AUTOMATED INSPECTION DEVICE FOR EXPLOSIVE CHARGE IN SHELLS - AIDECS*

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ABSTRACT

Certain defects in the explosive charge of an artillery shell can cause the projectile to explode prematurely in the barrel of the launcher from which it is fired. The sensitivity of the radiographic technique presently used is limited by the large influence of the steel shell casing on the transmitted radiation. A filmless radiometric technique utilizing the basic radiation principle of Compton scattering, which will detect cavities in the explosive filler with minimal interference from the steel casing, has been identified and tested.

By scanning the shell with a beam of radiation and observing the Compton scattering through a unique collimating system, it has been possible to detect voids as small as 1/16 inch in cross section. The hardware consists of the source, beam collimator, detector collimator, and a large plastic scintillator detector system. The projectile is inserted into the beam path and moved through a fixed scanning pattern by a mechanical handling system. The scanning sequence is computer controlled and results in a three-dimensional data matrix giving a direct representation of density within the projectile. Voids are identified and classified by computer analysis, and shell acceptability decisions are automatically generated.

An engineering prototype system is currently being assembled and tested. (A production prototype conceptual design is concurrently under development.) This new technique will replace an existing film radiography inspection procedure and eliminate the need for human interpretation of the defects, while providing more consistent and reliable inspections at lower costs.

INTRODUCTION

Experience has shown that certain defects in the explosive charge of an artillery shell can cause the projectile to explode prematurely in the barrel of the launcher from which it is fired. Since such failures are dangerous and costly, their incidence must be reduced to a minimum by ensuring that the defective shells are detected with the highest possible confidence. Therefore, a great need exists for a reliable, nondestructive inspection technique that provides a means of identifying defects inside a shell with a speed compatible with the production rates anticipated in the U.S. Army's Ammunition Base Modernization Program.

Inspection programs currently in use rely primarily on radiographic techniques, utilizing x-ray sources and film radiographs that inspect only a limited sample of the entire output of a given production facility. With the development of new, automated production facilities under the Ammunition Base Modernization Program, the demands on nondestructive inspection programs are becoming considerably more severe, since they must ensure with a high degree of confidence that the high-volume production output is sufficiently free of defects. It is recognized that currently employed radiographic methods do not provide a sufficiently accurate and economical inspection capability for automated production of shells, as evidenced by the Army's current sponsorship of the AIDECS program to develop an engineering prototype for the automated, filmless, high-speed inspection of 105 mm projectiles.

The inspection technique embodied in this approach is based on the measurement of Compton-scattered radiation. The method was identified as the most suitable method for inspecting explosive charges for cavitation defects. It provides high resolution data in a three-dimensional format which readily lends itself to a completely automated, cost-effective defect analysis. A further major advantage is that the technique is inherently less sensitive to defects in the steel projectile casing than transmission techniques.

After demonstrating the feasibility of the technique in laboratory experiments, an engineering prototype which embodies the scattering technique was fabricated. This prototype is capable of performing a complete three dimensional inspection of the explosive filler charge in 105 mm, M1 projectiles.

Based upon the full scale operation of the 105 mm engineering prototype system, it is projected that with some product improvements required to accommodate larger projectiles, several inspection modules will inspect artillery ammunition production on a 100% basis. The cost for this total inspection service is estimated to be significantly less than radiography costs incurred by the current sampling plan.

COMPTON SCATTERING TECHNIQUE

A review of the basic photon scattering physics and its relationship to artillery projectile inspection is presented below. This is followed by a brief description of an analytical

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model used as an aid in making design tradeoff decisions.

This photon scattering inspection technique is based upon the fact that sufficiently energetic gamma radiation interacts with the material in its path by scattering a portion of the incident beam. This interaction, known as Compton scattering, is the dominant mode of interaction between gamma rays and target materials for gamma-ray energies between approximately 200 keV and several MeV. In this interaction mode, part of the energy of the gamma ray is transferred to a target electron during a collision. Conservation laws require that the photon be deflected in a particular direction as a result of the collision. A small loss of energy is associated with a small angular deflection; while larger energy losses occur at larger deflection angles. The maximum energy loss occurs when photons are scattered 180 degrees, directly back into the incident beam. The probability for a gamma ray to be scattered through a particular angle is a clearly defined function of the incident beam energy and the angle. Also, for gamma-ray energies in excess of about 100 keV the number of scattered photons is independent of the material composition and depends almost wholly on the electron density of the scattering target. In other words, the number of scattering events from a unit volume in the target depends almost entirely upon target density (number of electrons per unit volume) in the volume element.

inspection volume element. The introduction of a void into the volume element means a reduction in the amount of material available to scatter gamma rays, and consequently results in a decrease in the detector response. On the other hand, the presence a higher density inclusion causes an increase in the detector response.

The photon scattering technique collects this scattered radiation over a very large solid angle through the use of a large scintillator which views the projectile through a "focusing" collimator. This is analogous to integrating the output of several detectors, each monitoring the scattered radiation at a different angle about the incident beam. The focusing collimator allows only radiation from a small segment of the incident beam to reach the scintillator; radiation scattered from other regions of the incident beam is blocked by the focusing collimator. The geometric design of the focusing collimator defines the inspection aperture, or one dimension of the inspection volume element. The other two dimensions of the inspection volume are formed by the collimation control of the incident beam.

If the inspection volume element is selected sufficiently small so as to represent only a small fraction of the entire shell volume, the detector response becomes highly localized, and consequently, is less subject to interference from signals from the rest of the shell. It also

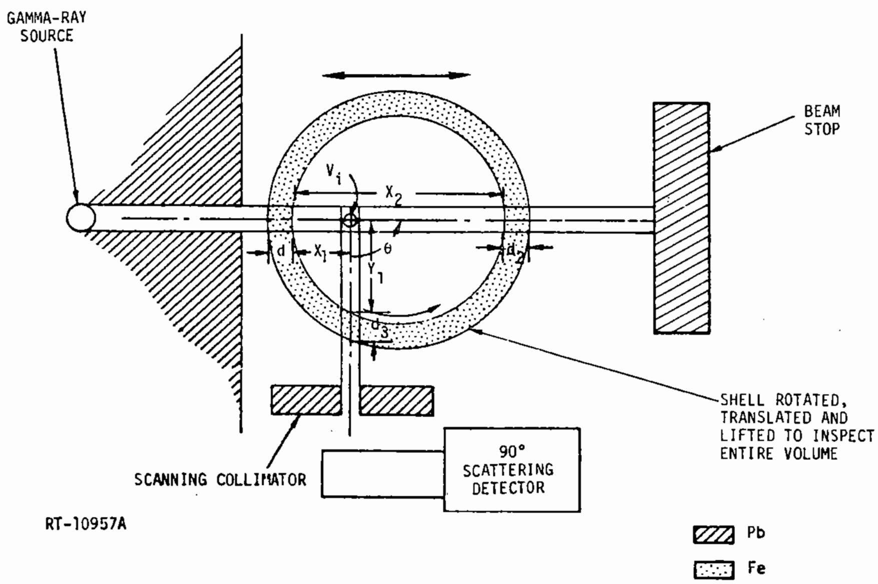

Fig. 1. Basic Compton Scattering Configuration

A selected portion of the scattered radiation can be measured by an appropriately collimated radiation detector placed at a certain angle to the incident beam. The detected scattered radiation results from Compton interactions in the volume element defined by the intersection of the incident beam and the detector collimator. Figure 1 schematically represents the basic measurement technique. The volume element from which the scattered radiation originates appears to the detector like a source of radiation whose intensity depends on the amount of material contained in this

becomes highly sensitive to even minute voids if the ratio of void and inspection volume falls within a suitable range. Detection of large voids, cracks, porosity, annular rings, piping cavities, and base separations is accomplished by software analysis of the defect signals which exhibit themselves throughout several neighboring volume elements.

A complete scan of one projectile is accomplished by rotating the shell about its axis, translating the rotating shell along a line parallel to the incident beam, and indexing the shell up or down. During a scan these combine into a continuous path covering the entire projectile volume. At discrete positions along this path (~0.2 inch), a number proportional to the amount of radiation scattered from the inspection volume is read by the computer from the detector electronics. These data points are stored in a three-dimensional data array representing a discrete volume map of the projectile. Subsequent analysis for variations in the scattering levels for each volume element indicates statistically meaningful deviations of material density. These deviations are then quantitatively analyzed to define size, shape, and orientation of defects.

Thus, the photon-scattering gauge is seen to be an inspection device which provides a high-resolution, three-dimensional scan profile of the entire explosive charge. It performs a differential measurement which, with an appropriately small inspection volume element, not only identifies the presence of discontinuities in the explosive (such as voids, cracks, annular rings, and inclusions), but also provides data about their size, three-dimensional location, and orientation.

In order to make engineering design tradeoff decisions, a model of this technique as it applies to artillery projectile inspection was developed. This analytical model contains two distinct parts. The first part consists of a detailed calculation of the gamma-ray penetration and scattering process within an artillery shell, and the second consists of an analysis of the viewing characteristics of the selected detector collimator. The spatial distribution of multiply scattered gamma rays is a crucial aspect of the analysis, and this is computed using a Monte Carlo technique to track large numbers of gamma-ray histories throughout the shell. The parameters of this distribution are then used by the collimator analysis code to predict the response to specified defects. The model has been validated against experimental data and is currently being used for its intended purpose*.

ENGINEERING DETAILS

A photon scattering inspection system capable of automatically detecting cavitation defects in artillery projectiles consists of six major subsystems:

1. Main Frame Structure
2. Mechanical Scanner
3. Source Collimator and Storage Assembly
4. Detector Collimator and Scintillator
5. Electronic Data Accumulator and Control System
6. Computers and Display Network

A discussion of the functional requirements for each subsystem follows.

The main frame consists of support members which provide leveling and alignment of the other system components. Safety shielding is also considered to be part of the main frame. The alignment between the collimated source beam, the inspection aperture defined by the focussing collimator, and the scanning mechanism is attained and maintained by the lower frame structural components. The entire frame rests on a steel base plate which is leveled on adjustable jacks. The other components are mounted to this plate by a variety of adjustable fixtures.

The functions performed by the mechanical scanner subsystem are (1) grip the projectile, (2) accurately register the projectile so that its location is always available for use by the computer, and (3) move the projectile through a controlled scan pattern such that the fixed inspection element travels through all of the internal shell volume. The mechanical scanner must be capable of supporting and transporting the total mass of the projectile in a smooth, rapid scan. It receives position commands from the computer and provides computer readable, actual projectile position signals.

A storage and beam collimation cask for the radioactive sources serves the dual role of (1) providing a shielded storage unit which allows personnel to safely work near the inspection system, and (2) collimating the output radiation to form a precisely defined gamma-ray beam. The sources are mounted on a transport slide which allows for movement from a storage position to an inspection position. It is required that the storage shielding be sufficient to reduce the radiation to levels which allow for safe personnel approach. When the source is in the inspection position, personnel are prevented from inadvertently stepping into the radiation zone by means of an interlock circuit which will automatically move the source to the storage location if someone attempts to enter the area. The engineering prototype contains 14,000 curies of Cobalt-60 in the form of three encapsulations similar to those used in commercial irradiators.

The detector collimator selectively transmits gamma radiation from the inspection element to the scintillator while blocking radiation scattered from other points along the incident beam. The effectiveness of the detector collimator is dependent upon its geometric configuration. The optimum geometric configuration is one which provides the largest possible solid angle for viewing the radiation scattered from the inspection volume element, consistent with efficient screening out of all other radiation. The detector collimator design for the engineering prototype consists of 16 coaxial lead cones with each having a 2.25-inch radius hole centered at the cone apex, for 105 mm projectile insertion. This 16-cone assembly as shown in Figure 2, is trimmed so that the final outside dimensions are flat surfaces which mate against the large flat plastic scintillator front faces.

The scintillator geometry is selected to capture most of the incident gamma radiation. The scintillator emits visible light photons proportional to the total incident gamma-ray energy.

The visible light generated in the scintillator by scattered gamma rays is collected by a network of photomultiplier tubes. The individual

*Details of the model and its validation can be found in IRT Report No. 8188.06 prepared for Contract No. DAAK10-79-C-0062, May 21, 1979

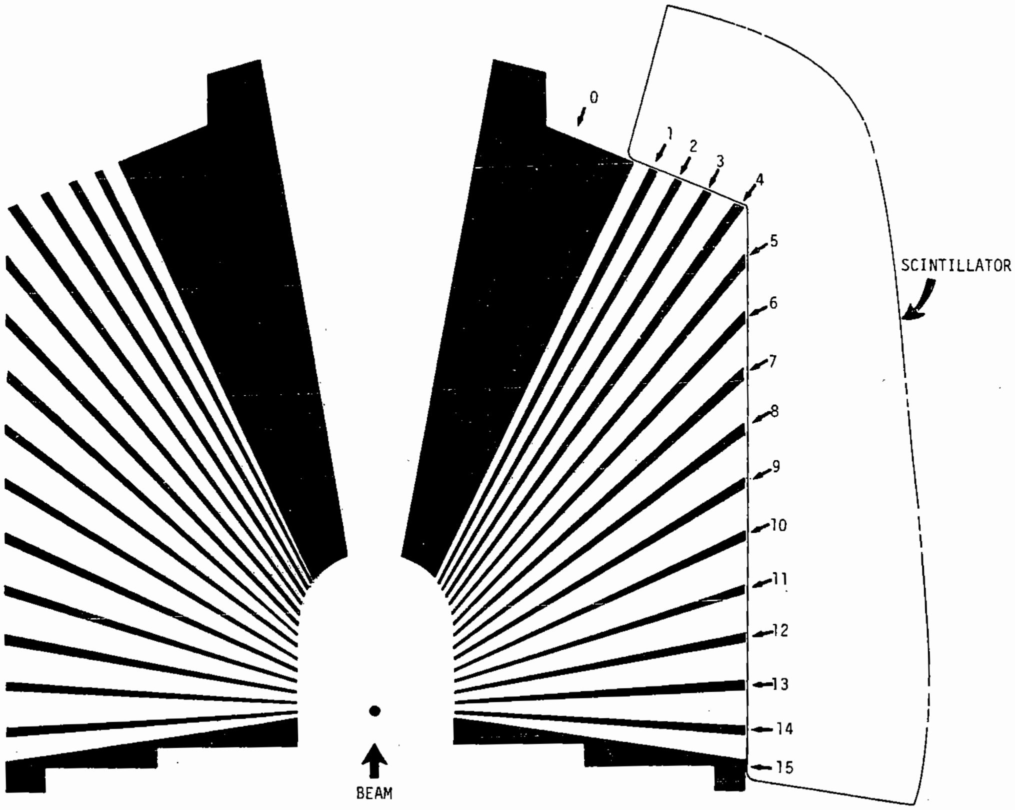

Fig. 2. Cutaway View of the AIDECS Detector Collimator Assembly Looking From the Top Down. The 16 Cones Focus to the Black Dot (Focal Point). The Gamma-Ray Beam Direction Corresponds to the Axes of Symmetry of the Cones.

tubes are balanced so that a particular incident gamma-ray energy results in specific electronic charge output. These current pulses are summed by a current integration circuit which generates an analog voltage. The output is tracked by a sample-and-hold device until an analog-to-digital converter outputs a digital number proportional to the amount of gamma radiation observed in the scintillator. The computer input to this signal accumulator controls the timing gates which determine the discrete count times for each volume element. Count periods are controlled by a high frequency crystal oscillator circuit. The computer gates the counting circuit on and off, reads the digital output value, and stores the value along with the three-dimensional coordinate information about the location of the data point in the projectile volume. This control system consists of hardware circuits designed to perform these functions within the designated sampling times.

The control, analysis, and display functions performed by the computer network perform the following tasks:

1. Control Mechanical Scanner
2. Start and stop counting periods
3. Read digital element values and coordinate data
4. Store all raw data
5. Analyze three-dimensional segment volumes
6. Classify defects
7. Perform accept/reject decision
8. Provide summary inspection data
9. Display defects
10. Automatic calibration
11. Perform maintanence and test functions

A pipeline, serial approach using several slow speed computers to divide these tasks has been applied to the engineering prototype. Appropriate software to accomplish the above tasks has been compiled.

DEFECT DETECTION CAPABILITIES

Several tests for defect detection capabilities have been performed. Initially data were taken in a laboratory setup using lucite plastic blocks with machined holes to simulate defects. Later a testbed facility was built around a 500 curie Cobalt-60 source. Automated scanning and data collection were finally added to this testbed. Projectiles with inert fillers which contained machined defects in known locations were Government supplied for these tests. Figure 3 shows a

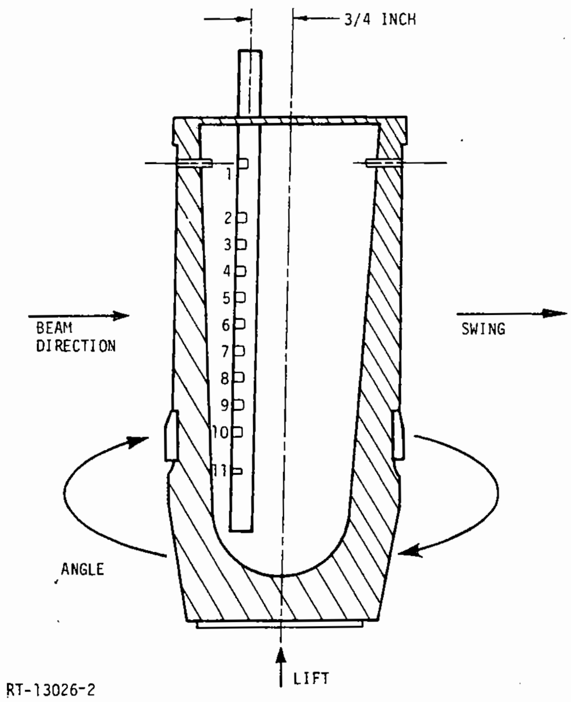

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Fig. 3. Cross-Sectional View of AIDECS Test Projectile Indicating Positions of Various Defects. The Coordinate System Used (Lift, Swing, and Angle) and Beam Direction Are Also Shown

representative test projectile. These standards are now being used to validate the engineering prototype. In all cases, the data collected showed that the Compton scattering technique was feasible for detecting cavitation defects in HE projectiles.

In early June 1979, fabrication of the engineering prototype was completed and data collection and analysis tasks were initiated. Scan data obtained for several long cylinderical voids positioned in the inert filler are shown in Figure 4. These data were taken with the full scale system using all 64 detectors and automatic data collection. It represents the first outputs after all the functional subsystems were assembled and operated together. It must be noted that the data shown in Fig. 4 does represent an optimum system response for geometry of the defects. The scan pattern used during the test was located so as to provide a maximum defect response in the plane for which the data is displayed. The data in Fig. 4 is raw data which has not been filtered to reduce statistical noise. Automatic operations under full software control will eliminate much of the statistical noise by taking advantage of the fact that neighboring data points are correlated by the finite width of the system response which extends over several contiguous finite volume elements.

To illustrate the statistically optimized response of the system to a defect when the statistical noise is reduced, slow speed scans of the test projectile have been made. The results of one of these scans is shown in Figure 5. The signals from two 1/16 inch diameter defects (one 0.2 inch long and located 1.09 inches from the bottom of the filler and the other 0.18 inch long and located

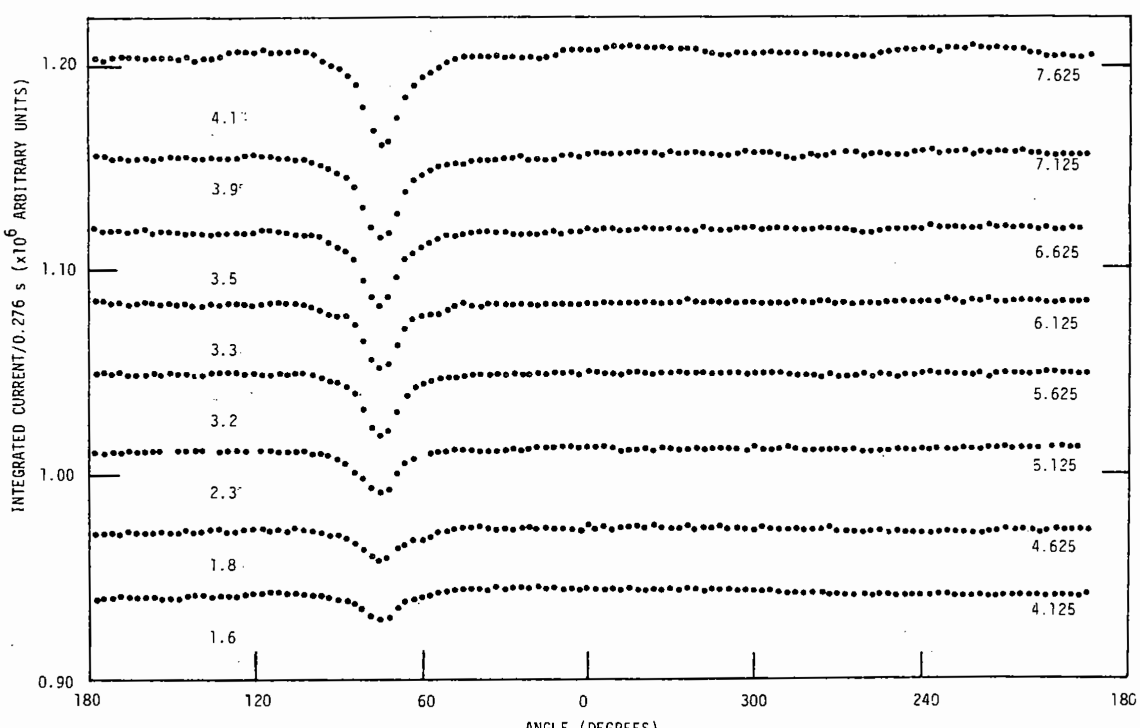

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Fig. 4. Response Functions for 1/8 inch diameter defects ranging in length from 0.156 to 0.192 inch at different distances from the bottom of plastic charge

2.09 inches from the bottom) are both clearly discernible. Notice that the system stability aids in allowing the detection of such signals.

SUMMARY

This paper has presented details concerning a Compton scattering inspection technique and the prototype engineering hardware built to provide a fullscale demonstration of the method. The work is directed toward the inspection of 105 mm artillery projectiles and provides a means of detecting cavitation defects. The hardware is automated and filmless. Accept/reject signals can be used to physically segregrate the detective projectiles.

Future work will include:

1. Delivery of the engineering prototype system
2. Design and fabrication of a 155 mm production prototype system
3. Production prototype testing at an Army load plant
4. The installation of multiple inspection systems to provide 100% inspection in a near realtime mode.

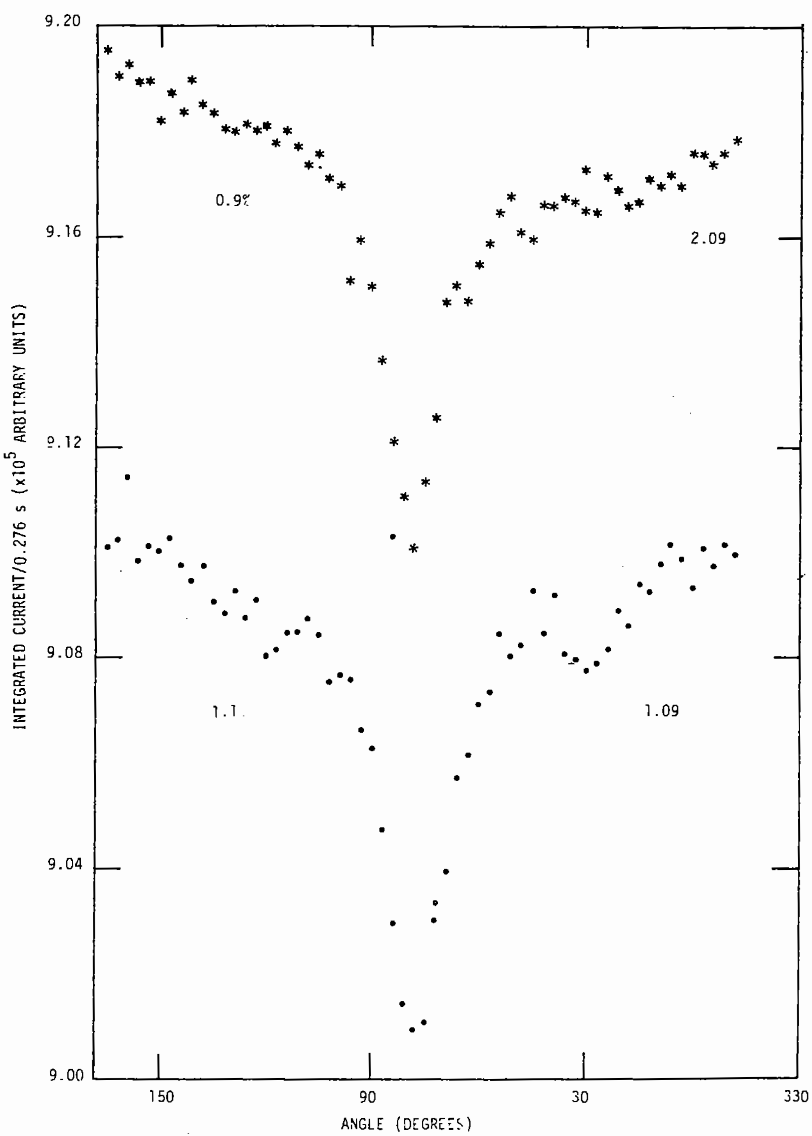

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Fig. 5. Response Functions for 1/16 inch Diameter Defects 0.180 and 0.200 inch in Length at Different Distances from the Bottom of the Plastic Charge

SUMMARY DISCUSSION
(J. John)

John Duke (Virginia Tech): What do you base your statement on there is a one-to-one correspondence between defect and response?

J. John: Okay. What I mean by one-to-one correspondence is that if there is a defect of a specific nature at a specific point in the shell, there is, first of all, a one-to-one correspondence between the coordinates of the defect and the location of the inspection point in the shell when the response is obtained. In addition to that, there is a one-to-one correspondence between the type of defect and the response you get. For example, if you have a void, then you have a negative response. If you have an inclusion, you have a positive response. Now, what we are measuring is the amount of material in the inspection volume. So, if you are trying to, let's say, characterize a long object, then what you want to do is to divide that up into a number of small inspection volumes. And in each inspection volume you measure the amount of material. So that there is no confusion between the results and reality. The effect is very localized.

Sam Snow (Union Carbide): I was impressed by the one-minute inspection time. I think that's very impressive for this type of measurement, which leads me to my question. What type of source?

J. John: The design intensity of the source is about 30,000 curies. The data-taking time is 2.3 milliseconds per data point. Now, the assembly that you saw there is geared for about 50,000 curies. The radiation level on the outside is one-tenth of a milli-roentgen. We have to spin the shell at various speeds, as high as 2,000 RPM.

Tom Derakacs (TRW): What size defect were you looking for?

J. John: In this particular case, it's a collection of things. There is at this stage no absolute, clear connection between the size of defects in the shell and it's performance. There is a whole lot of experience. The experience has now been summarized in the form of a set of specs, and the specs are related to X-rays. So, when you really come down to it, the specifications require that the sum of all the defects in the X-ray add up to a certain amount,in one case one-sixty-fourth of a square-inch. Now, we have translated that into some defect size. And for this particular system, the defect that you're looking at is 60 mils by a quarter of an inch. Very large defects. Very macroscopic. What we have done is to lay that requirement on our measurement system. We have a very large collimator, very large inspection volume. Now, in principle, we can look at extremely small defects. We can see one percent variation very easily. And, therefore, you could design you inspection volume such ahat it is about between ten or twenty times the smallest defect to be detected. So, in principle, there is no limit to the size we can get. There's a practical limit, of course. As you decrease the size of the inspection volume, the inspection time goes up.

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