GAMMA DETECTOR FOR USE WITH LUGGAGE X-RAY SYSTEMS

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Abstract

A new gamma radiation sensor has been designed for installation on several types of luggage x-ray machines and mobile x-ray vans operated by the U.S. Customs Service and the U.S. Department of State. The use of gamma detectors on x-ray machines imposed difficulties not usually encountered in the design of gamma detectors because the spectrum of scattered x-rays, which varied from machine to machine, extended to energies significantly higher than those of the low-energy isotopic emissions. In the original design, the lower level discriminator was raised above the x-ray end point energy resulting in the loss of the americium line associated with plutonium. This reduced the overall sensitivity to unshielded plutonium by a factor of approximately 100.

An improved method was subsequently developed wherein collimation was utilized in conjunction with a variable counting threshold to permit accommodation of differing conditions of x-ray scattering. This design has been shown to eliminate most of the problems due to x-ray scattering while still capturing the americium emissions. The overall sensitivity has remained quite high, though varying slightly from one model of x-ray machine to another, depending upon the x-ray scattering characteristics of each model.

1. System requirements

This gamma ray radiation detection system is intended to detect small amounts of radioactive material in luggage and parcels with a low false alarm rate. The system must operate in natural background and with the x-ray inspection system actively examining objects. Depending upon the operation of the x-ray machine the actual background due to x-ray scatter may significantly exceed the natural background rate. In addition, the length of time that a suspect package is actually within the field of view of the detector can be quite small as the package passes the detector while being loaded onto an x-ray machine conveyor belt. These constraints greatly complicated the selection of a detector and the design of the system.

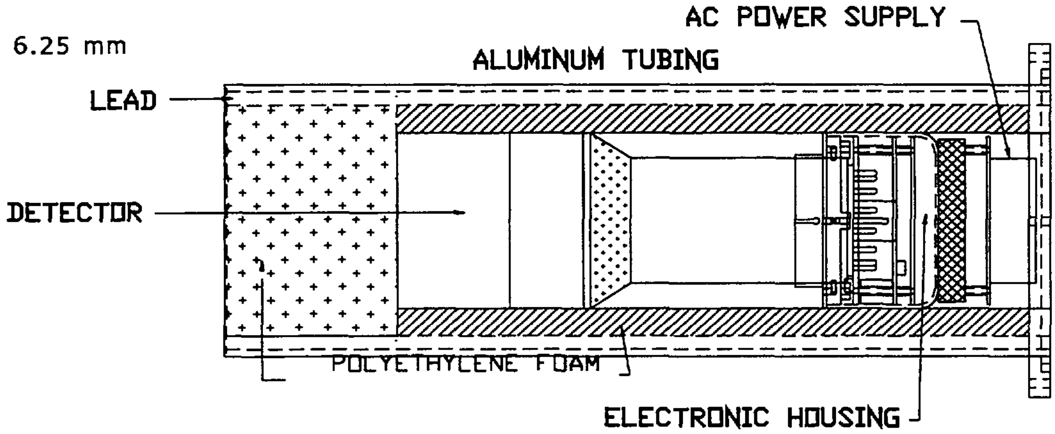
1.1. Luggage x-ray detector system

The first generation luggage x-ray detector system was based upon a 7.5-cm-diameter by 5-cm-thick NaI scintillator. The detector was housed in an enclosure lined with 6-mm-thick lead. This system readily met the sensitivity requirements. When this system was installed on x-ray machines, it was determined that x-ray scattering was generating high levels of erroneous or false alarms. A decision was made at that time to raise the energy threshold above the end point energy of the x-ray source (140 keV). When this was done, the false alarms disappeared but the unit could no longer detect the americium line from the plutonium decay chain (60 keV). The system could still detect the other higher energy gammas produced by plutonium, however, with reduced sensitivity.

The principal objective of the second generation luggage x-ray detector design was to enhance the original design to detect the 60 keV americium emission while operating in a moderate x-ray field. This problem was tackled on both electronic and mechanical fronts.

2. Mechanical design

Reduction of x-rays entering the detector was given the top priority in the new design effort. First, the detector shielding was increased to 6.25-mm-thick lead which reduced the 140 keV x-rays by greater than 99%. Next, a study was conducted to find the best method to minimize the field of view to that necessary to screen packages passing through the x-ray machine; excessive field of view presented a path for unwanted scattered x-rays to be picked up by the detector. Various collimator designs were tested using lead and steel assemblies placed over the detector face. The final design achieved the reduction in field of view by recessing the detector approximately 7 cm into the lead shield, creating a conical field of view of approximately 45 degrees from the centerline. Sensitivity was thus retained but the overall length of the instrument and the corresponding weight increased. A cross sectional drawing of the detector and electronics is shown in Figure 1.



The effectiveness of this shielding/collimation scheme can be shown by comparing the natural background count rate of the detector without any shielding (250 counts/second) versus the count rate with the detector installed in the enclosure, 60 counts/second. Measurements taken at the entrance to some models of x-ray machines with an unshielded detector showed that the scattered x-ray count rate could occasionally exceed 20,000 counts/second. Using this enclosure design, the count rate due to scattered x-rays was reduced to a maximum of 240 counts/second on the worst case model of x-ray machine (see Table I). The actual scattering was a function of the relative positions of parcels being x-rayed and the position of the operators who were loading the parcels and includes natural background of 34 to 73 counts/second depending on the orientation of the collimator.

Table I. Gamma backgrounds for various luggage x-ray installations

System	Detector Background, counts per second

Van x-ray, including handler scatter	240 ±59
Luggage x-ray	164 ±10
Luggage x-ray, with added curtains	105 ±7.5
Pallet x-ray (preliminary)	205

The detector assembly is connected to an operator's control panel. The control panel is generally mounted near the x-ray machine keyboard. The detector is mounted near the entrance or exit of the x-ray machine at a height approximately 35 cm above the surface of the conveyor belt.

3. Electronic design

To handle the residual x-ray scatter that the shielding did not eliminate electronic methods were developed. Raising the energy threshold was unacceptable; the only other variable of opportunity was the count rate threshold. The count rate threshold on the most sensitive alarm level has been historically set at 8 sigma of the natural background to achieve a low false alarm rate. Upon application of power, the unit collects the background count rate and stores this value in memory. The true background in the x-ray machine environment consists of the natural background plus the x-ray scattering background. Since the x-ray scattering is a function of the particular x-ray machine, each machine type required a different value for x-ray scattering background. A 16 position switch whose setting was proportional to the x-ray scatter count rate was installed inside the operator's control panel. The setting of this switch was determined empirically for each type of x-ray machine. An attempt was made to determine the worst case scattering condition. The switch setting is designed to reflect the worst case scattering condition. This switch, which is set at installation, is read by the microprocessor immediately after power is applied. The microprocessor then adds this value to the natural background count rate and calculates the standard deviation of the total background. The lowest alarm level is then set to eight times the standard deviation of the total background rate.

4. Installation

The detector design proved robust in actual practice. However, to maintain maximum sensitivity, some additional modifications were found to be necessary. On van-type installations, it was determined that scattering into the detector could be significantly reduced by placing the detector at an angle of approximately 15 degrees to the axis of the vehicle (the x-ray emitter slit is aligned with the vehicle axis). The angular placement of the detector still provided adequate scanning operation while loading the conveyor. Lead curtains were installed on another model to greatly reduce scattering into the detector.

5. System alarm levels

Operator alarm levels are given in Table IV. Alarm level 9 has been adjusted to represent 4 mR/hr from Cs-137 at the entrance to the detector collimator. Alarm level 3 is approximately 15 microR/hr.

Table IV. System alarm levels

Alarm Level	Net Counts per Second (cps)
1	0
2	120
3	350
4	860
5	1350
6	3110
7	17680
8	28190
9	41340

6. Sensitivity data

Table II presents the measured sensitivity for various isotopes in terms of the net counting rates found in the laboratory at a distance of 60 cm to the scintillator face.

Table II. Gamma radiation sensitivity

Source Type	Sensitivity
Medical Isotopes	
^{111}In	63900 cps/mCi
^{201}Tl	38400 cps/mCi
^{99m}Tc	36800 cps/mCi
^{67}Ga	38900 cps/mCi
^{133}Xe	15500 cps/mCi
Industrial Isotopes	
^{241}Am	9230 cps/mCi
^{137}Cs	5310 cps/mCi
^{60}Co	5210 cps/mCi
^{237}Np	26700 cps/g
^{238}U	135 cps/g
Special Nuclear Material	
^{235}U	9.2 cps/g
^{239}Pu, 40 to 3000 keV	29017 cps/g
^{239}Pu, 70 to 3000 keV	190 cps/g

6.1 Comparison with first generation detector system

Table III shows that a significant improvement in plutonium detection sensitivity has been achieved with the new design.

Table III. Detection sensitivity for plutonium

System	Grams Pu-239	Grams Pu-239 Lead Shielded
First generation	1	5
Second generation	0.02	7