AERE-G 4873

PCOMWP(88)P14

Evaluation of the Harwell Colour 3-D Television System for Windscale AGR Decommissioning.

P. M. Scheiwiller.
V. M. Reading.
Department of Visual Science
Institute of Ophthalmology
University of London
Judd Street
London.
WC1H 9QS

A. A. Dumbreck.
E. Abel.
Engineering Sciences Division
Harwell Laboratory
Oxfordshire
OX11 0RA

May 1988

Summary.

Trials of the Harwell colour stereoscopic (or three dimensional) television system are described. A task was based on a real operation planned as part of decommissioning Windscale´s Advanced Gas-Cooled Reactor (WAGR); two heavy steel plates were moved between stands and a plate rack using an overhead gantry crane. The task required translation, rotation and accurate positioning of the plates.

Operators were timed whilst using 2D or 3D television viewing systems. For analysis, the task was divided into components. The one which required accurate alignment of a plate benefited most from using 3D and was performed 17% faster. The difference was statistically significant. The data from this component are consistent with the supposition that 3D is particularly useful in unfamiliar situations or the initial learning of a task.

Videotapes of two of the operators recorded during the trials showed that a supplementary 2D view was used differently when the main view was 3D rather than 2D; with 3D, the operators looked at the supplementary view for only a small percentage of the time. A third operator showed a less marked difference, but was thought not to be typical of those who participated in the experiment.

A questionnaire was completed by 8 operators. Picture quality of both 2D and 3D was highly rated. All except one had preferred using the 3D and would have been happy to do so for extended periods. Most thought that they had performed the task better with 3D and that a supplementary view was less of a necessity with a 3D main view.

Two main improvements were suggested by the operators; that the camera should be fitted with either zoom lenses or a switchable angle of view, and that clip-on polarising glasses should be made available for spectacle wearers.

Some of the subjects´ comments suggest, in accord with earlier findings, that the positioning of a single 3D view is far less critical than the optimal siting of a pair of 2-D views.

Table of Contents. Page

List of Photographs.

List of Figures.

Appendices

1.0 Introduction

This report describes evaluations of the Harwell Colour Stereoscopic (or 3D) television system at Windscale in December 1987. Trials were carried out in the HERO vault, a facility designed to develop and test remote handling equipment and techniques for nuclear decommissioning, and in particular, the Windscale prototype Advanced Gas Cooled Reactor (WAGR).

Previously 3D television systems have been evaluated and compared with conventional two-dimensional (2D) television using the same facility and similar tasks [1], but the present trials were perhaps more rigorous, and used a camera and display incorporating the latest developments and design changes.

Evaluations in a realistic setting are important to ensure that future development progresses in the right direction; by allowing potential users access to the equipment useful feedback can be obtained. Our aim is to design and build a stereoscopic television system which not only improves operator performance, but is easy to use and comfortable to view.

In the trials reported here operators were timed executing a pick-and-place task of heavy steel plates with an overhead gantry crane. The crane was driven from a control room outside the vault, with no direct view of the task. It was envisaged that accurate position of the plates would be facilitated by stereoscopic television and the task would be completed measurably faster than with conventional 2D TV views.

When the main view of the task was 3D, it was expected that a supplementary, 2D view would be little used, but with a 2D main view it would be much needed. To this end, three of the operators were videotaped using both 3D and 2D television systems and the percentage of the time spent looking at each view was assessed.

In addition, all of the operators completed a detailed questionnaire. They were asked, amongst other things, to rate the quality of the 2D and 3D pictures, to quantify how much use the supplementary view had been and finally to express a preference.

1.1 The Harwell Stereoscopic Television System

The camera and display are described in detail elsewhere, [2,3]. Briefly, the camera (see photo. 1) uses two re-packaged, single-sensor CCD cameras and photographic fixed focal length lenses. Camera convergence is achieved by axial offset of the lenses to avoid trapezium distortion associated with camera toe-in. Camera focus is accurately coupled to the convergence by a mechanical link. The display (photo. 2) uses two broadcast quality TV monitors, to enable accurate picture matching. The pictures are optically combined by a semi-reflective mirror. Polarizing filters, in front of each monitor and in spectacles worn by the viewer, select the appropriate image for each eye. Improvements over previous systems include colour, enhanced resolution, better dynamic range, improved highlight handling, better matching of lens apertures and a more precise focus and convergence mechanism.

2.0 The Task

The task was based on an operation planned as part of WAGR decommissioning:- Steel plates dismantled from the pressure vessel will be transported out of the vessel, in a basket, into a specially constructed chamber called the Upper Sentencing Cell. Here they will be removed to a multiple plate rack by a remotely controlled crane mounted on an overhead slewing beam. In appearance the rack will be like a giant toast rack and when completely loaded, will be lowered through a hole in the floor into another chamber, the Lower Sentencing Cell, where it will be set in concrete for disposal.

The part of this operation mocked-up in the HERO vault was the transfer of plates to the rack. A full size rack was used, but the distance over which the plates were moved was smaller. The crane in HERO is mounted on a fixed beam rather than a pivoted one, so the plates initially rested in specially built stands, each holding a single plate and placed under the axis of the beam, rather than in a basket. Only five of the ten slots in the rack could be reached by the crane, but the task still involved rotation, translation and accurate positioning of the plates. Photograph 3 shows the layout and figure 1 the floorplan.

Two plates were used, a curved piece of thermal shielding, 1.54m by 0.61m and 5 cm thick with a radius of curvature of about 12m, and a flat plate 1.03m by 0.6m by 8cm thick. These were, respectively, inserted into slots in the toast rack 8.0 and 8.3cm wide. The plates were always inserted into the same slots in the rack and returned to the same stands, the slots and stands being identified by coloured tape wrapped round the neighbouring prongs. The stand for the curved plate was the further away from the rack and the slot was the second of the rack. The straight plate was inserted into the fifth slot of the rack, the furthest away from the stands reached by the crane. Thus both plates were moved through approximately the same distance and neither occluded the view of the other to any large extent during the task. (See fig.1.)

In the start position both plates were in their stands and the crane parked at the end of the beam furthest away from them. Subjects were required to transfer the flat plate to the rack, the curved plate to the rack and then return, in turn, the plates to their stands, curved plate first. The sequence was then repeated and finally the crane returned to the end of it´s beam.

The time taken for each plate transfer, from stand to rack or vice-versa, was divided into five components:-

Component 1 : From start position (or end of component 5) till first touch of plate with the crane grab.

Component 2 : End of component 1 till grab is attached and plate is lifted clear of a stand or the rack.

Component 3 : End of component 2 till plate first touches rack or stand.

Component 4 : End of component 3 till plate is inserted fully home in rack or stand.

Component 5 : End of component 4 till grab is released and lifed clear of the plate.

2.1 Task Lighting

The Task was lit by quartz-halogen lights, positioned as shown in figure 1. The key source was a 3.6 kW array of six 600W lights arranged in three banks and the fill lights were 800W Red Heads. The lighting was balanced by 3 channels of a 4 channel dimmer; 2 channels for the Red Heads and a third for one bank of the key light. The other two banks ran at full power.

No measurements of illuminance were made at the time, but subsequent measurements in a similar setting suggest that the plate rack was illuminated with around 6000-7000 Lux.

2.2 Cameras; Positioning and Views of the Task

Two television views of the task were provided - a MAIN view and a SUPPLEMENTARY view - based on camera positions possible for the real operation, (although at present only a single view -the MAIN view -is planned.) The MAIN view was from a height of 1.6m above the multiple plate rack, more or less square to the slots, and the SUPPLEMENTARY view was from a similar height but displaced to the left (see Fig.1). The MAIN view was either 2D or 3D, whilst the SUPPLEMENTARY was always 2D. Both could be panned and tilted through large angles.

Two cameras mounted on the same pan and tilt head gave the MAIN view; a Panasonic F10 colour CCD camera for 2D and the Harwell colour stereo camera for 3D. These were aligned so that their axes intersected at the centre of the plate rack. Picture quality and resolution were very similar for the two cameras, since the same type of sensor is used in both cameras. The SUPPLEMENTARY view, from an identical F10, and 2D MAIN view were fitted with 12.5 to 75mm zoom lenses giving an angle of view ranging from 7 to 39 degrees. In 3D, the MAIN view had a fixed angle of view of 30 degrees. Since the task subtended an angle of approximately 44 degrees, the whole scene could not be encompassed in 3D without panning.

The view from the stereoscopic camera, and the SUPPLEMENTARY view were matched, by eye, for brightness and contrast. It was not possible to match the 2D MAIN view from the zoom camera as accurately, -the picture was always slightly darker- but the difference was small and unlikely to have been of any consequence.

3.0 Viewing Station Layout.

Figure 2 is a plan of the viewing station showing the placement of television monitors and controls. The operator was seated directly in front of the stereoscopic display, which was always the MAIN view; a 2D picture could be displayed either by connecting the same signal to both monitors and viewing through the polarising glasses, or by connecting a signal to only one of the monitors and viewing without glasses. The SUPPLEMENTARY view was displayed on a JVC 14" colour monitor to the left of the operator, angled at about 120 degrees to the screen of the MAIN view.

A video camera was set up above and slightly behind the SUPPLEMENTARY monitor to enable recording a view of an operator during the task.

3.1 Crane Controls.

Traversing the crane was controlled by simple on/off push buttons, whilst raising and lowering the grab used two-stage buttons; when depressed to the full extent of their travel the faster of two speeds was selected. Rotation of the grab was controlled by a rotary switch and although a speed of rotation control was available, it was preset throughout. The controls acted so that the television image of the crane moved in the same sense as the controls: i.e. depressing the left button moved the crane to the left in the picture and turning the rotary control clockwise rotated the grab clockwise in the picture.

The grab attached to the crane was opened and closed by lowering until its weight was supported by the plate and the suspending cables were slack. This actuated a ratchet mechanism -like that in a retracting ball point pen- and the grab remained open and could be lifted clear, or closed as the suspending cables were tensioned. Thus there were no separate controls for the grab.

3.2 Camera Controls.

Camera pan and tilt were controlled by a proportional joystick for the MAIN view, and by push buttons for the SUPPLEMENTARY view. To tilt a camera down the joystick was moved forwards, or the push button furthest away was depressed.

Zoom, focus and iris of the 2D views were controlled by push buttons. For the 3D, iris control was automatic and focus was linked to the convergence control of the camera, a paddle switch. The convergence control was used to ensure that the object or area of interest appeared to be in the plane of the screen, giving an optimum stereo image and best focus. This was most easily achieved by viewing the display without polarising glasses and adjusting the control until the appropriate part of the images overlayed. Although the subjects were free to use the control, in this case it was perfectly acceptable to leave the convergence at its initial setting, -the centre of the plate rack.

4.0 Subjects

Eight male subjects aged between 22 and 43 years, with a median age of 24 years, participated in the trials. All had 6/9 or better visual acuity, five with spectacle correction, and scored 8/10 or better on the Titmus test of stereo acuity.

Driving the crane was not as simple as the controls suggest. A particular technique was necessary to avoid setting the load swinging uncontrollably and colliding violently with equipment and fixtures in the vault. Therefore all eight of the subjects had had some instruction and were registered as crane drivers, although experience varied from half an hour to several hours.

5.0 Experimental Design

Two viewing arrangements were compared:-

(1) 3D MAIN view + 2D SUPPLEMENTARY view.

(2) 2D MAIN view + 2D SUPPLEMENTARY view.

Conditions (1) and (2) are loosely referred to as 3D and 2D conditions. In condition (1) operators were free to switch the MAIN view between the stereo camera and the 2D camera if it was absolutely essential to use a wider angle of view or the zoom facility. The 2D could be viewed without removing the polarising glasses. Similarly in condition (2), operators could switch the MAIN view between the 2D camera and the left eye view from the stereo camera. By setting the zoom lens to its widest angle of view this facility could be used to toggle between two angles of view.

Each of the subjects did the task under both viewing conditions in two sessions, separated by at least three hours. Half used arrangement (1) first, the others arrangement (2). Three of the subjects were videotaped under both conditions. Two of these used 2D first and 3D second, the other 3D first. All subjects answered a questionnaire after completing both sessions.

5.1 Procedure

At the start of a session the viewing arrangement and camera controls were explained and the subject was allowed several minutes to familiarise himself with their operation. For a 3D session the subject was given the choice of three styles of polarising spectacles. Where spectacles were already worn to correct deficient eyesight, the polarising glasses were worn on top of normal spectacles. In this respect, some styles were more comfortable than others.

The task was explained and cameras were returned to a predetermined start position. When it was clear that he understood the task, the subject was instructed to start.

The experimenter ran a timing program on an IBM PC/AT and entered the start and finish of each component of the task by depressing a button on the computer mouse. A code was entered after each plate transfer, so that any components missed by the experimenter could later be identified. To monitor the subject's progress, the experimenter could view a TV monitor connected to the stereo camera and could see the SUPPLEMENTARY view over the subject's shoulder. The times (if any) when the subject switched the MAIN view from the stereo camera to the 2D camera were also recorded.

In theory, a session ended with the start position restored, but it was sometimes found that the plate rack or stands had been moved by heavy collision of a plate which had been allowed to swing excessively. The correct positions were marked by adhesive tape stuck to the floor and small adjustment were made by manual effort.

After the second session had been completed, the questionnaire was answered and the ophthalmic tests administered; a standard letter chart for visual acuity and the Titmus test for stereo vision.

6.0 Results, Analysis and Discussion

The facility to switch the MAIN view between the stereo camera and 2D camera was very seldom used; subjects preferred to pan or tilt the camera rather than switch to 2D and use the zoom. Therefore under condition (1) the the MAIN view was considered to be entirely 3D.

In the following, where t-tests were calculated the significance levels are for a one-sided test since it was expected, a priori, that 3D would give the faster times. A one-sided test addresses the question:- is A faster, or bigger, etc than B? A two-sided test asks the question:- is A different from B?

6.1 Speed of Performance

Response time or speed of performance is often analysed in conjunction with the number of, or rate at which errors are made, since it is possible that accuracy is traded against speed of performance or vice-versa. In this case it is difficult to say exactly what constitutes an error. It was inevitable that the plate would contact the rack or stands during insertion. What magnitude of collision should be considered an error ? However any serious misjudgement of position and subsequent collision set the crane swinging. The swing needed to be corrected or inserting the plate became very difficult. Therefore it was assumed that errors or inaccuracies were reflected in the time taken to complete the task and performance could be assessed by analysing time alone.

a) Overall Time.

The variability between subjects was considerable; with 3D MAIN view, the longest time taken to complete the session was 2278 seconds and the shortest 1097 seconds. With 2D the time ranged from

1279 to 2594 seconds. The result of a paired t-test (ie subjects 2D time minus 3D time) was not significant ($t=1.42$, $d.f=7$, $p=0.099$) although the mean 2D-3D difference was 141 seconds.

b) Component Times.

Unfortunately, it was not possible to recover most of the data for the 3D session of one subject. Therefore he was not included in the following analysis. In order to keep the experiment balanced and easily analysed, a second subject had to be dropped. The first had used the 3D viewing arrangement first session, so the other subject had to be one of those who had used 2D first. Rather than pick at random, the subject we chose not to include had considerably more experience of driving the crane and using conventional 2D television than the rest. The following is therefore based on data from 6 operators, and although there were some missing values where the experimenter failed to record the start or finish of a component, the experiment remains reasonably balanced.

If it is assumed that the two plates were of equal difficulty to move and that the directions, from stand to toast rack and from rack to stand, were equivalent, then each component was repeated eight times per session. For each repetition of each of the 5 components for each subject, the time taken with 3D was subtracted from the corresponding 2D time. This reduces the variability and allows for a more precise testing of statistical significance.

The mean time difference (2D-3D time) for each component could be tested for significance with a t-test. However this assumes a normal distribution of the data and normal probability plots revealed that the assumption did not hold for components 3 and 4. (See appendix 1.) This is important because these were the components most likely to have been affected by the choice of viewing system and a rigorous test is highly desirable.

It could be argued that accurate alignment of a plate will sometimes have been largely achieved before the first touch of the rack or stand, and sometimes afterwards. In the former case the plate could rapidly be inserted into the rack soon after the first touch, whilst in the latter case more time would elapse between first touch and the plate being fully inserted: there would be a negative linear correlation between the times for components 3 and 4. The correlation coefficient of the 2D-3D times for these components was calculated to be -0.31, which is statistically significant. ($d.f.= 46$, $p < 0.025$ one sided.) Therefore a better definition of components would be to combine components 3 and 4 in a single component which always included alignment of the plate. This component, termed component X, was calculated simply by adding the times for components 3 and 4. The distribution of the difference, 2D minus corresponding 3D time is now approximately normal. (See appendix 1.)

The correlation matrix of component 2D-3D times (see appendix 2.) indicates that there are two other significant correlations; between components 1 and 5, ($r = 0.42$ $d.f = 46$, $p < 0.005$) and between components X and 2 ($r = -0.37$, $d.f = 46$, $p <$

0.025). There is no intuitive reason why these components should be correlated, other than that they are repeated measures of subject's performance. However the main interest here is the difference between 3D and 2D, no strong claims are made about the differences between components, so they have been regarded as independent.

The mean 2D-3D component times are shown in figure 3. Table 1 gives the results of t-testing the hypothesis that these mean time differences are greater than zero.

Component	Mean 2D-3D Time (Seconds)	Standard error	N	T	p
1	2.7	± 3.5	47	0.76	0.23
2	3.7	± 5.5	47	0.67	0.25
X	18.2	± 11.0	46	1.72	0.04 *
5	-2.7	± 3.7	48	-0.74	0.77
Total	23.8	± 13.0	45	1.82	0.04 *

Table 1
T-tests of Mean 2D-3D times.

* indicates a significant result.

Note that 'Total' is the mean of the sum of components rather than the sum of the component means. Since there were missing values and the component means were not based on the same number of observations, these will not necessarily be the same.

Table 2 shows the absolute mean times (in seconds) for the components.

Component	3D Mean Time ± Standard Error	N	2D Mean Time ± Standard Error	N
1	39.9 ± 3.6	48	42.7 ± 3.4	47
2	36.8 ± 4.1	48	40.7 ± 3.3	47
X	103.1 ± 9.8	46	124.7 ± 10.0	48
5	20.8 ± 3.9	48	18.1 ± 2.0	48
Total	200.6 ± 13.4	46	226.2 ± 12.9	47

Table 2.
Mean Component Times

Component X was the part of the task which required the most positional accuracy and showed the most benefit from using 3D; an improvement of 17%.

c) Serial Order Effects.

Previously we have hypothesised that stereoscopic television is particularly useful in viewing unfamiliar situations [1]. Here it might be expected that differences between 2D and 3D will be most pronounced in the early repetitions of the first session.

However the cross-over nature of the experimental design does not allow a very precise comparison; considering the first session alone there would only be three subjects per viewing condition. Perhaps because of the large individual differences, the mean 2D and 3D times for each repetition do not show any recognisable trend.

There may also be another difficulty: any such effect could be confounded with periodic effects arising from violations of the assumptions (a) that the plates were of equal difficulty to move and (b) that the directions were equivalent (see section 6.1 b). For instance, if the curved plate was considerably more difficult to move than the straight plate, the mean time for every other repetition would be increased. If both assumptions were violated the periodic pattern would be quite complex.

For component X, which showed the largest percentage 2D-3D difference, a two-way analysis of variance revealed that the directions were distinct; moving a plate to the rack took longer than returning it to a stand ($F(1,89) = 17.1$, $p < 0.001$). However there was no statistically significant difference between the plates and no plate-direction interaction. The analysis of variance table is given in appendix 3 (table A3.1). There was no interaction between direction and viewing system and therfore no need to qualify the conclusions draw in the previous section (i.e using 3D facilitated moving plates both to and from the rack). Table 3 gives the mean times for each direction under 2D and 3D viewing conditions.

	3D Mean Time $\pm$ Standard Error	2D Mean Time $\pm$ Standard Error
Stand to Rack	125.4 ± 15.8	158.7 ± 16.4
Rack to Stand	82.7 ± 7.8	94.3 ± 9.8

Table 3.
Mean Time (Seconds) for Component X for Direction and View

Adjusting component X for direction, a further analysis of variance showed that the effect of repetition was statistically significant ($F(7,71) = 2.29$, $p = 0.04$, table A3.2), but the difference between sessions was not. Note that the analysis took into account the expectation that for each subject, performance in session 1 would be correlated with performance in session 2, but not necessarily with that of any other subject in either session [4]. It was also found there was no interaction between session and repetition. Therefore the two sessions can be pooled and the 2D-3D times used. Precision is improved, data from all six subjects are used and the periodic effects of direction are intrinsically removed. Figure 4 shows mean 2D-3D time for each repetition of component X.

Calculating the linear regression of 2D-3D time on repetition showed that there was no linear trend; the slope was not significantly different from 0 ($F(1,44) = 0.88$, $p = 0.35$, table A3.3). However a curve of the form:-

$$\text{Time} = a + b * \text{Exp}(-c * \text{repetition})$$

with the parameters $a = 9.4$, $b = 443$, $c = 1.9$, fitted the data somewhat better. This is the curve drawn in figure 4. The trend is not statistically significant ($F(2,43 = 2.04)$, $p = 0.12$, table A3.4), unless the same curve is fitted to the mean 2D-3D time for each repetition ($F(2,5) = 14$, $p < 0.01$, table A3.5, whereas linear regression is not significant:- $F(1,6) = 1.76$, $p = 0.23$), but does suggest two things. First that the principle difference between 2D and 3D is to be found in the first two repetitions and second, that thereafter the 2D-3D time is asymptotic to some small positive value; for this component performance will always be slightly better with 3D viewing.

6.2 Videotaped Subjects

Videotapes of two of the operators recorded during the trials showed that the SUPPLEMENTARY view was used differently when the MAIN view was 3D rather than 2D; with 3D the operators looked at the SUPPLEMENTARY view for only a small percentage of the time. (See table 4.) A third operator was videotaped but showed a less marked difference between 2D and 3D. However he was perhaps not typical and had more experience of using orthogonal, 2D viewing systems, preferring to use a way of working which was familiar and ignoring the depth information provided by the 3D.

	3D				2D			
Op.	**MAIN**	**SUPPL**	**Controls**	**Other**	**MAIN**	**SUPPL**	**Controls**	**Other**
1	94.9	<0.1	3.9	1.1	67.4	26.8	4.1	1.7
2	94.2	0.2	4.2	1.4	52.8	38.6	5.8	2.8
3	61.9	27.5	7.4	3.2	55.3	32.9	8.7	3.1

Table 4.
Percentage of time spent looking at MAIN view, SUPPLEMENTARY view, controls and elsewhere.

The sample is too small for any reliable statistics, but does strongly suggests that the depth infomation provided by the 3D view made the SUPPLEMENTARY view largely unnecessary for this task. There is also no evidence to suggest that these operators found the 3D system uncomfortable to watch; they did not frequently have to look away or peer into the display.

6.3 Questionnaire Results

All eight subjects answered the questionnaire; the text is given in appendix 4. The following summarises the main findings:-

a) Picture quality of both 2D and 3D views was rated highly. On a scale of 1 to 10, where 10 equals excellent, both had a median score of 9.

b) All except one subject thought that he performed the task either slightly better or very much better when the MAIN view was 3D. The exception found no difference. However, slightly at odds with this, on a scale of 1 to 10 (10=extremely difficult) the median score for task difficulty was 4 for 3D and 5 with 2D - only a small difference.

c) In concordance with the videotapes, the SUPPLEMENTARY view was used differently with 3D and 2D MAIN views. On a scale of 1 to 10, where 1 = no use at all and 10 = absolutely essential, the median rating with 3D was 3 and with 2D, 8.

d) With one exception, the subjects would have been happy to use the 3D system for extended periods. With 2D there were two exceptions.

e) The most difficult aspect of the task was driving the crane in a way which minimised swing of the load. This required a fair degree of skill, but was independent of viewing system. Two out of the eight thought that joystick controls would improve matters.

f) Seven out of the eight subjects thought that the display monitors for MAIN and SUPPLEMENTARY view could have been better positioned; closer together, particularly for 2D. Despite this, they thought that the effect on performance was slight or that there was no effect at all. However closer placing of the monitors would have made the videotapes difficult to analyse.

g) Finally, two subjects very much preferred using the 3D, five slightly preferred 3D and one slightly preferred 2D.

The subject in g) who preferred using 2D viewing was the exception in d) who would not have been happy to use 3D for extended periods. He was also the subject in b) who did not think he performed the task better with 3D viewing, and the third of those video taped. This lends support to the contention in the previous section that he was atypical.

A number of comments were made by more than 1 subject:-

a) A wider angle of view, a choice of angles or a zoom would be desirable for the stereoscopic camera. (4 subjects).

b) 3D was preferred because it gives a better spatial sense. (4 subjects).

c) For 2D viewing plan and elevation views would have been preferred. (2 subjects).

d) For those who normally wear spectacles, a clip-on polarising viewer, like clip-on sunglasses, might be more comfortable than wearing two pairs of spectacles. (2 Subjects).

7.0 Conclusions

The use of Stereoscopic television gave a worthwhile and statistically significant improvement in operator performance for part of the task. This was the one which required most positional accuracy, and with 3D the mean time was 17% faster. Considering the slow speed at which the crane moved and the relative clumsiness of the controls this is a fairly large margin. For a more dextrous task we expect this margin to be even wider.

It was not possible to demonstrate conclusively that 3D was particularly useful in an unfamiliar situation or during the initial learning phase, but the results are consistent with this supposition. With hindsight, such an effect would have to be very pronounced to be apparent from an experiment of the design used here.

The videotapes recorded during the trials suggest that for this task a single 3D view is almost entirely sufficient, and in addition, that the operators had no difficulty in using it. The use of stereoscopic television for the real operation is recommended.

Answers to the questionnaire and subject comments proved that the stereoscopic system was well liked and comfortable to view. In addition, support was given to the analysis of the videotapes; operators thought that the SUPPLEMENTARY view was of less use when the MAIN view was 3D rather then 2D. There is also the suggestion that perhaps 3D camera positioning is less critical than with conventional 2D views.

Two main improvements were suggested; that the camera should have a zoom lens, or switchable angle of view, and that some clip-on polarising glasses should be made available.

8.0 Acknowledgements.

We would like to thank Mr Ed Perrott of Windscale Laboratory for arranging the trials there.

Funding for this work was provided by the Department of Energy, the Generating Boards and BNFL.

9.0 References

[1] Dumbreck A A, Abel E, Holt J, Scheiwiller P M, Reading V M. " A 3D Television System for Remote Handling." Ergonomics Society, International Symposium on Teleoperation and Control, Bristol, 1988.

[2] Dumbreck A A, Smith C W, Murphy S P. " The Development and Evaluation of a Stereoscopic Television System for Use in Nuclear Environments." American Nuclear Society, International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, WA, USA, 1987, 106-113.

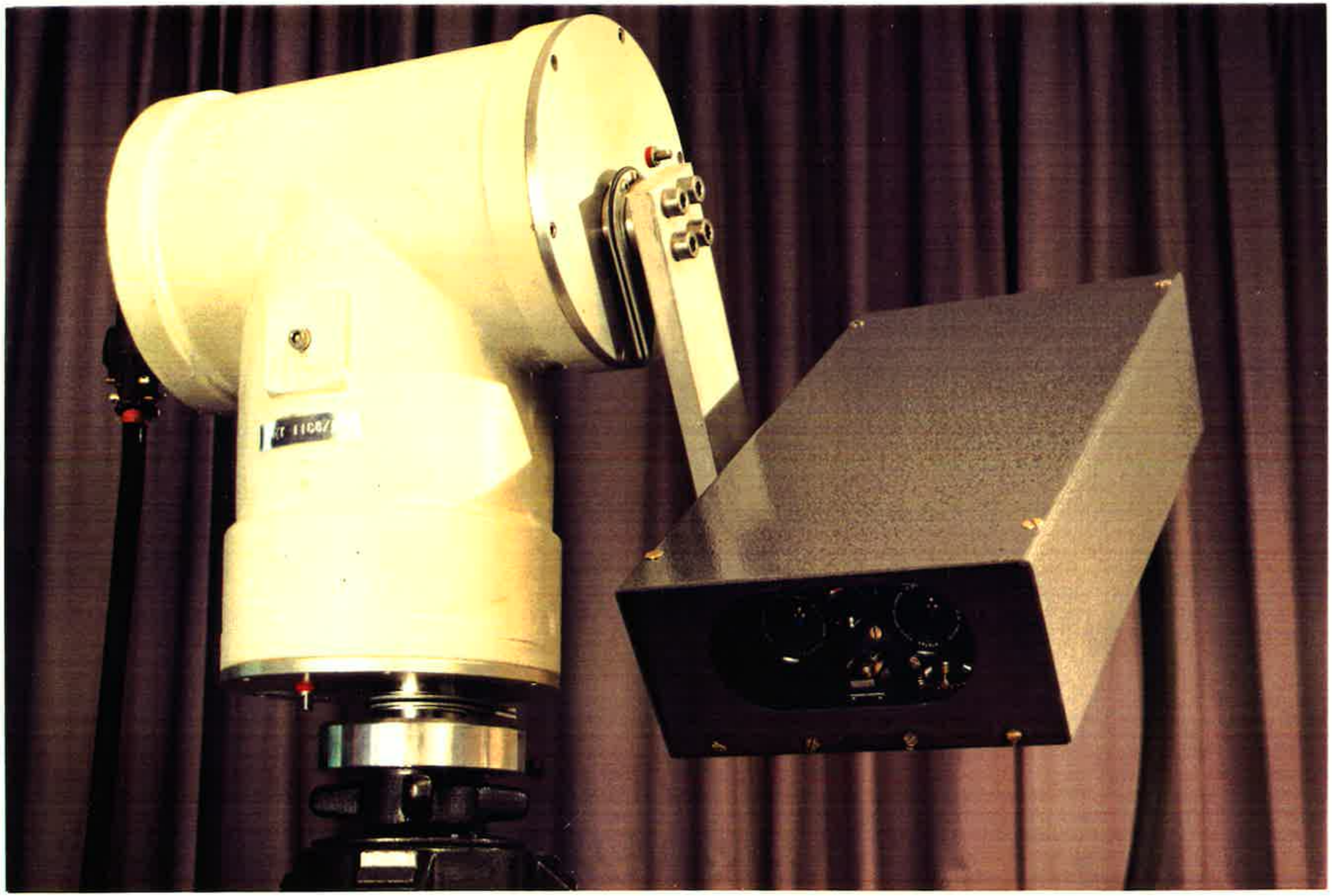
[3] Smith C W, Dumbreck A A. "3D TV: The Practical Requirements." Television, Journal of the Royal Television Society, 1988 Vol 25, 9-15.

[4] Montgomery D C. "Design and Analysis of Experiments." Wiley, 1976.

[5] BMDP Statistical Software, University of California Press 1981.

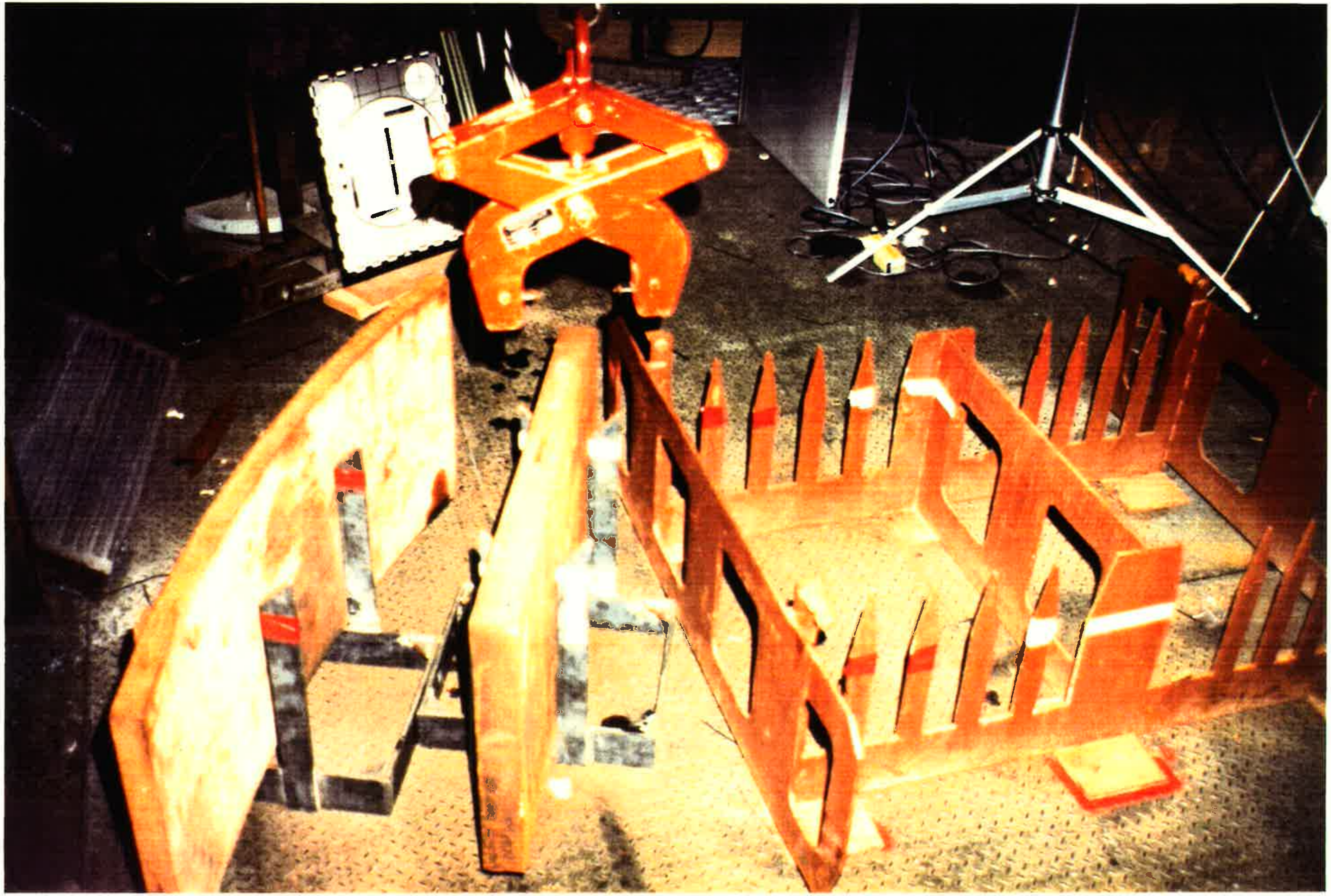
[6] GLIM Version 3.77 Statistical Software, Numerical Algorithms Group Limited, Oxford, 1985.

[7] MINITAB Statistical Software, Release 5.1, Minitab Inc. 1985.



Photograph 1: 3-D Television Camera.

Photograph 2: 3-D Display.



Photograph 3: Task in Hero Vault.

Floorplan of HERO Vault.

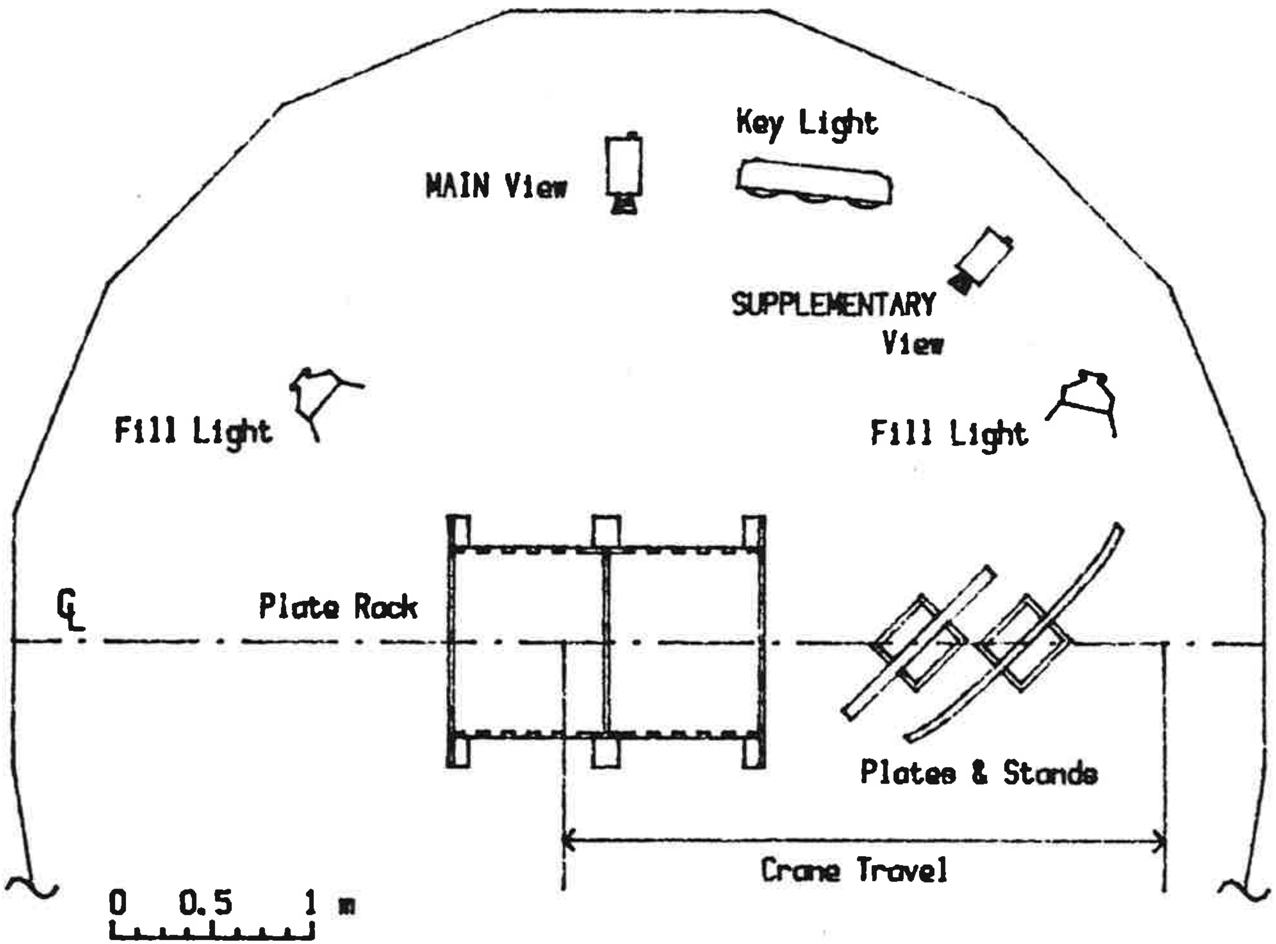


Figure 1.

Plan of Viewing Station.

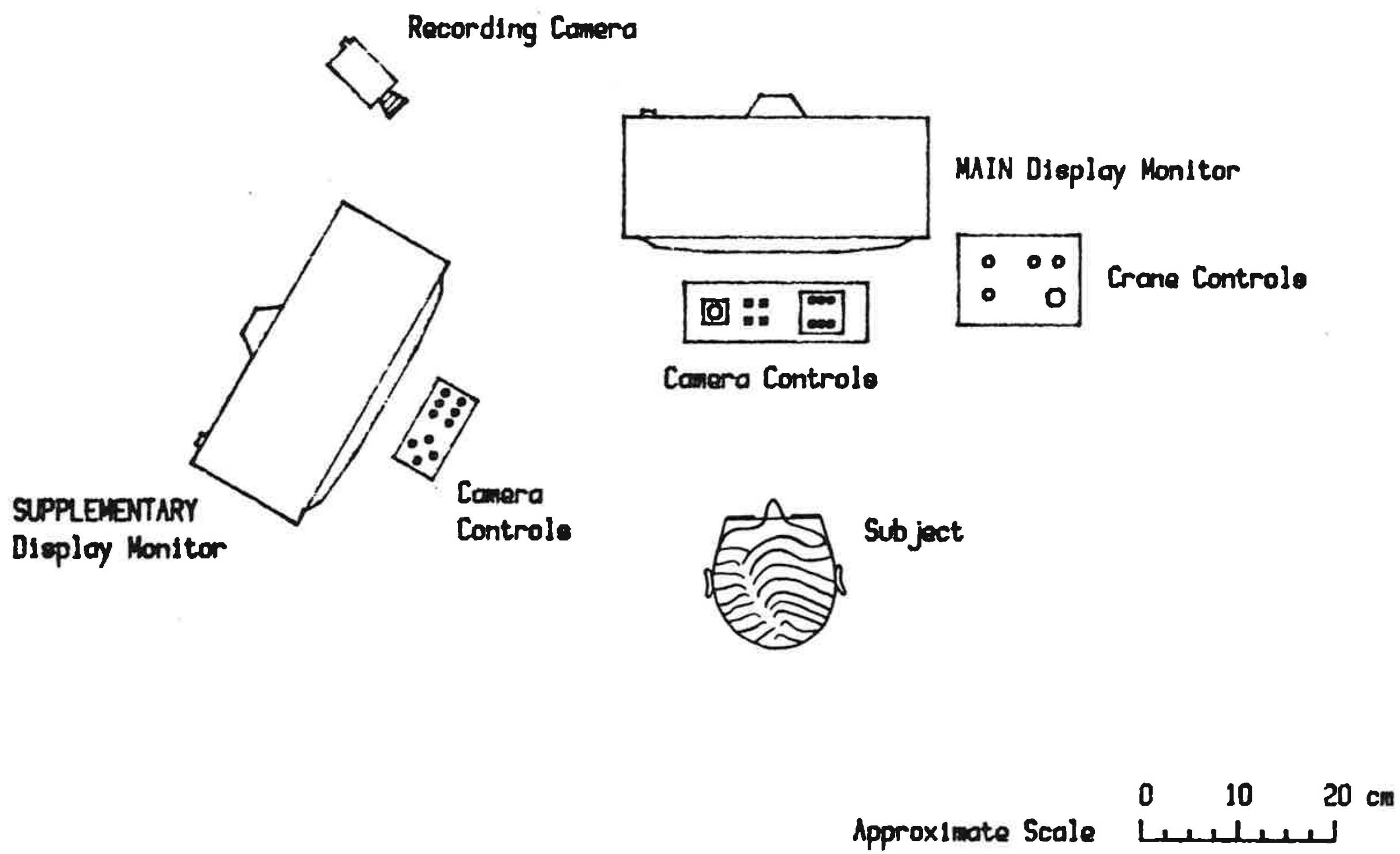
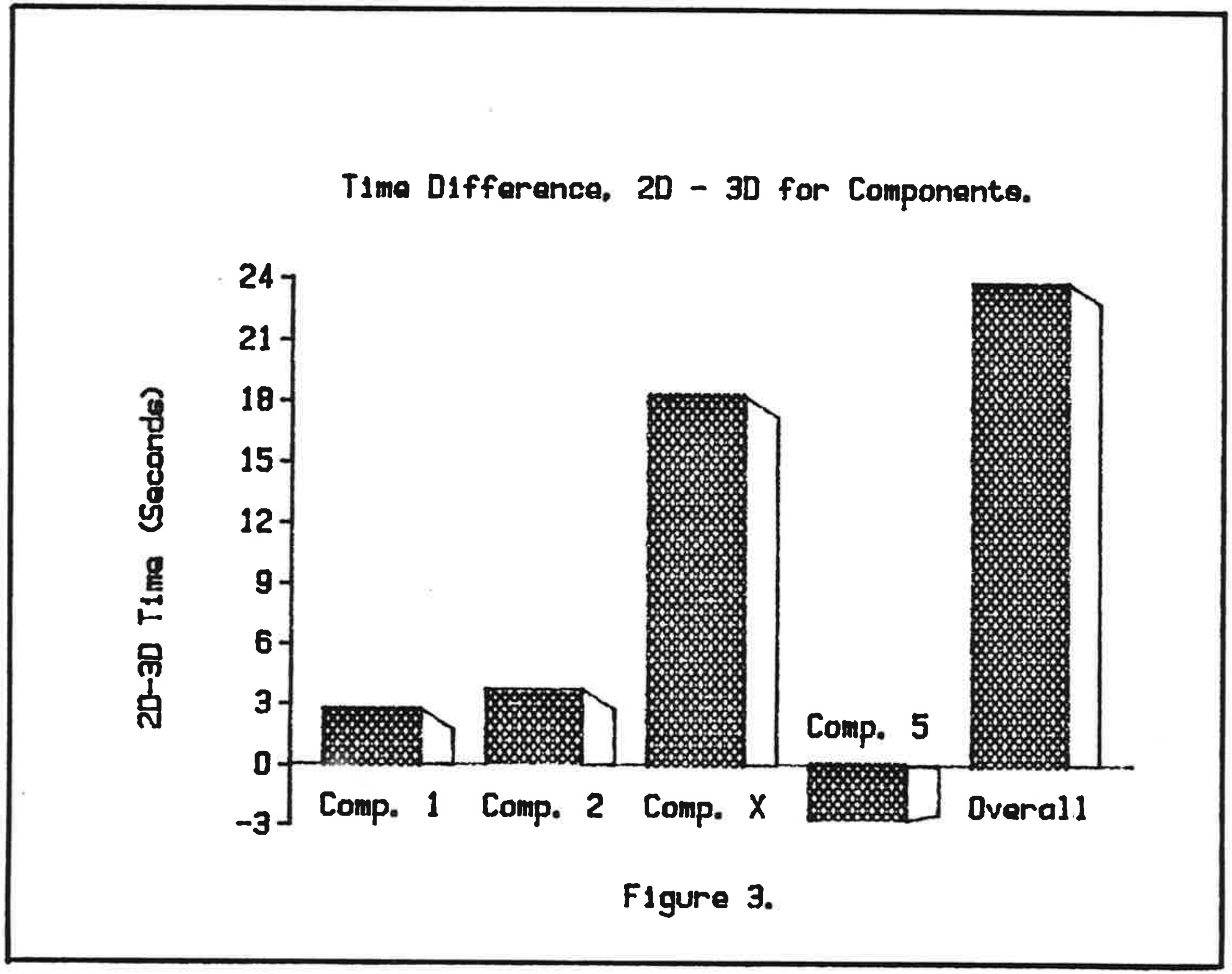


Figure 2.


Time Difference, 2D - 3D for Components.
2D-3D Time (Seconds)
24
21
18
15
12
9
6
3
0
-3
Comp. 1
Comp. 2
Comp. X
Comp. 5
Overall
Figure 3.

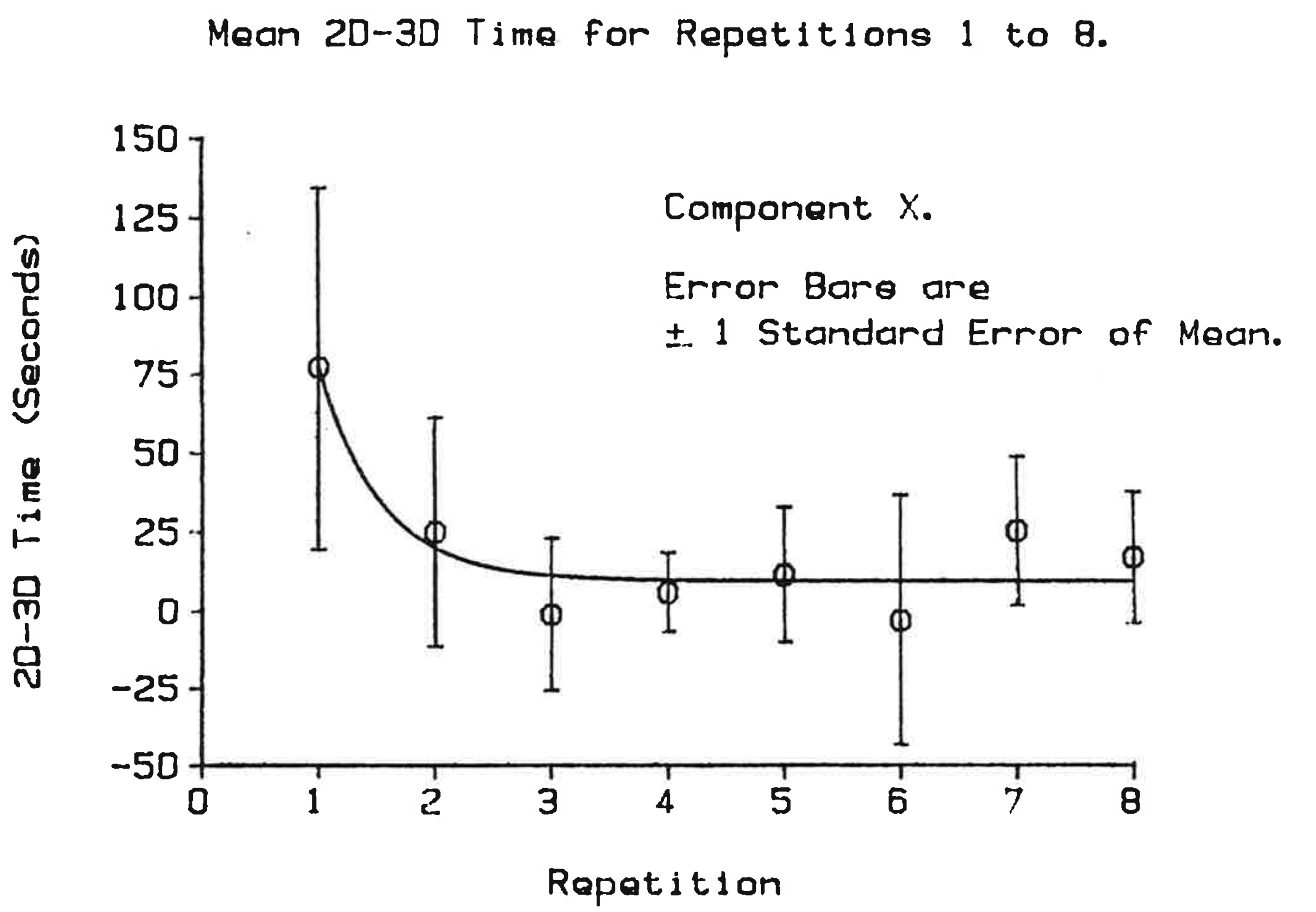

Mean 2D-3D Time for Repetitions 1 to 8.
Component X.
Error Bars are
± 1 Standard Error of Mean.
2D-3D Time (Seconds)
150
125
100
75
50
25
0
-25
-50
0
1
2
3
4
5
6
7
8
Repetition

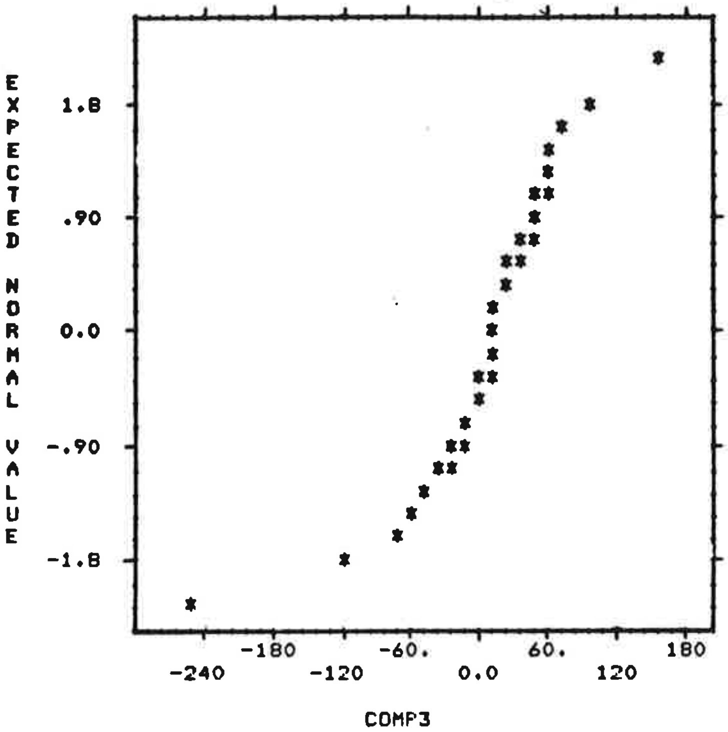
Figure 4.

Appendix 1

Normal Probability Plots for Components 3,4 and X.

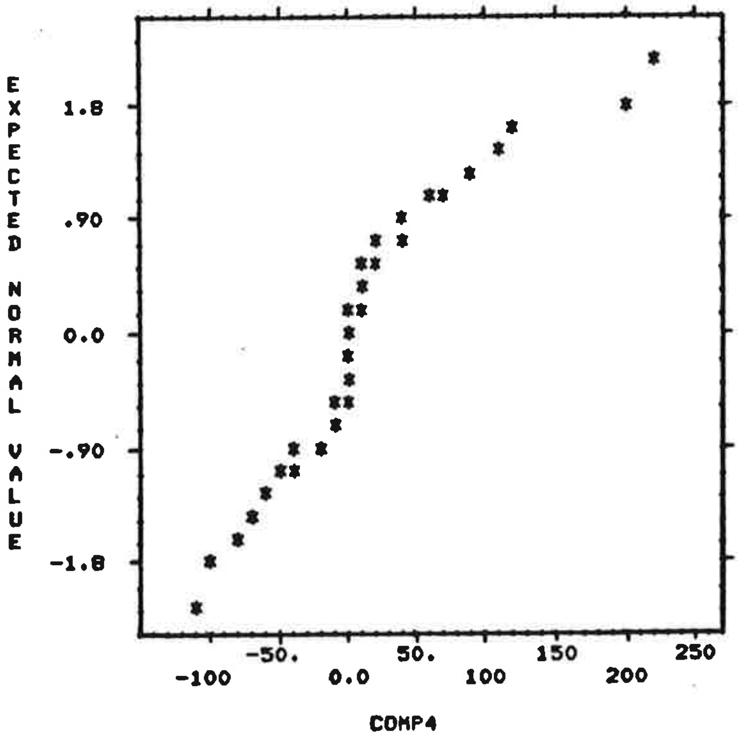
NORMAL PLOT OF VARIABLE 6 COMP3

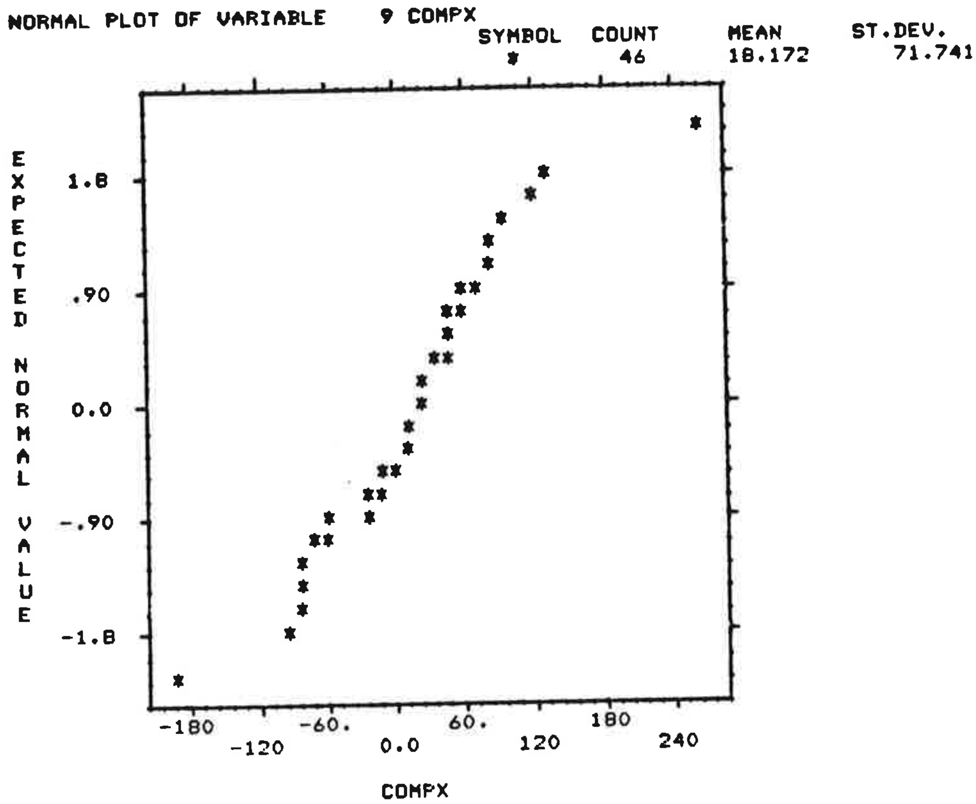
SYMBOL	COUNT	MEAN	ST.DEV.
*	46	7.278	59.998



NORMAL PLOT OF VARIABLE 7 COMP4

SYMBOL	COUNT	MEAN	ST.DEV.
*	46	10.894	62.407





Notes on Normal Probability Plotting

1) Data with a normal distribution will be plotted as a straight line.

2) Some deviation from a straight line is to be expected at the extremes.

Appendix 2

Matrix of Correlations between Components 1,2,3,4,5 and X.

	Comp1	Comp2	Comp3	Comp4	Comp5
Comp2	-0.16				
Comp3	0.11	-0.26			
Comp4	0.09	-0.17	-0.31*		
Comp5	0.42**	-0.04	0.01	0.29	
CompX	0.17	-0.36*	--	--	0.26

* indicates statistical significance at 5% probability level.

** indicates statistical significance at 0.5% probability level.

Notes on Correlation

1) The correlation coefficient between two variable x and y is given by:-

$$r = \frac{1}{N\ Sx\ Sy} . \sum_{i=0}^{i=N} (x_i - \overline{x}).(y_i - \overline{y})$$

Where:-

N is the number of observations of x and y,

Sx and Sy are respectively the standard deviations of x and y,

$\overline{x}$ and $\overline{y}$ are the means of x and y.

2) The maximum value of r is +1 and the minimum -1. A correlation of +1 indicates a perfect, linear functional relationship between x and y where increasing x is associated with increasing y. A value of -1 indicates a perfect functional relationship where increasing x is associated with decreasing y.

3) A correlation of 0 indicates that there is no linear relationship between x and y; they are uncorrelated.

4) Intermediate values of r indicate a trend rather than a strictly functional relationship. The larger the modulus of r, the stronger the trend. Positive values indicate that increasing x is associated with increasing y, whilst negative values indicate the association of increasing x with decreasing y.

Appendix 3

Analysis of Variance Tables

Source	Sum of Squares	d.f.	Mean Square	F	p
Plate	4312	1	4312	1.1	> 0.5
Direction	67720	1	67720	17.1	< 0.001*
Interaction	13777	1	13777	3.4	0.07
Residual	351451	89	3949		
Total	437259	92			

Table A3.1

Time for Component X, 2D and 3D.

Source	Sum of Squares	d.f.	Mean Square	F	p
Subject	97656	5	19531		
Session	2791	1	2791	1.0	0.43
Repetition	44051	7	6293	2.3	0.04*
Interaction	27327	7	3903	1.4	0.22
Residual	197713	71	2784		
Total	369539	91			

Table A3.2

Time for Component X, 2D and 3D, Adjusted for Direction.

* indicates a statistically significant result.

Source	Sum of Squares	d.f.	Mean Square	F	p
Regression	4585	1	4585	0.9	0.35
Residual	226996	44	5159		
Total	231581	45			

Table A3.3

Linear regression of 2D-3D Time on Repetition.

Source	Sum of Squares	d.f.	Mean Square	F	p
Regression	20141	2	10070	2.0	0.12
Residual	211440	43	4917		
Total	231581	45			

Table A3.4

Exponential Curve Fitted to 2D-3D Time on Repetition.

Source	Sum of Squares	d.f.	Mean Square	F	p
Regression	3926	2	1963	14	0.009*
Residual	665	5	133		
Total	4591	7			

Table A3.5

Exponential Curve Fitted to Mean 2D-3D Time on Repetition.

* indicates a statistically significant result.

Notes on Analysis of Variance for Table A3.2.

1) The times for each Repetition of component X were corrected for Direction by subtracting the appropriate Direction mean.

2) The factors Repetition and Session are repeated measures. They are within-subject factors, and likewise their interaction. Since repetition has the same meaning at each level of session, the factors are crossed.

3) For the correct analysis the mean squares should be compared with the within-subject residual. Hence the first line of table A3.2 gives the between-subject sum of squares and the required residual sum of squares can be calculated by subtraction.

Appendix 3

Questionnaire to be Completed After Using Both Viewing Systems

Please answer the following questions carefully; your answers are important. If there is anything you don´t understand, please ask.

Name:

Age:

---

1 Do you normally wear spectacles?

YES [ ] NO [ ]

If YES, then during the experiment, were you wearing glasses:-

FOR DISTANCE [ ] FOR READING [ ] BI-FOCALS [ ]

---

2 Are you right handed, left handed or ambidexterous?

RIGHT [ ] LEFT [ ] AMBIDEXTEROUS [ ]

---

3 Had you been drinking anything alcoholic in the 24 Hours prior to doing the experiment?

a) Using the 2D viewing system YES [ ] NO [ ]

b) Using the 3D viewing system YES [ ] NO [ ]

If the answer is YES to either of these, how much and aproximately how long before?

2D system:

3D system:

---

4 Are you taking any medication? YES [ ] NO [ ]

If YES please specify:

---

5 Were you cold during either part of the experiment?

First session YES [ ] NO [ ]

Second session YES [ ] NO [ ]

---

6 Did you find that the camera views were satisfactory?

a) 3D MAIN view YES [ ] NO [ ]

b) 2D MAIN view YES [ ] NO [ ]

c) SUPPLEMENTARY view YES [ ] NO [ ]

If not how could the views have been improved?

3D MAIN:-

2D MAIN:-

SUPPLEMENTARY:-

---

7 On a scale of 1 to 5, how would you rate the difficulty of controlling the crane? (1=very easy, 5=very difficult)

a) With the 3D viewing system: 1 2 3 4 5

b) With the 2D viewing system: 1 2 3 4 5 (Circle answer)

---

8 Would joystick controls for the crane have made the task easier?

YES [ ] NO [ ]

---

9 Which of the following two factors most affected your performance of this task; the method of viewing, or operating the crane? Did it help or impede your performance?

	HELP	IMPEDE
METHOD OF VIEWING	[ ]	[ ]
OPERATING THE CRANE	[ ]	[ ]

(Tick one box only)

---

10 On a scale of 1 to 10, how would you rate the overall picture quality of:-

a) The 3D view: 1 2 3 4 5 6 7 8 9 10

b) The 2D view: 1 2 3 4 5 6 7 8 9 10

(1=very poor, 10= excellent) Circle answer

---

11 Was the lighting of the task:-

TOO BRIGHT	ABOUT RIGHT	TOO DIM
[ ]	[ ]	[ ]

---

12 Was the lighting at your viewing position:-

TOO BRIGHT	ABOUT RIGHT	TOO DIM
[ ]	[ ]	[ ]

---

13 Did you find the controls for the cameras confusing?

3D MAIN view	YES [ ]	NO [ ]
2D MAIN view	YES [ ]	NO [ ]
SUPPLEMENTARY view	YES [ ]	NO [ ]

---

14 On a scale of 1 to 10, how easy did you find the task?

3D SYSTEM: 1 2 3 4 5 6 7 8 9 10

2D SYSTEM: 1 2 3 4 5 6 7 8 9 10

(1=very easy, 10=extremely difficult)

---

15 Could the display monitors have been better positioned?

YES [ ] NO [ ]

If YES please specify:-

---

16 Please indicate whether the following factors affected your performance:- (Tick one box per row)

	AFFECTED	SLIGHTLY AFFECTED	NO AFFECT AT ALL
The positioning of the monitors	[ ]	[ ]	[ ]
The camera positions			
a) 3D MAIN view	[ ]	[ ]	[ ]
b) 2D MAIN view	[ ]	[ ]	[ ]
c) SUPPLEMENTARY view	[ ]	[ ]	[ ]
The cold	[ ]	[ ]	[ ]
The lighting of the task	[ ]	[ ]	[ ]
The lighting of the viewing position	[ ]	[ ]	[ ]
Difficulty in controlling the crane	[ ]	[ ]	[ ]
Difficulty in controlling the cameras			
a) 3D MAIN view	[ ]	[ ]	[ ]
b) 2D MAIN view	[ ]	[ ]	[ ]
c) SUPPLEMENTARY view	[ ]	[ ]	[ ]

---

17 Did the viewing system make any difference to your performance of the task?

3D VERY MUCH BETTER [ ]

3D SLIGHTLY BETTER [ ]

NO DIFFERENCE [ ]   (Tick one box only)

2D SLIGHTLY BETTER [ ]

2D VERY MUCH BETTER [ ]

---

18 On a scale of 1 to 10, how much use was the SUPPLEMENTARY view? (1= no use at all, 10= absolutely essential)

3D SYSTEM: 1 2 3 4 5 6 7 8 9 10

2D SYSTEM: 1 2 3 4 5 6 7 8 9 10 (Circle answer)

---

19 Did wearing the glasses, whilst using the 3D system cause any problems or discomfort?

YES [ ] NO [ ]

If YES then please specify:-

---

20 Did you experience any of the following symptoms whilst using, or immediately after using either of the viewing systems? (If the answer is yes then tick the box)

	3D	2D
Headache	[ ]	[ ]
Double Vision	[ ]	[ ]
Difficulty in focusing your eyes on near objects	[ ]	[ ]
Difficulty in focusing your eyes on distant objects	[ ]	[ ]
Pain in your eyes or ´eyestrain´	[ ]	[ ]
Back or neck pain	[ ]	[ ]
Other	[ ]	[ ]

If Other, please specify:-

---

21 Would you be happy to use these viewing systems for an extended period of time?

a) 3D YES [ ] NO [ ]

b) 2D YES [ ] NO [ ]

---

22 On a scale of 1 to 5, how do you think that your performance of the task improved during the experiment?.

2D SYSTEM: 1 2 3 4 5

3D SYSTEM: 1 2 3 4 5

(1=not at all, 5=very rapidly)

---

23 Did any objects viewed by the 3D camera appear to be unusual or in any way "unrealistic"?

YES [ ] NO [ ]

If YES please specify:-

---

24 Overall, which system did you prefer using?

3D VERY MUCH PREFERRED [ ]

3D SLIGHTLY PREFERRED [ ]

NO PREFERENCE [ ]

2D SLIGHTLY PREFERRED [ ]

2D VERY MUCH PREFERRED [ ]

Why?

---

25 Please use the following space to add any comments.

[An A4 sheet of paper was attached for comments.]

DISTRIBUTION LIST: PCOMWP(88)P4 AND P14

POWER AND COMMUNICATION WORKING PARTY

Dr E Abel (Chairman) ...	B351.28, Harwell
Dr R S Adrain	CEGB, Marchwood Eng Lab
Mr K Basson	E257, UKAEA, Risley
Mr A G Castle	UKAEA, Dounreay
Mr J Doogan	B148, BNFL, Sellafield
Mr A J Finlayson	E and I DO, H400, BNFL, Risley
Mr T T Hanna	B351.28, Harwell
Mr M Kear	Culham Laboratory
Mr C Leeks	UKAEA, Winfrith
Mr C Stubbs	B3, UKAEA, Windscale
Mr G Telford	B A14.4 MoD, AWE(A)
Mr A Dumbreck (Secretary)	B401.4, Harwell (10)

CEGB OPTICAL INSPECTION LIAISON GROUP

Dr P Walton	CEGB, GDCD, Barnett Way, Barnwood, Glos, GL4 9RS
Dr D W James	" " " " " " "
Mr T Wickett	CEGB, Gravesend Lab, Canal Road, Gravesend
Mr S Mansfield	" " " " " "
Mr J Moorby	CEGB, SW Region, S and TG, Bedminster Down, Bridgewater Road, Bristol
Mr R P F Clayton	CEGB, S and TG, Timpson Road, Wythenshawe, Manchester, M23 9LC
Mr R Dixon	Hinkley Point 'B' PS, CEGB, Nr Bridgewater, Somerset, TA5 1UD

ADDITIONAL

Mr J Phillpott	EScD, B392.7, Harwell
Mr J Williams	AFPD, B10, Harwell
Mr S Hansford	Chairman, Viewing Working Party, BNFL, Risley
Mr H Whittle	Hinton House, BNFL, Risley
Mr P Vickery	R412, BNFL, Risley
Mr D Yeomans	Hinton House, BNFL, Risley
Mr G Stewart	B125, BNFL, Sellafield
Mr A Webster	B148, BNFL, Sellafield
Dr M Cross	B3, UKAEA, Windscale
Dr J Wakefield	" " "
Mr E Perrott	" " "
Mr D Perratt	CEGB, Marchwood Eng Lab, Marchwood, Southampton
Mr J Holt	" " " " " "
Mr R Carrey	CEGB, Hunterston Power Station, Hunterston, Ayrshire
Mr I Angell	CEGB, Hunterston Power Station, Hunterston, Ayrshire
Mr J A Ward	EScD, B351.28, Harwell
Mr M H Brown	Secretary, Steering Group for Active Handling, EScD, B351.28, Harwell
Dr E Abel	EScD, B351.28, Harwell
Mr S P Murphy	EScD, B401.4, Harwell
Mr P Scheiwiller	B401.4, Harwell
Dr J C Evans	EMScD, B364, Harwell
Dr V M Reading	Institute of Ophthalmology, Judd Street, London, WC1H 9QS