediately if the belt stops.
2. Primary chamber cleanout - Small quantities of dust and ash gather on the bottom surface of the incinerator. Cleanout ports were added to the ends of the chamber and a coarsely woven wire mesh belt was placed on top of the insulation on the floor to protect the insulation during vacuuming. The off-gas system will be fitted with a vacuum port so that the incinerator can be vacuumed safely.

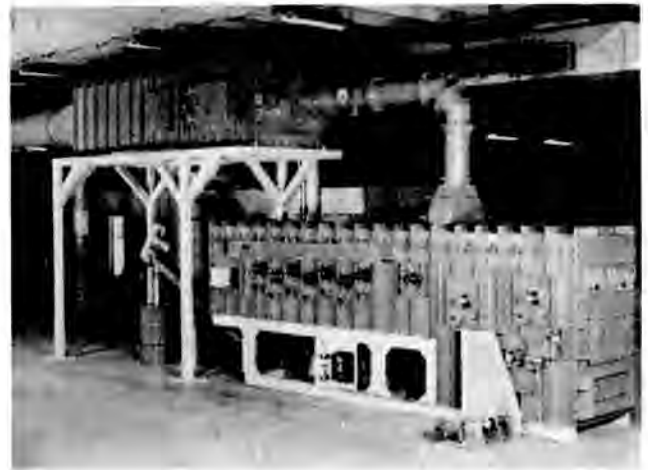


Fig. 7. Shirco Incinerator.

TABLE IV

400-Hour Belt Test Results

Alloy	---Initial---		-----Final-----				
	Dia, in.	TS at 870C	Diameter, in			TS at 800C	
			Ave	Min	Max	Ave	Min
Haynes 188	0.062	60700	0.053	0.037	0.062	46000	42000
Rolled Alloy 253	0.062	30600	0.048	0.040	0.058	34000	27500
AISI 314	0.062	18000	0.037	0.026	0.051	25000	19500
Inconel 625	0.062	40000	0.036	0.028	0.049	21500	17500

Based on this test, a Haynes 188 belt is projected to last for at least 3000 operating hours. The belt test materials exhibited embrittlement, which is not a major concern because the incinerator belt is not normally exposed to a bending moment. Ductility loss on these four alloys ranged from 85 to 97 percent.

3. Ductwork and secondary chamber - An auxiliary exhaust flange was added between the two heated zones in the primary chamber for testing purposes, as combustion of more volatiles in the primary chamber might reduce carbon load in the secondary chamber (hence higher throughput could be attained).

As just discussed, part of the utility loss during pilot testing was due to problems with an externally insulated exhaust duct. The full-scale unit was built with internally insulated ductwork. The secondary chamber (also internally insulated) was fitted with a restricting orifice at about 1/3 of its length to ensure turbulent flow throughout the chamber. It was designed to provide a residence time of 2 seconds. A continuous spark source was added to the entrance chamber to prevent unplanned detonations and maintain a stable flame front, especially when burning lean gases.

OFF-GAS SYSTEM

The off-gas system consists of an air dilution mixing tee, sintered metal filters, high efficiency particulate air (HEPA) filters, a pressure control valve, an induced draft blower, and a stack.

The air mixing tee was designed to efficiently mix dilution cooling air with the combustion gas entering the sintered metal filters.

The use of sintered metal filters for this type of process has been developed and demonstrated in prior SRL work.³ A full-scale unit was designed and built by Pall Trinity Micro Corp. in Cortland, NY. The unit consists of a stainless steel shell, a tube sheet, 162 porous metal filter elements totaling 200 square feet of filter area, and an air pulse blowback system. The porous metal filters are pre-coated with silica powder before startup and after each blowback cycle. The filter elements are inserted and pinned to the tube sheet and can be individually removed if necessary.

The HEPA and blower systems are of standard design.

PROCESS CONTROL SYSTEM

The entire PWI facility 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 Automation 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 reaction of events. This will be a valuable maintenance tool in a radioactive environment.

ACKNOWLEDGMENT

The information contained in this article was developed during the course of work under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

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