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**AUTOMATIC CONVEYOR TYPE LAUNDRY
ALPHA-BETA-GAMMA
CONTAMINATION MONITOR**

E. M. SHEEN AND G. D. CROUCH

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CONTAMINATION MONITOR

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ABSTRACT

An automatic radiation monitoring system was developed by the Pacific Northwest Laboratory for the Federal Support Services of International Telephone and Telegraph to scan laundered protective clothing and automatically reject contaminated garments. This system employs two stainless steel wire belt conveyors that transport the wearing apparel at a belt speed of 160 in./min between two large alpha-beta-gamma scintillation detectors that simultaneously monitor upper and lower surfaces of each item of apparel for alpha-beta-gamma contamination. The instrument reliably sorts items for further decontamination if they are contaminated to a level greater than the equivalent of 25,000 dis/min (11 nCi) of Ra DEF or 1000 dis/min (0.45 nCi) of 5 MeV alpha emitters distributed over 100 cm².

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AUTOMATIC CONVEYOR TYPE LAUNDRY
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INTRODUCTION

Protective clothing is worn by workers at Hanford in radiation zones to reduce the possibility of personal contamination and to inhibit the spread of radioactive contamination to clean working zones. After use, the protective clothing is returned to the Hanford Laundry Facilities, operated by the Federal Support Services of ITT, for washing and decontamination. Prior to being returned to the user groups, the wearing apparel is monitored for alpha-beta-gamma contamination, and clothing is sorted for possible further decontamination if necessary. Due to the large volume of protective clothing used by the various contractors throughout the Hanford complex, the monitoring process must be as rapid and efficient as possible.

This report describes a monitoring system, which was developed by the Pacific Northwest Laboratory of the Battelle Memorial Institute to fulfill these requirements.

SUMMARY

The developed protective clothing monitoring system incorporates a dual wire-belt conveyor to carry the miscellaneous types of protective apparel at a belt speed of 160 in./min between two large alpha-beta-gamma radiation detection probes. Eight, 5 in. diam photomultiplier tubes are combined with eight, 6 x 7 in. light pipes and dual-purpose scintillators to provide 1, 2, or 4 fully independent monitoring channels approximately 24, 12, or 6 in. wide, respectively, and to accommodate the various widths of miscellaneous garments.

Incorporation of the solid state pulse amplifying and counting circuitry within the probe housings resulted in a low-noise and interference-free pulse counting system. Voltage outputs from the alpha and beta-gamma count rate circuits operate the high-level trip circuits that actuate the electro-mechanical rejection mechanism. Altering the high-level trip point is accomplished through adjustment of a potentiometer located on the front panel of the main instrument console.

Beta-gamma background, measured by a separate detector and count rate circuit, is used to automatically compensate the high trip levels. With the conveyor motor speed adjusted to drive the wire belt conveyors 160 in./min, a reliable high level contamination trip is obtained using a 25,000 dis/min (11 nCi) Ra DEF beta-gamma source or a 1000 dis/min (0.45 nCi) ^{239}Pu source distributed over a 100 cm² area.

The upper conveyor assembly can be raised to permit monitoring rubber overshoes. In routine operation, the belt speed is 160 in./min and the beta-gamma count rate circuit time constant is 3 sec. If increased sensitivity is desired, it can be achieved by reducing the belt speed and increasing the time constant of the count rate circuits.

DISCUSSION

An overall front view of the monitoring system is shown in Figure 1. In monitoring miscellaneous protective clothing such as gloves, caps, etc., the upper conveyor belt is operated in contact with the lower belt. As the items of wearing apparel are loaded onto the conveyor, they are pressed between the upper and lower conveyor belts allowing the items being monitored to pass very close to the detectors to permit detection of alpha contamination. The stainless steel wire belts, manufactured commercially,* are 26.1 in. wide, constructed of

* Wire Belt Company of America, Winchester, Massachusetts

0.05 in. diam wire, with a mesh size 0.5 x 2.0 in. This implies a wire belt open area of approximately 90%.

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FIGURE 1. Front View of System

After the alpha-beta-gamma radiation is measured by the two scintillation probe assemblies, the item is conveyed to the rejection mechanism, shown in the rear view of the monitor, Figure 2. The rejection mechanism consists of a linear actuator* with holding solenoid, coil tension spring, actuating arm, shaft, and wearing apparel slide. Uncontaminated items are deposited into the forward receptacle, as a result of a trip signal (after a suitable delay time) causing release of the actuator-holding solenoid.

* "Polynoid Linear Actuator," Model 01B0403-10. Skinner Precision Industries, Inc., New Britain, Connecticut

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FIGURE 2. Rear View of Monitor

Figure 3 shows a block diagram of the electronic system, the operator panel switch control, the motor and control circuitry for raising and lowering the upper conveyor, printed circuit card locations, and provides references to the circuitry drawings.

DETECTION PROBE DESCRIPTION

Four 5 in. photomultiplier tubes (Amperex 54AVP) are used in each of the two large radiation detector assemblies and one 5 in. photomultiplier tube is used in the background radiation detector. Separate Lucite light pipes, 7 x 6 in. and 1 in. thick, were optically coupled to each of the photomultiplier tubes. Beta-gamma emitters are detected by a terphenyl-in-polyvinyltoluene scintillator* 0.02 in. thick and cut to cover the entire face of the light pipe. This thickness provides a nearly optimum ratio of beta-gamma contamination response to gamma background. The scintillator sheet is cemented to the face of the light pipe using epoxy cement.** This provides excellent optical coupling and a reliable bond.

The alpha detection scintillator*** is silver-activated zinc sulphide in decal form, cut to size and applied to the surface of the NE-102.

An aluminum foil light reflector is cemented to the back of the light pipe with rubber cement at the edges. This allows a small air space between the surface of the light pipe and the foil to permit total reflection of light rays striking the surface at the critical angle. The phototube and the foil-covered portion of the light pipe are covered with black plastic tape to provide light-tight assembly. The face of each detector is covered with two layers of 0.2 mg/cm^2

* Terphenyl-in-polyvinyltoluene (NE-102) manufactured by Nuclear Enterprises Ltd., Winnipeg, Canada.

** NE-580 manufactured by Nuclear Enterprises Ltd., Winnipeg, Canada.

*** Har-D-Cal., Williston, South Carolina.

aluminum "Dutch Leaf" and one layer of 0.9 mg/cm^2 double aluminized Mylar for light shielding. In the gamma background detection probe, the phototube and light-pipe assembly is fabricated in the same manner as previously described with the exception of deleting the ZnS(Ag) decal.

Four of the described assemblies are placed side by side in a light-tight metal container to form a composite radiation detector approximately 28 in. long and 7 in. wide. The radiation accepting surface of the detector is covered with copper household screenwire to protect the Mylar light shield. The two wearing apparel monitoring probes are mounted above and below the conveyor belts, allowing simultaneous alpha-beta-gamma monitoring of both sides of the item.

Figure 4 shows the probe photomultiplier base, pre-amplifier, amplifier, discriminators, and count rate circuit diagrams. Gain control is accomplished by varying the cathode end voltage of the resistance voltage divider network. A single transistor (2N3638) emitter follower preamplifier is utilized with each phototube to provide a low impedance voltage source to drive the beta-gamma and alpha pulse amplifiers. Alpha caused pulses are distinguished from beta-gamma caused pulses on an amplitude basis with the beta-gamma discriminators set at 1.5 volts. The beta-gamma amplifier voltage gain is approximately 50 and the alpha amplifier gain is approximately 10. Additional alpha to beta-gamma separation is accomplished by adjustment of a 2,500 ohm potentiometer in the emitter circuit of the preamplifier. Both pulse amplifiers are similar, employing a common emitter stage followed by a common collector stage. The effective collector circuit impedance of the input transistor (2N3605) is increased by a diode-capacitor bootstrap network to increase the open loop voltage gain for negative input pulses. Preamplifier output pulses (negative) are converted to current by the input

resistor and summed with the negative feedback current at the base of the input transistor. Amplifier output pulses are positive and are electronically compared with a 1.5 volt reference level for noise discrimination.

The positive discriminator beta-gamma pulses trigger a binary that drives a feedback diode pump from a complementary emitter follower output. Increments of positive charge are placed on the 47 μ F capacitor and slowly removed, principally by the resistance calibration network, but to a minor extent by the base current of the 2N3605 emitter follower. The 2N3605 emitter voltage is monitored by a 2N1132 that is maintained at constant emitter current by the 2N396 current source. This dc output voltage, directly proportional to beta-gamma count rate, is cabled to the main chassis for background subtraction and comparison with a fixed reference (trip) voltage.

A monostable multivibrator is used in the alpha channel in place of the beta-gamma binary because of the few alpha caused pulses normally detected during the brief scanning time. In other respects, the circuits are identical.

Photomultiplier No. 1 of the upper probe aligns vertically with No. 5 of the lower probe to provide a single narrow monitoring channel on the wire belt, and the other tubes align consecutively. The eight beta-gamma and alpha count rates are independently compared with the trip or reference voltage and a corresponding trip lamp is illuminated on the main cabinet (refer to Figure 1). Maintaining the count rates independently, assists in locating a light leak in the probe light shielding, should one occur.

All of the pulse circuits, through the count rate circuit, are located in the probe housing to avoid electrical interference from arcing relay contacts on the machine and from other possible noise sources.

TRIP CIRCUITS AND FAILURE INDICATOR

Trip circuits, both alpha and beta-gamma, are shown in Figure 5. Beta-gamma count rate dc voltage inputs are identified as to upper or lower probe and tube number. For example, the beta-gamma count rate output of phototube No. 1 in the lower probe is identified by L- $\beta\gamma$ -1, etc.

A solid state operational amplifier is used as a zero crossover detector to examine a 24.9 k Ω resistor summation network consisting of three resistors; one for the count rate, one for inverted background, and another for the trip reference voltage. Thus, at the trip point, the summation node voltage is within a few millivolts of zero, and the current from the count rate resistor is just equal to the sum of the reference current and inverted background current. For count rates in excess of this value, the operational amplifier output saturates to the -15 V dc level, and the output 2N3638 emitter follower provides a high current output capability to drive the logic network and the 1 k Ω base resistor of the 2N1373. This transistor drives the red trip alarm lamp. The trip voltage reference generator consists of a 10 k Ω , 10-turn potentiometer with the output voltage buffered by a solid state operational amplifier voltage follower that has an emitter follower current booster incorporated within the feedback loop.

The beta-gamma background count-rate voltage ($\beta\gamma$ -9) is observed by a panel meter, and inverted by a unity gain, solid state, operational amplifier, which also incorporates an emitter follower within the feedback loop to provide high output current capability.

Alpha count rate identification and trip circuits are similar to those employed in the beta-gamma channels, except that no background subtraction is needed.

Normal beta-gamma count rate background voltages are in excess of 1 volt, and a simple transistor switch, with the input current limited by a 100 k Ω base circuit resistor, detects failures such as open count rate circuit connections, pulse circuit failure, and high voltage supply voltage failure. Silicon signal diodes from the collectors of the 2N3638's form a 9-input "OR" circuit to give a 10 k Ω connection to common, if any input falls below approximately the 1 volt level. Current through one or more of these 10 k Ω paths operates a set of transistor switches in the low background failure indicator circuit. These switches energize the "SONALERT"* annunciator, and the red panel lamp "failure" indicator, and also disconnect the green panel lamp "normal" indicator.

The trip circuits and failure indicators are fabricated on printed circuit cards and located in a printed circuit file in the main cabinet. Figure 3 shows the card locations.

TRIP SIGNAL LOGIC, TIME DELAYS AND REJECT CIRCUITS

Both alpha and beta-gamma trip signals from vertically aligned photomultipliers are combined with two input negative-going "OR" circuits shown in the upper left in Figure 6. In Position 1 of the control panel switch, 12-pole reed relays K1A and K2B are energized. The relay K1A contacts, together with diode "OR" gates, permit the triggering of trigger time delay set No. 1 by an alpha or beta-gamma trip signal caused by either phototube No. 1 or No. 5. Time delay set No. 1 then actuates the first of four actuators after a suitable time delay. Trip signals from the other three pairs of vertically aligned phototubes similarly trigger time delays relay sets No. 2, 3, and 4; thus, in Position 1, the belt width is divided into four, narrow, independent monitoring channels.

* Mallory Type SC628.

In Position 2, time delay set No. 1 is triggered by either a beta-gamma or alpha trip from phototubes 1, 2, 5, or 6, and time delay set No. 1 drives both actuators No. 1 and No. 2. Similarly, trips caused by the other phototubes are combined to drive time delay set No. 3, resulting in two independent 13 in. wide monitoring channels.

In Position 3, all alpha and beta-gamma trip signals are combined with logical "OR" functions, and a trip signal from any phototube position operates time delay set No. 1 and subsequently all four reject actuators operate.

Time delays $\Delta T-1$ and $\Delta T-2$ of each time delay set are Unijunction* transistor circuits with binary control. The input pulse sets the binary, and after the delay time, the Unijunction transistor circuit generates a reset pulse to the binary. After the first delay period (approximately 6 sec) when the binary for time delay $\Delta T-1$ is reset, the connected holding coils on the electro-mechanical rejection mechanism are released, allowing each tension spring to pull the corresponding rejection slide to an upright or reject position (Figure 2). Simultaneously, with resetting time delay $\Delta T-1$, time delay $\Delta T-2$ is started. During its timing period, approximately 10 sec, the rejection slide remains in the reject position; and after the timing period is completed, time delay $\Delta T-2$ is reset, and power is applied to the two phase induction coils of the rejection actuator. This power, applied for approximately 0.7 sec, is determined by a mono-stable multivibrator (time delay $\Delta T-3$). At this time the rejection slide is returned to a non-reject position. The power is then removed, and the energized holding coil maintains the rejection slide in this non-reject position until another reject signal is received.

* Trademark of the General Electric Company.

Time delays are necessary because the radiation detecting probes are located some distance from the discharge end of the monitoring system. The timing period of time delay $\Delta T-1$ corresponds to the shortest possible time required for the item of wearing apparel to traverse from the probe to the discharge end of the conveyor belt. The period of time delay $\Delta T-2$ corresponds to the longest possible time required for the contaminated item to pass from the belt to the "contaminated apparel" hamper. Time adjustments for time delays $\Delta T-1$ and $\Delta T-2$ were determined experimentally, based on the conveyor belt speed and the longest item to be monitored.

The conveyor belt speed can be changed by means of a variable speed motor* to another preset speed. A second set of delay times are placed in operation by relays PK-1 through PK-3, which change the charging current to the emitter circuit capacitance of the Unijunction transistors.

An emitter follower (2N3638) pulse output from time delay $\Delta T-3$, operated a 2N1906 power transistor emitter follower which connects to the gate terminal of a TRIAC**. The TRIAC conducts the high ac current (8A) from the actuator two-phase coils.

ITEM LOADING INDICATION & TOTALIZER

To properly set the minimum space between items, four sets of loading indicator lamps (photo-resistor controlled) are used. Circuitry for this system is shown in Figure 7. As an item is loaded on the conveyor belt, in any channel, it passes between the photo-resistor and its light source. The resulting voltage change activates the input transistor switch, sets a binary, and energizes the red lamp. As the item approaches

* "Adjusto-Speed" induction motor, Model No. 5041 equipped with printed circuit board assembly No. 5-47 and speed reducer style A-2. Eaton Manufacturing Company, Kenosha, Wisconsin.

** General Electric Company, Type SC-450.

the discharge end of the conveyor belt, it passes between another photo-resistor and light source assembly. This action also energizes circuitry which de-energizes the red light, and a green light is energized. The green light indicates that another item may be placed on the conveyor.

An item totalizer, which operates from signals received from the red loading lights, indicates the number of items passed through the monitoring system.

For safety purposes, a stop switch (push-button) is located to the left of the panel control switch (Figure 1), and an adjustable slip clutch is located in the drive mechanism for the conveyor belt.

RESULTS AND CONCLUSIONS

Installed since February, 1967, the system has been well accepted by operating personnel with reliable operation achieved for several thousand hours of machine time.

Sensitivity to alpha and beta-gamma radiation exceeded requirements with 25,000 dis/min of Ra DEF and 1000 dis/min of 5 MeV alpha emitter (distributed over 100 cm² areas) reliability detected. Sensitivity can be readily increased, if desired, by decreasing belt speed and increasing the count rate circuits time constant.

Some minor mechanical difficulties were noted and corrected. Some rejected items were sufficiently stiff and failed to deflect downward, touched the bottom side of the slide, and move onto the lower conveyor assembly. This problem was solved by the addition of a soft-bristled wide brush between the item slide and the end of the conveyor belt. Table I shows the number of various types of wearing apparel that can be monitored per 8 hr shift.

TABLE I. *Wearing Apparel Items Typically Monitored
Per 8 hr Shift*

<u>Item</u>	<u>Arbitrarily Selected Shift</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
Cloth and Rubber Gloves	1468	1220	2946
Cloth Caps	1274	none	none
Cloth Hoods	none	562	404
Canvas Shoe Covers	475	140	1015
Canvas Boots	1400	290	none
Towels	none	none	52
Rubber Overshoes	<u>1371</u>	<u>1143</u>	<u>1048</u>
Total Items Monitored Per Shift	5988	3355	5465

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FIGURE 3. Block Diagram, Panel Control, and Printed Circuit Card Location

FIGURE 4. Probe Pulse Circuits and Wiring

FIGURE 6. Trip Signal Logic, Time Delays and Reject Circuits

FIGURE 7. Item Loading Indication, Totalizer, and Power Supplies

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