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Abstract

Neutron yields from DT-filled ICF targets have reached 10^{14}. Above 10^{13}, a significant neutron-induced background appears in images recorded with nearby streak cameras. Since camera components (streak tube, image-intensifier tube, and CCD array) are similar to components that will be used in many NIF instruments, streak camera images provide information about neutron-induced backgrounds that will be encountered in the NIF environment. At a fluence of 10^7 neutrons/cm^2, the background consists of two distinct components: a uniform component equal to nearly 20% of the camera's linear range and sharp, intense spikes each localized to just a couple of image pixels. About 80% of the uniform background is caused by interactions with the streak tube and image-intensifier tube. Nearly all the sharp spikes are caused by interactions with pixels of the CCD array. The spikes make the most significant contribution to image noise.

Introduction

Neutron yields from ICF targets filled with deuterium-tritium (DT) fuel reached new highs in 1995. The high yield at Nova increased from 2.2 × 10^{13} to 3.6 ×10^{13} DT neutrons; at the recently upgraded Omega facility yields have exceeded 10^{14}. At Nova, high-yield targets cause a significant radiation-induced background in images recorded with nearby streak cameras. Background levels are high enough to affect image interpretation and reduce signal dynamic range.

Target yields achieved at the Nova and Omega facilities are comparable to those expected for low power operation at the National Ignition Facility (NIF). Thus, instruments used at Nova and Omega can provide valuable qualitative and quantitative information about how they and similar instruments will perform in the NIF environment. Radiation-induced background characteristics can be observed, and the radiation and reactions causing the background can be identified. An understanding of background generation processes in specific instruments will be valuable for selecting NIF instrument locations and in establishing shielding requirements

This paper describes radiation-induced background signals observed in images recorded with an unshielded optical streak camera that is routinely used for fusion burn-history measurements. The camera, which is part of an instrument called the neutron timing diagnostic (NTD), has an excellent image data base for a variety of targets and yields, and its components are similar to photomultiplier tubes, photodiodes, streak tubes, image intensifier tubes, and CCD arrays that will be used in NIF diagnostics instruments. Two other unshielded optical streak cameras located near the target chamber also show significant levels of radiation-induced background. These cameras are used to record the incident 3ω power history for the ten Nova laser beams.

Background signals

For this paper, only details about the streak camera portion of the NTD system are important, its components and their orientation. The streak camera is located 3.5 meters from the center of the 2-m-radius Nova target chamber. Its optical axis is nearly perpendicular to a radial line extending from target chamber center. No special shielding is used to attenuate target radiation. The only significant material located directly between the target and the streak camera is the 2 1/2" thick aluminum wall of the vacuum chamber. (The experimental configuration for the NTD system is shown in Ref. 1.)

Figure 1 shows the relationship between the three major components of the streak camera: the streak tube (ST), the microchannel plate (MCP) image-intensifier tube (IIT), and the CCD readout array. In normal operation of the streak camera, photoelectrons are generated at the ST's S-20 photocathode and are accelerated to 15 kV before they strike the tube's P–11 output phosphor and produce light. Fiberoptic face plates couple the light between the ST and the S-20 photocathode of the IIT. Photoelectron current from the IIT photocathode is proximity focused to the IIT's MCP where the current is amplified. Electrons exiting the pours of the MCP are accelerated to 6 kV before they strike the IIT's P-20 phosphor. The IIT voltages are set for a luminous gain of 4,000, and the IIT is gated on for 100 µs with the voltage applied between its photocathode and MCP input.

Images from the IIT are lens coupled to a 384 × 576 pixel CCD array with a magnification of about 0.3. Individual pixels are 24 µm × 24 µm squares. Optimum coupling of the 40-mm-diam IIT to the rectangular (1.38 × 0.92 mm) CCD array produces two distinct recording regions (see Fig. 2). A central region, referred to in this paper as the "IIT" region, contains signal generated in the ST, IIT, and the CCD. Outside the IIT region near the edge of the CCD is a "CCD-only" region where any observed signal is generated only within the CCD.

Figure 3 shows an image recorded for a target experiment that produced 3.6×10^{13} DT neutrons which corresponds to a direct neutron fluence of 1.1×10^{7} neutrons/cm^2 at the streak camera. The circular outline of the IIT region is evident; the region contains a set of evenly spaced fiducial pulses and the main pulse of interest for the experiment. The upper third of the image contains only background information as no signal data are recorded in this area of the image. Two distinct features of the background are evident in the IIT region: a uniform component and sharp spikes. In the CCD-only region of the image, sharp spikes are noticeable, but the uniform background is less intense.

Image Analysis and Discussion

The uniform background and sharp spikes in an image are quantified using statistical analysis. First, the uniform background is separated from the spikes by applying a 5 × 5 median filter to the raw image. Then a difference image, which contains only the spikes, is created by subtracting the filtered image from the raw image. The basic characteristics of the background are shown in lineouts taken from these images (Figure 4). A lineout from the filtered image shows that the uniform background is much more intense in the central IIT region than in the CCD-only region. This indicates that interactions in the ST and IIT dominate the formation of the uniform background. In the difference image lineout, spikes appear to be uniformly distributed throughout the IIT and CCD-only regions indicating that they are formed primarily in the CCD.

Averages and standard deviations have been calculated for raw, filtered and difference images. The calculations are for the outlined portions of the central IIT region and the CCD-only region shown in Fig. 3. Results for targets with neutron yields between 10^{11} and 3.6×10^{13} are plotted in Figs. 5 and 6. The data show the uniform component of the background and the standard deviation at these neutron levels to be proportional to the neutron yield. Averages for the filtered image show that

80% of the uniform background is caused by neutron interactions in the ST and IIT. The standard deviation for the raw and filtered images show that filtering reduces the effective image noise by 90% in both the IIT and CCD-only regions. This shows that the large spikes form mostly in the CCD and not in the ST or IIT.

Neutron-induced background in the IIT output phosphor was found to be negligible compared to that induced in the ST, IIT, and CCD. By recording data with the ST and MCP turned off, the central IIT region contains signal from only the IIT output phosphor and the CCD. Signals recorded this way look identical to those recorded in the CCD-only region. Thus showing the contribution of the IIT output phosphor to the background is very small.

Additional work was done to further characterize the nature of the radiation induced spikes. First, the number of pixels for each image spike was determined. For this work, contiguous pixels above a threshold represent a single spike. Next, an amplitude for each spike was determined by summing the CCD counts for all pixels forming the spike. There are an average of 2 pixels per spike with a standard deviation of 2 pixels per spike. The CCD is read out with a 14-bit ADC. The peak streak camera signal, however, is normally limited by the charge available from the IIT. For this camera hard saturation is around 10,000 counts per pixel. Linear streak camera operation is typically about 4,000 to 5,000 counts per pixel. On average there are about 6,000 counts per spike with a standard deviation of 6,000 counts per spike. This result is independent of fluence up to the 10^7 neutrons/cm^2 recorded in these measurements. This shows that the spikes are very localized and that many have very large amplitudes. There are occasional spikes that are comprised of 10 to 15 pixels in a straight line. These appear to be caused by a charged particle, such a proton, slowing down in the plane of the CCD.

In summary, the basic characteristics of neutron-induced background have been determined for streak camera images recorded at Nova. Virtually all background observed appears to be neutron induced, either by direct neutron interactions or by neutron-induced secondary reactions. The background has two distinct components: a uniform background and random spikes. The ST and IIT generate 80% of the uniform background. At a fluence of 10^7 neutrons/cm^2 uniform background levels represents 20% of the streak camera's linear operating range. Nearly all the local, large amplitude spikes, however, are created by interactions in the CCD. The nature of the random spikes allows a simple median filter to remove 90% of the effective noise. The contribution of the IIT output phosphor to the noise negligible.

While neutron-induced background in streak camera images has been characterized and some of the background has been associated with specific camera components, many questions remain to be answered. Is the background caused by direct 14-MeV neutron interactions with streak camera components, or is part of it caused by lower energy scattered neutrons or by neutron-induced γ rays and x rays. Is the uniform background caused by interactions in the ST phosphor or by interactions in the photocathode or MCP of the IIT?

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REFERENCE

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FIGURE CAPTIONS

FIG. 1. Arrangement of major streak camera components: streak tube, microchannel plate (MCP) image intensifier tube (IIT), and CCD array.

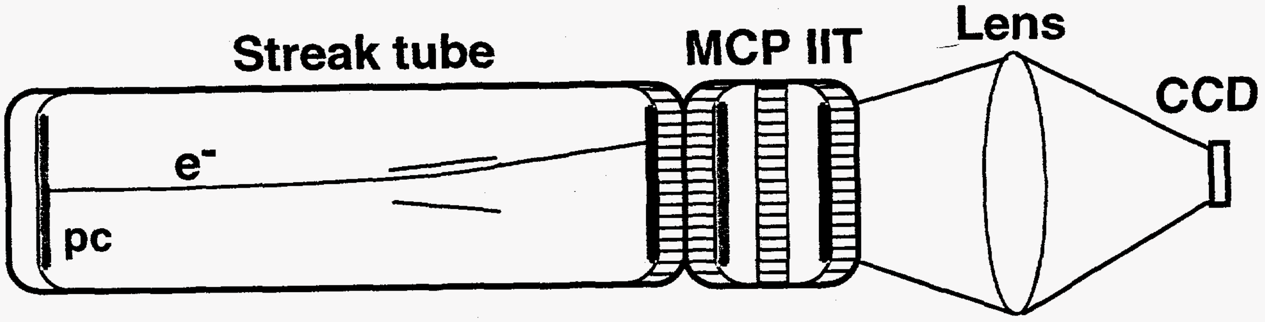
Fig. 2. Relationship between the CCD field and the IIT output image.

Fig. 3 Streak camera raw image for high yield (3.6×10^{13}) shot. The rectangular outlines define the areas used for calculating background statistics. The dashed line shows the location for the intensity lineouts plotted in Fig. 4.

Fig. 4. Background intensity along the row of CCD pixels shown by the dashed line in Fig.3: (a) raw image, (b) filtered image, and (c) difference image.

Fig. 5. Uniform background signal as a function of neutron fluence. Background in the CCD-only region is about 20% of that found in the IIT region. Data are for filtered images, background for raw images is about 100 counts higher at 10^7 neutrons/cm^2.

Fig. 6. Image noise (represented by the standard deviation in image background level) versus neutron fluence. Circles represent CCD-only region, diamonds represent IIT region. Solid points are for raw data and open data points are for filtered images.



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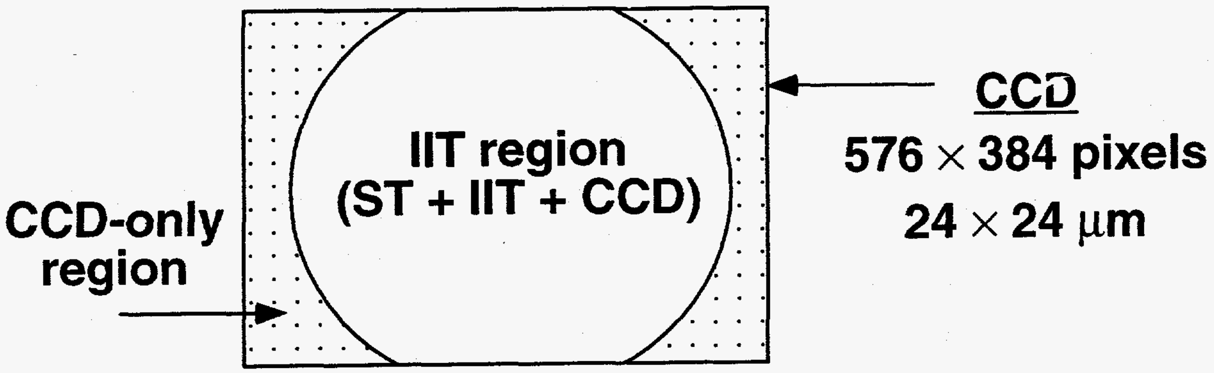

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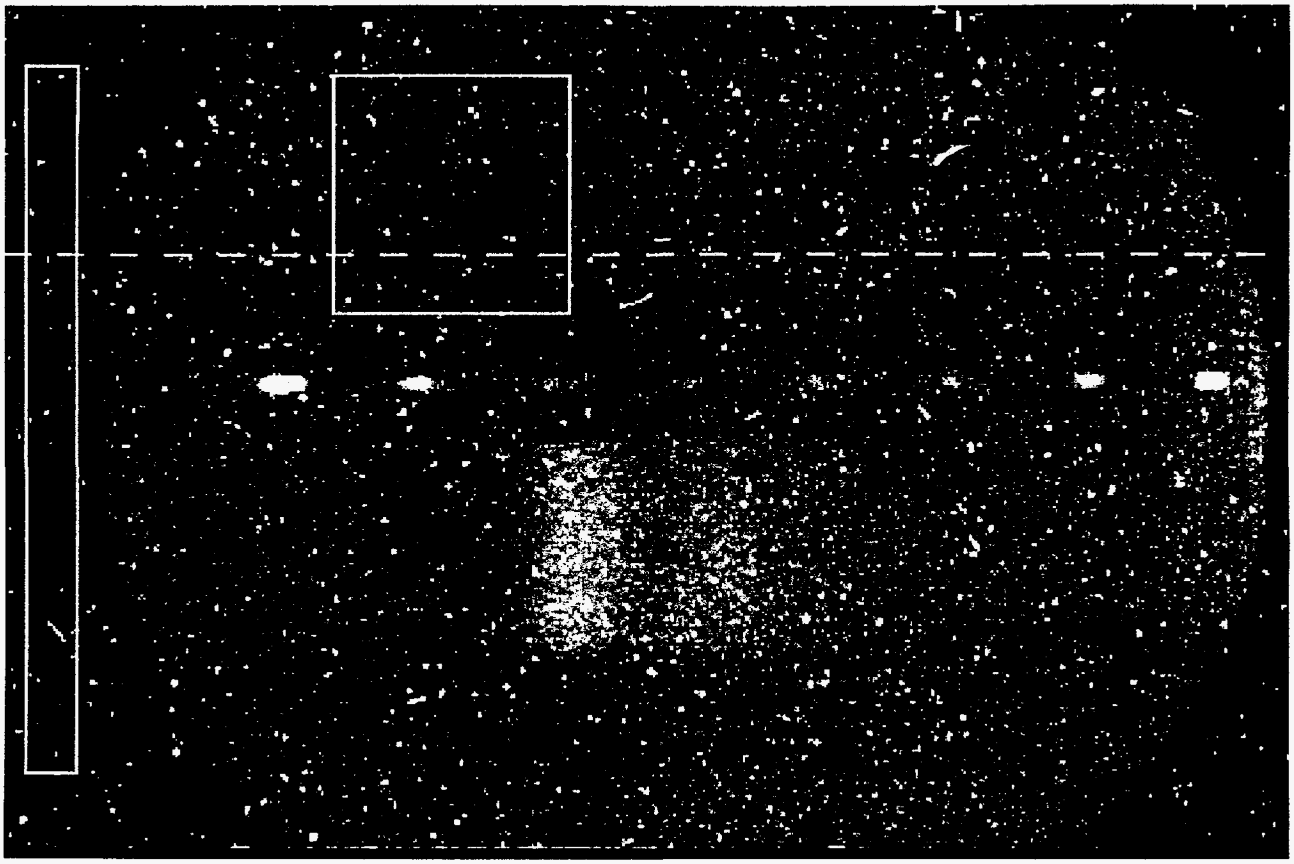

Fig. 3 R. A. Lerche
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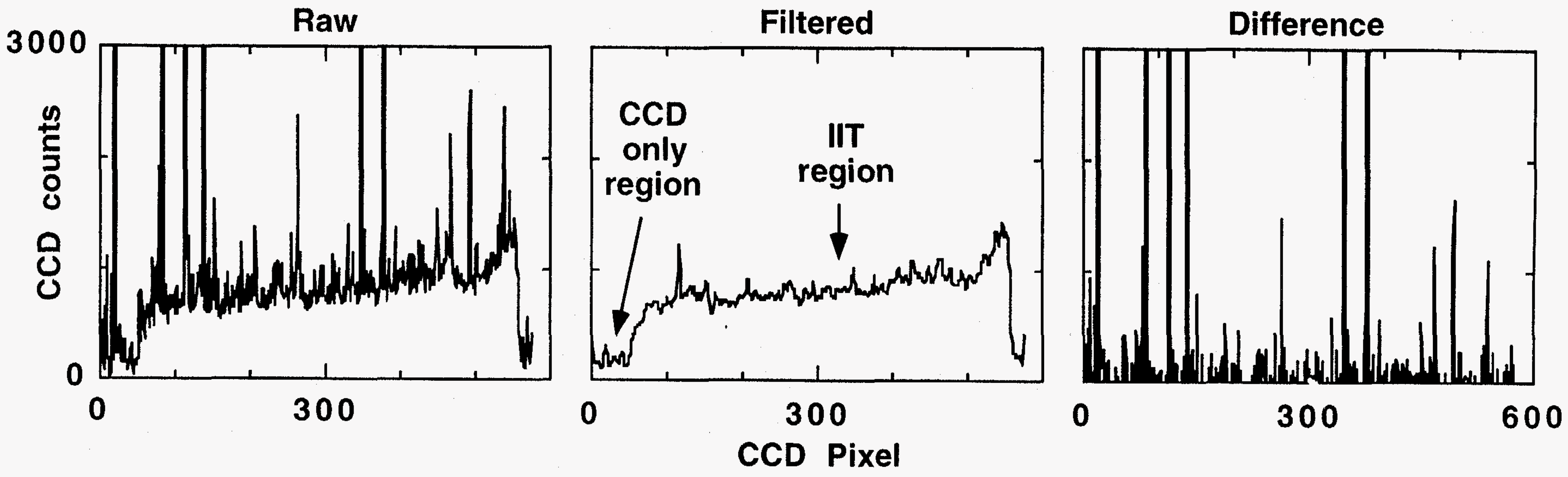

Fig. 4 R. A. Lerche
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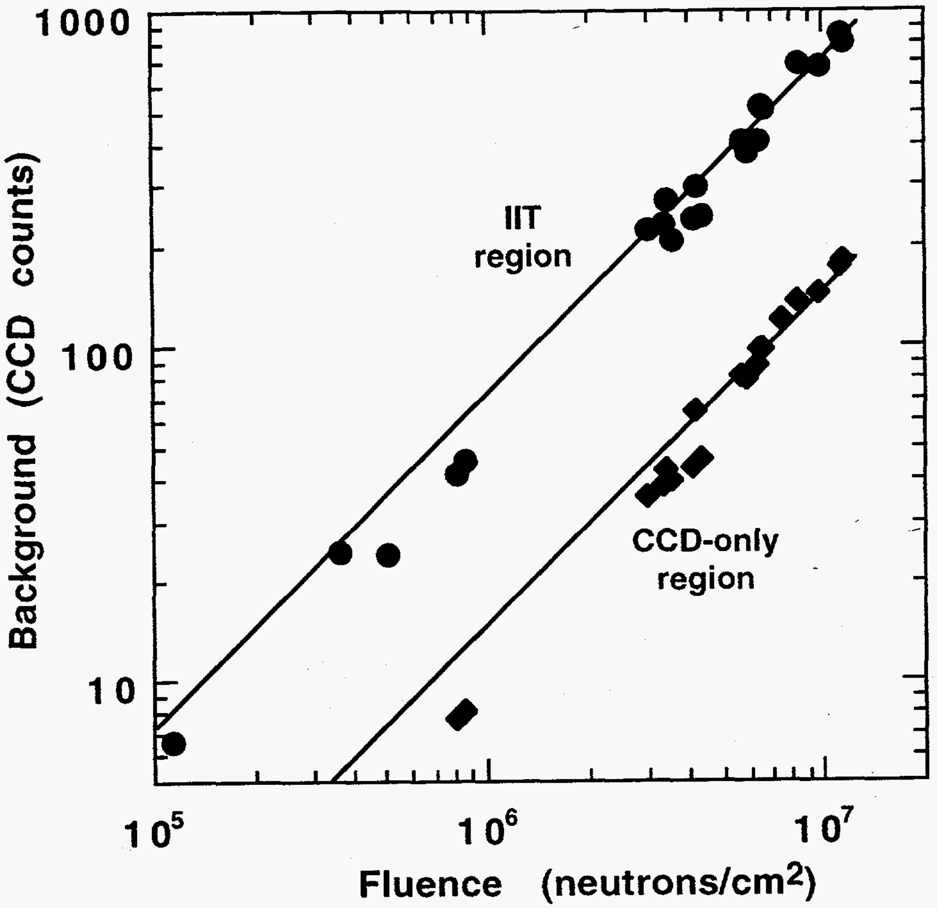

Fig. 5 R. A. Lerche
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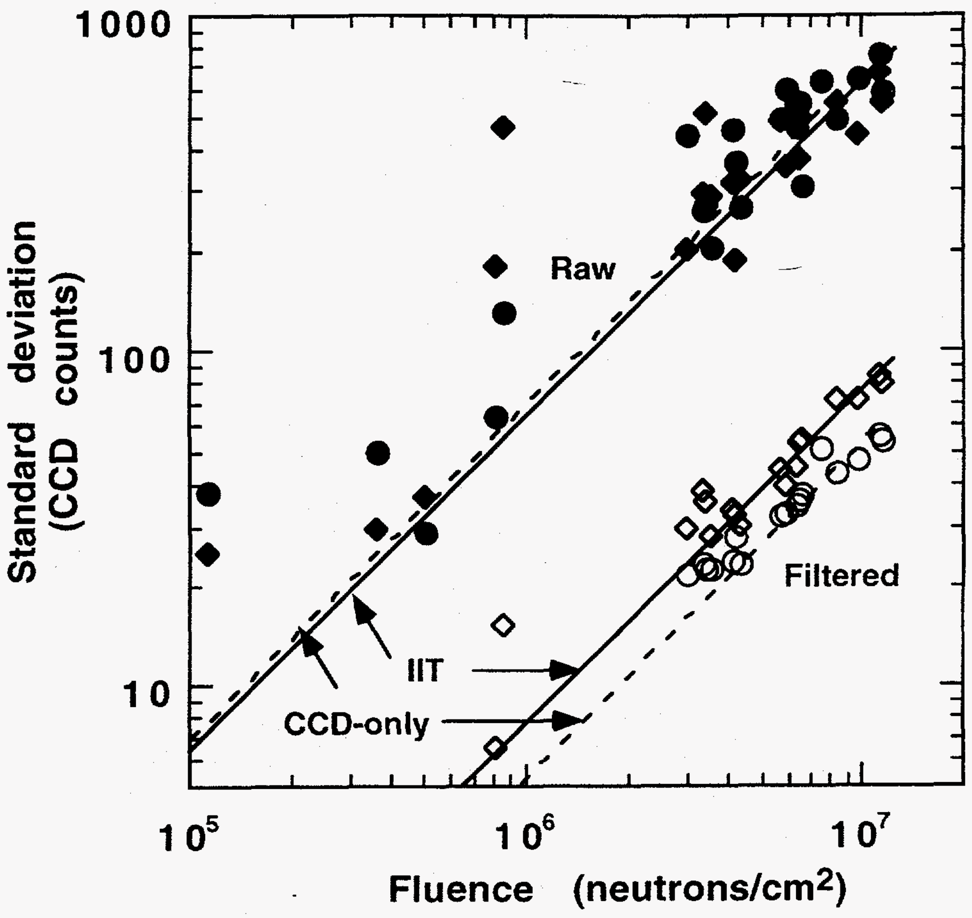

Fig. 6 R. A. Lerche
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