XMM Optical Monitor

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The DEP 2 MCP (Chevron) Image Intensifier Tube

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1 Maximum operating voltage.

This is governed by the appearance of a switched-on channel which appears when the anode voltage exceeds 6500v. Strangely, this is not related to MCP1/2 voltage (see Table 1). The MCP1/2 voltage is safe up to 3000V. No photocathode emission points are seen up to Vc=330V. It was decided to limit the intensifier maximum voltages to 300-2800-6200.

Vc	Vmcp1/2	Vanode	description
0	3000	6200	
0	2800	6500	the sw-on channel starts on
0	2500	6810	the sw-on channel grows up

Table 1. Maximum H.V. to the intensifier

2 Pulse Height Distribution

2.1 Pulse Height Distribution and Gain

The gain is sufficiently high for photon counting mode with H.V. settings of 300-2450-5320. Figure 1 shows the PHD sampled over a 17.6mm x 17.0mm rectangle, almost the whole detector area. The PHD is broad, namely $\delta G/G = 1.42$. The lower energy end falls fairly quickly but the higher energy wing has a long tail associated. It might have been possible to obtain a narrower PHD by lowering Va and applying higher gain to the MCPs but this could not be checked due to limitations of the H.V. Divider Box settings, the minimum achievable anode voltage being 5320V.

A very attractive feature of this tube is the P45/6, very fast phosphor. With the standard P20 phosphor an exponential-like low energy noise component to the PHD is seen and it is believed that this is caused by residuals from events occurring in the previous frame due to the long phosphor decay. With the P46 phosphor this noise component is not present, also showing that the MCPs in this tube have very low noise. It should be noted that SIBs were carefully excluded from the analysis.

One possibility for the broad PHD is small event size. As events are undersampled by CCD pixels in normal operation, the peak value will be dependent upon the position of each event inside a pixel leading to broadening of the PHD. With the chevron intensifier, the event width could be smaller as one less MCP is associated and this could lead to additional broadening.

PHDs were measured separately according to event positions inside a CCD pixel. The area used was 0.57mm x 1.13mm at the detector centre. The peak position is 124.6 ADUs for central events and 74.4 ADUs for events positioned at the corner of a CCD pixel. This difference can explain a broadening level of $\delta G/G=0.5$ but not $\delta G/G=1.4$. The width of the distribution for the central events is still large, $\delta G/G=1.51$. The width for corner events could not be determined because the threshold value for this measurement was not low enough. Therefore, the broad global PHD can only be partially explained by this mechanism.

Other evidence supporting this conclusion is obtained from the pulse energy distribution. Using Event energy (each event summed over 3 x 3 pixels), the problem of position dependence associated with the PHD is overcome. However, the Pulse Energy distribution (PED) shows exactly the same features as the PHD (see Figure 1).

2.2 PHD variation along whole detector area.

A detector area of 17.6mm x 17.0mm was divided into 8 x 8 sectors (individual sector size 2.20mm x 2.13mm) to derive local PHDs. It was found that the gain changes systematically from the centre to the boundary. The gain at the boundary is only 57% of that at the centre (see Figure 2). The broad global PHD shown in Figure 1 can only be partially explained by this variation in gain, the width of the local PHDs shows $\delta G/G=1.35$ at the centre and $\delta G/G=1.42$ at the boundary of the detector. These are still very broad.

A PHD from a smaller area 1.1mm x 1.1mm also showed $\delta G/G=1.36$. An extreme test was carried out by the illumination of 11 pinholes with a diameter of 60μm. The pinholes were located at the boundary of the detector. PHD parameters derived from the individual pinholes are tabulated in Table 2a. In spite of the very small area sampled, the width of the PHD is large. The variation in the peak position of the PHD between pinholes is 15% peak to peak. Therefore global gain variations is not only the reason of the broadening of the PHD.

All of the results are summarized in Table 2b. This table suggests the width is relatively narrow at the detector centre where the gain is higher. This could be attributed to variations in the very small gap between MCP1 and MCP2 resulting from non-flatness of the MCPs.

row	peak(ADC)	$\delta G/G$
1	78.6	1.58
2	81.7	1.64
3	78.2	1.68
4	79.8	1.65
5	76.6	1.72
6	76.9	1.64
7	73.7	1.58
8	75.1	1.56
9	76.2	1.59
10	71.1	1.70
11	70.6	1.50

Table 2a. PHDs from 11 pinholes at the detector boundary (column No.8) – 19 June '97 from PHD032

position	area	peak(ADU)	$\delta G/G$	Date
whole	18 x 17mm	87.0	1.43	17 June '97
boundary	2.2x2.1mm	58.8	1.42	"
centre	2.2x2.1mm	103.6	1.35	"
centre	1.1x1.1mm	98.3	1.36	15 July '97
boundary	pinhole-8	75.1	1.56	19 June '97

Table 2b. PHDs from different places

2.3 PHD with x3 magnification

The HV settings used were 300-2450-5320. The sample area was 1.6mm x 1.6mm square at the detector centre. As each event profile is perfectly resolved in this configuration, the nucleus and the total energy of each event could be analysed separately. The PHD (Figure 3) for the event core was derived from within a 22.4 x 22.4μm square. The PED (Figure 4) used an area of 82 x 82μm. The width of the peak distribution is narrower than the energy distribution, $\delta G/G=1.09$(FWHM), and $\delta G/G=1.36$ for energy distribution. The latter width is well matched with the results in Table 2b.

The PHD is symmetric between the lower and the higher energy wings. However, if the HV is increased to 295-2540-5240, strong asymmetry appears due to steeper cutoff in the high energy wing. The energy distribution is still symmetric at the higher voltage settings. These results suggest that the pores in the event core are well saturated when Vmcp1/2 = 2540 is applied, but the pores in the event wings are not. Since the PED contains both the core and wings, it does not show saturation for a high energy event even at high gain. In contrast, the PHD contains core pores only, hence its gain is saturated for a high energy event.

3 Flat Field images

3.1 Flat Field image in photon counting mode.

The flat field in photon counting mode looks very clean. During detector set-up, it was a struggle to derive accurate subpixel boundary values for minimisation of fixed pattern noise, oscillations occurring between x:boundary-4 and x:boundary-5 during the iteration process, this being expected due to the small event size.

The image was acquired at a count rate of 11kHz/(full detector area) and for an exposure time of 15 hours. It shows very uniform photocathode sensitivity, better than S/N = 40 (limited by non-uniform illumination). A remnant fixed pattern is present, associated with the instability between the X-subpixel 4 and X-subpixel 5 boundaries (Figure 5). The S/N achieved on the raw image was 9.4 locally (32x32 subpixel square box). After removal of the 8 x 8 fixed pattern noise, the S/N = 10.1. As the accumulated data was 162 photons/pixel, a S/N of 12.8 should have been obtained from photon statistics. However, this uniformity is the best obtained when compared against other DEP tubes.

There is some level of fringing present, due maybe to local non- uniformity in event profile. The amplitude is, however, much smaller than that of our DEP taper incorporated tube or of the DEP z-stack tube. There is a global variation in efficiency, 14%, between the centre and the very edge of the detector. This is mainly due to the non-uniform gain of the MCP. The global variation in PHD, 43%, could cause 10.3% variation in the photon counting image. The bright disk at the centre, which is brighter than the adjacent area by 25% and is created by multi- reflections in the relay lens, is excluded for this evaluation. There is a dark ring and adjacent bright ring at the boundary of the detector. These may be an intrinsic feature of the intensifier.

3.2 Flat Field image in analog mode

40,000 F-F frames were accumulated at a count rate of 50kHz/(full detector area). The resultant image is quite smooth and looks like solar photosphere (Figure 6). There is no significant variation locally. A S/N=27 is achieved within a 16x16 CCD pixel square box at the detector centre. There is a global variation, 45%, centre to the very edge of the detector. This is mainly due to the non-uniform gain (43%) of the MCPs. There is a dark ring and adjacent bright ring at the boundary of the detector. The bright disk at the centre is again excluded from this analysis. There are a few blemishes which correspond to those seen in the photon counting image.

3.3 Flat Field image in analog mode with x3 magnification

655,360 F-F frames were accumulated at a count rate of 200,000 c/s/(full detector area) in analog mode. Assuming an event width of 45μm (see Section 4), the average number of photons acquired at any position was 8500 in the summed image, and hence sigma, from photon statistics, is 1.1%. The image looks like a solar chromosphere around a sunspot (Figure 7). It includes the variation in MCP gain and all artefacts of the detector system. There is a lot of modulation and many black spots which cannot be seen in the analog F-F image with 3:1 minification optics (Section 3-2). The typical depth of the black spots is 20-30%, and the typical width is 20-35μm (Figure 8).

The size of these features looks to conflict with the event size of 45μm. There are two possibilities for their origin: (1) after the phosphor screen and (2) within the MCPs. The shape and size of the features shows that their origin is unlikely to be associated with either the fibre optics or phosphor screen. If end-spoiling in MCP2 provides high collimation, leading to very small blurring in the anode gap (e.g. $<$10 μm), features originating in that plate could possibly be seen. If this was the case, the local MCP gain variations could then provide a contribution to the broad PHD.

4 Event profile with x3 magnification

The event width is very small, 44.6μm +/-5.6μm (FWHM) along the x- direction and 45.4μm +/-6.2μm along the y-direction. The width is broader in brighter events, 47.8μm and 48.5μm in the x and y directions respectively. The x and y widths for faint events are 40.2μm and 41.2μm respectively.

5 Signal Induced Background

5.1 SIBs with x3 magnification

SIBs were analyzed with x3 magnification, the CCD pixel size equalling 7.47μm on the phosphor screen. There are noticeable SIBs for all events, typically 5 satellites/event. The shape of each main event is distorted and looks like an amoeba (Figure 9). Fortunately, the energy of SIBs is fairly low, about 3% of the main event. They are at various distances but typically 100μm from the centre of the main event. 48 snap frames were stored for each of four different HV settings to allow analysis. The SIB becomes more obvious when increasing MCP gain from 1 to 4.

1. 306-2400-5340
2. 300-2450-5320
3. 300-2500-5270
4. 295-2540-5240

5.2 SIBs after optical scrubbing

SIBs were briefly inspected with 3:1 reduction after optical scrubbing associated with the lifetime experiments. The intensifier had been illuminated at 160,000 c/pinhole/s for 21 hours. Tiny satellite events and some distorted events were present. 40 snap frames were stored for the analysis. However, it will be necessary to magnify the image to quantify the characteristics.

6 Centroiding accuracy

64 sub-pixel centroiding with a flat field illumination was carried out for 4 nights, a total of 5.9 million frames being processed. A few defects in the MCPs can be clearly seen in the image (Figure 10a). The pore structure, though, cannot be clearly seen unlike the straight tube image (Figure 10b). However, where they coincide with the CCD pixel corners the pores are resolved. This implies that the poor resolution is not associated with the undersampling of electron cloud by MCP2 but with the readout system. Possibilities are :

1. the event size being too small might have reduced the centroiding resolution – the parabola centroiding algorithm was used, which is less accurate when the event size is small. This possibility could be checked be carrying out 64 sub-pixel centroiding with either the normal (centre of gravity) or Guassian algorithms.
2. SIBs randomly affecting the event profile
3. The broad PHD. The gain and the event width are well correlated. The large variation in gain therefore leads to large variation in event width.

7 Intensifier operation.

7.1 Phosphor screen

Use of the fast phosphor gives very encouraging results. Coincidence between events is the most difficult detector artefact to overcome. Real Flat Field images acquired at high count rate are always of lower quality than simulations. The main reason for this is the slow decay of the P20 phosphor. The chevron tube has an extremely fast phosphor, and so it is expected that at high count rate better image quality will be obtained.

The phosphor does have a lower electron to photon conversion efficiency which means operating the MCPs at higher electron gain. However, if the damage level is reasonably low, this phosphor is preferred.

7.2 Blemishes

The blemish quality of the intensifier is excellent. Only several spots can be seen in the photon counting F-F image, some of which may be cause by scratches on the input and/or output windows.

7.3 Stability

The tube is easy to use. The CCD camera was very stable for the 1 month period of these experiments implying that no charge-up on the output window occurred.

The performance of the tube seems to be stable except the oscillation in the centroiding boundary value between X sub-pixels 4 and 5 (Section 3.1). This problem may be merely due to the iteration procedure used for defining the boundaries and use of the normal (Centre of Gravity) centroiding algorithm. For the 1/64 pixel software centroiding a different approach to defining the boundaries was employed (mapping M/N values) and a parabola centroiding algorithm. Here, stable operation was achieved.

7.4 DQE

The count rate for a constant F-F illumination was measured at different HVs. It was found that the DQE increased with the MCP1/2 as shown in Table 3. It is assumed that this results from the voltage to MCP1 not being individually controllable and is lower than required for efficient operation. If the tube had individual HV connections to MCP1 and MCP2, the DQE problem would be solved.

H.V.	count rate measured
300-2450-5320	48.5 kHz/(full detector area)
300-2500-5270	50.0
295-2540-5240	51.2

Table 3. The change of count rate with HV

8 Discussion

The two main problems with the chevron tube are the broad PHD and SIBs.

Potential contributing reasons for the PHD are :

1. The zero gap between MCPs 1 and 2. Hypothetically, if a pore in MCP1 is aligned with a pore in MCP2, only a single pore in MCP2 will be involved in amplification of the electron cloud hence leading to low overall gain. If a pore in MCP1 is aligned with the webbing in MCP2 then 4 pores in MCP2 are involved, hence leading to high overall gain. If this mechanism is dominant in broadening the PHD, the width will not reduce even with a very high voltage and high saturation in MCP2.

However, this limiting case was not obtained in practice as is shown by the PHD at x3 magnification. Increasing applied voltage shows that, whilst central pores in MCP2 appear to be saturated, some lower level of the electron cloud from MCP1 is captured by adjacent pores. Secondly, the nucleus component, which could dictate a significant broadening due to this mechanism, contributes only a quarter of the event energy. Furthermore, the nucleus shows a narrower distribution. Therefore, the evidence suggests that any broadening due to this mechanism is minimal.

2. The data shows that a high contribution to an events' energy is contained in the wings of that event and its distribution is broad. From this, it can be assumed that the MCP pores associated with the wings are operating far below saturation. This would then lead to large fluctuations in gain between events.

3. As the pores in the wings are operating in a linear range, the gain variation between individual pores could also result in a broad PHD. Micro features in the magnified analog F-F suggest this mechanism being responsible partially.

4. A very small event size, which leads to broadening of the PHD associated with MIC event detection algorithm, is partially responsible.

5. Global variation of gain is partially responsible.

The comparison between peak and energy distributions with x3 magnification shows that higher gain improves the PHD, $\delta G/G$ being 1.09 on the nucleus of events. The energy distribution, which is more representative of the real MIC system, contains the non-saturated wings of each event, therefore resulting in a broad PED. This implies that the chevron tube would provide better performance with higher MCP saturation, the key point being improvement in the wings. If the gain of MCP1 were higher and a gap between MCPs 1 and 2 was included, then the wings would be fed by more electrons, and hence may exhibit higher saturation.

The difference in the saturation level through an event profile is not good for SIB either as, in general, the gain on SIBs located in the wings of an event will be much higher than those at the centre, enhancing distortion in event profile. This is particularly true in the zero gap tube where only 4 pores are supposed to be extremely saturated. It is hopes that a small gap between MCPs 1 and 2 will suppress SIBs and improve the PHD.

9 Requirement of long life time

The UV-optical telescope (XMM-OM) has a wide field of view, 1000 arcsec. Typically, within each field, there will be one or two 10th mag. stars, this number being affected greatly by the direction in which the telescope is pointing. The star density along the Galactic plane is more than twice as high as the average and the number of stars of a particular brightness increases in inverse proportion to the total number. Table 4 shows the average star numbers vs star brightness within the OM field of view.

The detector field will encounter a 7mag or brighter star every 20 observations and an 8mag star every 7.7 observations whereas medium brightness stars (e.g. 14 mag, 1000 c/s) will be common. These bright stars will damage the image tube, causing gain depletion and sensitivity loss, when using a clear filter even if the exposure time is only an hour. Any damage must not be allowed by high illumination in an hour otherwise, the intensifier will not be usable after just a few days of clear filter observations. It should be noted that the duration of the XMM mission is 10 years.

Fortunately, a filter will be used in the majority of exposures, and the filter can attenuated the intensity 4-10 times. The relative transparencies are roughly tabulated in table 5. Even so, the space craft will point to a particular star field continuously for up to 2 days in order to collect sufficient number of X-ray photons for the high dispersion spectrograph in the main X-ray telescope. The pointing of the space craft is very accurate, hence stars will illuminate the intensifier at the same positions for 2 days. In this observation mode, the target star is in the centre of the field. If this is bright it can be blocked by an occulting disc located at the centre of the filter surface. However non-targeted 7 mag star may be somewhere in the field. If a B-filter is used, that star will illuminate the image tube with an intensity of 200,000c/s for 2 days. Even if UV filters are used, the intensity will still be 30,000c/s to 60,000c/s.

To gauge the affect of high, localized illumination, a series of life time experiments have been carried out with the DEP chevron tube in photon counting mode (high gain). The intensity range was 145 c/s to 170,000 c/s and the total illumination period 101 hours. The results are summarized here.

The same experiments had previously been carried out with the DEP straight tube (purchased in November 1994). A great improvement in the photocathode sensitivity loss was found with the chevron tube when compared with the straight tube. In addition, the photocathode fluorescence due to the high illumination reduced drastically, which suggests improved cleanliness in the new tube.

MCP gain depletion, however, did not show remarkable improvement. The gain dropped by half resulting in loss of DQE in photon counting mode. Also, change in shape of the output electron clouds affected centroiding accuracy and created a localized modulation pattern. The MCP performance for life time should be improved further.

Magnitude	Counts/Sec in clear filter	Number in the F.O.V.	Integrated Number
7	750 000 c/s	0.03	0.05
8	300 000 c/s	0.08	0.13
9	117 000 c/s	0.22	0.35
10	47 000 c/s	0.65	1.00
11	19 000 c/s	1.63	2.63
12	7 500 c/s	4.30	6.93
13	3 000 c/s	10.5	17.4
14	1 200 c/s	24.3	41.7
15	480 c/s	59.9	101.6
16	192 c/s	129	231
17	77 c/s	262	493
18	30 c/s	524	1017

Table 4. Expected star number in the OM field of view

Filter	Ratio
clear	1.00
V	0.18
B	0.26
U	0.11
UVW1	0.08
UVW2	0.04

Table 5. Transparency ratio of each filter relative to CLEAR FILTER

10 Set-up of experiment

An 11 x 11 pinhole array image was projected onto the intensifier through a fast IPCS lens. The diameter of the pinholes was 60μm at the detector to allow a high intensity illumination from the light source. The light source was a green fluorescence panel, its brightness being tuneable by changing the applied voltage (100V max). Different ND filters were placed beneath each of the columns in the grid array to create 11 sample pinholes at 11 different brightness levels. This wedged ND mask pattern was newly made for the test of the chevron tube, therefore the illumination brightness of the pinholes will be different to that used in testing of the straight tube last year. The brightness ratios within the columns had been accurately calibrated prior to the lifetime tests using the same detector by taking a 15 hour image at a low illumination level (Figure 11). Since the photocathode sensitivity is higher than the DEP straight tube in the green (520nm), the detector system captured more photons than previous experiments when the same voltage was applied to the fluorescence panel.

To save hard disk space, only 512x512 out of the 2048x2048 pixel full detector area were stored when operating in photon counting mode. The selected 512x512 area contained only 9x9 pinholes from the array. Hereafter, results of photon counting image analysis(eg. F-F and fluorescence) are based on the

9x9 pinhole array data. Results from data where photon counting was not employed, for instance PHD, F-F image in analog mode etc., are based on the full 11x11 pinhole array.

Two pinhole images for calibration were stored in 512x512 pixel format files to record all 11 columns (only 9 rows though). A CCD camera format of 256x256 was employed, which provided a frame rate of 100Hz. 1/8 pixel centroiding was then employed to obtain the 2048x2048 area from which the 512x512 stored sections were obtained. The calibration count rates in pinhole columns 1 and 2 needed correction by 3.8% and 4.2% to account for coincidence loss. The brightness ratio along the 11 pinhole columns is tabulated in Table 6.

High intensity illumination was obtained by setting the voltage on the fluorescence panel to 99V. The pinhole array provided a brightness range of 170,000 to 145 counts/sec/pinhole. To obtain these values the brightness of the faintest pinholes (column 11) was monitored in photon counting mode during the high illumination using a CCD camera format of 256Hx32V. The 800Hz frame rate associated provided the widest dynamic range (Figure 12). The conversion of acquired count to real count was carried out as explained in Appendix 1. The intensity of the brighter pinholes was then deduced from the brightness ratio of pinholes.

The sensitivity losses after bright illumination were investigated by taking a 15 hour low light level F-F. The F-F light source was a blue LED (centred at 460nm) with a diffuser, and the light level was tuned to 8,000–12,000 counts/sec/18x18mm area. PHD and fluorescence were also investigated, both immediately after the high illumination and on the following day. F-F images in analog mode, which include effects due to both photocathode sensitivity loss and MCP gain depletion, were sometimes recorded. The above processes of illumination and assessment were repeated 8 times. The exposure time of the high illumination increased day by day from 1 hour to 20 hours, the total exposure reaching 101 hours. All of experiments carried out are summarized in Appendix 2 and all data files associated with this experiment are Appendix 3.

Pinhole column	Total Counts in 15 hours in 9 pinholes	Calibration Count Rate	Brightness Ratio	Count Rate during Dose
1	3693470	7.60 c/s	1008.6 x1.038	151,804 c/s
2	4086394	8.41	1115.9 x1.042	168,602
3	851151	1.75	232.4	33,698
4	673602	1.39	183.9	26,665
5	143686	0.296	39.2	5,684
6	117879	0.243	32.2	4,669
7	127765	0.263	34.9	5,061
8	45257	0.0931	12.36	1,792
9	20154	0.0415	5.50	798
10	10268	0.0211	2.80	406
11	3662	0.00753	1.00	145

Table 6. Brightness of 11 pinhole columns during calibration and dose. 9x11 pinhole array were used. From "PIN025" 15 June 1997

11 Gain Depletion

The pulse height distribution for individual pinholes was measured before starting the experiment and were recorded as 4 sets of PHD, namely group- 1) 152-169kHz, group-2) 27-34kHz, group-3) 4.7-5.7kHz and group-4) 1.8kHz. The PHD for the pinholes fainter than 0.8kHz were not measured. PHDs for the four groups were then recorded immediately after each high illumination exposure and on the following day. The recovery on the next day, which was seen in the straight tube, is not obvious in this chevron tube. Figures 13a and 13b show the original PHDs and the ones after the 101 hours high illumination for the intensities of 160,000 c/s and 5,000 c/s. The gain reduced to half of the original for an intensity of 160,000c/s. It became 79% for an intensity of 5,000 c/s. Figure 14 shows the F-F image in analog mode after the 101 hours photon dose. The black spots are easily recognized down to the column of 145 c/s. The loss in DQE associated is mainly due to the MCP gain depletion.

The reduction of gain with exposure time is summarized in Table 7a. Figure 15 shows the gain depletion against total photon dose. The gain depletion in high intensity pinholes is relatively lower than that in the low intensity pinholes. This seems to be an effect of pore paralysis.

Figures 16a and 16b show the PHDs before and after 101 hours photon dose at 160,000 and 5,000 c/s respectively. The energy axis is expanded for the "after" PHDs to quantify the gain depletion. Since the threshold level in the photon counting mode will be 30 ADU in the flight detector, the figures reveal how many photons will be lost due to gain depletion. The event loss due to gain depletion was calculated every day and is tabulated in Table 8.

Not just the MCP gain changes with photon dose but also the event profile which causes inaccuracy in centroiding position. This results in a localized modulation pattern in a F-F photon counting image at the positions of the high illumination (> 27kHz) pinholes.

Compared with the straight tube, the life time of the MCPs is greatly improved for relatively short exposure times. The gain depletion of the straight tube was 16% for a pinhole illumination of 29,000c/s for 1000sec (see Figure 7 in "Performances of DEP Straight Tube with a Bright Light Source, 30 July 1996"). For the chevron tube no gain depletion is seen in a 1 hour exposure.

The gain depletion of the straight tube was characterized last year for a long time exposure. There is significant difference between the 2 tubes if the total dose is relatively low, but becomes similar if the total dose is heavy. The MCP gain depletion of the chevron tube should thus be improved further to maximize life time.

Note. A number of short power cuts happened on 22nd June 1997 (Day-4), which halted the bright illumination several times. After these, the MCP gain fluctuated although a constant HV was being applied. It is regretted that the PHD from whole imaging area was not measured at that stage as a reference. Thus, the accuracy in the change of PHD is limited to 5%.

Dose(hr)	152-169kHz	27-34kHz	4.7-5.7kHz	1.8kHz	0.8kHz
00	1.000	1.000	1.000	1.000	–
01	1.02	1.01	1.03	1.03	
01	1.04	1.04	1.05	1.05	
06	0.865	0.885	0.978	0.999	
06	0.855	0.885	0.954	0.963	
11	0.794	0.820	0.935	0.942	
11	0.758	0.794	0.897	0.910	
21	0.704	0.763	0.844	0.844	
21	0.781	0.833	0.952	0.978	
21	0.741	0.806	0.940	0.975	
41	0.625	0.704	0.844	0.880	
41	0.690	0.758	0.861	0.889	
61	0.588	0.694	0.826	0.854	
61	0.588	0.680	0.819	0.852	
81	0.541	0.645	0.820	0.865	
81	0.541	0.690	0.814	0.850	
101	0.500	0.606	0.781	0.799	
101	0.505	0.606	0.788	0.829	

Table 7a. Gain Depletion. DEP Chevron Tube. 11 pinhole rows are used. 14 June - 3 July 1997

Dose(hr)	140kHz	5kHz
05	0.763	0.862
05	0.862	0.926
10	0.690	0.840
10	0.800	0.901
15	0.645	0.826
15	0.862	0.909
20	0.719	0.877
20	0.654	0.719
25	0.667	0.741
30	0.532	0.676
30	0.625	0.752
35	0.571	0.730
35	0.588	0.741
40	0.541	0.714
40	0.556	0.746
40	0.633	0.769
45	0.562	0.725
45	0.606	0.833
50	0.520	0.704
50	0.535	0.694
55	0.481	0.676
55	0.568	0.758
60	0.538	0.746
60	0.588	0.763
60	0.617	0.833
65	0.521	0.741
65	0.588	0.813
70	0.541	0.758
75	0.526	0.730
75	0.578	0.769
80	0.546	0.758
80	0.541	0.752
85	0.488	0.699
85	0.513	0.741
90	0.476	0.676
90	0.513	0.694
90	0.541	0.725

Table 7b. Gain Depletion. DEP Straight Tube. 5 hours x ~~17~~ 18 Days.

12 Sensitivity loss at photocathode

Three 15 hour F-Fs were acquired in photon counting mode at 1/8 CCD pixel centroiding resolution before starting the high illumination experiment. A 15 hour F-F was taken after every photon dose to assess the sensitivity loss of the photocathode. Figure 17 is the F-F image on the 8th day, after 101 hours photon dose, and it shows clearly an array of black spots corresponding to the pinhole illumination positions. This image had been divided by the three 15 hour F-Fs taken prior to remove any detector artefacts.

Figure 18 is a magnified image and it shows the details of the individual black spots. The scale is 8.86μm/(subpixel). The shape around the damaged areas is not circular but in the form of a cross. This shape is caused by centroiding inaccuracy due to the change of event profile and energy. The position of the black cross is related to the position within a CCD pixel of each pinhole area.

The 9x9 array of black spots were added together along the columns to improve photon statistics. This procedure can also suppress fixed pattern noise associated with the change in event shape. Figure 19 shows the daily change in the damage level. The threshold level for photon counting was changed from 30 ADU (= normal value) to 13 ADU on Day 4. The purpose of the F-F imaging in photon counting mode was to assess sensitivity loss at the photocathode. However, quantum efficiency loss due to gain depletion would be high in photon counting mode after Day 4. To counteract this the threshold level was then lowered to 13 ADU. The measured loss is tabulated in Table 8. To cross calibrate between the two threshold positions, F-F exposures at 30 and 13 ADUs were taken on Day 4. It was found that the level of photocathode damage agreed within 2%.

Figure 20 shows profiles of the averaged black spots from day 4 to day 8. All were acquired with the threshold level at 13 ADU in photon counting mode. To quantify the sensitivity loss, a Gaussian profile was fitted to each image. The effect of the gain depletion was then subtracted. The results are tabulated in Table 9. The sensitivity loss is only 20% after 101 hours exposure of 169,000 c/s pinholes. This is very encouraging.

The sensitivity losses are almost the same, 10%, between 1,800 c/s and 34,000c/s after 101 hours exposure. A strong pore paralysis might have contributed to this result. As 160,000 c/s is very bright, a deeper layer in the photocathode might be destroyed which could explain the higher damage. The intensity up to 34,000 c/s might only affect the Cs layer of the photocathode resulting lighter damage occurred.

Figure 21 plots the photocathode sensitivity loss against the total photon dose. The sensitivity loss at high intensity is lower than that at low intensity for equal photon doses. This could be due to pore paralysis. It may be that total exposure time and not total photon dose is the right parameter to use when describing sensitivity for intensities below 34,000 c/s.

Compared with the straight tube, the improvement in photocathode lifetime is noticeable. The straight tube showed a sensitivity loss of 27% at the centre of the black spots after 90 hours exposure at 140,000 c/s. With the chevron tube 17% loss occurs after 101 hours exposure. The FWHM of the black spots is 100μm for the straight tube, and 75μm for the chevron tube. Therefore, the energy loss (= peak depth x area size) ratio is 2.8.

The sensitivity loss at the centre of the 5,000 c/s pinholes is 18% for the straight tube and 10% for the chevron tube. The FWHMs of the black spots are 106μm and 90μm, respectively. The energy loss ratio is 2.5 for this medium intensity.

Dose(hr)	152-169kHz		27-34kHz		4.7 --- 5.7kHz			1.8kHz	800Hz
Threshold = 30ADU									
1	-.007	-.007	-.006	-.006	-.008	-.008	-.008	-.006	.000
6	.037	.037	.032	.032	.008	.008	.008	.004	.000
11	.067	.067	.060	.060	.020	.020	.020	.015	.000
21	.083	.083	.064	.064	.025	.025	.025	.018	.000
Threshold = 13ADU									
21	.018	.018	.016	.016	.003	.003	.003	.001	.000
41	.030	.030	.025	.025	.010	.010	.010	.007	.000
61	.043	.043	.031	.031	.012	.012	.012	.009	.000
81	.055	.055	.034	.034	.012	.012	.012	.009	.000
101	.066	.066	.045	.045	.014	.014	.014	.012	.000

Table 8. Effect of PHD on the sensitivity loss in photon counting mode. 14 June - 3 July 1997

Dose(hr)	152-169kHz		27-34kHz		4.7 --- 5.7kHz			1.8kHz	0.8kHz
6	.940	.929	.961	.962	.963	.961	.956	.962	.962
11	.923	.932	.960	.960	.959	.948	.954	.947	.949
21	.892	.895	.952	.932	.941	.935	.940	.928	.933
21	.912	.918	.930	.930	.946	.944	.933	.941	.942
41	.921	.903	.922	.920	.937	.935	.933	.939	.933
61	.881	.863	.905	.891	.923	.916	.911	.925	.917
81	.872	.855	.919	.921	.929	.913	.915	.911	.916
101	.826	.810	.904	.915	.921	.917	.902	.905	.900

Table 9. Photocathode sensitivity change. 9 pinholes are used. 14 June - 3 July 1997

13 Fluorescence

The chevron tube shows photocathode fluorescence immediately after the intense illumination (Figure 22). However, it decays extremely quickly (Figure 23). The 9x9 array of glowing spots were added together along the columns to improve photon statistics. The glow intensities at different illumination levels are derived after background subtraction. The surrounding 41x41 square pixels excluding central 21x21 pixels were used for determining the background dark.

Figure 24 and Table 10a show the intensity variation of the glow with a time interval of 10min after 20 hours high illumination. The fluorescence for the 169,000 c/s pinhole is 160 c/hour/spot in the 10 minute period starting 4 mins after illumination, but this decays with a time constant of 1 hour. The fluorescence looks to settle to 30 c/hour/spot, but this may be the effect of over correction by the dark background as around damaged area this is lower than the average as is seen in Figure 23. Because of the low intensity and fast decay, the contribution of the glow to the 15 hours F-F is only 0.28 counts/subpixel at the pinhole centres if the F-F integration starts 4 hours after high illumination. The size of the glow is 80-110μm (FWHM) and is a little larger than that of the black spot (75μm) in the photon counting F-F image.

The straight tube showed much higher intensity and longer decay time. The intensity is 750 c/hour/spot, 2 hours after a 5 hour illumination at 140,000 c/s. This decayed fairly quickly with a time constant of 9 hour, but then slowed down to 38 hours at 2 days later. The glow lasted greater than 6 days (still 37 c/hour/spot). Because of the high intensity and slow decay, the contribution of glow to a 15 hour F-F is 6.6 counts/subpixel at its centre if a F-F integration starts 4 hours after the high illumination. As the brightness of the F-F is 150 counts/subpixel typically, the glow buries the black spot by 4.4%. The size of the glow is 160-170μm (FWHM), and is much larger than that of the black spot (100μm) in the photon counting F-F image.

The chevron tube was illuminated for 17 hours with HV off to investigate the glow mechanism. The fluorescence was not seen. This suggests that the fluorescence in this tube is related to ion feedback from the MCPs. The very low level and short duration of the fluorescence directly proves the great improvement in cleanliness of the chevron tube when compared with the straight tube.

	152kHz	169kHz	34kHz	27kHz	6kHz	5kHz	5kHz	1800Hz	800Hz
1)	158.7	159.6	61.9	83.3	17.6	19.8	25.8	18.7	8.5
2)	106.8	117.0	61.9	50.5	18.1	16.6	11.3	-0.1	8.2
3)	79.4	92.9	41.2	36.1	8.2	10.0	2.3	15.6	-0.3
4)	95.5	66.8	35.2	39.8	12.0	4.6	27.3	10.0	4.1
5)	64.9	80.8	43.5	42.6	7.4	16.9	-0.6	-2.5	8.4
6)	77.6	52.9	34.2	34.2	12.7	-3.2	17.2	8.9	-6.3
7)	48.4	62.2	25.0	43.0	19.6	0.5	8.0	6.1	-12.7
8)	50.0	55.3	26.5	24.1	13.7	-7.9	17.9	0.0	-8.1
9)	46.7	60.8	17.2	13.5	10.2	12.0	-0.4	9.7	-10.4
10)	40.9	40.0	10.1	22.0	21.8	8.7	12.2	-1.8	13.6
11)	27.1	32.6	27.8	21.3	9.0	-0.2	12.4	-12.0	5.5
12)	40.3	34.9	12.6	35.5	-4.6	0.0	11.4	16.8	-0.1

Table 10a. Total Count of Glow/(hour x spot). Every 10 min. DEP Chevron Tube. Day-7. 30 June 1997

count rate (c/s)	Peak height (c/hr pixel)	Width (pixel)	Total Count (c/hr spot)
152000.	4.903575E-01	7.047837	76.9
169000.	4.930919E-01	7.051123	78.8
34000.	3.414478E-01	5.636867	35.7
27000.	3.323984E-01	5.725427	38.9

Table 10b. Gaussian Fitting for averaged profile. 10 frames used. DEP Chevron Tube

Elapsed Time(Hrs)	140kHz	140kHz	29kHz	25kHz	6kHz	4kHz	2kHz	700Hz
2	352.0	316.6	128.4	107.5	23.6	31.9	6.3	4.0
17	65.9	59.0	29.7	24.9	7.8	9.3	3.6	3.1
46	30.7	27.5	12.9	10.6	3.4	3.3	1.0	1.2
70	29.8	26.7	10.8	7.9	3.7	2.6	2.7	1.0
87	21.2	20.4	7.5	7.6	4.1	3.1	-0.4	0.7
135	14.0	17.1	9.6	8.6	-0.2	2.4	3.0	-0.6

Table 11a. Decay of Glow/(Hour x Spot) after 18 Day damage test. DRK441 – 455 every day. DEP-Straight Tube. 12 Sept 1996

count rate (c/s)	Peak height (c/hr pixel)	Width (pixel)	Total Count (c/hr spot)
140000.	1.738419E-01	11.466110	47.5
140000.	1.747666E-01	10.173500	43.8
29000.	7.393017E-02	11.140760	19.5
25000.	6.051474E-02	10.916030	16.5

Table 11b. Gaussian Fitting for averaged profile. 6 frames used. DEP-Straight Tube

14 Summary

1. The longer life time of the photocathode and
2. very fast phosphor

are the beauties of this intensifier, while

1. broad pulse height distributions
2. short life time of MCP and
3. poor centroiding resolution

are the problems.

The problem (2) actually kills the benefit of advantage (1), because the threshold level in photon counting mode must be 30 ADU for the MIC flight detector, and then the gain depletion causes significant loss in quantum efficiency.

The problems (1) and (3) are associated with the zero gap between MCP1 and MCP2. The high gain at the detector centre and low gain at the edge are typical characteristics of DEP's zero gap intensifier (seen with three intensifiers). By having a small gap it seems that this would be overcome. The straight tube, whose gap is only $3\mu m$, does not show this problem.

Also, under-sampling of the event profile by the CCD seems to result in loss in centroiding accuracy. Hence the pore structure of MCP1 could not be resolved at 1/64 pixel centroiding.

It is not clear whether having a gap can extend the lifetime of MCP2, but having a large gap (for instance $25\mu m$) would improve the characteristics.

There are a lot of SIBs in this intensifier, although their energy is quite low. The relatively short scrubbing employed in manufacture of the tube might be responsible. However, a longer scrubbing should be considered carefully as this increases risk of blemishes, and does not guarantee removal of SIBs. A brief inspection of SIBs in the high illumination area with 3:1 minification optics (standard MIC configuration) does not show significant SIB improvement.

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