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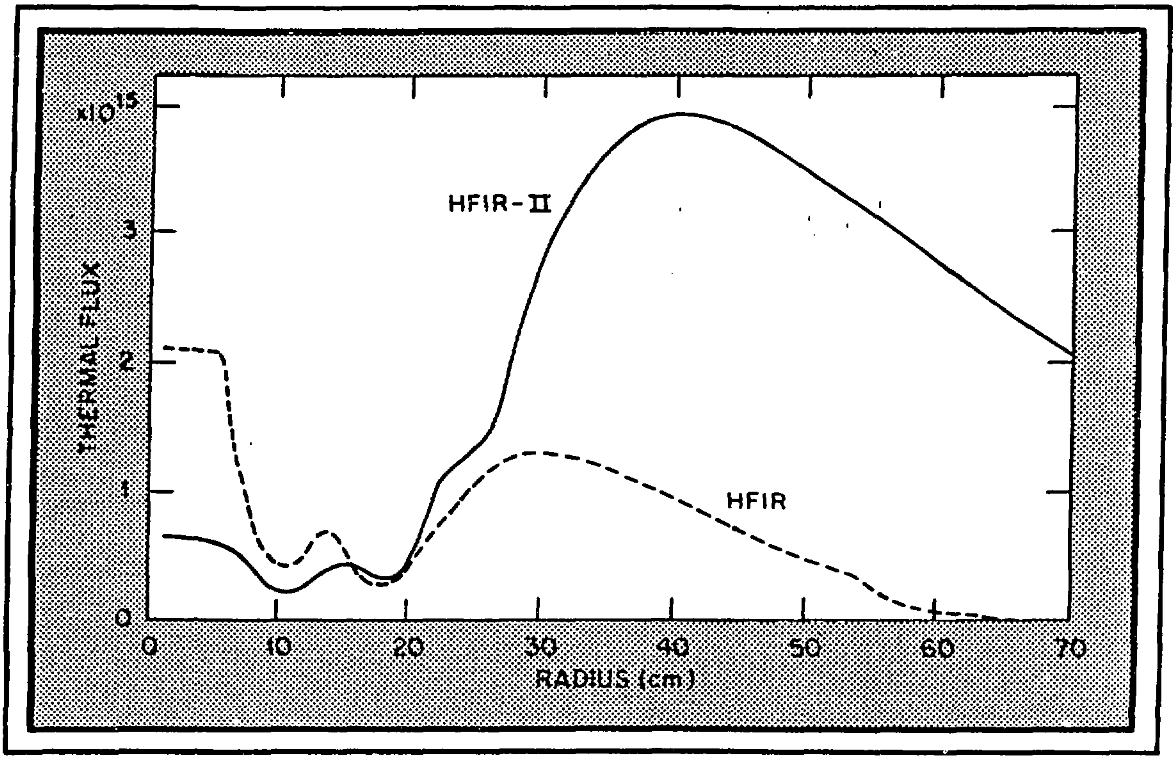
INSTRUMENTATION for the ADVANCED HIGH-FLUX REACTOR



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SCINTILLATION NEUTRON DETECTORS

J. B. Davidson
Instrumentation and Controls Division
Oak Ridge National Laboratory*

Two basic types of scintillation area neutron detectors are reviewed. The first is the prompt detector which uses photomultipliers (PM) to convert the neutron scintillations to electrical pulses. These signals are combined in weighting or encoding circuits to give event location. Then the number in the corresponding address in a computer memory is incremented. Both timing and amplitude information are available. Timing is necessary for energy measurements by time-of-flight when using pulsed sources. The amplitude information is useful for background discrimination. Several embodiments of the weighted and coded scintillator approach will be mentioned. For a fuller description of these and other neutron area detectors an excellent recent book by Convert and Forsyth[1] should be consulted. Much of the following brief information has been taken from this source which contains many references.

The second type of scintillation detector is based on television techniques and has a delayed readout. It will be discussed in more detail because it is the approach I have taken here at ORNL and also it seems to be the one type not fully discussed in Ref. 1.

Weighted or Coded Detectors

The Anger camera was originally developed in the 1950s for imaging γ-rays in nuclear medicine and has been adapted for neutron detection by substituting first a ^{6}Li-ZnS phosphor (Rutherford Laboratory) and later a thin (1-2 mm) Li glass layer (ANL) for the original sodium iodide scintillator. In the Argonne version 49 square photomultiplier tubes are coupled to the scintillator through plexiglass and boron glass layers and an air gap. Because of this separation the light from a neutron interaction spreads in a cone and is "seen" by several phototubes. Weighting resistors, summing and dividing circuits at the PM outputs locate the centroid of the light cone and deliver x and y coordinate pulses to the computer and display. Some salient features and specifications of the Argonne system are shown in Fig. 1 which was adapted from Ref. 1 as were Figs. 2 and 3.

Several laboratories have used smaller discrete scintillator "chips" instead of the larger continuous glass sheet of the Anger system. Each scintillator element is coupled to each of several PM tubes by optical fibers or rods and an electronic decoder determines the particular element in which an event occurs. Figure 2 shows the basic features of the Rutherford Laboratory system being developed by Davidson and Wroe.

Details of a third approach applied to a curved, one-dimensional detector are shown in Fig. 3. This is the work of groups at Jülich and the

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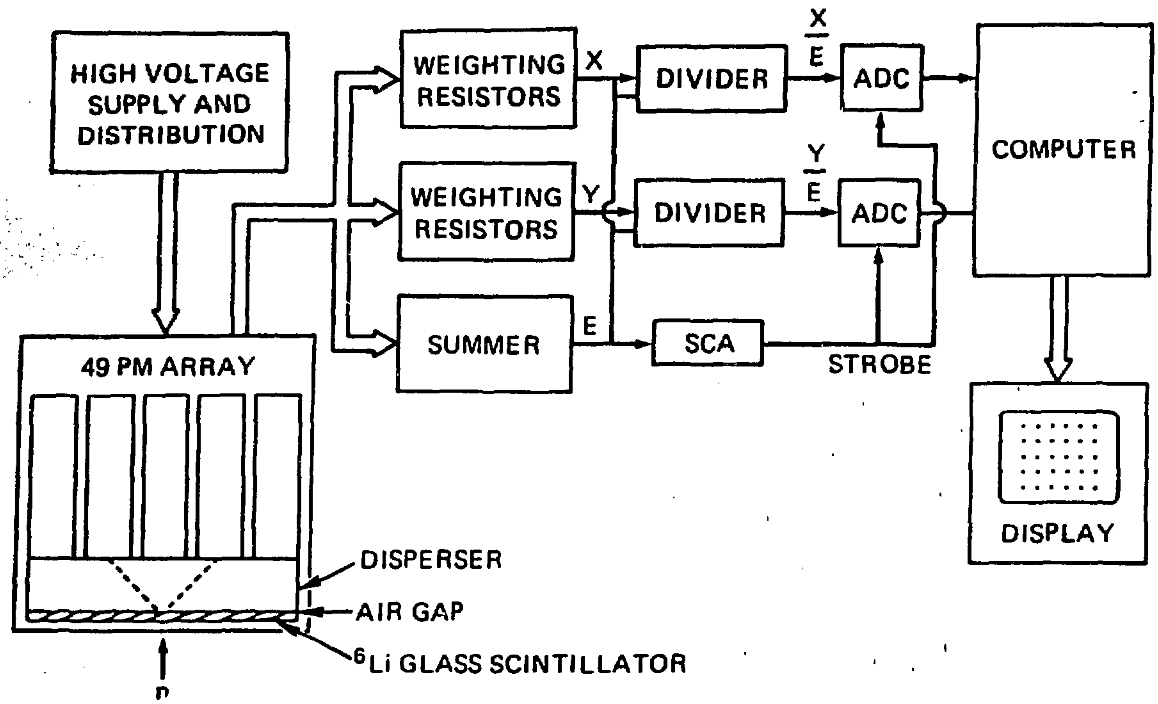

Fig. 1. ANL detector based on the Anger Camera

Developers: Strauss et al. - Argonne National Laboratory

$30 \times 30\ cm^2 \times 2$ mm
≈10000 resolution elements
^6Li glass
49 photomultiplier tubes
Resolution: 2.7 mm
Efficiency: 67-97%

University of Bonn. Two phototubes per scintillator element are used in this decoding scheme.

TV-Based Detection

In the above systems the light from an event is shared by a number of PM tubes which tends to reduce the signal-to-noise ratio at each tube because of the poorer photon statistics. In the TV method all the light (or as much as possible) is either focused with a fast lens or is coupled by being put in direct contact with the fiber-optic faceplate of an image intensifier tube. Furthermore, since the readout of the event is delayed because of the scanning method, the light is integrated for ≈16 milliseconds before being detected. Thus the "tail" of the scintillator decay can contribute significantly to the signal. For the ^6LiF-ZnS scintillators which

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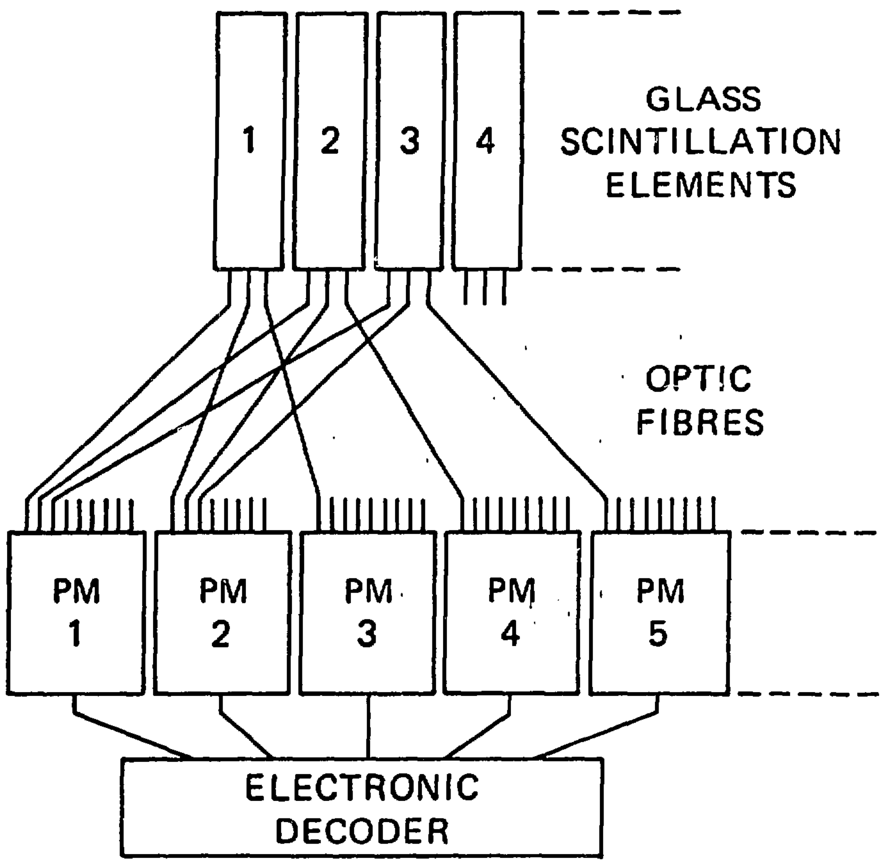

Fig. 2. Rutherford Lab Detector

Developers: Davidson and Wroe - Rutherford Lab

1600 elements 3 x 150 x 2 mm
^{6}Li glass
20 phototubes (1140 elements)
171 connections to each PMT
Resolution: 3 mm
Efficiency: 70%

we have used (having decay times of microseconds) the gamma sensitivity is reduced because the integrated light for the gammas from the ≈0.5-mm thick layer is less than for the neutrons. In the prompt readout systems described above which use Li glass the neutron and gamma pulses are more nearly equal. Their decay times for neutrons and gammas are different and can be used for pulse-shape discrimination of gamma background.

In the TV systems the light from the phosphor screen is intensified 50-50,000 times and coupled to a television camera tube instead of a PM tube

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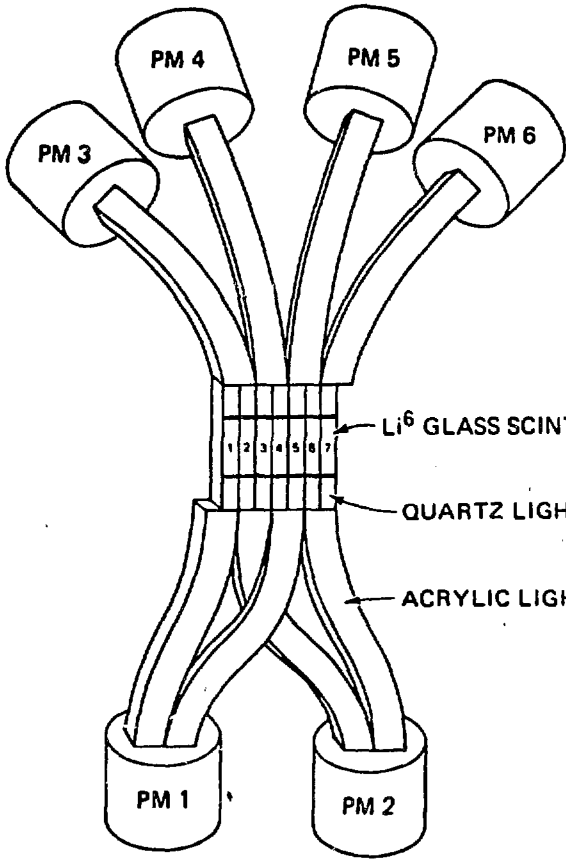

Fig. 3. Jülich-Bonn Curved Linear Detector

Developers: Kurz et al. - Jülich
Pfeiffer et al. - Univ. Bonn

400 elements 5 x 100 x 1 mm
^{6}Li glass
60 photomultipliers
5 mm (0.2°) resolution
80° arc
Efficiency: 75%

as shown in the left side of Fig. 4. Further amplification is produced in the camera tube by accelerating the photoelectrons by 6-8 kV so that 50-100 secondary electrons per incident electron are produced in the target layer of the tube by bombardment. These secondaries are collected by an adjacent positively biased screen leaving the target positively charged in a spot whose location is related to the original neutron impact location. The target layer has high lateral resistance and as a result stores the neutron event (in the form of positive charge) without spreading until the scanning

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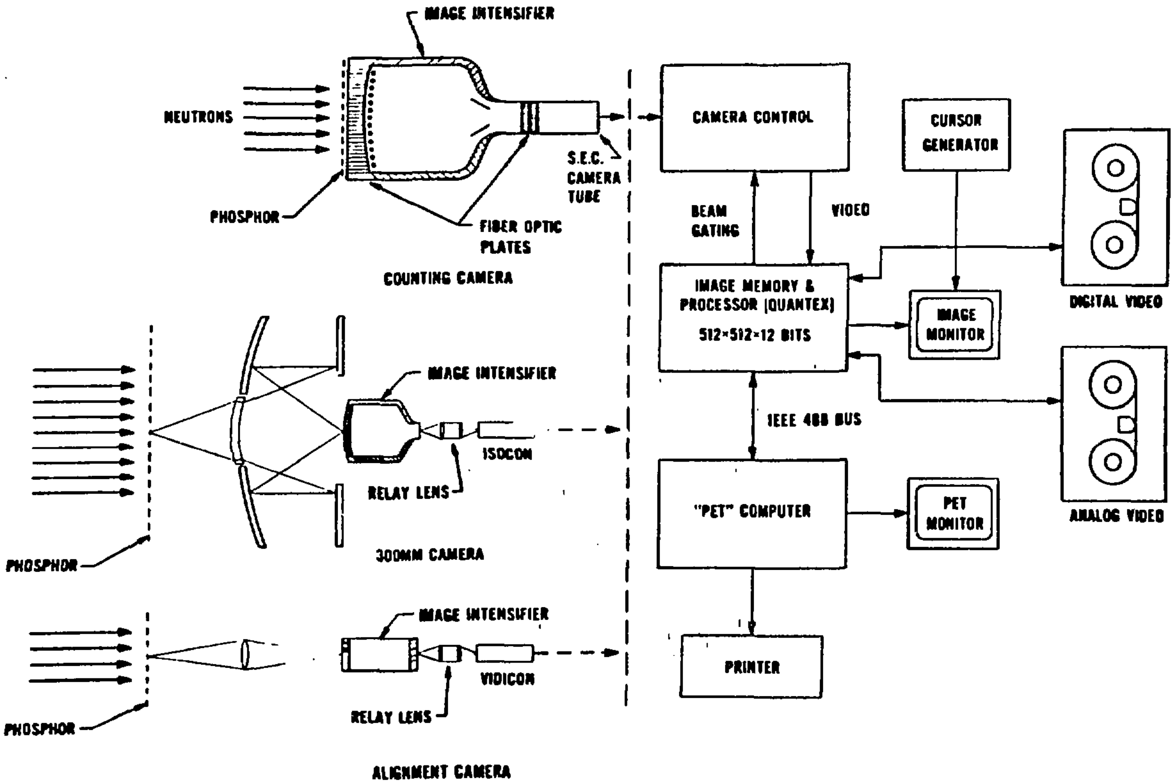

Fig. 4. TV-based detectors

Developer: Davidson - ORNL

150-300 mm diameter x 0.5 mm
0.3 - 1.5 x 10^5 resolution elements
^{6}Li-ZnS
Image intensifier and camera tube
Resolution: 0.3 - 1.5 mm
Efficiency: ≈20%

electron beam passes over it, neutralizing it and inducing a pulse in the external circuits. Since the position of the scanning beam is known (in time) from the raster scanning pattern, the coordinates of a neutron event are located by time measurements from the horizontal and vertical synchronizing pulses. The TV system thus becomes a counting camera (Ref.2). Because the registering of an event is delayed by 8 ms (average), time-of-flight measurement is not possible. As shown in Fig. 4 the events are accumulated in a digital memory for display and analysis.

At the normal scan rate of 30 frames/s the counting rate per picture element is limited to ≈10C/s, or for a uniform distribution over 10^5 elements the limit is ≈10^6C/s for the whole detector. An important feature of the TV detectors is the limited parallelism of the resolution elements. The consequence of this feature is that one or more intense Bragg spots (for example) do not paralyze the detector although they may saturate it at their locations. Weak scattering near these intense spots can still be recorded. This has been demonstrated recently in diffuse scattering observations (Ref. 3).

For highest intensities the system can be operated in the analog mode with the intensifier gain reduced to limit the contribution of each neutron to the output signal. Virtually any intensity can be handled in this way so that for alignment purposes the camera can be used in the direct beam to position a sample.

The three cameras shown in Fig. 4 are a 150-mm diameter counting camera (resolution = 0.3 mm), a 300-mm diameter analog camera (resolution 1-2 mm) operating at near counting sensitivity and a 150-mm diameter (resolution ≈0.5 mm) alignment camera recently improved to show single neutrons at maximum gain. These have been described more fully elsewhere (Ref. 3) along with applications to crystal inspection by diffraction topography and tomography, powder diffraction, diffuse scattering, observation of charge density waves and "table top" small angle scattering (sample-to-detector distance 0.5-2 m). All of these observations were made at the HFIR in real time (30 frames/s) or near real time (1-10 s integrations). Figure 5 shows TV images

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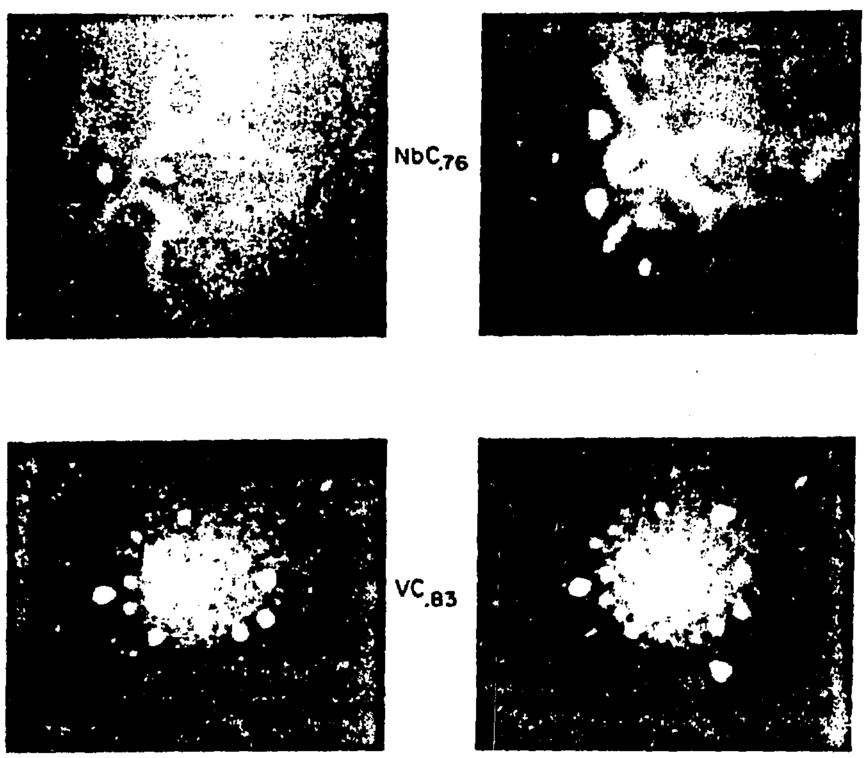

Fig. 5. TV images of scattering from short and long-range order of carbon vacancies in NbC and V_C

of neutron scattering from short and long range order of carbon vacancies in NbC and VC. (A short TV tape recording of some of these observations was shown at the workshop.)

References

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