ISIS NEUTRON DETECTORS

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ABSTRACT

ISIS is currently operating 14 instruments for neutron scattering measurements. Of paramount importance to each of these instruments is its neutron detector system. The detector systems on ISIS include a variety of scintillator detectors which have been developed in house, together with ^{3}He proportional counters which have been obtained commercially. The detectors may be characterised by their shape, neutron and gamma efficiencies, intrinsic background, dead time and the stability of these quantities with time. The characteristics of the ISIS detectors are discussed in relation to the different ISIS instrument requirements.

INTRODUCTION

The ISIS neutron scattering instruments comprise of 6 diffractometers, HRPD, LAD, SXD, POLARIS, LOQ and SANDALS and 6 spectrometers MARI, eVS, HET, TFXA, IRIS and PRISMA, together with the neutron reflectometer CRISP. In addition there is a TEST BEAM which can quickly be configured into a number of different roles including a facility for measuring neutron scattering from samples under high pressures in the Paris/Edinburgh High Pressure Cell and an instrument for residual stress analysis. These instruments will shortly be joined by ROTAX, a rotating analyser crystal spectrometer. Each of these instruments operates one or more types of neutron detector.

An overview of the types of neutron detector operational at ISIS is shown in Figure 1. These detectors can be divided into ^{3}He gas proportional counters which are available commercially and scintillator detectors which have largely been developed at the Rutherford Appleton Laboratory, RAL. The scintillator detectors can be differentiated according to the type of scintillator used; whether the scintillator is ^{6}Li loaded zinc sulphide, ZnS, or ^{6}Li loaded glass. Each of the three groups can be sub divided according to the degree of position sensitivity; whether it be a single counter, a linear counter with one dimensional position sensitivity or an area detector with two dimensional position sensitivity. The scintillator detectors can be further characterised according to the method of coupling the scintillator to photomultiplier tubes, PMT's. The PMT's may either view the scintillator directly or via fibre optic light guides.

In assessing the performance of each of these detector types then a number of characteristics need to be considered. These include the following:

1) Neutron detection efficiency as a function of energy.
2) Sensitivity to gamma radiation.
3) Intrinsic detector background.
4) Spatial resolution and detector geometry.
5) Pulse pair resolution, ppr.
6) Stability of detector characteristics with respect to time.
7) Ease of maintenance.
8) Cost.

The efficiencies of gas proportional detectors can be calculated from a knowledge of the gas pressure of the neutron absorbing component. For the scintillator detectors the efficiency with which light is generated from a neutron event, the efficiency of light transmission to the PMT's and the quantum efficiency of the PMT's can all result in a decrease in neutron detection efficiency compared with that calculated from the concentration of neutron absorber in the scintillator. Neutron detection efficiencies of the scintillator detectors have therefore been determined experimentally from neutron count rates measured near to a PuBe source which has a broad neutron energy spectrum centred around 1 Angstrom. The neutron flux from the PuBe source is calibrated using a 10 mm x 10 mm scintillator sheet directly coupled to the end window of a PMT. For a glass scintillator this gives a detector with an excellent pulse height resolution of 12 %. In most cases scintillator detection efficiencies have been confirmed on

ISIS by comparing count rates from standard ^3He single proportional counters under similar conditions. The sensitivity of neutron detectors to gamma radiation has been measured using a 1 curie ^{60}Co gamma source placed 100 mm from the active detector area. Gamma sensitivity is expressed as a ratio of photons detected to photons incident on the detector, account being taken of intrinsic detector background levels where significant. Pulse pair resolution is used as a means of comparing the time response of the detector types and is a measure of the shortest time in which successive neutron detector events can be recorded.

Detector characteristics are discussed in detail for the various types of detector operational at ISIS. It is the optimisation of these parameters to meet the requirements of a particular instrument which leads to a successful detector design.

SINGLE ^{3}He PROPORTIONAL COUNTERS

Nine of the ISIS instruments make use, either in part or in total, of single ^3He proportional counters. Over 1000 of these detectors will be operational on ISIS by the end of the year. By far the largest user is the MARI spectrometer which operates Reuter Stokes detectors at 10 atmosphere ^3He and generally 300 mm long and 25 mm diameter. Typical detector characteristics are given in Table 1. For these detectors the neutron detection efficiency at wavelengths of 1 Angstrom and greater is good, the gamma sensitivity and intrinsic detector backgrounds are low while the pulse pair resolution is moderate. The single neutron proportional counter has been in use for many years at neutron scattering centres throughout the world and its detector characteristics have become a yardstick by which the performance of other more novel detector systems can be measured.

ONE AND TWO DIMENSIONAL POSITION SENSITIVE ^{3}He PROPORTIONAL DETECTORS

ISIS operates three position sensitive ^3He proportional counters. The CRISP reflectometer uses a linear position sensitive detector while LOQ and SXD/TEST BEAM use two dimensional area detectors. All theses detectors have been purchased from the Ordela company, ref 1, and use rise time encoding methods to determine position sensitivity. Detector characteristics as published by the Ordela company are summarised in Table 2.

DIRECTLY COUPLED LINEAR ZINC SULPHIDE SCINTILLATOR DETECTORS

SANDALS, IRIS, POLARIS and TEST BEAM all operate one dimensional position sensitive ZnS scintillator detectors in which the PMT's directly view the scintillator elements. In each of these detectors scintillator elements are contained in aluminised mylar light guides and the PMT's are displaced laterally a half tube diameter from the light guide axis. Each PMT views two scintillator elements, while each scintillator is viewed by segments of two adjacent PMT's. Neutron events in any one scintillator are determined by the coincident output from adjacent pairs of PMT's. This PMT arrangement uses on average one PMT per detector element while allowing detector noise due to random PMT events to be largely eliminated.

The detectors of this type on POLARIS and TEST BEAM have become known as 'BRICK' detectors due to a design requirement to achieve a self stacking detector. The POLARIS BRICK detector modules are used for diffraction measurements while two BRICK detector modules on TEST BEAM have been incorporated in an instrument for residual stress analysis, ref. 2. Essential differences between the SANDALS, IRIS and BRICK detectors are associated with the arrangement of the scintillator in the detector element, Figure 2.

The SANDALS elements consist of 20 strips of ZnS, 200 mm x 10 mm x 0.4 mm stacked one behind the other and separated by crown glass strips of similar dimensions. This arrangement gives a neutron path length, p, through the scintillator of 8 mm. In the IRIS detector the strips are non-overlapping, but are oriented at an angle of 60 degrees to the neutron beam giving a neutron path length of 0.8 mm. This arrangement has a much lower ZnS scintillator density compared with the SANDALS detector elements and a corresponding improvement in the collection of the scintillator light. In the BRICK detector the scintillator elements are arranged as a smaller version of the SANDALS sandwich. Each element is made up of 4 strips of ZnS scintillator sandwiched between crown glass strips of similar dimensions giving an average neutron path length of 1.6 mm. The number of detectors of each type operational on ISIS together with their characteristics are given in Table 1.

Detector characteristics are largely determined by the magnitude of the neutron path length, p, through the scintillator elements. For SANDALS where p is high, neutron detection efficiency is relatively high, even at 10 eV. Although gamma sensitivity and intrinsic detector background is also high, this is an acceptable compromise for SANDALS requirements. In the IRIS detectors, p is low and neutron efficiency at 1 Angstrom is correspondingly low. However IRIS operates at wavelengths of 3 - 10 Angstroms and in this region neutron detector efficiency is relatively high. Full advantage is therefore obtained from the excellent gamma rejection and low intrinsic detector background available with this detector geometry. These characteristics are comparable with the best ^{3}He detectors. The BRICK detectors exhibit characteristics intermediate between these extremes with a relatively high neutron detection efficiency for a detector which is only 5 mm deep.

FIBRE COUPLED LINEAR ZINC SULPHIDE SCINTILLATOR DETECTORS

A detector system has been designed specifically for data collection from samples in the Paris/Edinburgh high pressure cell. Four modules of this type have been installed on POLARIS and a further two modules are operational on TEST BEAM. All six modules have been operating since November 1992. Each module has 36 elements, 300 mm high and 3.5 mm wide, connected by a fibre optic array to 9 PMT`s. The fibres are arranged in a 2CN code so that any pair of PMT` outputs uniquely specifies one of 36 detector elements. This is an extension of the detector design employed on the 90 degree HRPD detector described previously, ref. 3. In this detector 6 modules are vertically stacked one on another. Each module has 66 scintillator elements 200 mm high and 3 mm wide. The scintillators are again viewed by a fibre optic 2CN coded array in which pairs of outputs from 12 PMT`s specify one of 66 elements. The characteristics of these detectors are very similar and given in Table 1.

Neutron detection efficiencies are 30% - 36% at 1 Angstrom with gamma sensitivities and intrinsic detector backgrounds only marginally worse than those of the IRIS detector or the standard 10 atmosphere ^{3}He proportional counter. Since only one electronic channel is needed per 36/9 or 66/12 detector elements this gives rise to a relatively cost effective detector system.

FIBRE COUPLED AREA ZINC SULPHIDE SCINTILLATOR DETECTORS

The 4096 SXD detector is a fibre coupled two dimensional ZnS scintillator detector. The detector consists of a single sheet of ZnS scintillator, 192 mm x 192 mm, which is located onto the front of a mylar light guide grid. The grid divides the detector into a 64 x 64 array of pixels, each of 3 mm x 3 mm resolution. Each pixel is viewed by four 1 mm diameter fibre optic light guides arranged in a quad coincident code, Figure 3. In this manner 4096 detector pixels are encoded by 32 PMT's and associated electronics. This detector has been in continuous use on SXD since April 1992 and has become the principle means of data collection on this instrument. Detector characteristics are given in Table 1 and show exceptionally low gamma sensitivities, low intrinsic detector backgrounds and moderate pulse pair resolution.
There are a number of other interesting features regarding this detector. The active detector element is only 0.4 mm thick and thus a short 250 mm sample to detector distance may be used on SXD without causing a parallax error and enabling a large solid angle to be covered. The fibre coded array ensures that detector resolution is linear across the whole of the detector and there is no degradation of resolution at the detector edges. Position sensitivity is achieved by the disposition of the fibre optic array , complex encoding electronics is largely avoided and detector stability is more easily achieved.

SINGLE GLASS SCINTILLATOR DETECTORS

A new glass scintillator detector is under construction for the Electron Volt Spectrometer, eVS. eVS measures neutron energy transfers between 4 and 30 eV and requires efficient neutron detectors within this range. Due to the high neutron flux on the detectors pulse pair resolution is also a detector characteristic of prime importance. The eVS detector consists of four 8 element detector modules. Each element contains a block of 200 mm x 25 mm x 10 mm GS20 scintillator glass purchased from Levy Hill Laboratory, ref. 4. Each block is viewed at the end of an aluminised mylar light guide by a single PMT. Thus the eVS detector is a directly viewed single glass scintillator detector. The detector characteristics are given in Table 1 where the high gamma sensitivity and high intrinsic detector background associated with a detector of this type are readily apparent. However, eVS uses a filter difference technique where these effects can be largely eliminated. Figure 4 shows time of flight spectra recorded on eVS using an experimental detector of this type compared with a 300 mm long 25 mm diameter 10 atmosphere ^{3}He detector. Despite the larger area of the helium detector the glass scintillator count rate is 12 times that of the helium tube. This is a combination of an increase in detector efficiency and a reduction by a factor of two in the sample to detector distance, a feature made possible by the improved pulse pair resolution of the glass scintillator detector.

FIBRE COUPLED LINEAR GLASS SCINTILLATOR DETECTORS

The back scattering detector of the High Resolution Powder Diffractometer, HRPD, has been described previously, ref. 5. Briefly it consists of six detector modules, each module containing 20 elements arranged in concentric annuli. The annuli of each module span radii of 70 mm to 370 mm perpendicular to the beam axis, with 15 mm resolution and an included angle of 45 degrees. Each element consists of two strips of GS20 glass 1 mm thick arranged one behind the other and connected to set of eight PMT's by a fibre optic array arranged in a 3CN code. The concentric detector geometry approximates the Debeye Scherrer cones of diffraction and largely eliminates geometrical contributions to the profile line shape. Detector modules of this type have been operational on ISIS since December 1984 and detector characteristics are given in Table 1. Although this detector has good neutron detection efficiency at wavelengths greater than 1 Angstrom and has produced some outstanding results on HRPD, detector performance is limited by the high gamma sensitivity and high intrinsic detector background.

FORTHCOMING DETECTORS

Currently under development is a fibre coupled zinc sulphide detector to replace the high angle glass scintillator detector on HRPD. This new detector will exhibit lower gamma sensitivity and lower intrinsic background associated with ZnS. The arrangement of the scintillator elements to match the Debye Sheere cones of diffraction has been maintained while the spatial resolution has been improved from 15 mm to 5 mm. The scintillator light guide and the precise scintillator geometry has been modified to increase the neutron detection efficiency compared with the fibre coupled ZnS HRPD 90 degree and pressure cell detectors. The fibre code is arranged to enable data to be collected separately from two orthogonal strips across the detector if so desired. This will yield improved spatial resolution in single crystal diffraction experiments on HRPD.

SANDALS is an ongoing detector project. A further 10 detector modules are expected to be operational this year, followed by 20 and 22 modules in the subsequent two years. SANDALS electronics design is undergoing a major overhaul. The amplifier discriminator/decoder and HT being made more compact, of less power consumption and relocated onto individual detector modules inside the detector block house. This removes the need for extensive cabling and racks, reduces the likelihood of electronic interference from pickup and maintains the detector electronics in a temperature controlled environment. Remote control of the detector HT and discriminator level is provided. Eventually these parameters will be under computer control which will not only facilitate detector set up but also provide a means of automatically checking detector performance.

A second ZnS fibre coupled two dimensional position sensitive detector is soon to be commissioned on the CRISP reflectometer. This detector has an active area of 50 mm x 100 mm which is divided into 440 pixels of 5 mm x 2.5 mm resolution and is decoded by 21 PMT's. Detector characteristics similar to the SXD 4096 detector are anticipated.

SUMMARY OF DETECTOR PERFORMANCE

In general standard ^{3}He proportional counters exhibit high detection efficiencies for thermal neutrons, very low gamma sensitivity and low intrinsic detector backgrounds. Choice of spatial resolution and geometry is limited, pulse pair resolution is moderate and the cost is relatively high.

Two dimensional position sensitive gas technology can provide high spatial resolution, but pulse pair resolution is low and the cost is high. To achieve an acceptable neutron detection efficiency the gas pressure inside the detector is high which necessitates a thick detector window, 10 mm in the Ordella 2250n detector. Detector depth can be significant for some instrument applications leading to position errors due to parallax while non linearity in position sensitivity at the detector edges can also degrade the data. In the rise time encoded position sensitive detectors, breakdown in the high resistive wire coating may lead to a maintenance problem which can only be solved at the site of manufacture.

Scintillator technology offers the opportunity to exploit a different set of detector characteristics from those currently available with gas technology. The most obvious difference is the ability to exploit a more flexible detector geometry as in the HRPD back scattering glass scintillator detector. Neutron detector efficiency in the epithermal region, detector resolution and cost can be emphasised as in the case of SANDALS. Neutron detection efficiency and pulse pair resolution are the major requirements in the eVS glass scintillator detector. The HRPD 90 degree and the Paris/Edinburgh pressure cell ZnS fibre coupled detectors are cost effective detectors which maintain low gamma sensitivities and low intrinsic detector backgrounds. The two dimensional position sensitive ZnS scintillator detectors offer good spatial and pulse pair resolution, insignificant distortions due to parallax, while maintaining low gamma sensitivity and low intrinsic detector background.

In considering the detector requirements of a particular instrument it is necessary to optimise a variety of characteristics. To date no single technology is superior in every respect.

FUTURE DETECTOR DEVELOPMENTS

Improvements in gas technology must centre around a more flexible geometry and a greater pulse pair resolution. It is possible that both these needs can be met by the development of the gas micro strip detector first introduced by Oed in 1988, ref. 6. Solid state technology which has been successful in so many detector technologies has yet to make a major impact in neutron detector systems. Much development is needed to determine whether it is possible to incorporate neutron absorbing materials into solid state detectors in sufficiently high concentrations to obtain viable neutron detector systems. Scintillator technology requires faster, more efficient scintillators which nevertheless maintain the excellent low gamma sensitivity and low intrinsic detector background associated with ZnS.

To meet the needs of future spallation sources which will generate much higher neutron fluxes some or all of these technologies will have to be developed in the near future.

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INSTRUMENT	DETECTOR	MODULES x ELEMENTS	TYPE	ELEMENT SIZE/MM	NEUTRON EFFICIENCY	GAMMA SENSITIVITY	QUIET COUNT/hr	PPR/us
MARI	HELIUM	500 x 1	Gc	300 x 25 dia.	70 % at 1 A	10 (EXP - 8)	5	2.5
SANDALS	SANDALS	23 x 20	SZLD	200 x 10	1.7 x std He at 10 eV	10 (EXP - 8)	360	2.5
POLARIS	BRICK	4 x 20	SZLD	150 x 5.7	45 % at 1 A	3 x 10 (EXP - 8)	23	2.5
TEST BEAM	BRICK	2 x 20	SZLD	150 x 5.7	45 % at 1 A	3 x 10 (EXP - 8)	23	2.5
IRIS	IRIS	2 x 51	SZLD	52 x 12	36 % at 1 A	10 (EXP - 8)	< 2	2.5
HRPD	HRPD 90 DEG.	6 x 66	SZLF	200 x 3.0	36 % at 1 A	10 (EXP - 7)	3 to 10	2.5
POLARIS	PRESS. CELL	4 x 36	SZLF	300 x 3.5	32 % at 1 A	10 (EXP - 7)	12	2.5
TEST BEAM	PRESS. CELL	2 x 36	SZLF	300 x 3.5	32 % at 1 A	10 (EXP - 7)	12	2.5
SXD	SXD	1 x 4096	SZTF	3.0 x 3.0	20 % at 1 A	< 10 (EXP - 8)	0.6	2.5
eVS	eVS	4 x 8	SGsD	200 x 25	3 x std He at 6 eV	2 x 10 (EXP - 2)	150 / min.	0.3
HRPD	HIGH ANGLE	6 x 20	SGLF	45 deg x 15	60 % at 1 A	10 (EXP - 3)	0.2/min/cm2	0.05

TABLE 1. Detector characteristics of scintillator detectors operational on ISIS compared with characteristics of MARI 3He gas proportional counters. Gc = gas proportional counter, S = scintillator, Z = Zinc Sulphide, L = linear, D = directly coupled, F = fibre coupled, T = two dimensional, G = glass, s = single.

INSTRUMENT	DETECTOR	MODULES x ELEMENTS	TYPE	ELEMENT SIZE / MM	ACTIVE DIMS. L x W x D / MM	NEUTRON EFFICIENCY	WINDOW THICKNESS / MM	PPR / us
CRISP	ORDELA 1202N	1 x 100	GcL	50 x 2	200 x 50 x 25	45 % at 1 A	3.8	10
SXD/TEST	ORDELA 2250N	1 x 16 364	GcT	2 x 2	254 x 254 x 25	32 % at 1 A	10	10
LOQ	ORDELA 2651N	1 x 4 096	GcT	10 x 10	640 x 640 x 44	22 % at 1 A	12	10

TABLE 2. Detector characteristics of Ordela rise time encoded position sensitive detectors operational on ISIS. Detector type specification is as given in Table 1.

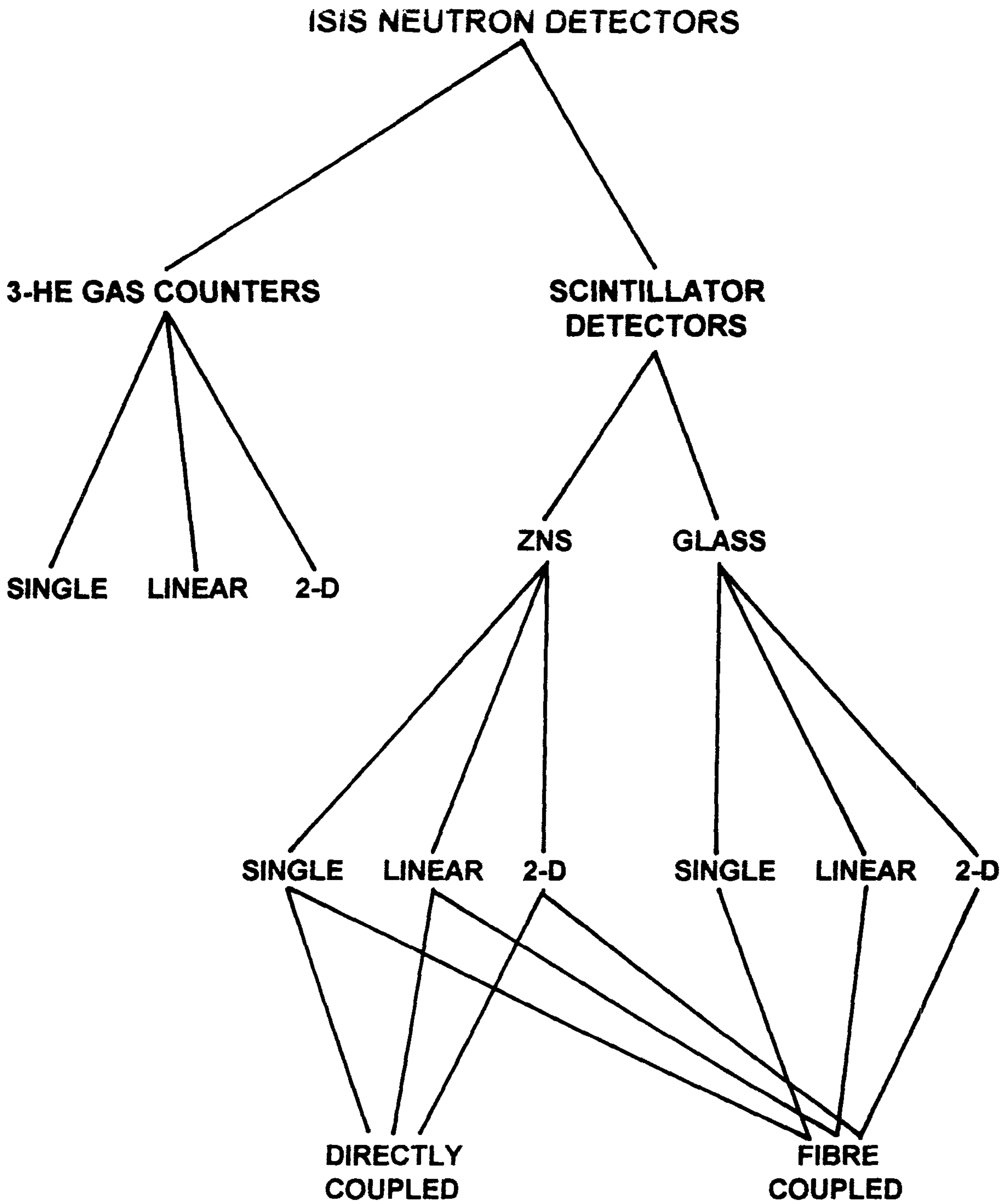

FIGURE 1. Neutron detector types operational on ISIS

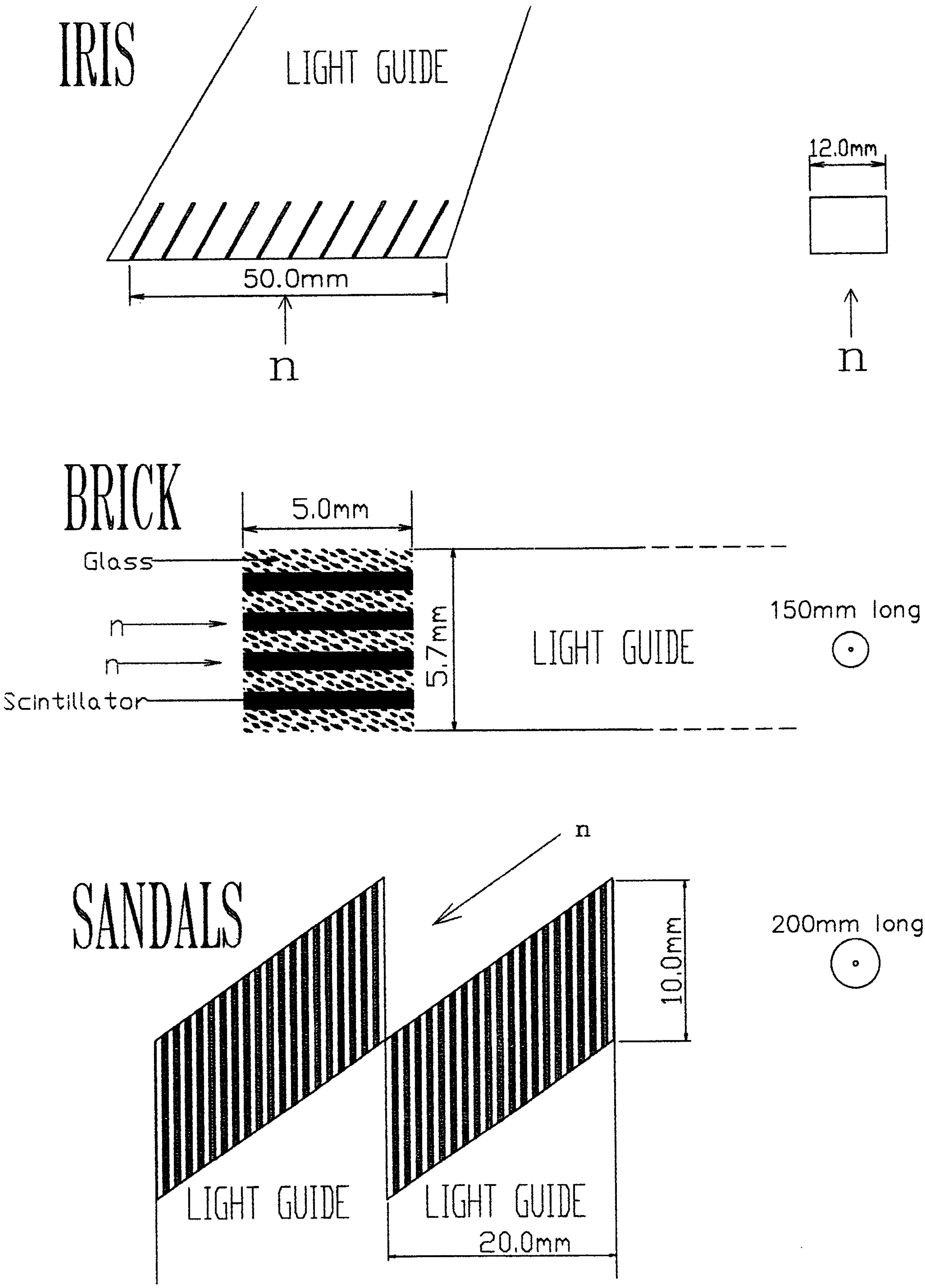

FIGURE 2. Scintillator arrangement in the IRIS, BRICK and SANDALS directly coupled linear Zinc Sulphide scintillator detectors.

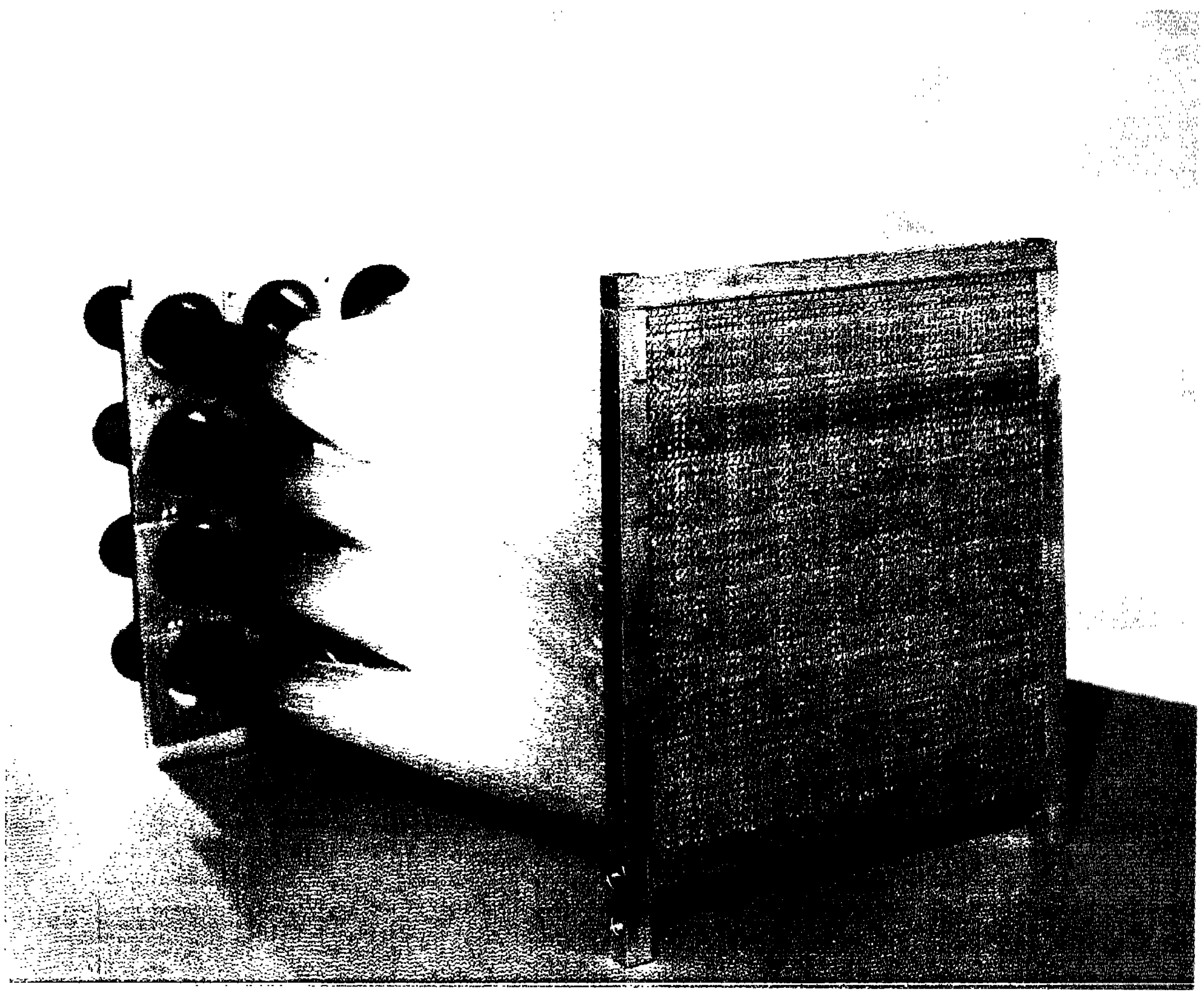

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FIGURE 3. The front end of the SXD 4096 detector showing the mylar light guide grid and the fibre optic array.

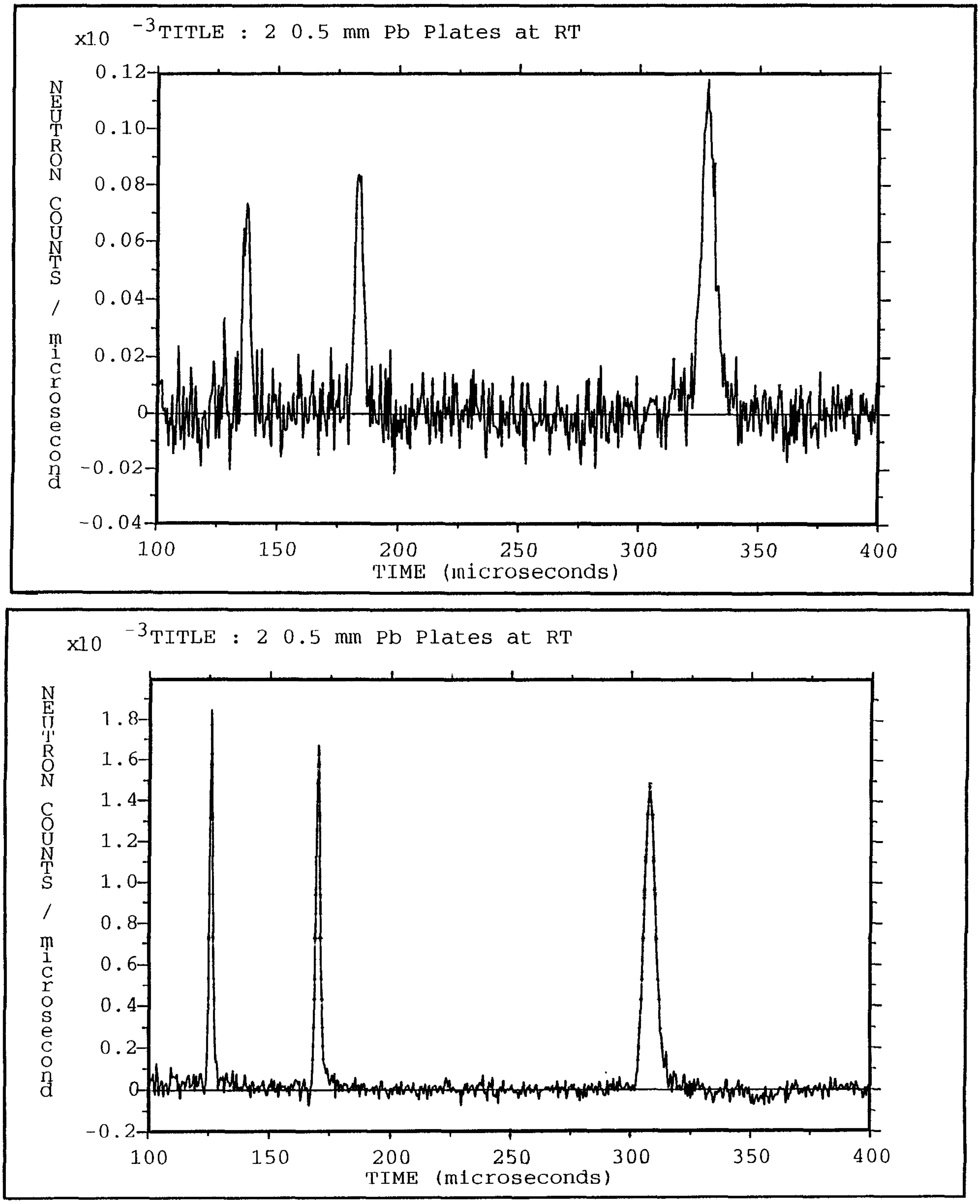

FIGURE 4. Uranium foil resonances recorded on eVS from a lead sample using a foil difference technique. The upper spectrum is obtained using a 300 mm long 25 mm diameter 10 atmosphere ^{3}He detector, the lower spectrum is from a 200 mm long 25 mm wide GS20 glass scintillator detector.