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UNUSUAL CAPABILITIES AND NEW PROGRAMS

by

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INTRODUCTION

At the Los Alamos National Laboratory we have expanded Nondestructive Evaluation (NDE) as necessary to meet a number of needs beyond those that have been typically encountered within the nuclear weapons community. These needs are met with a variety of technologies that can be transferred to the problems of the weapons community. In that sense, to this audience, these technologies are solutions looking for problems. A major purpose of WANTO must be to help match solutions and problems. For this reason, we use this paper to present WANTO with a number of NDE technologies which have had only minimal impact on weapons activities. We do this without apology.

X-RAY FLUORESCENCE

We sometimes need to know what trace chemical elements are present in a material. X-ray fluorescence offers a means for making this determination. Any chemical element can be excited to x-ray fluorescence. An x-ray source of photon energies greater than those of the fluorescent photons is required. Photons from the primary source remove electrons from the atoms of the material, leaving the atoms excited. As the atoms return to their normal state, they emit x-rays that have energies characteristic of the atoms. Thus, energy-resolved, photon-counting methods can be used to identify the atoms. Atomic concentrations of a few tens of parts per million are routinely detectable. The limit in any specific case will be dependent upon the atomic numbers of the trace materials in question and of the material in which these traces are embedded.

We do most of our x-ray fluorescence excitation with radioisotope sources. The only requirement is that the source have photon emission at high enough energy to excite the atoms under study. Isotopes often used for excitation are Iron-55, Cadmium-109 and Samarium-145. With these isotopes we have excitation energies ranging from 2 keV to 40 keV. The fluorescent x rays from the excited atoms are detected with lithium-drifted silicon detectors and analyzed in a standard pulse height analyzer.

At Los Alamos we now use x-ray fluorescence routinely as part of the quality assurance on nuclear-reactor materials and for identification of mislabeled materials as received from outside suppliers. Under agreements with various museums, these techniques are used for archeological studies.

The fluorescent x rays which are characteristic of various elements may be nearly at the same energy on occasion. In this case, even state-of-the-art photon detectors are inadequate for quantitative analysis of the material. Techniques of signal processing will improve the separation of "nearly equal," x-ray energies. We have studied application of the Maximum A Posteriori (MAP) method of image restoration to the problem of improving the x-ray fluorescence data (1). In this application, "improve" means to minimize the effects of the limited energy resolution available from the photon detector. The MAP scheme was initially developed at Los Alamos (2) for application to images. X-ray fluorescent spectra may be thought of in this context as one-dimensional images. The details of the MAP mathematics are beyond the scope of this presentation; however, a somewhat vague verbal statement of the problem is reasonably meaningful. In finding MAP restorations we ask a probabilistic question: given the measured spectrum and a detector response characteristic, what is the most likely input spectrum subject to known (or assumed) statistics for the noise and the spectrum? We note that the assumed statistics for the input data will influence the final result. More study is clearly needed. However, by means of computer simulations, we can demonstrate that marked resolution improvements are now available even in our imperfect state of knowledge. Figure 1 shows the spectrum derived by algebraically adding copper and zinc spectra plus noise. Both a "normal" and an "expanded" scale are shown. Our most successful restoration of this spectrum is shown in Fig. 2, where again we use both a normal and an expanded scale. Note the vastly improved resolution of the peaks.

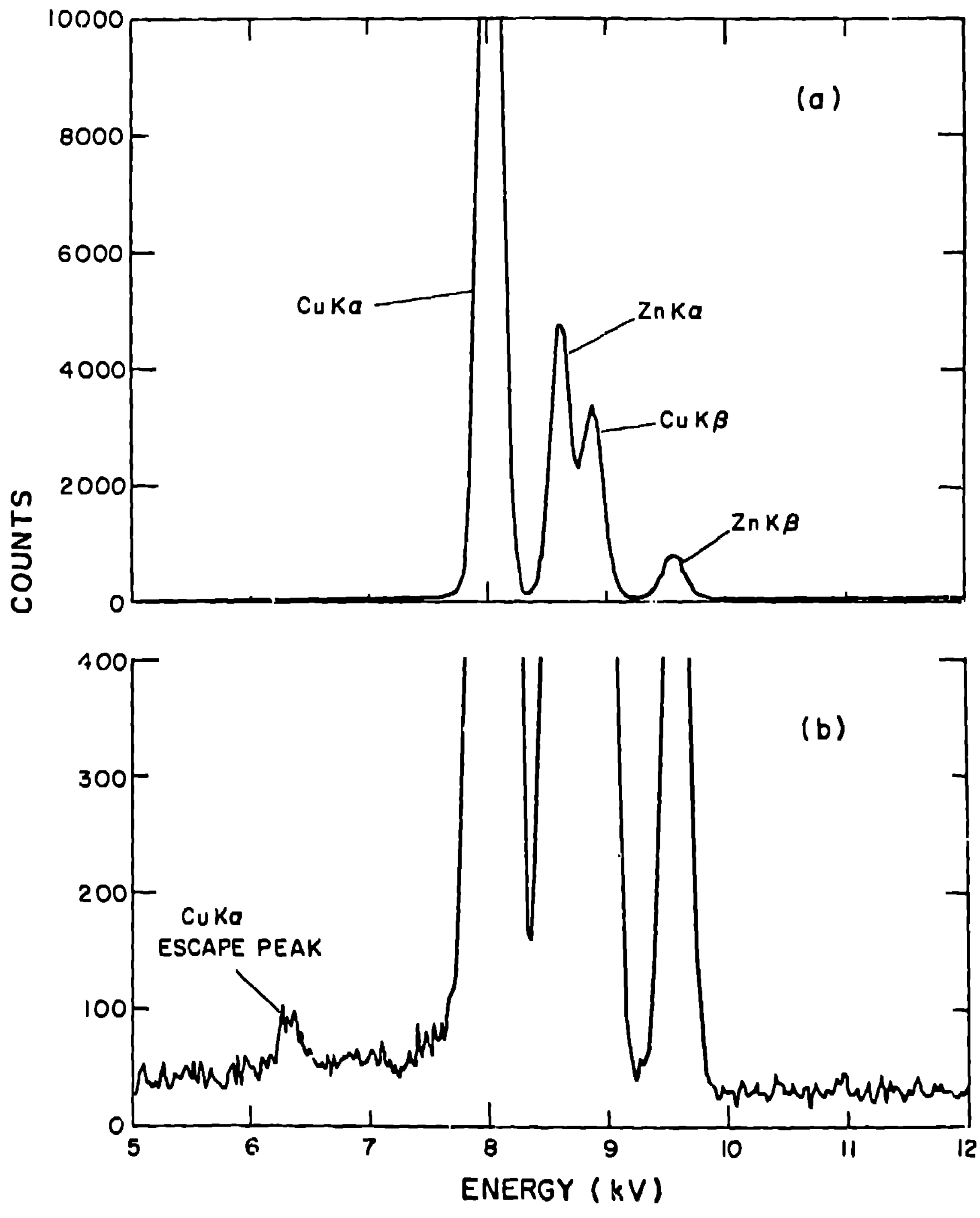

Fig. 1 Synthesized X-ray Fluorescence Spectrum for Mixture of Copper and Zinc.

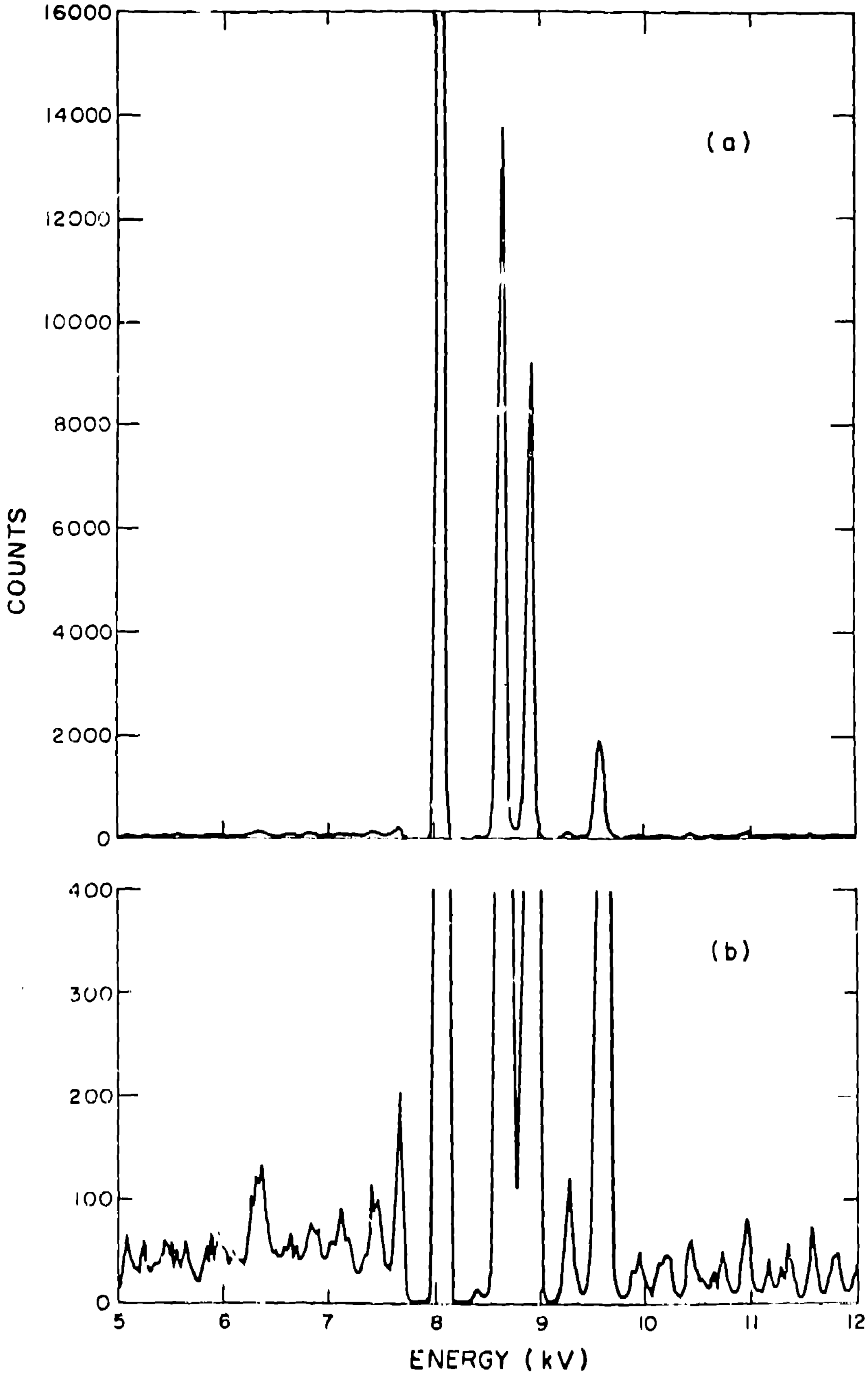

Fig. 2 Restored Spectrum for Mixture of Copper and Zinc from Original Shown in Fig. 1.

COMPUTERIZED AXIAL TOMOGRAPHY (CAT)

X-ray images are inherently poor ways to obtain depth information parallel to the x-ray beam. Tomographic schemes in which the x-ray source and the film are physically moved in synchronism have enjoyed limited popularity.

In recent years, computerized-axial tomography (CAT) or computer-aided tomography (CAT) has become very popular for medical diagnostics. In this procedure we are able to construct a view of an object such as we would obtain if we could slice the object and look at a cross section (3). Since the technique is relatively time consuming and expensive, it has had very limited applications in the industrial world. Nonetheless, it is a technique of great potential for those instances in which the time and money are warranted. It can produce data that cannot be obtained by any other means. We are developing a tomographic system at Los Alamos for examination of nonmedical objects.

CAT requires a large number of x-ray views taken at a series of angles around the object. In general, the more views which are obtained, the better the visualization of detail in the resultant cross-section. In our system we obtain these multiple views by rotating the object about an axis between a fixed x-ray source and a detector. Sixty or ninety views over 180° of rotation are commonly obtained. Figure 3 is a schematic of the tomographic system.

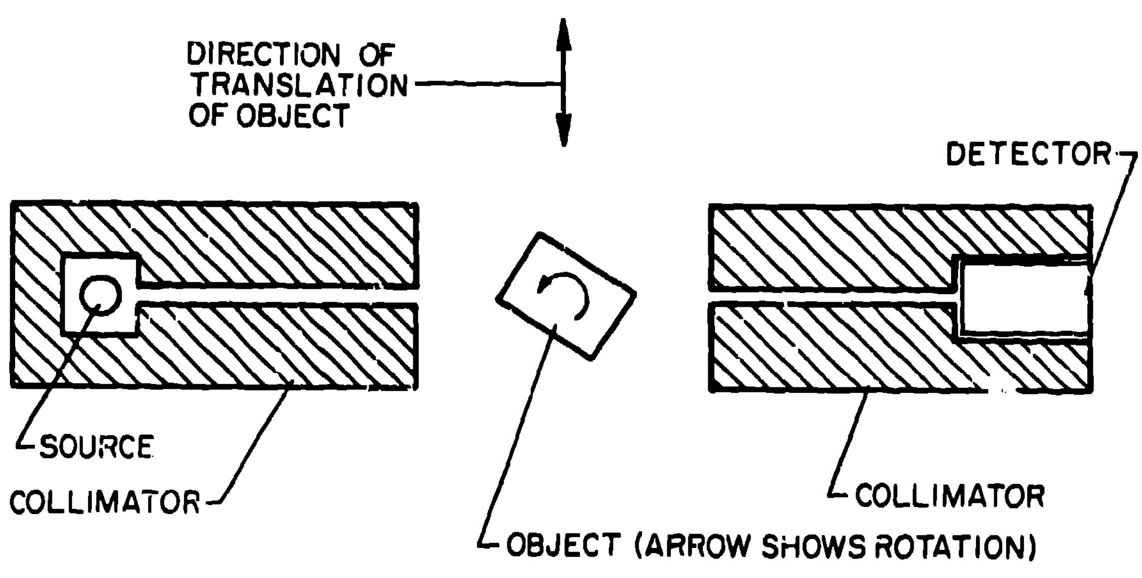

Fig. 3 Schematic of the CAT System.

Most of our tomographic work to date has been with radioisotope sources of x rays. The emission passes through a collimator, then through the object and into a NaI-photomultiplier detector.

The system is under computer control of the object position and data collection. At a given rotational position the object moves across the collimated x-ray beam. The angular position is then incremented for the next view. The object again moves across the beam. The procedure repeats, as needed, for all views. The data from each passage of the object across the beam is recorded on a floppy disc for later analysis on a 7600 computer.

The analysis, or reconstruction, furnishes the cross-section view of the object. The entire process must be repeated for each plane through the object which we wish to examine in cross-section. A major reduction in the time for data acquisition is possible by collection of the data as a two-dimensional image for each rotational position of the object. In principal, then we could reconstruct numerous planes simultaneously. Development of the mathematics for this analysis, known as cone-beam reconstruction, is a major undertaking, still waiting for adequate funding.

Prior to beginning a complete tomographic scan we always take a few conventional radiographs. These radiographs furnish the needed technique data for the tomographic procedure. If we cannot get a good conventional radiograph, the tomographic visualization will not be satisfactory.

Figures 4 and 5 show an example of the Los Alamos tomographic work. The object in Fig. 4 is a conventional electric capacitor. Electrically, this capacitor was beginning to show signs of failure. But what was the mechanism of the failure? Efforts to invasively section similar capacitors had been futile, as the sectioning operation deformed the details of failure. Simple radiography was of only limited value because of the difficulty in visualization of three dimensions. In Fig. 5 we show a single plane, or slice, of the capacitor in cross-section. A series of such slices shows the three-dimensional characteristics of the failure region.

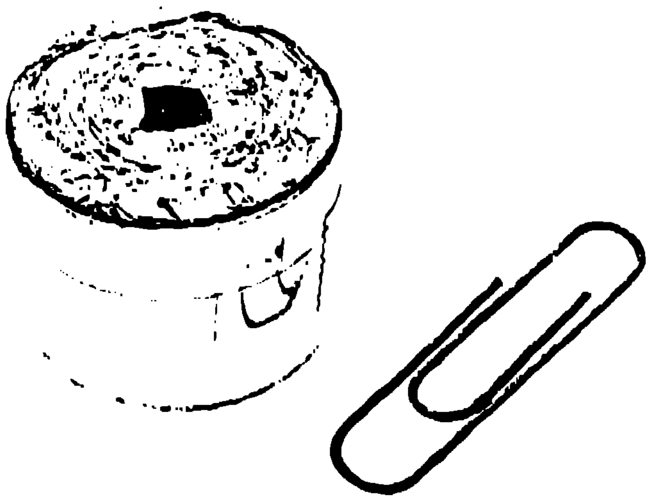

Fig. 4 Electric Capacitor, Shown in CAT Reconstruction in Fig. 5.

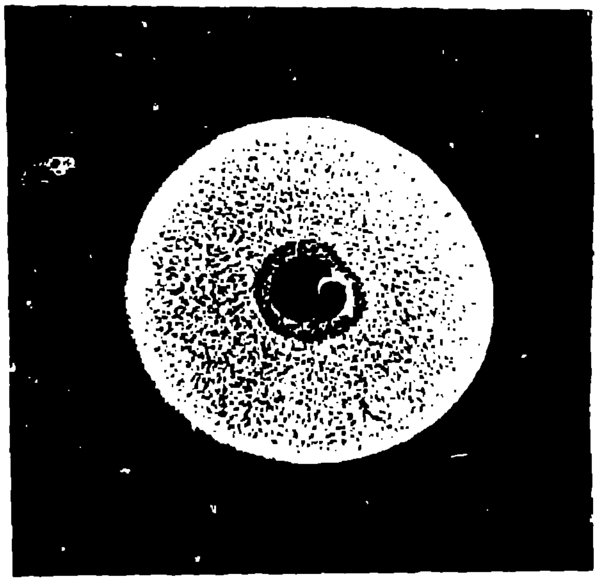

Fig. 5a CAT Reconstruction of Un-Damaged Capacitor that is Shown in Fig. 4.

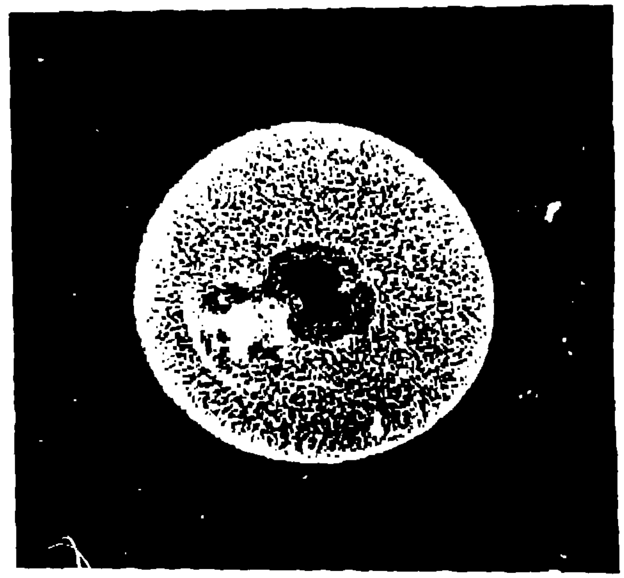

Fig. 5b CAT Reconstruction of Damaged Capacitor.

CODED APERTURES

We occasionally need to image a self-luminous object; for example, a piece of radioactive material. In a principle, we could image this material with a simple pinhole. In practice, the pinhole is often not satisfactory. In order to obtain adequate spatial resolution the pinhole must be very small, resulting in a very low flux and very faint image. The coded aperture offers a way to overcome this problem (4). Think of many pinholes so close together that their individually formed images overlap. The composite of overlapped images can be unscrambled in the computer to form a representation of the self-luminous object. Further, since the size of the image formed by each pinhole and the offset of overlapping images are functions of the distance from the object to the pinhole screen, the unscrambling can yield three-dimenstional data from the object. This screen with several pinholes is the coded aperture. A detailed analysis shows that often the best conditions for this scheme require a screen that is transparent to the emitted radiation over half of its area. The other half is opaque to this radiation. Thus, enormous gains in flux of the order of 10 over a simple pinhole are available.

The successful unscrambling of overlapping images requires certain mathematically defined relations between the open and the opaque regions of the pinhole screen. Various laboratories each have a favorite set of relations. Our favorite at Los Alamos is the uniformly redundant aperture (URA). We have shown, on a theoretical basis, that in many cases of practical interest this aperture will give a superior representation of the object. The other apertures in common use, all tend to produce much worse artifacts, halos, etc. A typical URA is shown in Fig. 6.

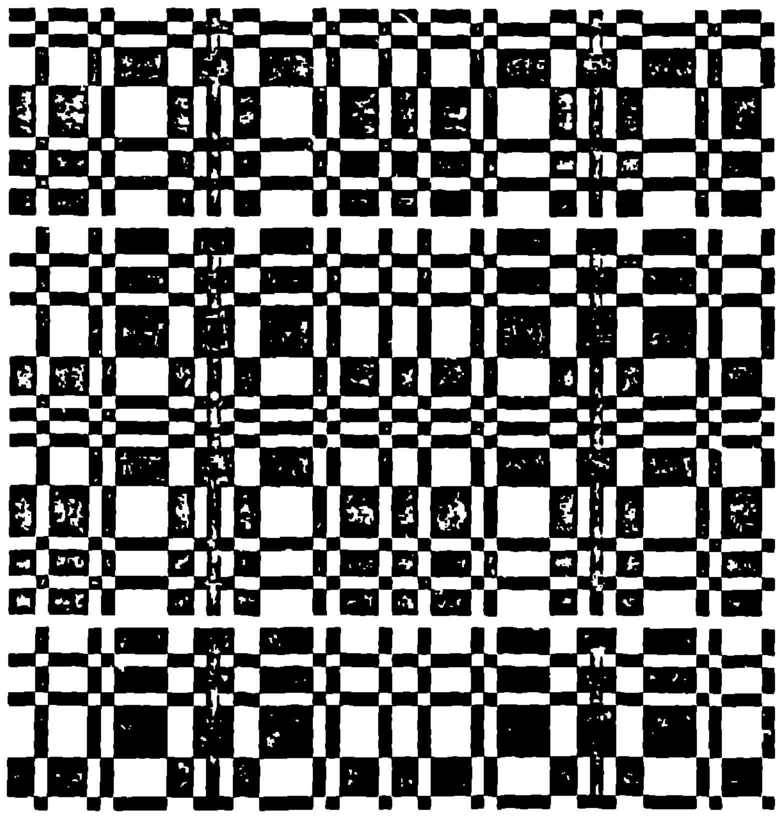

Fig. 6 Uniformly Redundant Coded Aperture. Dark Areas are Opaque, Light Areas are Open; or Vice-versa

The three-dimensional properties of the coded aperture have not yet been fully developed. Without extensive further analytical development, we note simply that the spatial resolution in the third dimension is much worse than in the transverse directions.

A comparative example of a URA image and a pinhole image is shown in Fig. 7. This figure shows the images from a small sphere of Pu-239 and a 15-cm disc of U-235. Both were at a distance of approximately 12 m from the URA camera. Both images were formed with a 30-minute exposure to the 120 keV gamma rays emitted by the objects. Though even the URA image is far from ideal, it is vastly superior to the pinhole image. This superiority results from the much larger aperture of the URA than of the pinhole. With longer exposures or sufficiently intense sources, excellent images can be obtained.

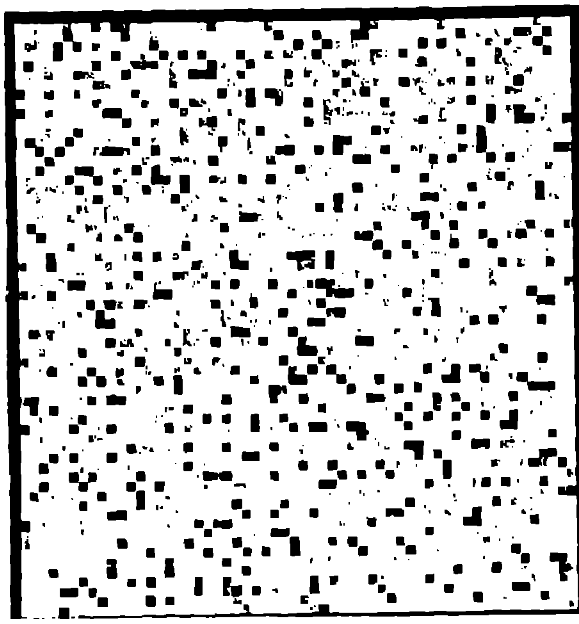

Fig. 7a Pinhole Image of Two Radioactive Sources.

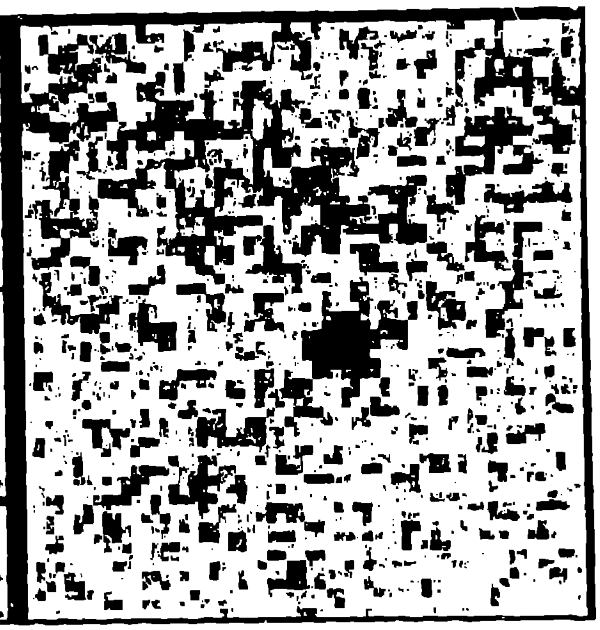

Fig. 7b URA Image of Same Two Sources as Shown in Fig. 7a.

We have not tried a coded aperture camera on an object that is not self-luminous. In theory, such an object could be made to behave as a luminous object by irradiating it with x rays and observing the sideways scattered rays with a coded aperture. Such a technique would yield limited threedimensional data. Its feasibility depends upon primary intensity, scattering cross-section, detector efficiency, and absorption of the incident and scattered x rays. In the absence of a detailed analysis, it is this author's opinion that this type of scattered radiography is of limited utility.

GAMMA-RAY COUNTING

A problem from the reactor fuel-element fabrication facility concerns the uniformity of element loading with fissile material. Uniformity is measured in terms of gamma emission per unit length of element. We make this measurement with an ad hoc system to position the fuel element with respect to scintillation detectors. The element slides through a scintillation assembly. See Fig. 8. The motion ceases at frequent intervals while the gamma counting rate is recorded. In principle the entire operation can be performed under computer control, though at the moment the control system is incomplete. Of interest here, however, is not the fundamental experiment or the computer controller. Rather, we ask how the lengthwise resolution of the system can be improved.

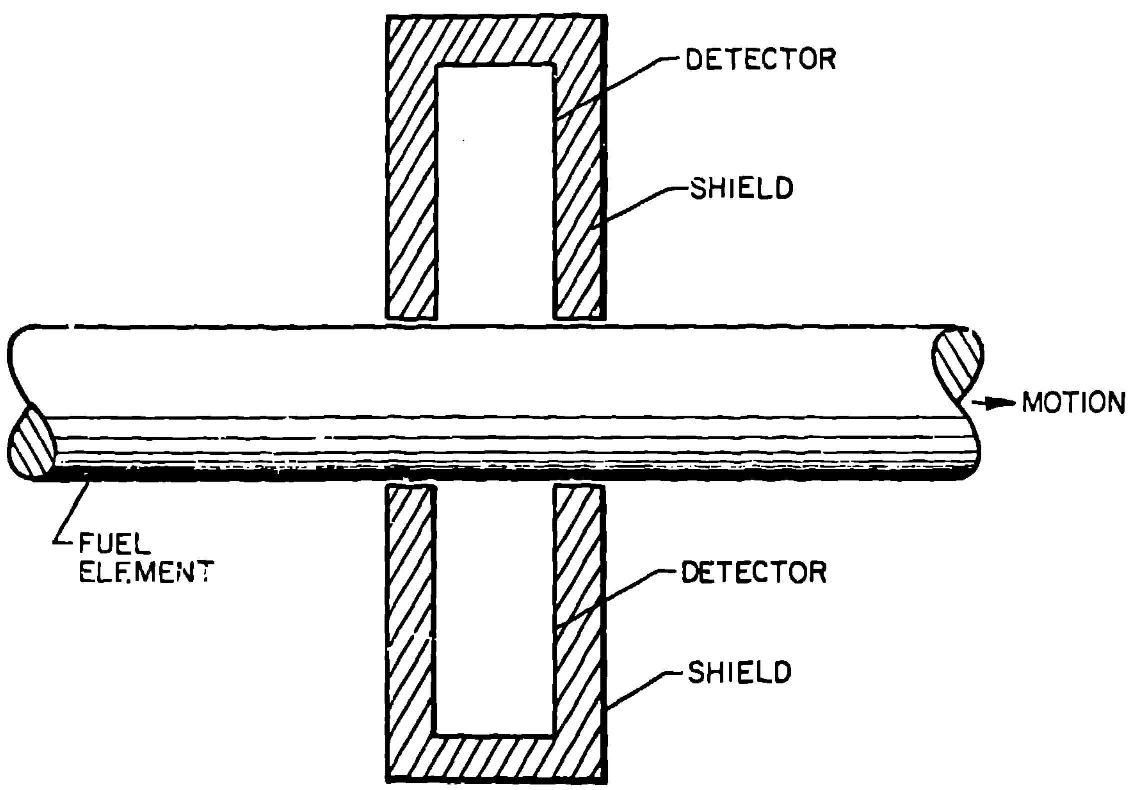

Fig. 8 Simplified Schematic of Gamma-ray Emission Inspection of Fuel Elements.

To answer this question, consider a hypothetical fuel loading that consists of a single emitting slice through the fuel element. When this slice is a great distance from one side of the scintillation counters, the signal will be essentially zero. As this emitting slice moves toward the detectors the signal will increase. It will be a maximum when the slice is in the midplane of the detectors. As the slice moves on past the detectors, the signal will drop, becoming essentially zero again at a large distance. This variation of counting signal with element position may be thought of as a point-spread function (PSF) for the system. Stated under this name, it is clear that in principle the effects of the PSF can be deconvolved from the data. This deconvolution will give better length resolution of the fissile loading in the element. Any of several deconvolution, or restoration methods, are potentially applicable. The choice will probably rest upon the signal-to-noise ratio that is obtainable with a reasonable counting time at each position of the fuel element.

This method of analyzing the counting data is still under study. Should it prove to be feasible and useful, the idea is applicable to any situation in which a radiation detector of broad areal response is needed.

ULTRASONICS

Though ultrasound is now a classical form of NDE, the relation of scattered acoustic signal to the scattering inhomogeneity is still often determined empirically. A need exists for adequate theoretical computational methods to relate the scattered signal to the inhomogeneity. In collaboration with our theoretical division, we have begun such a program at Los Alamos. Due to a lack of funding for experimental work, the theoretical effort is far ahead of corroborating experimental activity. The theoretical activity to date has considered single scattering inhomogeneities within a large homogeneous piece of material (5). We are still developing suitable schemes for data analysis from these relatively single scatterers. Theoretical activity continues toward multiple interacting inhomogeneities. This latter problem is also more difficult experimentally. Currently our experimental fabrication group is studying ways to build such a system with a known distribution of inhomogeneities.

CONCLUSIONS

A multipurpose NDE laboratory develops many techniques for special purposes. Without an intentional effort to relate these techniques to problems of the nuclear weapons community we pass by opportunities for valuable interchanges. In this paper we have described several solutions looking for weapons problems. Out of these descriptions we hope that better NDE techniques will emerge for use in examination of weapons and weapon components.

ACKNOWLEDGEMENTS

Several developers of specialized techniques have contributed to this paper. Specifically, I mention, L. A. Schwalbe, R. P. Kruger, T. M. Cannon, J. R. Breedlove, and R. D. Strong. To the many who have played less prominent roles, I offer an apology for my failure to acknowledge them by name.

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