optical image forming system is almost negligible. In principle, subtle contrasts in the low-luminance initial fluorescent image are not affected by the light-transformation (the $\gamma$ of the image intensifier is unity). In practice, however, there is a slight, but unavoidable loss of contrast owing to "fogging", that is, a luminance contribution distributed more or less uniformly over the whole image. On the other hand, the increase in contrast sensitivity of the eye with increasing luminance far outweighs this slight loss. In photography, it can be made good by employing a film with a higher $\gamma$.

Although it is essential that the properties and possibilities of the image intensifier be fully investigated in the laboratory by means of "phantom tests" (see article II), its merits from the medical point of view can be determined only in actual medical practice. Such practical tests are being carried out in a number of places, e.g. in the Philips Health Centre at Eindhoven under Professor Burger and Dr. Feddema 2), and in Maastricht by Dr. van der Plaats 3).

Without particularizing unduly, we may quote the following examples of the usefulness of the image intensifier from these investigations (see article V).

In chest fluoroscopy, the intensifier gives good results with only one tenth of the normal X-ray dose. Apart from the fact that the resolution is at least as good under these conditions as in the direct image, the image intensifier enables the subject to be examined in a moderately lit room and without any preliminary adaptation of the eyes.

The intensifier is eminently suited for locating foreign bodies (e.g. metal particles), and for the routine examination of the setting of bone fractures. For the examination of an oesophagus, stomach or colon into which contrast medium has been introduced, the investigation is considerably facilitated by the image intensifier.

An important use of the image intensifier is as an aid to visual positioning before the taking of an ordinary, full-size radiograph (spot film technique).

Medical experience has shown that in fluoroscopy, better results are obtained with, than without the image intensifier, especially in circumstances where the relatively small size of the field, i.e. 13 cm in diameter, is not a handicap.

As applied to fluorography, that is, photography of the viewing screen of the intensifier on film with a camera, the medical uses of the intensifier may be divided into two categories:
1) The taking of still photographs, singly or in series.
2) X-ray cinematography.

A great deal of information concerning both these uses has already been collected. It is found that the quality of a photograph taken with the image intensifier on fine-grain 35 mm film is very much the same as that of an ordinary full-size radiograph, although, with a suitable optical system, the X-ray dose required per photograph is a factor of 2-3 smaller than in full-size radiography. With regard to X-ray cinematography, it is enough to say that even with quite a long film, the X-ray dose is not heavy enough to endanger the patient; hence photographic X-ray examination can now be employed in physiological, as well as anatomical studies.

Briefly, then, we may safely say that the present image intensifier has demonstrated its value in many medical applications. However, it is still far from perfect. One of the practical improvements still required from the medical point of view is a larger image field. Moreover, the methods of presenting the image to the observer also require attention; this is important not only in fluoroscopy, but also from the point of view of cinematography. Another problem is how best to convey all the information in the film strip to the observer.

Finally, it should be pointed out that the image intensifier is also useful in industrial radiography. The relatively brighter image produced permits the visual examination of much thicker objects than has been possible hitherto. One or two examples are given in article VI.

II. THE PERCEPTION OF SMALL OBJECT-Detail

by T. TOL and W. J. OOSTERKAMP.

In X-ray diagnosis, the principal aim is to obtain the desired information concerning the organ examined, with the smallest practicable X-ray dose to the patient. In general, direct visual examination of the fluorescent image involves a very much larger dose to the patient than the taking
of a single radiograph: in fluoroscopy the radiologist requires a certain amount of time to examine all the details of the image properly, whereas in radiography the time during which the patient is irradiated, is relatively short, and the radiologist has ample opportunity to study the film when once it is developed. On the other hand, a radiograph provides the radiologist with only one instantaneous picture and therefore tells him nothing about the condition of the particular organ at different moments; such information is important when moving organs or an unrepeatable effect, say, the injection of contrast medium, are to be observed. Accordingly, the relatively larger X-ray doses associated with fluoroscopy give, in general, more information. Both methods, the visual and the photographic, are still in use in X-ray diagnosis; they are complementary. We shall now consider in how far the two can be improved by employing an image intensifier; this involves investigating both theoretically and practically the minimum limits of contrast and detail that can be observed for a given dose in fluoroscopy and radiography, with and without the image intensifier.

**Theoretical limit of detail perception**

As stated in an earlier article 1), the perception of small object-detail is limited, according to Rose 2) and Sturm and Morgan 3), by the fluctuations or noise in the number of quanta involved in the observation of the particular object-detail. In fluoroscopy, for example, such detail cannot be resolved unless the difference in luminance between it and the surroundings exceeds the natural luminance fluctuation. With a radiograph, a similar argument holds good for the local fluctuations in photographic density owing to the finite size and varying concentration of the silver grains in the picture.

The magnitude of the resultant fluctuations is governed mainly by the particular stage of the image transmission at which the average number of quanta or particles, \( \bar{N} \), is smallest (\( \bar{N}_{\text{min}} \)). The standard deviation of the actual values of \( N_{\text{min}} \) is \( \sqrt{N_{\text{min}}} \). The contrast between two zones of different luminance, \( I_1 \) and \( I_2 \), may be defined as:

\[
C = \frac{I_1 - I_2}{I_1}.
\]

The fluctuations in luminance produce contrasts determined by \( I_1 \propto N_{\text{min}} \) and \( I_2 \propto N_{\text{min}} - \sqrt{N_{\text{min}}} \); hence \( C_{\text{fluct}} = 1/\sqrt{N_{\text{min}}} \). The minimum contrast clearly perceptible despite these fluctuations is therefore \( C_{\text{min}} = k/\sqrt{N_{\text{min}}} \), where \( k \) is greater than unity; it will be shown from the experimental results that the actual value of \( k \) is roughly 3. Given \( N_{\text{min}} \), then, it is possible to calculate this minimum contrast, and also, since \( N \) is proportional to the area of the detail observed, the minimum perceptible contrast as a function of the detail diameter (\( d \)). Here we have, then, a theoretical, quantitative limit on the detail perception. If \( C_{\text{min}} \) is plotted against \( d \) on logarithmic co-ordinates the resulting curves are straight lines.

**Numbers of quanta involved in the different stages of image transmission**

The numbers of quanta involved in the different image-stages in fluoroscopy with, and without the image intensifier are shown diagrammatically in fig. 1. The integration time of the eye, that is, the time during which the eye is able to co-ordinate a certain number of light quanta into a single light-impression, is assumed to be 0.2 sec. 2)

In fluoroscopy without the image intensifier, only a very small fraction (roughly 0.02%) of the light from the screen enters the pupil of the eye. In the complete image transmission chain, then, it is at the retina that the number of quanta per image-element is smallest; the screen must absorb 100 X-ray quanta to produce one effective light quantum on the retina. Hence the perception of detail is fundamentally limited by the relative fluctuations in the number of quanta effectively absorbed by the retina.

In fluoroscopy with the image intensifier, however, the number of light quanta is so increased by the 1000 times luminance intensification, as to exceed the number of X-ray quanta absorbed; here, then, perception of detail is limited by the number of absorbed X-ray quanta.

The smallest numbers of quanta are then a factor of 40 larger, and the relative fluctuations a factor of \( \sqrt{40} \approx 6 \times \) smaller than in fluoroscopy without the image intensifier; the theoretical minimum perceptible contrast (for a given detail size) is therefore likewise smaller by a factor of 6.

If the fluctuations in the number of X-ray quanta could be neglected, the factor by which the minimum perceptible contrast is reduced by the 1000 \( \times \) luminance intensification would be very much larger 4). In fact, such an improvement would be

---

obtained if the light from the screen were generated, not by X-rays, but by a very much larger number of relatively low-energy quanta.

The number of quanta for miniature radiography with and without the image intensifier are shown diagrammatically in fig. 2. Here, the time factor is not determined by the fixed period already referred to (0.2 sec), but depends upon the exposure time, since the photographic emulsion stores all the radiation imparted to it. However, the integration time of the eye is involved in the actual examination of the radiograph (last two points in fig. 2).

The radiograph (without image intensifier) refer-

<table>
<thead>
<tr>
<th>Stage of image transmission</th>
<th>Particles</th>
<th>$\bar{N}$ without I.I.</th>
<th>$\bar{N}$ with I.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>On object</td>
<td>X-ray quanta</td>
<td>$2.5 \times 10^5$</td>
<td>$2.5 \times 10^5$</td>
</tr>
<tr>
<td>Transmitted by object</td>
<td>&quot;</td>
<td>$5 \times 10^2$</td>
<td>$5 \times 10^2$</td>
</tr>
<tr>
<td>Absorbed by fluorescent screen</td>
<td>&quot;</td>
<td>$4 \times 10^2$</td>
<td>$1.2 \times 10^2$</td>
</tr>
<tr>
<td>Emitted by fluorescent screen</td>
<td>Light quanta</td>
<td>$4.5 \times 10^6$</td>
<td>$6 \times 10^5$</td>
</tr>
<tr>
<td>Emitted by photo-cathode</td>
<td>Electrons</td>
<td>&quot;</td>
<td>$6 \times 10^4$</td>
</tr>
<tr>
<td>Emitted by viewing screen</td>
<td>Light quanta</td>
<td>&quot;</td>
<td>$6 \times 10^7$</td>
</tr>
<tr>
<td>In eye pupil</td>
<td>&quot;</td>
<td>$1.2 \times 10^3$</td>
<td>$4 \times 10^5$</td>
</tr>
<tr>
<td>Absorbed by retina</td>
<td>&quot;</td>
<td>$3 \times 10^3$</td>
<td>$4 \times 10^3$</td>
</tr>
</tbody>
</table>

Fig. 1. Average number of quanta or particles ($\bar{N}$), for a round detail 2 mm in diameter, effective for 0.2 sec, in different image-stages in fluoroscopy without the image intensifier (dotted line) and with it (full line). Object: 8 cm "Philite" + stationary scatter grid. Distance to focus 90 cm. 40 kV, 1 mA.

<table>
<thead>
<tr>
<th>Stage of image transmission</th>
<th>Particles</th>
<th>$\bar{N}$ without I.I.</th>
<th>$\bar{N}$ with I.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>On object</td>
<td>X-ray quanta</td>
<td>$2.2 \times 10^8$</td>
<td>$7.5 \times 10^5$</td>
</tr>
<tr>
<td>Transmitted by object</td>
<td>&quot;</td>
<td>$4.5 \times 10^6$</td>
<td>$1.5 \times 10^4$</td>
</tr>
<tr>
<td>Absorbed by fluorescent screen</td>
<td>&quot;</td>
<td>$3.5 \times 10^6$</td>
<td>$3.5 \times 10^3$</td>
</tr>
<tr>
<td>Emitted by fluorescent screen</td>
<td>Light quanta</td>
<td>$4.0 \times 10^8$</td>
<td>$1.8 \times 10^6$</td>
</tr>
<tr>
<td>Emitted by photo-cathode</td>
<td>Electrons</td>
<td>&quot;</td>
<td>$1.8 \times 10^5$</td>
</tr>
<tr>
<td>Emitted by viewing screen</td>
<td>Light quanta</td>
<td>&quot;</td>
<td>$1.8 \times 10^8$</td>
</tr>
<tr>
<td>On photographic emulsion</td>
<td>&quot;</td>
<td>$1.6 \times 10^7$</td>
<td>$10^7$</td>
</tr>
<tr>
<td>In photographic emulsion</td>
<td>Blackened grains</td>
<td>$5 \times 10^4$</td>
<td>$6 \times 10^4$</td>
</tr>
<tr>
<td>In eye pupil</td>
<td>Light quanta</td>
<td>per 0.2 sec</td>
<td>$1.5 \times 10^7$</td>
</tr>
<tr>
<td>Absorbed by retina</td>
<td>&quot;</td>
<td>$2.5 \times 10^4$</td>
<td>$2.5 \times 10^5$</td>
</tr>
</tbody>
</table>

Fig. 2. Average numbers of quanta or particles ($\bar{N}$), per detail 2 mm in diameter, effective in miniature radiography without the image intensifier (dotted line) and with it (full line).

Without the image intensifier: Fluorescent screen photographed with a mirror camera, $f/d = 1$, on 70 mm film ("Scopix Ortho"). Total reduction 7×. Exposure 40 kV, 180 mA sec.

With the image intensifier: Viewing screen of the image intensifier photographed through an optical system (two lenses: $f/d = 1.5, f = 55$ mm, and $f/d = 2.0, f = 75$ mm) on 35-mm film (Agfa "Fluorapid"). Total reduction 6.5× (that is, reduction in image intensifier $9 \times$, optical magnification 1.4×). Exposure 40 kV, 0.6 mA sec.

Object: 8 cm "Philite" + stationary scatter grid. Distance to focus 90 cm.
red to in fig. 2 was taken with the aid of a fast mirror camera. Owing to the low aperture ratio at the object side of this system, only a small fraction (roughly 0.4%) of the light from the fluorescent screen is photographically effective. Roughly 70 X-ray quanta must be absorbed by the fluorescent screen to produce enough light to cause the subsequent development of one silver grain in the film emulsion; hence the number of silver grains determines the theoretical limit of contrast. The precise relationship between the density fluctuations and the relative standard fluctuation in the number of grains per object-detail is not known. It is probably associated with the contrast (γ) of the emulsion. However, it is reasonable to suppose that unless the density is very large, its fluctuations will decrease as the number of grains per individual detail increases (that is, as the size of the grains decreases).

In radiography with the image-intensifier, as referred to in fig. 2, a roughly 1.4 times enlarged photograph of the viewing screen is taken on the film with the aid of an optical system. As in fluoroscopy, the increase in luminance compensates for the loss of light in the optical system. Hence each X-ray quantum gives rise to several silver grains (roughly 20) in the developed photographic emulsion. As in fluoroscopy with the image intensifier, then, the number of X-ray quanta absorbed by the initial fluorescent screen of the intensifier determines the theoretical limit of contrast.

With full size radiography, almost all the light from the two screens (so-called “intensifying screens”) is effective, because the film is in actual contact with the screens. Measurements of the numbers of light quanta involved have shown that the smallest number (that is, the fluctuations) is governed in this case by the number of X-ray quanta absorbed by the screens.

Given the value of $k$, then, $C_{\text{min}} = k/\gamma N_{\text{min}}$ can be calculated from the measured numbers of quanta, for object detail of any size.

Experimental results

The next step is to determine by experiment to what extent the theoretically established threshold of perception is approached in fact.

Such measurements can be carried out with the aid of an X-ray phantom, as described in an earlier issue of this Review 5).

The present measurements were carried out with a modified phantom provided by Prof. G. C. E. Burger. In principle, it comprises a number of plates of

“Philite” (a phenol resin) one of which, known as the “phantom plate”, contains several cylindrical holes of different diameters and depths. The differences in depth of the holes correspond to differences in absorption, and therefore to differences in intensity of the X-radiation passing through the

---

plate (frequently but misleadingly called “X-ray contrast”). A number of observers then indicate, either during fluoroscopy or on a radiograph of the phantom, which of the holes they are just able to see. Curves plotted from the depth and diameter of these just perceptible holes, as shown in figures 3 and 4, thus represent the boundary between perceptible and imperceptible contrast ($C_{\text{exp}}$) plotted against the diameter of the object detail.

Comparison of experimental and theoretical results

It is evident from figures 3 and 4 that in fact the measured curves are not straight, as predicted from the theory. However, the fluctuation theory holds good only for an ideal apparatus; it takes no account of imperfections, such as the invariable blurring of the image on fluorescent screens, the loss of contrast in the image intensifier, and the limited contrast sensitivity of the eye.

In most fluorescent screens, for example, the blurring exceeds 0.4 mm, and therefore precludes the resolution of detail below a certain size, depending upon the contrast.

What is the situation with regard to detail which is not unduly small, that is, say, 2 mm in diameter? Measurements to determine, for various fluoroscopic and radiographic methods, by what factor the experimental lower limit of perceptible contrast ($C_{\text{exp}}$) exceeds the fluctuation contrast ($C_{\text{fluct}}$) show that this factor is not constant (see last column of Table I). The extreme values occur in image intensifier fluoroscopy with X-rays of low intensity ($2.2$) and image intensifier radiography on film of low sensitivity ($11.5$); an intermediate value ($4.5$) is found for image intensifier radiography on sensitive film. The smaller the number of X-ray quanta employed (say, in image intensifier radiography on sensitive film), the higher $C_{\text{fluct}}$ and the smaller the ratio $C_{\text{exp}}/C_{\text{fluct}}$. A ratio $C_{\text{exp}}/C_{\text{fluct}} = 4.5$ must be very close to the optimum. The lowest ratio, viz. 2.2, occurs in image intensifier fluoroscopy with X-rays of low intensity. However, it does not necessarily follow that $k = 2.2$ or, more precisely, that an X-ray contrast equal to 2.2 times the average relative standard fluctuation is invariably perceptible. The probability of a moment with a low fluctuation level increases with the period of observation, so that relatively longer examination may enable the observer to perceive a contrast lower than that corresponding to $C_{\text{min}} = k/\sqrt{N_{\text{min}}}$.

In view of these arguments, we consider that $k = 3$ is a good approximation to the optimum value.

Table I. Minimum contrast observed ($C_{\text{exp}}$), minimum number of quanta ($N_{\text{min}}$), the fluctuation contrast computed from it ($C_{\text{fluct}}$), and the ratio $C_{\text{exp}}/C_{\text{fluct}}$, for the observation of a detail 2 mm in diameter in a “Philite” phantom 8 cm thick, by different methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>kV</th>
<th>mA or mA sec</th>
<th>$C_{\text{exp}}$ %</th>
<th>$N_{\text{min}}$</th>
<th>$C_{\text{fluct}}$ %</th>
<th>$C_{\text{exp}}/C_{\text{fluct}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluoroscopy without Image Intensifier</td>
<td>75</td>
<td>4</td>
<td>8</td>
<td>$1.2 \times 10^6$</td>
<td>2.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Fluoroscopy with Image Intensifier</td>
<td>67</td>
<td>0.2</td>
<td>4.4</td>
<td>$2.5 \times 10^6$</td>
<td>2.9</td>
<td>2.2</td>
</tr>
<tr>
<td>Radiography with Image Intensifier on “Fluorapid” 35-mm film, Optical system $d/f = 1 : 4.5$</td>
<td>67</td>
<td>0.2</td>
<td>4</td>
<td>$12.5 \times 10^6$</td>
<td>0.89</td>
<td>4.5</td>
</tr>
<tr>
<td>Miniature radiography without Image Intensifier; mirror camera</td>
<td>67</td>
<td>14</td>
<td>3.25</td>
<td>$30 \times 10^6$</td>
<td>0.58</td>
<td>5.6</td>
</tr>
<tr>
<td>Fluoroscopy with Image Intensifier</td>
<td>67</td>
<td>3</td>
<td>2.8</td>
<td>$37.5 \times 10^6$</td>
<td>0.52</td>
<td>5.4</td>
</tr>
<tr>
<td>Radiography with Image Intensifier on “Micro-File” 35-mm film, Optical system $d/f = 1 : 2$</td>
<td>67</td>
<td>1.5</td>
<td>1.55</td>
<td>$100 \times 10^3$</td>
<td>0.31</td>
<td>5.0</td>
</tr>
<tr>
<td>Radiography with Image Intensifier on Pan F 35-mm film, Optical system $d/f = 1 : 4.5$</td>
<td>67</td>
<td>2</td>
<td>2.6</td>
<td>$125 \times 10^3$</td>
<td>0.28</td>
<td>9.3</td>
</tr>
<tr>
<td>Full-size radiography</td>
<td>67</td>
<td>3</td>
<td>1.5</td>
<td>$450 \times 10^3$</td>
<td>0.15</td>
<td>10.0</td>
</tr>
<tr>
<td>Radiography with Image Intensifier on “Micro-File” 35-mm film, Optical system $d/f = 1 : 4.5$</td>
<td>67</td>
<td>8</td>
<td>1.6</td>
<td>$540 \times 10^3$</td>
<td>0.14</td>
<td>11.5</td>
</tr>
</tbody>
</table>

For the full-size radiograph and for the image intensifier radiograph on fine-grain film, the experimental values of $C_{\text{exp}}/C_{\text{fluct}}$ are relatively high ($>10$). Here, then, the perception of a round detail 2 mm in diameter is virtually independent of the quanta fluctuations, but is governed almost exclusively by imperfections in the apparatus. Although difficult to eliminate such imperfections are not of a fundamental nature.

Direct perception of the quanta fluctuations

Confirmation of the above arguments is obtained by the fact that the X-ray quanta fluctuations can be observed direct in the X-ray image. In image intensifier fluoroscopy with X-rays of not unduly high intensity, the image exhibits a certain
amount of "noise". This noise is closely connected with the relatively small number of X-ray quanta involved in the forming of the luminous image. The higher the intensification factor of the image intensifier, the more readily are the fluctuations perceived by the observer, especially when the viewing screen is observed through an optical system of high magnification.

As already explained, in photographs taken with an image intensifier we generally find an appreciable difference between the experimental threshold of perception and the theoretical threshold determined by the quanta fluctuations (high ratio $C_{exp}/C_{fluct}$). Hence it is unlikely that the fluctuations will be perceptible in such radiographs. However, they are seen distinctly in image intensifier radiographs taken with a relatively very much smaller amount of X-radiation but a faster optical system. Fig. 5 gives an example. Here we have four reproductions of parts of image intensifier photographs. They differ only in respect of the amount of X-radiation per photograph, which is in the ratio $a:b:c:d = 1:5:32:160$; this variation was made possible by varying the stop of the lens system.

It can be seen that the photographs differ quite appreciably. Photograph $a$, for example, taken with the maximum lens aperture of the system, shows a coarser structure than the others. The high intensification produced by the intensifier, combined with the use of the maximum stop, enabled this photograph to be taken with a relatively small number of X-ray quanta; the very noticeable local fluctuations in density arise from the fact that each X-ray quantum blackens an individual cluster of grains in the emulsion. Photograph $d$, taken with a very much smaller aperture, necessitated a very much larger number of X-ray quanta to expose the grains. Because the number of X-ray quanta and hence that of grain clusters in $a$ is very much smaller, the relative statistical fluctuation in the number of individual aggregates is more noticeable. Hence the grain distribution of photograph $a$ is appreciably less uniform than that of photographs $c$ and $d$. A fine rose on a watering can sprinkles more evenly than a bucket.

**Fundamental and practical advantages of the image intensifier**

The advantages of the image intensifier as applied to fluoroscopy and radiography will be evident from fig. 1 and fig. 2. Without the intensifier, only a small proportion of the X-ray quanta are absorbed by the screen, on an average, in fact, only 1 in every 100, is effective; hence the relative value of the fluctuations is roughly 10 times the fluctuation inherent in the quanta absorbed. Accordingly, the detail perception is then fundamentally inferior to that obtained with the image intensifier, which makes all the X-ray quanta absorbed effective. Here, every quantum of radiation absorbed by the screen gives rise to a threefold stimulus in the retina, or exposes several silver grains in the film (e.g. 20—30), the precise number depending upon the type of film and the aperture ratio of the optical system.

Certain conclusions regarding the observation of not unduly small detail (one or two mm) with low contrast may be drawn from the values of $C_{exp}/C_{fluct}$ established.

In fluoroscopy with the image intensifier, a very close approximation to the theoretical threshold of perception is reached experimentally; hence we cannot expect to gain very much from technical improvements when employing the conventional examination procedure.

Again, in image intensifier radiographs taken on 35-mm film with the aid of a fast optical system, the threshold of perceptibility is governed, in practice, by the fluctuations of the X-ray quanta. Consequently all that can be done to obtain more information in such a case is to increase the X-ray dose: a film of finer-grain may then be used. Ultimately, then, a limit is imposed by the imperfections of the apparatus.

Finally, let us consider one or two values taken
from figures 3 and 4 to demonstrate the advantages of the image intensifier technique. It is seen that the X-ray dose to observe a given threshold-contrast with the image intensifier is only 1/40 of that required in conventional fluoroscopy without the intensifier. The dose to take an image intensifier photograph on 35-mm film is a factor of 70 smaller than that required for a 70-mm miniature radiograph taken without the image intensifier, the film-sensitivity being the same in both cases and the X-ray images being reproduced roughly 7 times smaller on the film. There is very little difference in detail perception as between the two photographs. This is very important from the point of view of the filming of moving organs with the aid of the image intensifier.

With a very fine-grain film, the image intensifier enables us to take 35-mm photographs of a quality comparable with that of a full-size radiograph; moreover, if a fast optical system is employed, the dose required is several times smaller than in conventional radiography.

### III. OPTICAL AIDS FOR THE IMAGE INTENSIFIER

by P. M. van Alphen

It is neither necessary nor customary to employ optical aids in the examination of an X-ray image on a conventional fluorescent screen. However, to resolve the detail of the image, the eye must be properly adapted to the low luminance level of the screen.

With the image intensifier, however, precisely the reverse holds good. Although bright enough to be examined under ordinary room lighting, the visible image formed in the intensifier is so reduced by the electron optical system that optical instruments are required to enable the details to be perceived.

The image intensifier therefore necessitates a different approach, not only to fluoroscopy, but also to photographic work. The mirror camera, although eminently suitable for photographing the conventional low-luminance X-ray image, by virtue of its high aperture ratio, cannot be used without modification to photograph the relatively small image in the intensifier.

The problem of magnifying small objects for observation or photography is of course not new and many ways of doing it are known. The magnifying glass, microscope, telescope, camera, etc. are well-known examples. It is however, desirable to review the general requirements to be imposed on an optical system for use with the image intensifier. In so doing, we shall also discuss various designs examined during the development of the Philips image intensifier.

Quantities and concepts used in photometry

As an introduction to the above-mentioned discussion, let us consider the quantities employed as measures of light, quantities which are frequently misinterpreted.

A light source radiates energy; that part of this radiant energy whose wavelength is within the visible spectrum forms the luminous flux (unit: the lumen).

Luminous flux, then, is the light proceeding from the entire surface of the light source in all directions. For certain problems it is necessary to determine the distribution of this flux in space; in other cases, we are more concerned with the flux-distribution as between different points on the surface of a light source or an illuminated surface.

In many cases we require the quantity luminous flux (throughout the solid angle) per unit area; in other cases we wish to know the luminous flux (from the whole of a surface) in a given direction that is, per unit solid angle. We may also go a step further and consider the luminous flux emitted by a given surface in a certain direction. Thus the overall luminous flux output may be divided according to area or direction, or area and direction. The quantities thus defined have acquired individual names, i.e. illumination level (or briefly illumination), luminous intensity and luminance (or brightness), respectively. They are shown diagrammatically in fig. 1 and Table I.

How, then, are these quantities affected by such optical elements as lenses and mirrors? Since optical systems do not generate light, they do not increase the overall luminous flux, which therefore remains constant, apart from some absorption in the system. However, the illumination and luminous intensity do not necessarily remain constant. The luminous flux can be concentrated, with the aid of a lens or mirror, upon certain points (or areas), or in certain directions (solid angles). This concentration may produce substantial changes in both luminous