PNL-SA-17137

PNL-SA--17137

DE90 006124

NEUTRON DETECTION BASED ON SUPERHEATED MATERIALS

D. R. Sisk
C. M. Stroud
K. L. Swinth
R. E. Apfel*

January 1990

Presented at
IEEE 1989 Nuclear Science Symposium
San Francisco, California
January 22-26, 1990

Prepared for
the U.S. Department of Energy
Assistant Secretary for Environment
Safety and Health
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

*Apfel Enterprises, Incorporated

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INTRODUCTION

The environmental and radiation responses of the Active Personnel Dosimeter/Superheated Drop Detector (APD/SDD) combination have been evaluated at the Pacific Northwest Laboratory (PNL) for the U. S. Department of Energy's Neutron Measurement and Evaluation Program. This paper provides results of the evaluation and discusses possible improvements for the current system.

Radiation detection based on the radiation sensitivity of superheated liquids has been studied for some time [1,2]. A liquid is superheated if it exists as a liquid at a temperature-pressure state normally associated with the vapor phase of that material. The liquid does not vaporize because there are no bubble nucleation sites in the sample. These sites usually exist 1) in microscopic cracks on solid container surfaces, 2) in crevices of imperfectly wetted solid particles suspended in the liquid, or 3) as a result of the radiation-matter interaction producing a microbubble that is large enough for bubble growth to be thermodynamically favorable. By suspending small drops of superheated liquid in an immiscible, inert, impurity-free medium, potential for bubble nucleation by the first two mechanisms is eliminated. Therefore, each drop becomes a miniature radiation detector. Using superheated liquids for neutron dosimetry was first described by Apfel [3] who would later patent the Superheated Drop Detector (SDD)[a] [4]. Subsequently efforts at Chalk River, Canada, have resulted in a similar neutron dosimeter, the BD-100 [5,6].

The SDD consists of a large number of superheated droplets (30,000-40,000) suspended in a semisolid medium (a mixture of water, glycerine, and gel). The composition is contained in a small glass vial (4 ml), sealed with a screw cap to maintain static pressure on the composition. The SDDs are stored in a refrigerator prior to use. Neutron interactions with the superheated droplets result in vaporization of the superheated drops and bubble formation. Bubble formation is accompanied by an acoustic pressure pulse. Once a bubble is formed, it slowly rises out of the suspension gel. The number of bubbles generated by the interaction is proportional to the intensity of the neutron radiation, and therefore, the dose equivalent. The SDD has a sensitivity of approximately 30 bubbles/mrem.

The Active Personnel Dosimeter (APD) is a portable electronic instrument (15.9 cm X 11.4 cm X 2.9 cm; <0.5 kg) that provides an integrated digital count of bubbles formed in the SDD (Figure 1). The SDD slips into a holder in the APD. A gas collection cap on the SDD collects gases liberated by the bubbles that rise to the surface of the gel. Acoustical transducers surrounding the SDD detect the pressure pulse which accompanies bubble formation. The signal from the transducers is routed through discrimination

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(a) Apfel, R. A. March 1979. "Detector and Dosimeter for Neutrons and Other Radiation." U.S. Patent 4,143,274.

and anticoincidence circuitry before entering the counting circuitry (Figure 2). The anticoincidence circuitry employs an additional acoustical transducer located away from the SDD. The transducer detects acoustical noise and vibration. Signals from the SDD transducers arriving in coincidence with signals from the noise transducers are rejected as noise and the APD disregards any signals from the SDD for the next 250 msecs.
The APD/SDD system's environmental and radiation response was tested. The environmental tests performed at PNL were on temperature, pressure, and mechanical vibration. The radiation response tests analyzed intermittent use, variability, linearity, x-ray sensitivity, and energy dependence. In addition, dose equivalents measured by thermoluminescent dosimeters (TLDs) and a standard neutron survey meter were compared with SDD responses.

ENVIRONMENTAL TESTS

Temperature Test

The APD/SDD system's response to temperature changes was tested by obtaining APD/SDD response data at temperatures of 10°C, 22°C (room temperature) and 32°C. At each temperature, the APD/SDD was exposed to a ^{252}Cf neutron calibration source with a strength of 100 mrem/h. The test was performed in two rounds. In the first round, the same SDD was exposed at all temperatures. In the second round, a new, fresh SDD was exposed at each temperature. The responses of the SDD at the test point temperatures were compared with the response at room temperature. The response of the SDD decreased by 6 to 7% per °C from 22°C to 10°C and increased by 4 to 5% per °C from 22°C to 32°C.

Pressure Test

The response of the SDD was measured at three pressures below room pressure to determine the effect of pressure changes. The three pressures corresponded to altitudes of 1000 ft, 2500 ft, and 5000 ft. The altitude of the laboratory is approximately 400 ft. The SDD was exposed to a ^{252}Cf neutron reference source (~50 mrem/h) at each pressure including room pressure. The responses of the SDD reflected no significant dependence on ambient pressure within the test range.

Vibration Test

Vibration testing involved vibration of the APD/SDD on each of three orthogonal axes and comparing pre- and postvibration responses to a ^{252}Cf neutron reference source (50-60 mrem/h). The APD/SDD was vibrated on an electrodynamic vibration table between 15 Hz and 200 Hz at an acceleration of 3 X g. Previbration and postvibration responses did not differ significantly. However, during vibration, significant numbers of false events registered on the APD, resulting from the imbalance of the discriminators in the anticoincidence circuitry. Vibrations were repeated after adjustments were made to the noise transducer discriminator. The discriminator was set to increase the sensitivity of noise channel of the anticoincidence circuitry. The increase in sensitivity resulted in a nearly complete rejection of false events.

RADIATION RESPONSE TESTS

Intermittent Use Test

The effect of intermittent exposure on the SDD was evaluated over 48 hours in two 24-hour intervals. The SDD was first exposed to a ^{252}Cf neutron reference source (100 mrem/h). The SDD was then removed from the APD, sealed with a screw cap, and stored in a refrigerator for 24 hours. At the end of this period, the SDD was inserted back into the APD after equilibrating at room temperature and re-exposed. This was repeated for a second interval of 24 hours. The test was performed with two SDDs. The SDD response at 24 hours and 48 hours did not differ by more than a standard deviation from the response at the start of the test. Therefore, no degradation in response was observed.

Variability Test

Variability testing was performed by exposing SDDs of identical composition to the same reference source and comparing their responses. The APD/SDD was exposed four times to a ^{252}Cf neutron reference source (300 mrem/h) for 20 minutes, using a new, fresh SDD for each exposure. The average responses of the SDDs did not differ beyond their associated standard deviations (~17%).

Linearity Test

The linearity of the SDD was evaluated by exposing it to a ^{239}PuBe neutron source (9.7 mrem/h) for 18 hours. The response of the SDD was recorded by video camera during the exposure period. Figure 3 illustrates the integrated response of the SDD as a function of elapsed time. Table 1 lists linearity characteristics of the SDD at different intervals of accumulated dose equivalent. The reduction in linearity with increased dose equivalent results from the decrease in concentration in superheated droplets in the SDD composition. The manufacturer recommends the use of one SDD for one month or 150 mrem, whichever comes first. In the event of a single large exposure (to 2 rem), the manufacturer states that the dose can be quantified with the assistance of calibration data supplied with the SDDs.

Table 1. Maximum Percent Change in SDD Response from True Linear Response Based on 0-10 mrem Response

Dose Equivalent Range, mrem	Maximum Percent Change from Linear Response
0-20	$\leq$ - 5%
30-50	$\leq$ -10%
50-120	$\leq$ -20%
120-175	$\leq$ -25%

X-ray Exposure Test

The SDD sensitivity to M150 (70-keV average) and H150 (120-keV effective) x-rays was evaluated. One SDD was exposed to each x-ray at a high exposure rate (M150, 197 R/h; H150, 11.8 R/h) for 5 minutes. X-ray exposures were preceded and followed by 15-minute exposures to a ^{252}Cf neutron reference source (150 mrem/h). Pre- and postexposure responses of the SDD did not differ beyond associated standard deviations (~15%). Therefore, the M150 and H150 x-rays do not significantly affect the response of the SDD.

Energy Dependence Test

The SDD was exposed to a D_2O-moderated and unmoderated ^{252}Cf encapsulated neutron source to determine energy response. The average neutron energy of the moderated flux is 0.5-MeV fluence weighted and the neutron energy of the unmoderated flux is 2.0 MeV fluence weighted. The moderated flux is generated using an National Institute of Standards and Technology (NIST) D_2O sphere to surround the source. The moderated and unmoderated SDD responses did not differ beyond their associated standard deviations and, therefore, were not significantly different. Similar measurements by the manufacturer show the SDD to agree well with NCRP recommendations for energy response (Figure 4) [7].

COMPARISON MEASUREMENTS

Comparison measurements were performed with the APD/SDD system, five-element thermoluminescent dosimeters (TLDs), and a standard neutron survey meter. The measurements were performed in a plutonium processing facility. The APD/SDD was placed on a shelf and used as an area monitor. Three five-element TLDs were mounted on a chest phantom and the phantom was placed adjacent to the APD/SDD. The dose equivalent rate near the APD/SDD was measured by the neutron survey meter at regular intervals over the exposure period. The total neutron dose equivalent for the exposure period was determined from the APD/SDD, TLDs, and survey meter data. Target accumulated neutron dose equivalents ranged from approximately 10 mrem to 200 mrem. Room temperature remained between 68°F and 74°F. The response of the APD/SDD was converted to dose equivalent using the calibration data supplied by the manufacturer. Dose equivalents measured by the APD/SDD varied in comparison to TLD and survey meter dose equivalents. Table 2 lists the relative response of the APD/SDD to that of the neutron survey meter at several dose equivalents.

Table 2. Ratios of the Response of APD/SDD to Neutron Survey Meter at Selected Dose Equivalents

Dose Equivalent mrem*	Ratio of APD/SDD Response to Neutron Survey Meter Response
37.5	0.86
79.0	0.76
109.0	0.82
176.0	0.50

* Neutron survey meter

Temperature corrections were not applied to the APD/SDD responses in Table 2. The exact temperature during each exposure was not available. A temperature correction could be applied to increase the APD/SDD response by approximately 11% assuming the temperature remained at 68°F during the exposures. This would bring some of the APD/SDD responses in line with the TLD and survey meter data. However, differences still exist and further study will continue.

CONCLUSIONS

The APD/SDD system provides real-time display of dose equivalent resulting from neutron exposure. The APD/SDD has good neutron sensitivity and a practical readout system. The SDD is insensitive to moderate pressure changes and vibration, and is not affected by M150 and H150 x-rays or intermittent use within a reasonable time period. The energy response of the SDD agrees well with recommended response. The linearity of the SDD decreases with increasing accumulated dose equivalent due to the reduction of superheated droplets. The SDD is also severely temperature-dependent. The useful range is roughly 0-150 mrem; use at higher levels requires a manufacturer-supplied calibration curve. The temperature sensitivity requires use in a relatively stable thermal environment, or the use of a "thermal isolation chamber" (provided by the manufacturer) to keep the APD at a relatively constant temperature.

Improvements can be made in several areas of the APD/SDD system. Using surface-mount and microprocessor technology could reduce the size and weight of the current system by a factor of 2 or more. The APD/SDD could be configured to automatically perform temperature and linearity corrections using onboard calibration data. These modifications will extend the effectiveness and dynamic range of the APD/SDD, thereby making the system a more viable method as a real-time neutron dosimeter.

ACKNOWLEDGMENTS

This work was performed for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830. The authors would like to thank T. J. Wirth, Westinghouse Hanford Company, for conducting the comparison measurements.

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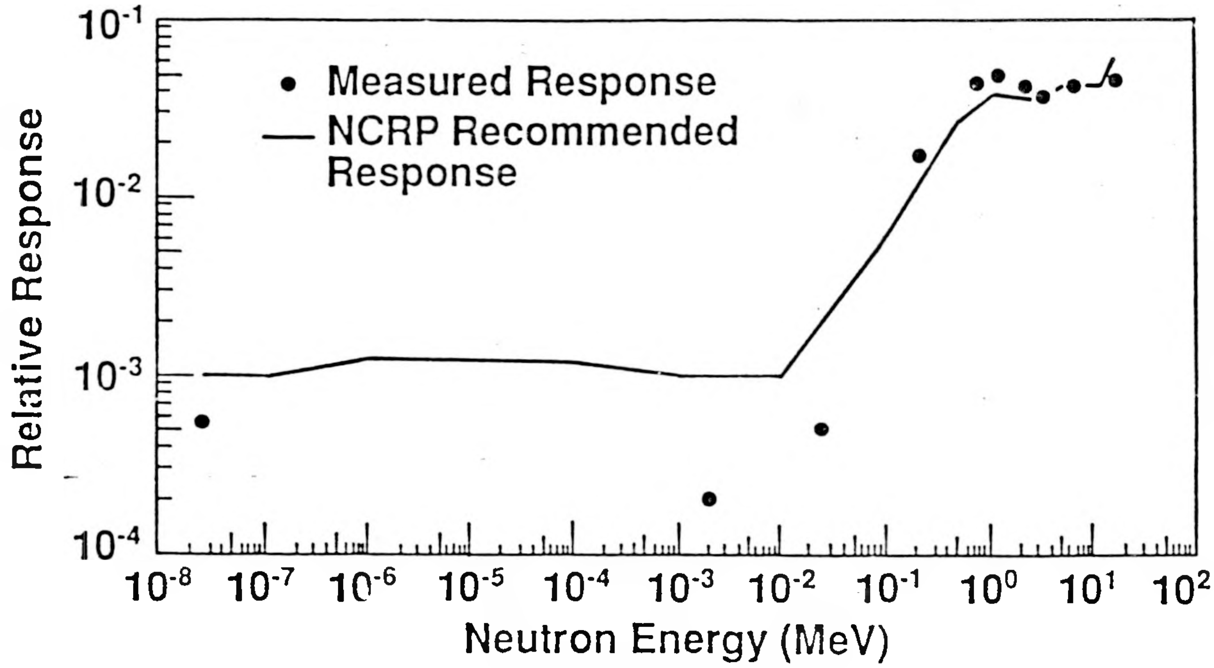

Figure 4. SDD Response Versus Energy

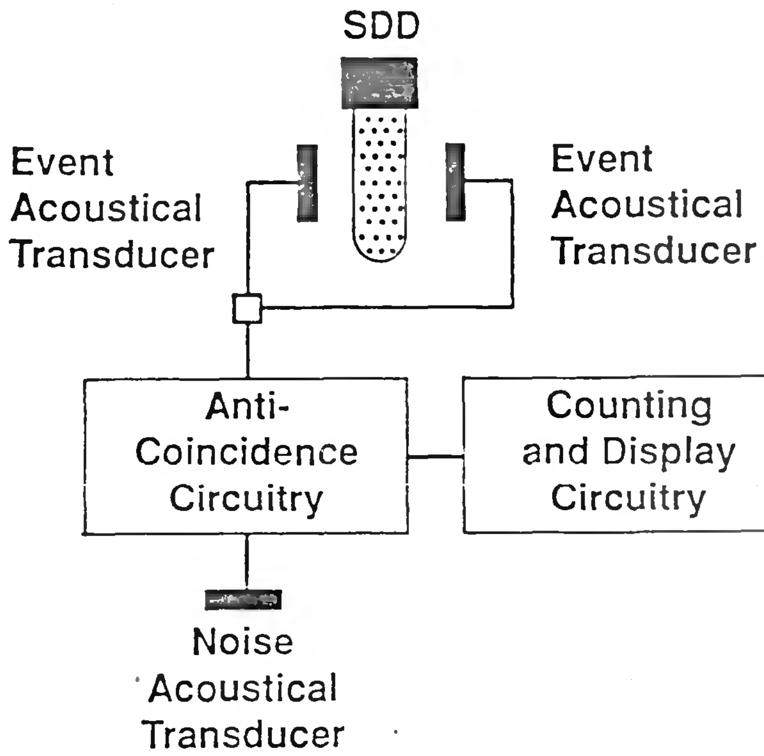

Figure 2. Block Diagram of APD/SDD

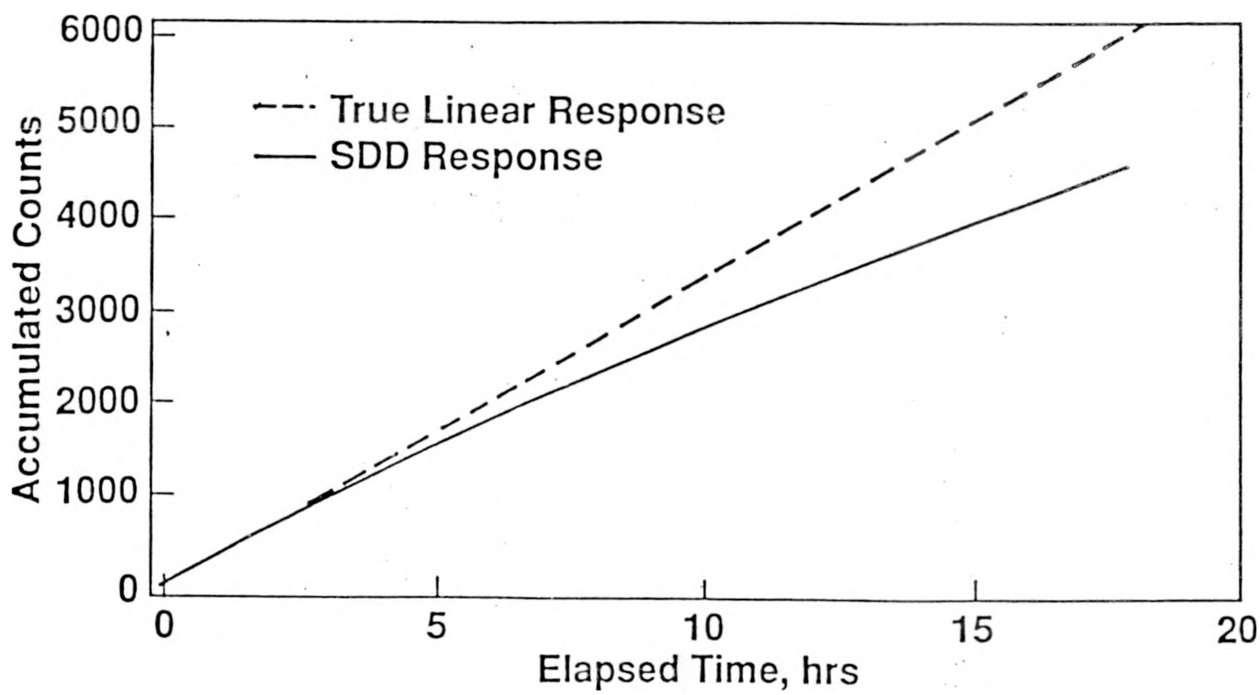

Figure 3. SDD Response at Constant Dose Equivalent Rate (10 mrem/h)

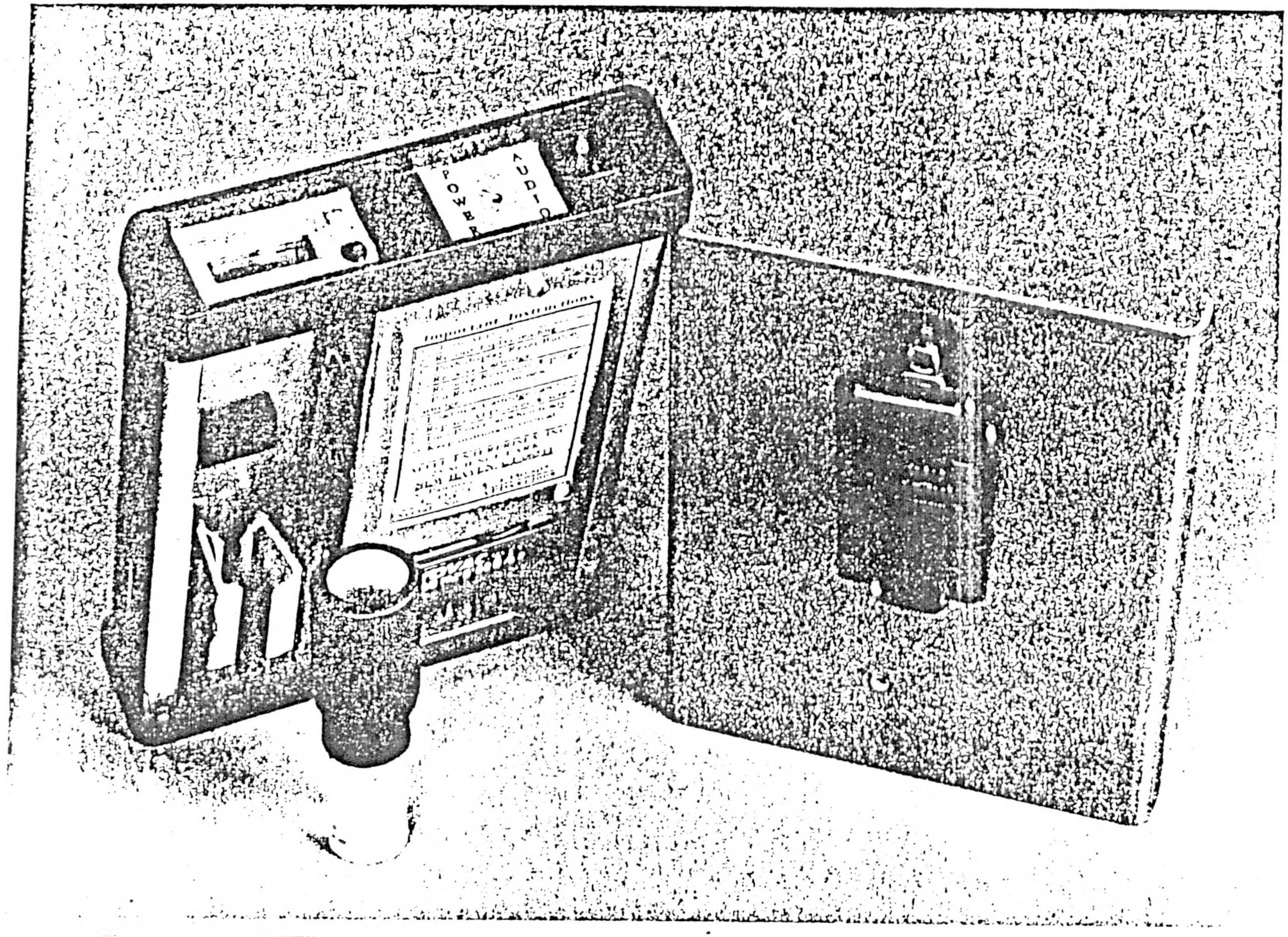

Figure 1. APD/SDD System