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COMPARISON OF GAMMA DENSITOMETER DETECTORS USED IN LOSS OF COOLANT STUDIES*

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COMPARISON OF GAMMA DENSITOMETER DETECTORS USED IN LOSS OF COOLANT STUDIES[1]

Roy L. Shipp[2]

ABSTRACT

Ionization chamber type gamma detectors are used in water-steam density measurements in loss of coolant studies at Oak Ridge National Laboratory. Ionization chambers have replaced current-mode scintillation detectors to obtain stability and freedom from magnetic field interference. However, this change results in some loss of fast transient response. Results of studies comparing the transient response of ionization chamber detectors, plastic scintillation detectors, and sodium iodide (NaI) detectors to rapid changes in gamma intensity demonstrate that plastic scintillation detectors have the fastest response and most closely reproduce the transient; ionization chambers have an initial fast response followed by a slower response, which may produce errors in fast transient measurements; and NaI scintillation detectors have a moderately fast initial response followed by an extremely slow response, which produces errors in even slow transient measurements. We are using ionization chamber detectors with data acquisition systems having response times of 1 and 16 ms. With the 16-ms system, the transient response is limited by the system rather than the detector. However, with the 1-ms system the response is detector limited. At present, the extreme stability of the ionization chamber detector system is more important than the loss in fast transient response.

Introduction

Gamma densitometry is extensively used for measurement of steam-water and air-water density in LOCA (loss of coolant accident) studies. LOCA-related experimental facilities at Oak Ridge National Laboratory include the THTF[1] (Thermal Hydraulic Test Facility) and associated air-water and steam-water loops. Much of the following detector discussion is related to the THTF, which is a large nonnuclear pressurized-water loop that incorporates a bundle of 49 electrically heated rods. Four gamma densitometers are installed on this loop and are located in horizontal and vertical instrumented spool pieces in both the inlet and outlet runs of the rod bundle. Typical preblowdown, steady-state conditions are power to rod bundle, 6 MW; inlet temperature, 574°F; outlet temperature, 640°F; and system pressure, 2250 psi. At blowdown, the system is vented to the atmosphere through rupture disks in the inlet or outlet circuits, and the ∿160 gal content of the loop is transferred to a pressure supression system in 20 to 100 s.

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The gamma densitometers of this system consist of a 25-Ci ^{137}Cs source in a shield assembly, with a collimator and shutter mounted on one side of a 4-1/2-in.-OD × 3-1/2-in.-ID pipe and a gamma detector mounted in a collimating shield on the opposite side of the pipe. The signal from the detector is integrated by two amplifiers: one with a time constant of about 1 ms; the other, 16 ms. The 1-ms output is recorded continuously on magnetic tape, and the 16-ms output is sampled and recorded at a rate of 20 times a second by a computer-controlled data acquisition system.

The density measurement objective is to accurately follow the air-steam density transient during blowdown. This density range of interest extends from water filled pipe (0% void fraction) to empty pipe (100% void fraction), with appreciable interest in the void fraction region of 99% and higher.

Valid density measurement in a high-void fraction region is difficult due to the low attenuation by water of energetic gammas which are required for efficient penetration of the heavy steel walls of pressure vessels and pipes. For example, at 99% void fraction and room temperature, the intensity of a ^{137}Cs gamma beam traversing the 3-1/2-in. ID of the pipe is 99.2% of the empty pipe intensity. For valid density measurements from this 0.8% difference in intensity, the system must be stable, and the statistical variation in the measurement of empty-pipe and attenuated gamma intensities must be small compared with the difference in intensity. These difficult measurements are further complicated by a hostile environment which includes shock, vibration, temperature variation, and strong magnetic fields.

The magnetic field at the THTF densitometers from the 28-kA dc rod heater circuit is about 150 gauss.

The four scintillation detector systems initially installed in the THTF loop, although designed to minimize the inherent instabilities of scintillation detectors, were not sufficiently stable, and extensive efforts to stabilize them were unsuccessful. Thus, the scintillation detectors in these systems were replaced with ionization chambers. Ionization chambers are inherently more stable, because, for example, they are not sensitive to variations in temperature or magnetic fields; and, when operated above voltage saturation, they are insensitive to the variations of a regulated high voltage supply.

As a result of this improved stability, the scintillation detectors in other THTF associated air-water and steam-water loops were also replaced with ionization chambers. However, the increased stability resulting from this change was obtained at the expense of some loss in transient response and statistical precision. Since transient response is also important in these experiments, a comparative study was made of the transient response of various scintillation and ionization type detectors.

Detector Experiences

Initially, the gamma densitometer detector of the THTF was a plastic scintillation detector operated in the current mode. This detector system had been selected because other LOCA experimenters were using NaI scintillation detectors in the current mode, and project management had dictated that current-mode scintillation detectors be used. When the initial system was designed, it was equipped with a plastic scintillator instead of a NaI scintillator because the plastic scintillator can follow a fast transient response, whereas the NaI scintillator has a slow component in its transient response. This slow response, which is referred to as afterglow, is reportedly present to some degree in all inorganic scintillators.[2]

Even though it had been conservatively designed, that is, operation well below maximum photocathode and anode current ratings, powered by a stable power supply, water cooled, and heavily shielded from magnetic fields, the plastic scintillation system was plagued with instability problems. Calibration drifts were intermittent in occurrence, random in polarity, and, apparently, spontaneous in onset. Most of these instabilities were probably due to the inherent instability of photomultiplier tubes, which are sensitive to variations in temperature, magnetic fields, and bias voltage. After attempts to stabilize the scintillation detector system had failed, it was replaced with an ionization chamber, which is not sensitive to these variables. The chamber is of coaxial design with a sensitive annulus 1-5/8 in. *OD* × 1/2 in. *ID* × 5-3/4 in. long, filled with xenon at a pressure of 20 atm. A small solid-state electrometer is housed at the end of the chamber. No stability problems have been encountered with this chamber, which is operated at above voltage saturation from a regulated high voltage supply.

Some of the triple-beam gamma densitometers installed on air-water and steam-water loops were procured as complete systems with NaI detectors because coaxial ionization chambers could not be used due to the geometrical arrangements of these new densitometers, and to design and fabricate new ionization chambers for these densitometers would have required an intolerable delay.

In the interim, before the new ionization chambers became available, problems were encountered with the NaI detectors: rapid failure by loss of sensitivity, and a slow component in the signal output following a step increase in gamma intensity (Fig. 1). The example in Fig. 1 is typical of the slow component, or afterglow, that we have observed with other NaI scintillation detectors operated in the current mode. A failed detector was disassembled; the cause of failure was diagnosed as photomultiplier tube failure, apparently caused by excessive photocathode current.

For comparison, no photomultiplier tube damage was observed with the plastic scintillation detectors which were exposed to a higher incident gamma level. This lack of phototube damage is attributed to the lower light yield of the plastic scintillators (about 1/30 that of NaI) and the use of photomultipliers having Cs-Sb (cesium-antimony) photocathodes, which have a higher current capacity than the bialkali photocathode of the failed detector.

The problems with the NaI detectors of the triple-beam gamma densitometers were eliminated by replacing the detectors with the new ionization chambers of a parallel-plate design (Fig. 2). These chambers, which have a sensitive volume of 1 in. diam and 5-1/4 in. long and are filled with xenon to 20 atm, are working satisfactorily. However, these parallel-plate chambers are more microphonic and more expensive to fabricate than the coaxial chambers. As a consequence of this experience, the triple-beam densitometer design was modified to make it compatible with a coaxial ionization chamber.

Transient Response of Detectors

Since some loss of transient response was anticipated in the change from plastic scintillators to ionization chambers, we made comparative measurements of the transient response of the following detectors: plastic scintillator, NaI scintillator, coaxial ionization chamber, and parallel-plate ionization chamber.

The gamma transient for checking the detectors was generated by the apparatus shown in Fig. 3. This consisted of a 25 mCi ^{137}Cs gamma source which was spring-propelled over two lead-brick shadow shields. The detector was located under a 2-in. gap between the bricks. A step increase in gamma intensity was generated by spring-propelling the source carrier from a position over one shadow shield to a position over the detector slot. A step decrease in gamma intensity was generated by a spring-propelled striker hitting the source carrier and driving it from a position over the detector to a position over the second shadow shield. The transient rise time was varied by changing the springs and varying the compression of the springs.

All comparisons of the transient responses were made for a transient rise time of about 0.7 ms. This rise time was determined from the rise time of the plastic scintillation detector output and a 0.5-ms amplifier response time. To compare the transient responses, the detector outputs displayed by an oscilloscope were photographed. The scope sweep was triggered by either the source carrier or the striker as it passed under an electro-optical detector just before entering the exposure position.

Although the detector responses were examined for both increasing and decreasing intensity transients, the decreasing transient responses were essentially inversions of the increasing transient responses. For this reason, only responses to increasing transients are illustrated in the discussion to follow.

After excessive noise was encountered at an amplifier response time of 0.5 ms, a change was made to a response time of 2 msec for the detector comparisons. Noise is more troublesome at the weaker gamma signal of these tests than it is at the higher gamma signal of the densitometers.

Plastic Scintillation Detector

The response time of the plastic scintillator detector tested is fast, and no slow components are observed in the output. The responses shown in Figs. 4a, e, and f are degraded by the amplifier response time of 2 ms. In the comparisons of Figs. 4e and f, the rise of the plastic scintillator is faster and exhibits only a fast component compared with the responses of the NaI scintillator and the coaxial ionization chamber, both of which are slower in initial response and also have slow components that interfere with fast transient response.

NaI Scintillation Detector

The initial response of the NaI scintillation detector (Figs. 4b, e, and f) is not as fast as that of the plastic scintillator. There is also a slow component, which was discussed previously in relation to Fig. 1. This slow component, which in Fig. 1 shows a time constant of several minutes, interferes with the accurate measurement of even the slowest transients.

Coaxial Ionization Chamber

The transient response of an ionization chamber is characterized by a fast response, followed by a slow response (Figs. 4c, e, and f). The fast response is due to collection of the highly mobile electron component of the ionization, and the slow response is due to collection of the large, positive xenon ions.

This slow component interferes with accurate measurement of fast transients, but it does not interfere with slower measurements at the 16-ms response time of the amplifier used with the computer-controlled data acquisition system. At this response time, the transient response of the coaxial ionization chamber is essentially identical to that of the plastic scintillator.

The transient response of an ionization chamber is a function of both the strength and polarity of the ion collection field. The curves of Figs. 4c, e, and f are for a negative bias of 1,600 V, the maximum voltage of the power supplies we are using. Increasing the bias voltage decreases the rise time of both the fast and slow components and increases the relative amplitude of the fast component. With the bias polarity changed to positive, there is a slower initial component, followed by a faster component.

Parallel-Plate Ionization Chamber

The closer electrode spacing of the parallel-plate ionization chamber (Fig. 2) produces a higher collection field at the same bias voltage. As a result, the transient response of this chamber is faster than that of the coaxial chamber, and the ratio of fast rise to slow rise is greater. Unfortunately, the noise level of the parallel-plate chamber, part of which is microphonics, is greater (Fig. 4d). These tests were made with the prototypic chamber, which is more microphonic than chambers fabricated as a production run.

Comments and Conclusions

The choice of a detector for gamma densitometry is governed by the application and environment. For stability, ionization chambers are superior to scintillation detectors. However, stability is gained with some loss of fast transient response.

For applications where fast transient response is more important than stability, plastic scintillation detectors offer the fastest transient response.

The use of NaI scintillation detectors operated in the current mode is not advised because their slow response component, or afterglow, may introduce appreciable measurement errors. This caution also applies to other scintillators with appreciable afterglow.

For applications where there is a high gamma background, such as in nuclear-heated LOCA experiments, NaI scintillation detectors operated in the pulse mode with pulse height discrimination is the preferred detector system. Afterglow is not a problem with NaI operated in the pulse mode.

Acknowledgment

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References

1. Project Description ORNL PWR Blowdown Heat Transfer Separate Effects Program - Thermal-Hydraulic Test Facility (THTF), ORNL/NUREG/TM2 (February 1976).

2. R. L. Heath, R. Hofstadter, and E. B. Hughes, "Inorganic Scintillators, A Review of Techniques and Applications," *Nucl. Instrum. Methods* 162, 431-476 (1979).

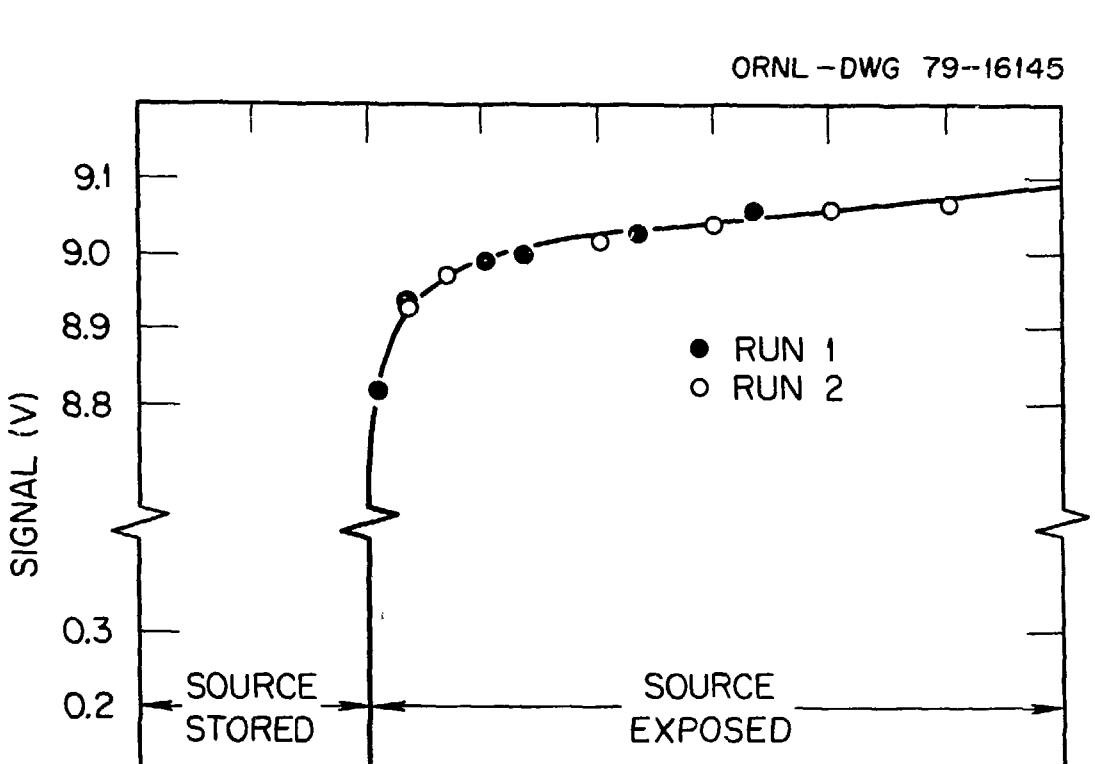
FIGURE CAPTIONS

Fig. 1. Slow response of NaI scintillation detector.

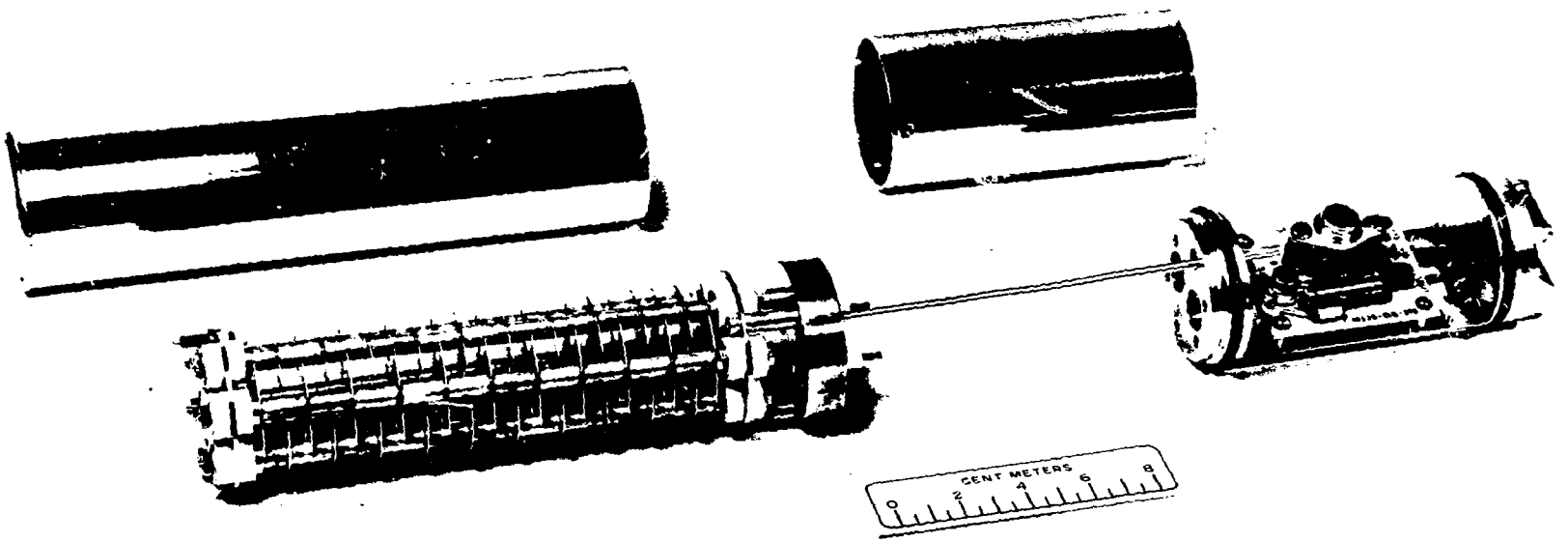
Fig. 2. Parallel-plate ionization chamber.

Fig. 3. Gamma transient generator.

Fig. 4. Transient response comparison of detectors.



NaI Scintillation Detector Response in γ Densitometer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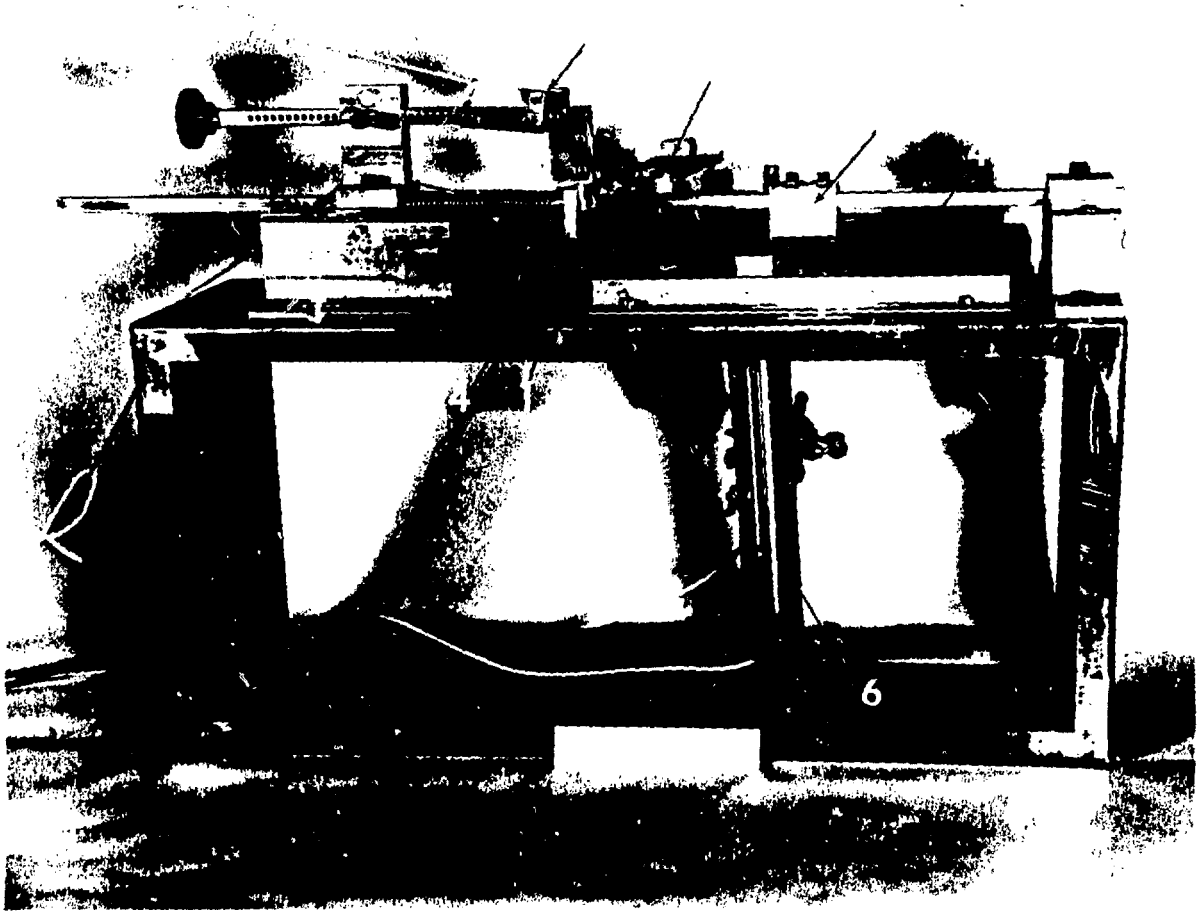
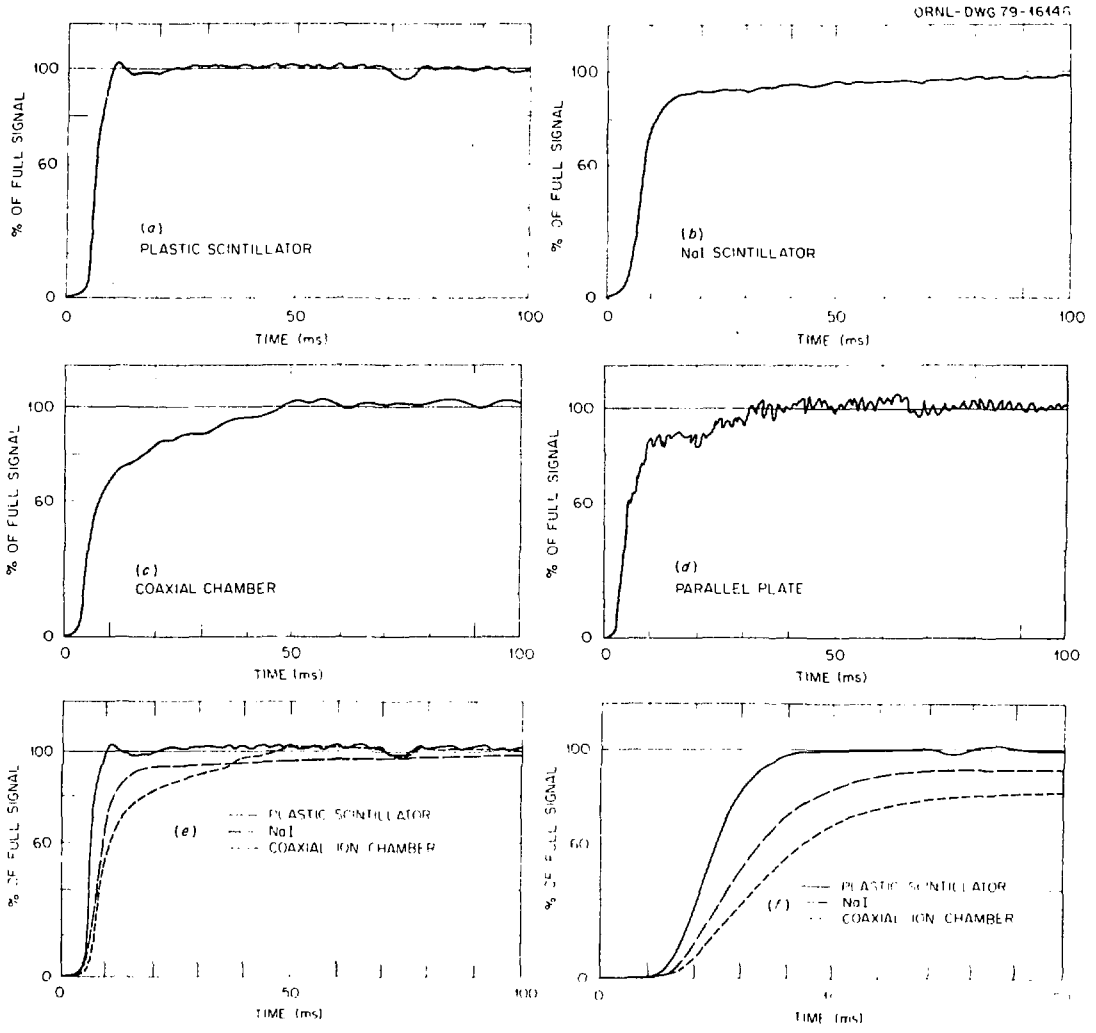


1. 25 mCi ^{137}Cs SOURCE IN SPRING-LOADED CARRIER
2. RELEASE TRIGGER AND LANYARD
3. SOURCE CARRIER STOP
4. SHADOW SHIELDS AND EXPOSURE SLOT FORMED BY TWO LEAD BRICKS
5. ELECTROOPTICAL DETECTOR FOR OSCILLOSCOPE TRIGGER
6. GAMMA DETECTOR MOUNTED UNDER EXPOSURE SLOT

Gamma Transient Generator.



DETECTOR COMPARISON