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Quality Control and Assurance in Diagnostic Radiology

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INTRODUCTORY LECTURES

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AIM OF QUALITY ASSURANCE IN THE MEDICAL CARE

The importance of quality assurance (QA) in many aspects of daily life is without question. Measures for QA are performed

- to reduce the life risk factors in the technical and civilized world
- and to ensure workable consumer protection regulations.

As medicine and medical practices today play a prominent role in public opinion, the call for a control in this field increases.

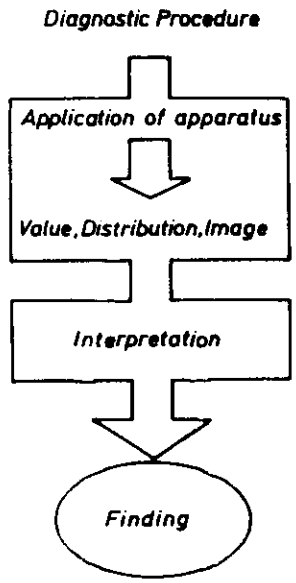
The term quality control (QC), which has its origin in industrial production, is very often rejected and should therefore be substituted by the term QA, although one should keep in mind that QA always includes a form of QC.
The rapid development of QA has shown, when looking back on the words of the late epidemiologist M. Pflanz, who 10 years ago wrote:

"In a restricted manner there exist codes of quality judgement. In general is the attainment and judgement of quality more a matter of intuition and good sense combined with the experience of the investigator" (Pflanz 1973).
That in the past a change has occurred, can be witnessed in many fields of medicine. However it should be clear, that the methods of QA are quite different in the different medical disciplines.
For example, the QA program proposed by the German Society of Surgery has the following aims:

Quality assurance and improvement
- through detailed information concerning ones own surgical work
- by extern comparison with other surgical departments
- by acceptance of extern consultation and assistence in the analysis of ones own work and the realization of the consequences
- by obtaining statistical information in answering current surgical questions

In order to realize these aims a committee for QA was formed, which used the experience of a pilot study to develop special programs. The programs rely on free participationship.
When looking at the aims demonstrated it is obvious, that in the meaning of Pflanz, only in a very restricted manner quantitative values or critiria are considered. Only in one point statistical material is mentioned.
I wish to restrict myself to the main theme of this workshop. The thoughts presented concern QA in diagnostic procedures (DP). In doing so, I wish to elaborate on general points of view and to discuss the possiblility of obtaining quantitative criteria for QA.
First it is necessary to look at a DP in general.

Fig. 1: Diagnostic Procedure, General



The aim of a DP is to obtain a diagnostic finding. Within a DP various kinds of instruments may be used.
The instruments deliver relevant medical information in the form of values (i.e. blood pressure), value distributions (i.e. ECG) or images (i.e. X-ray images). This information requires the interpretation of a physician, who makes his diagnostic finding.

In the case of X-ray diagnostics, a DP may be represented as shown in Fig. 2

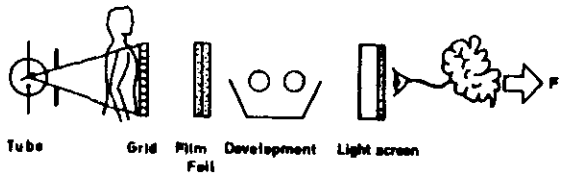


Fig. 2: Diagnostic procedure in Diagnostic Radiology

During the procedure the schematically shown apparatus are used (tube, grid, film, screen, film-processor, light screen). From one or more DPs, after compilation and further interpretation by a physician, the diagnosis is fixed. The diagnosis is the statement, whether or not a certain disease is present.

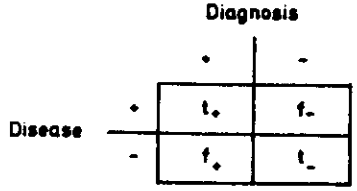
The decision making process can be performed either deterministically by a decision tree procedure or statistically, for example using Bayes theorem. In the last mentioned case one arrives at probability statements. The decision matrix used in the statistical procedure may be thought of as an expression of the total medical experience gained untill now.
The QA discussed here concerns the endproduct of a DP, i.e. the diagnosis.
However in order to compare DPs, it is necessary, to extend the considerations also to other aspects of procedures. In practice quality is not always the main factor, when selecting a procedure for a certain aim.
As already mentioned, within a DP technical instruments of different kinds are used. Experience has shown, that it is useful to judge instruments independently from the special DP. The same instrument may be used in various kinds of DPs. It is therefore necessary to know, whether a technical instrument is able to perform the task required within a certain DP. Therefore the aspects mentioned in Fig. 3 apply to instruments as well as to the procedures themselves.

QUALITY
SAFETY
PRACTICABILITY

APPARATUS and PROCEDURE

Fig. 3: General aspects for the judgement of instruments and procedures

What are then the considerations, that will lead us to a judgement of quality of a DP?
Let us imagine, we wish to test a routine procedure, which will give us information about the existence of a disease. There may also exist a comparative DP, that will give us an exact answer, whether or not a disease is present. We examine with both procedures a certain group of people, in which the disease with a certain frequency is present. A comparison of the results obtained with both procedures indicates 4 possibilities, i.e. the group of people examined is divided into 4 subgroups:



Sensitivity: $P_+ = \frac{t_+}{t_+ + f_-}$

Specificity: $P_- = \frac{t_-}{t_- + f_+}$

Failure rate: $P_0 = \frac{n_0}{n}$

Fig. 4: Quantities to characterize the quality of a DP

t_+ true positive
t_- true negative
f_+ false positive
f_- false negative

From the number of people in each subgroup two important quality criteria (P_+ and P_-) may be derived. Where
P_+ describes the relation of t_+ to the total number of positve cases
P_- describes the relation of t_- to the total number of negative cases
P_+ and P_- are two independent variables, which may be labelled as VALIDITY criteria. Both reach the value 1, if there are no false determined cases.
Depending on the aim of a DP, a high P_+ or a high P_- value is expected:
In screening studies, high P_+ values are necessary to avoid overlooking sick persons. P_- needs not to be so high, because further examinations will lead to the exact diagnosis.
In clinical diagnostics other points of view are important. For example in life and death diseases, which have good effect to therapy, P_+ must be high.
With less dangerous diseases, with little effect of therapy, P_- should be high, while P_+ may be lower.
As a further criteria the failure rate of a DP should be mentioned. That is the frequency of cases, in which a procedure delivers no result. These cases may happen due to a

failure of an instrument, but in many cases, there also exists a failure due to the patient, when for anatomical or physiological reasons, no result may be obtained.
The validity criteria have - with respect to their use in practice - two main disadvantages

- they rely on the existence of an exact comparative procedure
- they are only valid for comparable patient or proband groups.

In spite of these disadvantages, they are widely accepted in the judgement of procedures and increasing use of them should be made in the future.
A special application of validation methods in radiography are model studies (Barett 1982) to validate the recognization ability of human image observers. Because clinical photographs are in most cases unsatisfactory for such investigations, test images may be produced with a gamma camera of a homogenious phantom filled with a radioactive liquid. Anomalies in the test images may be produced by introducing non active bodies into the phantom. In this way series of test images with and without anomalies in any shape and size desired may be produced. Furthermore the photon numbers used for imaging can be varied.

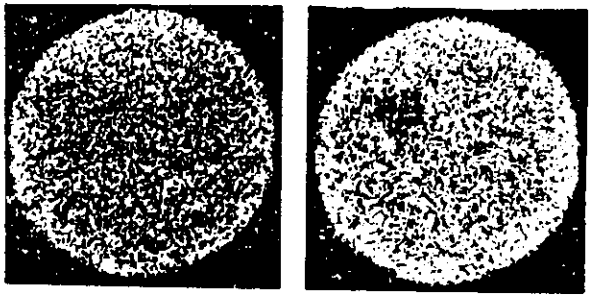


Fig. 5: Is there any information present?

The series of test images (two of them are shown in Fig. 5) were presented to an observer with the question, in which image he recongnizes an anomaly. The evaluation of the test,

i.e. the comparison of the decision with the actual situation, gives one value for P_+ and for P_- respectively.
The evaluation procedure of the test images can be varied by introducing a scale of assurance of the findings:

The anomaly is

- (1) with certainty not present
- (2) probably not present
- (3) possibly not present
- (4) possibly present
- (5) probably present
- (6) with certainty present

By judging all images on the basis of the different steps of assurance one after the other, different P_+ and P_- values are obtained. By putting both values as coordinates into a diagram, it can be seen that the determined points lie on a smooth curve. This curve is called "receiver-operating characteristic-curve (ROC-curve)".

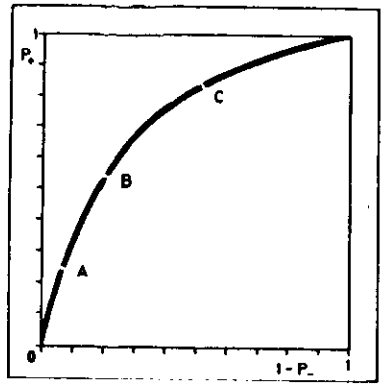


Fig. 6: ROC-curve. The points A, B and C represented different readings

Different observers in general have a different ROC-curve. But in the case of normal visual abilities these curves will not differ very much from each other.

The mentioned procedure may be transferred to other image evaluating systems. In this case each system can have a very different ROC-curve.

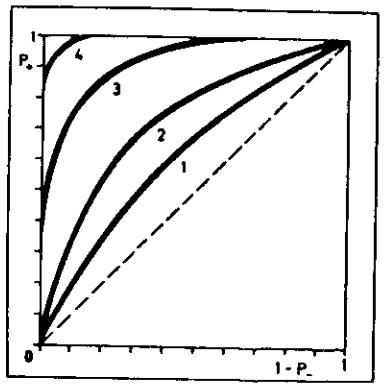


Fig. 7: ROC-curves of different imaging systems

These curves offer a possibility for a comparative judgment of image evaluating systems. An ideal curve has a 90 degree angle. Suitable procedures should approach such a curve very closely.
Untill now we have discussed mainly the QA of DPs. The criteria obtained can be summarized as follows:

Fig. 8:

Quality criteria

apparatus	procedure
reliability	validity
correctness precision	specificity sensitivity failure rate

In Fig. 8 also quality criteria for the judgement of technical instruments are given, as far as a result in the form of a measured value is obtained. The criteria concerned are the correctness and the precision. Both criteria can be summed up under the main beading RELIABILITY.

The correctness results from the systematic error, i.e. from the deviation between the real value and the mean value calculated from repeated measurements. The smaller this deviation, the larger is the correctness. Because there is no usual mathematical definition for correctness, it is more proper to speak of the systematic error.
The precision derives from the distribution of random errors. This distribution in many cases is represented by a Gaussian curve. A measure of precision is commonly the standard deviation or a multiple factor thereof. Of course the information of the standard deviation is not restricted to Gaussian distribution functions.
The methods used for the determination of correctness involves the application of standards. The exact value of the standard is often determined by another method (if possible a precision method).
For the determination of precision repeated measurements are performed. However, because in medicine reliability measurements are difficult and may be a burden to a patient, the use of phantoms is the best way to carry out such measurements. Phantoms thus play an important role in medical measurement techniques.
The above described reliability criteria are as mentioned only applicable to values measured by an instrument. It is on the other hand possible to transfer the criteria to instruments, which have as output value distributions. In imaging procedures the criteria are of little use, as long as they are not used for quantitative image measurements. Image criteria will be discussed further during this workshop.
Now the group of safety and practicability criteria will be considered. The safety criteria may be quantified by their risk. They can be summarized as follows:

Fig. 9:

Safety criteria

apparatus	procedure
risk - of use - in handling	risk - to patient - to personal - to the environment

The risk of DPs can be understood as the relation of the number of investigations in which an incident occurs to the total number of investigations. Also other definitions may be used to quantify risks. Especially in radiology often dose values, i.e. gonad dose values, may be used.

Risks which characterize medical instruments are
- the risk of use (e.g. risks due to defective electrical safety)
- the risk of handling (e.g. incidents due to misuse) and procedural risks consisting in danger
- to patient and personnel (e.g. by radiation burden)
- and to environment (e.g. by radioactive waste products).

As an example of risk, the radiation burden of a patient due to X-ray examinations will be considered. This concerns the question of diagnostically effective radiation in relation to the radiation, which is only a burden to the patient. For this purpose we performed calculations, in which we were specially interested in the scattered radiation originating in the patient. We used a simple model consisting of water layers of varying thickness, which were penetrated by a photon radiation field.

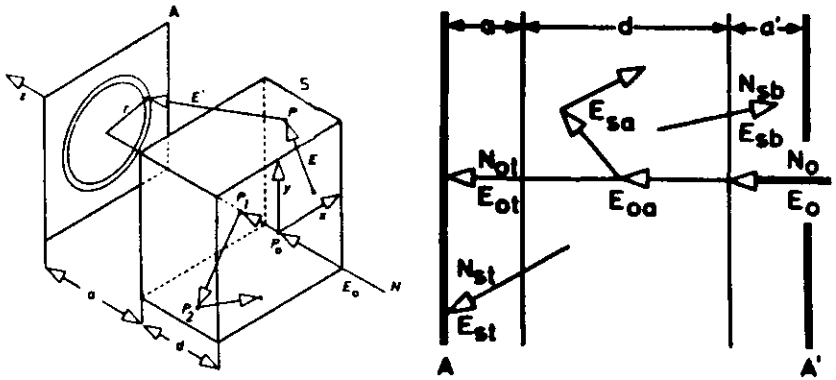


Fig. 10: Photon interactions in a water phantom

To answer our question, the primary radiation field can be reduced to a pencil beam. Using the Monte Carlo method all collision processes undergone by the photons were simulated. Collision processes considered are the Compton- and the photoeffect.

When assuming N_o photons of energy E_o which penetrate into the water layer, we have a certain number, which suffer a primary collision. The total energy deposition to the medium from these photons will be E_{oa} (o stands for primary and a for absorbed).
Another number of photons, number N_{ot}, passes through the medium without any collision. The whole energy of these photons is E_{ot} (t stands for transmitted).

The scattered photons produced in the layer can be divided into 3 groups:

1. those being absorbed in the layer (total energy E_{sa}, s stands for scattered),

2. those leaving the layer in forward directions (number N_{st}, total energy E_{st})

3. those being back-scattered (number N_{sb}, total energy E_{sb}, b stands for back-scattered)

Considering the energies, the following equation of an energy balance applies:

$$E_{oe} = N_o E_o = E_{oa} + E_{sa} + E_{ot} + E_{st} + E_{sb}$$

The incident energy splits up into 5 components. It is of special interest for the medical use of X-rays to know, how the different summands behave as a function of the incident energy E_o and the thickness of the layer d.

For radiation protection of a patient subject to X-ray examinations the behaviour of the harmful energy components $E_{oa} + E_{sa}$ is important, because these two components are absorbed in the body of a patient.
The percentage of the absorbed energy in shown in Fig. 11 for 3 phantom diameters as a function of quantum energy. Basically, the values increase rapidly with increasing thickness of the absorbing layer. Considering the dependence upon primary energy E_o, we see the rapid decrease with increasing photon energy in the region that is used in X-ray diagnosis. The advantage of high kV techniques can clearly be seen, but only with respect to the integral body dose.

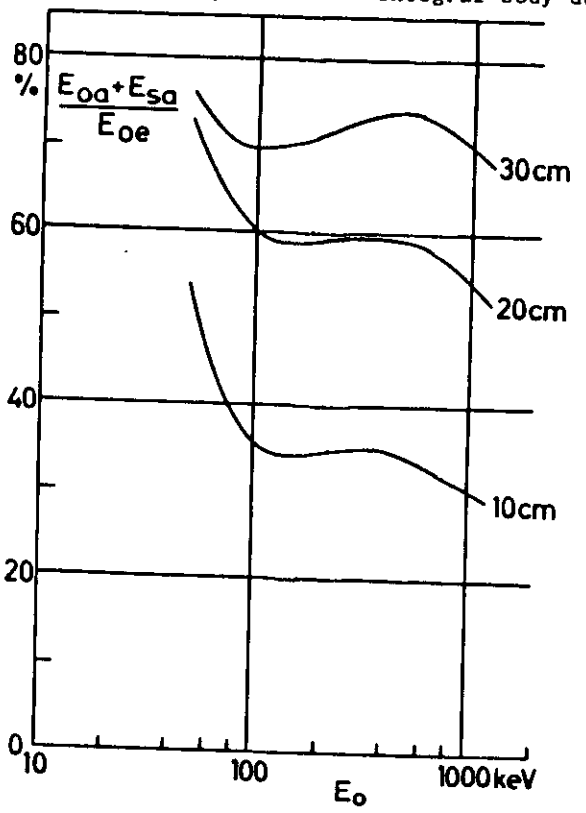


Fig. 11: Percentage of absorbed energy as a function of phantom thickness and photon energy

A further increase of X-ray voltage does not reduce the integral dose, but produces a much lower contrast in the radiograph. If using a voltage of more than 1 MeV, we see a further decrease of the integral body dose.
From the curves shown, we can calculate a ratio U_r of useful to harmful radiation energy, on the premise that forward-scattered radiation can be completely removed by a grid. When calculating this ratio without the knowledge of scattered radiation, we would use the exponential expression, where μ is the absorption coefficient for primary radiation. This leads to a value U'_r which can be expressed in terms of our energy components.

Eo keV	d cm	Ur %	Ur' %
50	5	114	46.7
50	10	18	11.3
50	20	1.4	1.0
50	30	0.12	0.10
100	5	252	72.7
100	10	49	21.6
100	20	5.2	3.2
100	30	0.86	0.56

$$U'_r = \frac{e^{-\mu d}}{1 - e^{-\mu d}} = \frac{E_{ot}}{E_{oa}+E_{sa}+E_{st}+E_{sb}}$$

$$U_r = \qquad = \frac{E_{ot}}{E_{oa}+E_{sa}}$$

Fig. 12: Relation of diagnostically useful to harmful radiation

Considering that part of the scattered photons leaving the scattering medium, we have to neglect the two summands E_{st} and E_{sb}, so that we get the correct value U_r.
A numerical comparison of the values U_r and U'_r for 50 and 100 keV photons and d values from 5 to 30 cm is also in given in Fig. 12. U_r and U'_r decrease very rapidly with increasing thickness d. The exact values are higher than the values U'_r calculated for primary radiation alone. But we can see, that for thick layers, both values will approach each other. The result of such calculations will give us a better understanding of the influence of scattered radiation to the risk to patients in X-ray examinations.

As the last point in judging DPs, practicability has to be mentioned. Here also one can separate apparatus and procedure criteria.

Fig. 13:

Practicability criteria

apparatus	procedure
handling space requirement susceptibility of defects cost	personel load work load time factor cost

This uncompleted list of possible judgement criteria ends in both cases with the necessary financial considerations. Although I mentioned practicability as the last point, it is this point which in practice often is the most important and which decides the procedure with which a patient in each case is treated. This occurs even in spite of the fact that not all quality criteria are optimally fulfilled.

In summary it must be emphasized, that the question of QA in medical diagnostics should not be treated as an isolated problem, but also considerations should be given to safety and practicability. This is especially true in those cases, where one diagnostic method is in concurrence with others. For resons of safety it may be useful to substitute radiological procedures by ultrasonic or thermographic procedures, although the validity criteria for these are not optimal. In any case there is still much work to be done in the field of QA. I hope that with my above representation I have shown a possible path to the systematic realization of this task.

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QUALITY ASSURANCE PROGRAMMES IN DIAGNOSTIC RADIOLOGY: AN IMPORTANT FACTOR IN IMPROVING HEALTH CARE

1. Introduction

Quality assurance (QA) in diagnostic radiology has a history no longer than a few years, although efforts to improve the quality of the diagnostic image have accompanied the development of radiology since its beginnings.

WHO initiated its programme in this area with a workshop held in Neuherberg in December 1980, with the kind financial support of the Government of the Federal Republic of Germany. The report of this workshop, now published as a guide (1) for the development of QA programmes, constitutes the first step in the implementation of this activity, while the present training workshop is a second and more practical stage, aimed at giving practical training to a number of medical and health physicists from 16 countries in how to initiate or expand QA in diagnostic radiology in their countries.

A pertinent question which could be asked is why WHO is interested in starting QA programmes in diagnostic radiology at a time when the major efforts of the Organization are directed towards the better coverage of populations with health, and therefore radiological, services. The answers to this question will be given in this paper but three major reasons can be mentioned from the beginning as essential, namely:

cost containment

reduction in radiation exposure of the patient

improvement of the diagnostic imaging

All three are valid for the devoloping as well as for the industrialized world and justify the WHO programme on quality assurance, not only in the field of diagnostic radiology but also in nuclear medicine, being conducted in parallel to that in radiotherapy, and which needs further consideration and expansion to cover new technologies such as ultrasound.

It should be mentioned that similar programmes in the field of clinical laboratory services, biological products, pharmaceuticals, etc. have been effectively conducted by the Organization for a much longer period of time and with encouraging results.

2. Cost containment

Let's consider the principal implication of a QA programme, namely cost containment. The data available are not exhaustive and are particularly restricted to a small number of countries. Such data are related to film retakes or film wastage, both representing means of identifying the need for measuring the efficacy of QA programmes.

Trout, E.D. and collab. (2) analysed in 1973 the rejection rate of chest radiographs obtained during the coalmine black lung programme. To qualify for participation in this programme the facilities had to be certified for competence and for this reason all facilities and film readers were screened. Despite this screening, Trout et al. found that 44 % of the facilities participating in the first round had from 10 % to 40 % of the films submitted rejected as being of inadequate quality for diagnosis of pneumoconiosis. After this finding the National Institute of Occupational Health (NIOH), the certifying body, took active measures to improve the quality of chest radiographs and the rejection rate decreased, as shown below:

Period	% of radiographs unreadable
June 1973 - March 1975	2.3
March 1975 - Dec. 1975	1.4
Jan. 1976 - Sept. 1976	0.6

A preliminary evaluation of dental radiographs submitted to Pennsylvania Blue Shield by facilities asking for authorization found that 50 % of the films were inadequate to determine the efficacy of the proposed treatment, as shown by Beideman and collab. (3).

Berry and Oliver (4) in the UK have found the following results regarding the percentage of spoilt films and examinations where a spoilt film was produced:

Table 1: Spoilt films in various types of hospitals

Type of hospital	No. of films	No. of exams	percentage of spoilt films	percentage of exams with spoilt films
Teaching	17 500	4 198	4.9	12.4
District-General	4 995	1 896	8.0	21.8
Accident/emergency	7 366	3 951	6.0	13.6
Private nursing home	498	174	3.0	9.1
	30.359	10.219	5.7	18.0

The main causes of spoilt films were: exposure faults, ranging from 33 % to 87 %; positioning faults 13 % to 33 %; machine faults, approximately 14 %, and non-contributory film, approximately 11 %.

Mc Kinlay and Mc Cauley (5) analysed the spoilt films in Australia in a hospital performing approximately 30 000 examinations/year. The total film wastage rate is 8.9 %. A higher rate of 13.1 % was found for low limb exams, 12.9 % for films for extremeties, children, gall bladder, and a lower rate of 3.7 % for chest and 3.2 % for spine.

The cause of wastage analysed quantitatively for chest films showed: radiographer error, which is exposure fault - 79 %; machine fault - 8.5 %, faults due to machine cleaning, testing - 12.5 %, etc. The authors consider that a film wastage reduction to less than 5 % is not possible without sacrificing diagnostic accuracy and radiographic quality.

Koga in Japan (1968) found a retake rate of 2 % with the following causes: radiographer error - 40 %; machine failure - 20 %.

Whittaker in Kenya (1979), analysing 100 consecutive skull radiographs, found 9 % to be of unacceptable quality due to: incorrect positioning, incorrect exposure, movement blurring, etc.

A WHO enquiry made in 1980 found the following figures for the percentage of rejected films: university hospitals

in: F.R. Germany - approx. 6 %;
in the UK - approx. 10 %;
in Switzerland - approx. 18 %;
in Kenya - 6 %;
in Sierra Leone - 2 %.

All the above figures are based on average data mentioned in the WHO questionnaire.

In the USA a number of radiological departments where QA programmes have been applied have changed their retake and waste rate, as shown in Table 2, taken from the BRH Publication Quality Assurance Programs for Diagnostic Radiology Facilities (6).

Table 2: Retake and Waste Rate for Films in a Number of US Radiological Facilities before (1) and after (2) a QA Programme

Radiological Facility	% Retake Rate (1)	% Retake Rate (2)	% Waste Rate (1)	% Waste Rate (2)
University of Connecticut	14.3	8.4	-	-
Baltimore PHS Hospital	8.0	6.2	-	-
Donelson Hospital, Tennessee	9-10	3-5	-	-
Hammond Clinic	-	-	6.5-8	2.7-3.7
Medical College, Virginia	8	3	-	-
Morton F. Plant Hospital	-	-	12.6	6.2
McLaren Hospital, Michigan	10	7.4	-	-
Mercy Hospital, Baltimore	14	8.6	24	13.6
Fountain Valley Community Hospital	15	7.7	-	-
Mercy Hospital, Iowa	14	7.5	-	-

In addition to the data appearing in Table 2 the Riverside Medical Center, Kanakee reported a 50 % drop in retake rate and the Washington Hospital, Pennsylvania a 40 % reduction after the introduction of QA programmes.

The cost of radiodiagnosis is evaluated to be 6-10 % of the total cost of health care in various countries in Europe and the United States. No figures are available from African, Asian or Latin American countries, but considering the fact that in such countries the major part of the cost of a procedure is represented by the equipment, films and chemicals, reaching 70 % of the total, while in industrialized countries these items represent only 25-30 % of the procedure cost, it is possible to estimate the cost containment resulting from a drop by 40-50 % in retake or waste rate.

For example, if a country spends US$50 per inhabitant/year on radiodiagnosis and the present waste rate is 10 %, a saving of US $ 5 per head/year for wasted films could be made. Reducing such waste by 50 % would result not only in a saving of US $ 2.5 per head/year but in a decrease of the depreciation figure for x-ray equipment, tubes, generators, film processors, etc., and in a reduction of unnecessary patient exposure.

There are insufficient data demonstrating that investment in QA equipment, salaries of personnel performing QA activities, could be easily covered by the containment resulting from the reduction of the retake and waste rate as shown above. More such data are necessary, particularly for developing countries, to convince the health authorities that such activities are worthwhile.

3. Reduction in patient exposure

This is another consequence of a QA programme. Patient exposure is reduced as a result of at least three factors:

decrease in the retake rate, which is a complex process;

appropriate collimation, and appropriate beam quality — both needed for an image of good quality.

As a result of the factors mentioned above the dose reduction due to QA activities is not restricted to the patients, for whom a lower rate of retakes has saved exposure, but applied to all patients undergoing examinations with adequate collimation of the beam and with an adequate beam penetration. The savings in exposure are much greater than the few percent resulting from the examinations which are not made as a result of the decrease in retake rate. If proper collimation reduces the body exposure of an individual by 10 - 15 %, this reduction applies for all patients exposed under similar conditions. To be added to this reduction from correct collimation is that resulting from a beam of appropriate energy spectrum, which will contribute another percentage to the reduction of dose, particularly the dose at the entry area.

If a QA programme is applied a reduction in patient exposure of up to 20 - 30 % can be expected as a result of the combination of the factors mentioned above. If the collective effective dose from diagnostic radiology calculated by UNSCEAR (1981) for various countries is as presented in Table 3, applying a 25 % reduction as a result of QA will substantially reduce the dose.

Table 3: Collective Effective Dose Equivalent (man Sievert per 10^6 pop.) for Diagnostic Radiology in Various Countries (UNSCEAR 1981)

Country	Year	Initial Dose	Dose after QA prog. (25 % reduction)
Australia	1970	332	249.0
Finland	1975	1114	835.5
Japan	1979	1314	985.5
Poland	1976	511	383.3
Romania	1977	665	498.8
Sweden	1977	452	339.0
UK	1977	276	207.0

If a value is given to each man Sievert saved, an additional sum can be obtained to balance the cost/benefit of the QA programme beyond the benefit resulting from the decrease in population exposure. An analysis made by the Bureau of Radiological Health, USA, estimated savings of US $ 145 million and 3300 Sievert bone marrow dose as a result of extrapolation to the US of data obtained in the states of Baltimore and Alabama studies (6). Other data quoted by the same publication (6) suggest reductions of US $ 195 million and 3750 Sievert.

4. Improvement of diagnostic imaging

Although as a physical fact the diagnostic image, whether radiographic of fluorescopic, depends for its quality on factors which are listed in Table 4 and which will be repeatedly discussed during this Workshop, the radiologist has a psychophysiological perception of this image and on this perception he/she bases the assessment of the quality of the image. This is one of the main reasons why no standard definition of image quality has been adopted in any country.

Table 4: Factors influencing the Image Quality in Diagnostic Radiology

Radiography	Fluoroscopy
Density	Brightness
Contrast	Contrast
Latitude	Sharpness
Resolution	Noise
Noise	
Signal/noise ratio	

These factors influence the retake and waste film analysis, which will depend on the level established for acceptance of a radiograph. The wide variation seen even between radiological departments in university hospitals in Europe, ranging from 6 % to an 18 % rejection rate, demonstrates the influence of these factors.

It is true that there are available today a number of methods aimed at rendering this evaluation more objective and these include:

1) Radiologist's impression - representing the evaluation by a radiologist of the quality of image produced. This method is widely used for comparison of film/screen system, scatter reduction techniques, etc. and has the limitations already discussed.

2) Visibility of anatomical landmarks - this is a more objective method, based on an evaluation of the visibility of pre-defined landmarks in images selected for study. As an example, a bone radiograph will be considered of good quality if the structure of the bone is seen clearly on the radiograph. The landmarks are selected on the assumption that their visibility will lead to the detection of lesions of interest.

3) Receiver operating characteristic (ROC curve) - represents a more objective approach in evaluating the ability of one or more observers to detect the signal and permit the establishment of a confidence level for the observer's decision if the signal is present or not. For the ROC curve a statistically significant sample is needed and the results are specific to the imaging system analysed.

4) Test objects (phantoms) - two types of test objects are used in the evaluation of the image quality:

i) anthropomorphic phantoms: phantoms which tend to reproduce the radiographic appearance of a given part of the human body. These permit an evaluation of the image based on anatomical landmarks, avoiding the ethical problem of irradiation of a human being. They also avoid problems related to anatomical variations, physiological movement, etc.

ii) physical phantoms: test objects of various complexity, which allow the evaluation of one or more of the parameters influencing the image quality and/or detect the faults in the x-ray machine performance. A large variety of such physical phantoms are continually being designed for various purposes and during the Workshop a number will be presented. The main use of physical phantoms is:

- displaying the dynamic range - the stepwedge filter;
- evaluating the high and low contrast resolution - via, star patterns, wire mesh of high radio-opaque material, array of holes, plastic spheres, discs of low contrast material, etc.

As a general result of the QA programme an improvement of the diagnostic image quality would have the pattern seen in Fig. 1, taken from BRS publication QA Programs for Diagnostic Radiological Facilities (6).

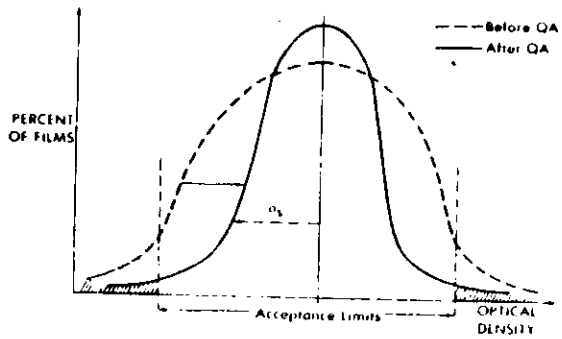

Figure 1. The effect on retake rate from reducing system variation.

It is difficult to evaluate the impact of the improvement of image quality on health care and health economics since this is a complex matter. Nevertheless, if diagnostic images produced are of better quality the following consequences could be expected:

i) earlier cases of a number of diseases to be discovered, as less obvious lesions will be detected with a higher degree of reliability;

ii) more precise diagnoses being made as misleading factors such as artifacts, motional blur, etc. will be reduced;

iii) better follow-up of patients in need of confirmation of disease evolution, complications, healing process, etc. will be possible with images of higher reliability.

No study evaluating the consequences mentioned here is currently available. This area remains open for further research which I am sure will be able to find methods to define the contribution of better quality diagnostic images in the improvement of patient care and in the reduction of direct and indirect health costs. When such data becomes available a true evaluation of the health and economic consequences of a QA programme in diagnostic radiology will be possible.

I have analysed here the importance of having QA programmes in diagnostic radiology in operation in order to increase the impact which this diagnostic technology has on patient care and health economics. I shall devote the following part of the paper to the organizational aspects of such QA programmes.

5. Organization of QA programmes in diagnostic radiology

The wide differences between health services in various countries oblige me to discuss here only those aspects of the organization of QA programmes which are of general value.

The first aspect which should be considered in starting a QA programme is to obtain the acceptance and support for such an activity. This means convincing on one side the health authorities and on the other side those who are practising diagnostic radiology (radiologists, radiographers, non-radiologists using x-ray diagnostic equipment, etc.) of the importance of having a QA programme routinely performed. For this reason WHO has prepared a publication (1) and has introduced this subject into its programme, aiming at raising the awareness of national health authorities. The present Workshop is another step in this direction and the arguments presented under points 1 - 4 of this paper are intended to provide the participants with the necessary information to convince their national health authorities and members of the radiological profession concerning the results - in terms of health care improvement and exonomics - of QA programmes.

It may be necessary for obtaining the acceptance and support for the QA programmes to demonstrate that the problem of quality performance in diagnostic radiology exists in the given country. This could be shown by an enquiry into the waste and retake film rate in a number of radiodiagnostic departments at various levels of health care, including very busy departments.

I should like to point out that waste film analysis is a most useful entry point for a QA programme, since it is able:

i) to evaluate the problems leading to poor image quality, such as: positioning, motional blur, machine setting, machine performance, film processing, etc.;

ii) to serve as a data base for the QA programme;

iii) to serve as a tool for self-improvement of the performance of radiographers.

At the same time it should be mentioned that the reliable collection of wasted films or of information on retakes needs the conscientious cooperation of radiographers in all departments where the analysis is made and demands that no sanctions of any sort are applied for correct reporting of the situation. In this context the method used by film producing companies of asking radiographers to dispose of all wasted films in a box which is collected and analysed periodically connot always produce accurate results.

Let's consider that the QA programme is accepted and supported by the health authorities and radiological profession. Next comes the problem of organization of such a programme in order to cover all radiodiagnostic services which should be involved. Three different levels could be envisaged:

1. the radiological facility;
2. an area covering a given number of radiological facilities;
3. the whole country

for the definition of tasks, designation of persons to perform these and provision of instruments for QA performance. Of course, in small countries, levels 2 and 3 could be combined.

The radiological facility's input in QA programmes is essential and further details of the tasks to be undertaken at this level will be presented later. It should be mentioned here that the facility should perform a QA programme adapted to its needs (type of equipment and x-ray procedures effected). For such reasons small facilities will be unable to conduct QA activities which need a certain degree of knowledge and adequate instruments. There are two possible solutions to this difficulty:

- postal monitoring from a central institution supervising the QA for the whole country;

- field visits from an area specialist in QA, who will monitor all small facilities and supervise the more advanced QA procedures in larger facilities within the same area.

6. Content of a QA programme

A quality assurance programme is defined as an organized effort aimed at ensuring that the product of a facility is of a consistently high quality. This general definition can be applied to radiodaignosis, where a QA programme should maximise the likelihood that the images obtained will provide consistently adequate diagnostic information for the least possible cost and radiation exposure to the patient. In order to produce such results each phase of the operation of a radiological facility, beginning with the request for an x-ray examination and ending with the report sent to the referring physician should be covered by the QA programme.

At the same time the QA programme should be conceived and applied from the moment the facility is planned, following the various phases of development, as seen in Table 5.

Such a comprehensive QA programme as presented in Table 5 could be applied only to newly planned facilities; most of the existing facilities will have to develop a programme adapted to phase III.

Table 5: Phases of Development of a Radiological Facility and QA Activities to be applied

Phase of development of a radiological facility	QA activities to be applied
I. Equipment selection phase	1. Identification of imaging requirements 2. Development of equipment specifications 3. Selection of appropriate equipment
II. Equipment installation and acceptance phase	4. Installation and acceptance, equipment testing
III. Operational phase	5. Release of equipment for clinical use 6. Routine and after repair equipment monitoring

6.1 Content of a QA programme at the radiological facility level

The following tasks should be defined:

6.1.1 Responsibility

The owner or person in charge of the facility must be responsible for the QA activities. He/she may delegate specifically this responsibility to a radiographer or a medical physicist with adequate training and the practical expertise to perform the necessary tests, evaluate the results and take corrective measures.

In large facilities a QA Committee could be envisaged.

6.1.2 Purchase specifications

As mentioned in Table 5, such specifications are necessary to assure the most appropriate equipment for the type of diagnostic imaging needed by the facility. Equipment advertising often biases adequate selection of equipment, particularly in developing countries.

6.1.3 Acceptance testing

This is a compulsory step after the installation of new equipment in order to verify the performance of the machine in relation to given parameters.

6.1.4 Routine testing

This represents the most essential part of QA activities and should include:

a) criteria for image quality - defined by the facility itself or with the help of an expert;
b) definition of all essential parameters to be monitored - this will differ from one facility to another, but the following key components should be considered:

- performance of the x-ray generator
- beam limiting device
- image receptor: films, cassettes, screens, image intensifier, grid, etc.
- darkroom and processing equipment
- viewing equipment

The frequency of the routine monitoring should be established as well as the techniques to be used.

c) Definition of parameters which will be monitored by the staff of the facility and of those which need outside expertise. For such monitoring the facility will have an arrangement with the area or national authority for QA.

6.1.5 Evaluation of results of routine testing

This is necessary in order to apply any corrective measures and preventive maintenance.

6.1.6 Record keeping

Records should be kept on the following subjects:

- persons responsible for QA monitoring and maintenance;
- parameters to be monitored and frequency;
- standards and criteria for image quality;
- techniques used to monitor various parameters;
- results of the monitoring and their evaluation;
- description of corrective measures applied.

6.2 Content of QA programme at area level

This will be similar, at least in part, to that at facility level, particularly with regard to points 2, 3, part of 4, 5 and 6. At this level higher competence and expertise is expected and some of the tasks mentioned for the national level could also be performed.

6.3 Content of QA programme at national level

Authorities at the national level could be of valuable assistance, if properly staffed and equipped, to perform the following tasks:

6.3.1 Drawing up standards and regulations concerning the QA procedures and the technical performance of the equipment to be used in the country;

6.3.2 Monitoring of technical parameters of QA which need more advanced knowledge, equipment and expertise than are available at the facility and area levels;

6.3.3 Monitoring programmes for a large cross section of facilities throughout the country to evaluate the effect of the QA activities;

6.3.4 Training of the personnel performing QA activities;

6.3.5 Research and development related to QA programmes.

Professional and scientific societies, particularly those connected with the radiological profession, medical physics, etc., could play a role in QA programmes, expecially in:

- training,
- discussion of results,
- preparation and discussion of scientific papers, etc.

Manufacturers of x-ray equipment could have an important role in developing:

- special protocols for testing some parameters;
- QA programmes for complex radiological equipment;
- better technical information on the performance of the equipment, its suitability for particular geographical and climatic areas, etc.

Furthermore, the manufacturers could learn from the results of QA programmes what are the major breakdowns and changes in the function of x-ray machines.

I have attempted to present in a brief review the importance of QA programmes in diagnostic radiology for the improvement of patient care. A rational QA programme could also contribute to a more efficacious use of diagnostic radiology, as already pointed out in the report of a WHO Meeting on Efficacy/Efficiency in Diagnostic Radiology and Nuclear Medicine, 1979. It is hoped that the participants of the present workshop will be able, using the knowledge acquired here, to initiate QA programmes in their own countries and therefore to contribute to the aims mentioned in the introduction of this paper.

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IMAGE QUALITY-HOW CAN IT BE DESCRIBED IN TERMS OF PHYSICS

Presently available or proposed descriptors of image quality can be sorted roughly into 3 categories:

1. Physically measurable numbers or functions which describe a single aspect of an image or an imaging system, such as unsharpness, contrast or noise.

2. Derived numbers or functions which attempt to provide some correlation to image quality by combining or extracting the number one descriptors, such as for example signal to noise ratio, information capacity or various figures of merit.

3. Descriptors of the measured performance of human observers. Such empirical descriptors are functions like ROC-curves or detection curves and result from the decisions an observer has to make, whether he detects a detail or not.

1 CONTRAST

In connection with X-ray diagnosis the term contrast can have a three fold meaning:

X-ray contrast
Photometric contrast
Physiological contrast

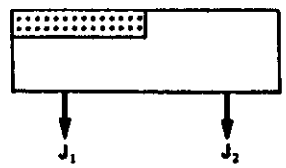
X-ray contrast and photometric contrast are only physical descriptors; physiological contrast includes by far more, but must be mentioned in this context, because X-ray contrast and photometric contrast offer only an incomplete description of contrast in an imaging situation and in general the physio-

logical contrast is meant unspokenly when the term contrast is used.

1.1 X-ray Contrast

Confined to comparatively large details embedded in a homogeneous surreounding, X-ray contrast describes the different amounts of radiation behind the detail and behind its surroundings, depending on the different absorption for both pathways thorough the object.
With the exception of CT a direct measurement of X-ray contrast is practically never performed. Buth this could be done by ionisation chamber or spectrometric devices measuring the exposure or the photonfluence. The latter method however makes one problem evident, namely that not only the number of photons is different behind detail and surroundings, but also their spectral distribution. Normally when details differ only slightly by density or atomic numnber from the surroundings, this change of the spectrum can be neglected, because the object altogether is equivalent to a heavy filtration and the small difference of filtration caused by the detail is really unimportant. But this does not hold, when contrast materials are applied, or when step wedges made out of copper or aluminium are brought into the beam. In this case it must be specified very exactly in terms of which quantities the X-ray contrast is described. But not only the quantities, also the formulas used are to be specified.
Describing the same imaging situation all these formulas provide different results (Tab. 1). Generally K_1 is proposed. The values for K_1 vary between 0 and 1 and an exchange of J_1 and J_2 changes only the sign of K_1 but not its absolute value, like with the other definitions.

In table 2 the parameters are listed from which the X-ray contrast depends.
Although X-ray contrast represents only the first step of image formation, attempts could be made to correlate the parameters mentioned here with quality control.



$$K_1 = \frac{J_1 - J_2}{J_1 + J_2}$$

$$K_2 = \frac{\Delta J}{J_1} \qquad \Delta J = J_1 - J_2$$

$$K_3 = \frac{\Delta J}{J_2} \qquad \Delta J = J_2 - J_1$$

$$K_4 = \frac{J_1}{J_2}$$

$$K_5 = \lg \frac{J_1}{J_2}$$

Tab. 1 Definition of contrast

Radiation quality	**Geometry**
Tube voltage (setting, ripple, tube current)	Field size
Filtration (inherent, added)	Distances (Focus - object - film)
Anode (Material, angle, roughness)	**Grid**
	Selectivity
Object	Focusing
Thickness, density, atomic number	Adjustment

Tab. 2 Parameters influencing the contrast

Theoretically all the parameters listed could be subject to quality control measures. Of course not all of them can be investigated in detail in a quality assurance program. But it is one of the tasks of this workshop to nominate the most crucial parameters and to propose adequate procedures for their control.

1.2 Photometric Contrast

1.2.1 Radiography

X-ray contrast results in a density difference, measurable by a densitometer in terms of density or in a difference of luminance, measurable by a lightmeter in terms of candela/m^2 or by usual comparison with images of standard objects like stepwedges.
For the assessment and discussion of the photometric contrast knowledge of the H & D curve is mandatory. Figure 1 shows a typical H & D curve for a film screen combination. The shape and the position of this curve can be quantitatively described by 4 figures:

1. Sensitivity or speed, the reciprocal of the exposure to achieve a net density.

2. The gradient, the slope of a straight line between points on the curve on D = 0.15 and D = 2.0.

3. The maximum density achievable.

4. The fog.

All these figures, in the first place depend on inherent properties of the films and screens used. In so far the aspect of quality control is restricted to a sufficient specification of these figures by the manufacturer to assist in a reasonable selection of image recording system by the user. But there are still other strongly influenced parameters to be considered.

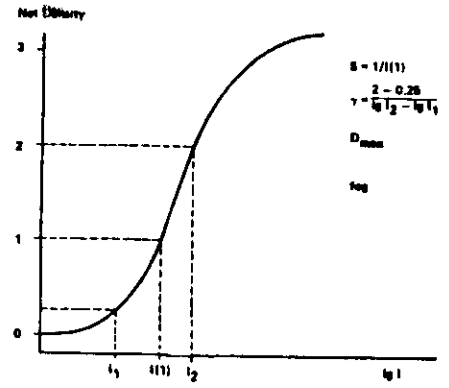


Fig. 1:
H & D curve and the quantities to describe it

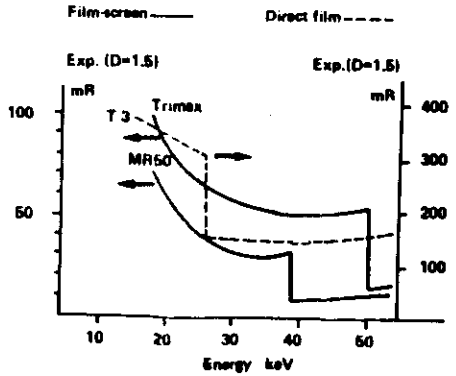
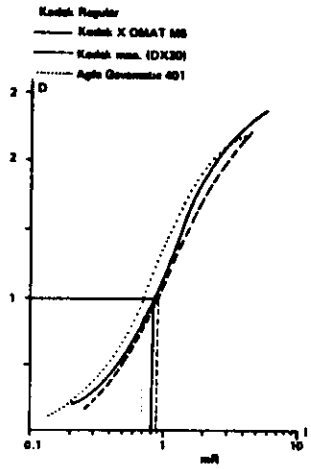


Fig. 2:
Energy dependence of sensitivity depending on the system used

Fig. 3:
Influence of different modes of film processing



1. Radiation energy.
A change of the spectral distribution by varying tube voltage or filtration will cause a shift of these curves, increasing or decreasing the sensitivity.

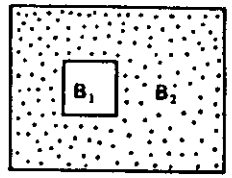
The effect of the energy dependence of sensitivity is shown in Figure 2, for a direct film and a film screen combination. The dependence will not be as prominent under routine conditions, when comparatively broad Bremsspectra are used, but nevertheless, the radiation quality remains an essential parameter which has to be specified when H & D curves are present.

2. Another parameter, which may be of minor importance, has to be considered with screen-film combinations, namely the exposure time.
For example an expand of exposure time from .2 to 2 seconds can reduce the sensitivity by 30 % and a comparable change of exposure time during the measurement of a H & D curve can cause severe distrotions of the resulting H & D curve.

3. The most crucial influence on H & D curve however is performed by the film processing. In Figure 3, three H & D curves are shown from an identical film screen system, irradiated under the same conditions regarding radiation quality and exposure time. The two processing machines were in proper condition and with the manual processing the prescription of the manufacturer were strictly followed. Nevertheless there is to state a difference in senitivity of more than 20 % under such standardized conditions.

1.2.2 Fluoroscopy

In the case of fluoroscopy the conversion of a incoming X-ray contrast into a photometric contrast is quite simple, as long as we consider systems containing only a fluorescent screen as image recorder.



$$K_1 = \frac{B_1 - B_2}{B_1 + B_2}$$

$$K_2 = \lg \frac{B_1}{B_2}$$

$$K_2 = \Delta S = S_2 - S_1$$

$$K_2 = \lg \frac{B_1}{B_2} = \lg \frac{B_0 / 10^{S_1}}{B_0 / 10^{S_2}}$$

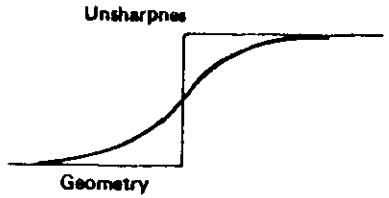
$$= \lg \frac{10^{S_2}}{10^{S_1}}$$

$$= \lg 10^{S_2} - \lg 10^{S_1}$$

$$= S_2 - S_1$$

B_0 : Luminance of viewing box

Tab. 3 Photometric contrast



Focal spot (size, shape)
distances (focus-object-film)

Exposure time
Object thickness
Load capacity
tube voltage (output)
focus-film distance (inv. square law)
grid
sensitivity of image detect.

Inherent parameters
Film
screen
cassette

Tab. 4 Parameters causing unsharpness

There exists a linear correlation between the radiation quantity (in terms of exposurerate or photon flux density) resulting in a straight line under 45° in a double logarithmic plot. Higher or lower sensitivity would cause a parallel shift of this straight line (Fig. 4).
In the case of a TV image intensifier and TV chain, three characteristic curves are to be considered. The parameters determining these characteristic curves are in first place inherent properties, depending on the construction of the different parts; but two external influences must be mentioned.

1. Curves for fluorescent screen and image intensifier are energy dependent. They strictly hold for one energy only and will suffer a shift when the radiation quality is changed. Figure 5 shows this energy dependence of a image intensifier. Most remarkable is the strong decrease in sensitivity for energies below 40 keV with older instruments having thick glass entrance windows.

2. Another crucial parameter influences the <u>right</u> curve in Fig. 4. By arbitrary adjustment of the monitor brightness the user can shift the signals coming from the camera to higher or lower values and so heavily influence the conversion of X-ray contrast into photometric contrast.

The quantitativ description of the resulting photometric contrast, is based on the different luminances by wich detail and surrounding are imaged (Tab. 3).
This can happen by the formula for K_1 where B_1 and B_2 are respective luminances on the radiogram in front of a viewing box or on the TV monitor. But, especially for describing the photographic contrast on film, more often the second formula is used yielding the photometric contrast in terms of density.
Also $K_2 = \lg B_{1/B_2}$ is synonymous with $S = S_2 - S_1$
as can easily be seen, because B_0, the basic luminance of the viewing box, is cancelled out.

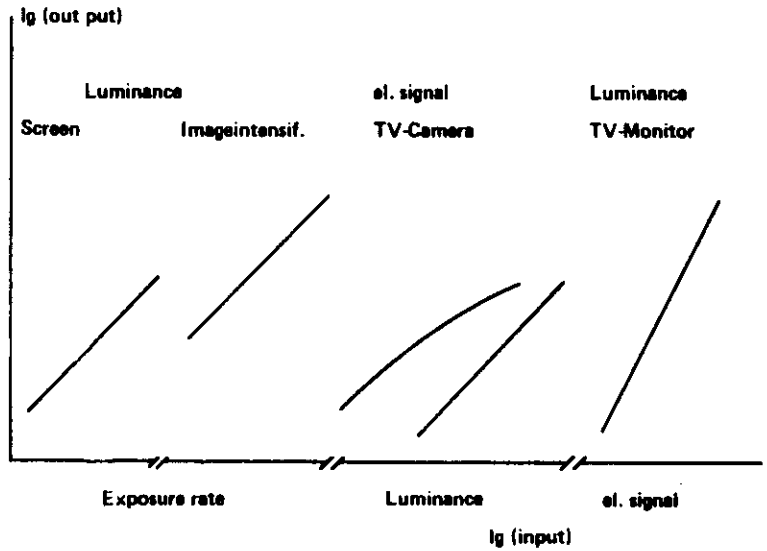


Fig. 4 Input vs. output for the single stages of an image intensifier

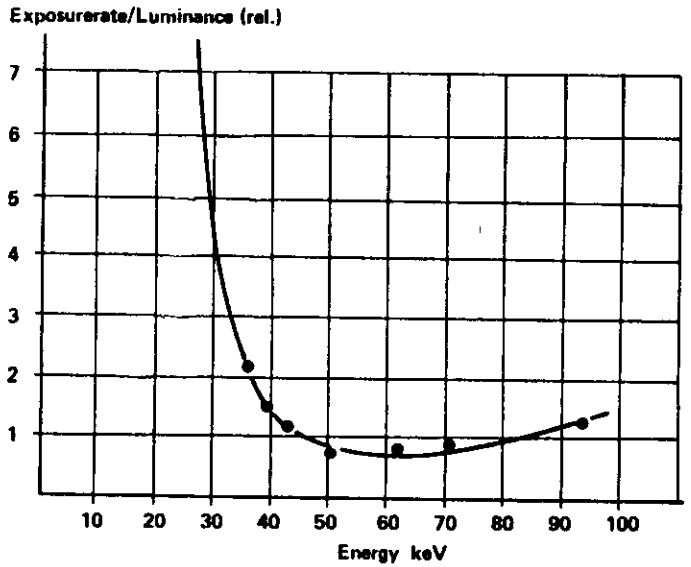


Fig. 5 Efficecing of an image intensifier as a function of radiation energy

In spite of its wide use in radiography the formula for K_2 is suffering from a severe drawback: The eye does not see density, but luminance and a contrast defined by this second formula is evidently independent from the basic luminance of the viewing box; and this is quite contradictory to all experiences made in practise, where the viewing box luminance proves to be a very important parameter. And so all data on densities in connection with viewing problems are of restricted value only, when they are not correlated to viewing box luminance.

1.3 Physiological Contrast

How a photometric contrast appears to the observer depends on many parameters like

- shape of detail
- structur of detail and surrounding
- presence of other details
- time of presentation
- illumination
- adaption, glare

phsychological factors like interest, experience and concentration. All these factors are often turning round or masking the ranking of image quality given by the physically measurable contrasts.

2 UNSHARPNESS

The image, even of a very simple object like an edge is associated with a certain unsharpness (Fig. 6). The phenomena causing this unsharpness are well known and understood. But still there are some problems in defining and quantifying this unsharpness, at least in the routine field.

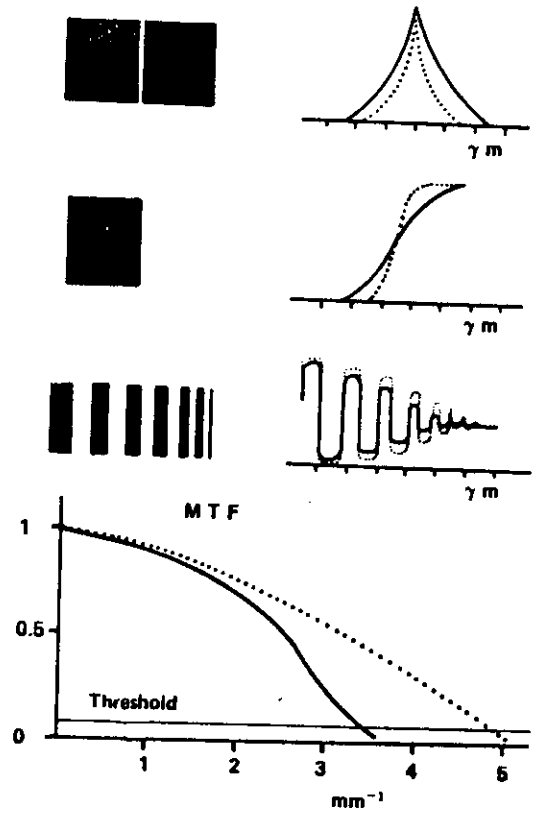


Fig. 6 The MTF as means of describing the imaging process

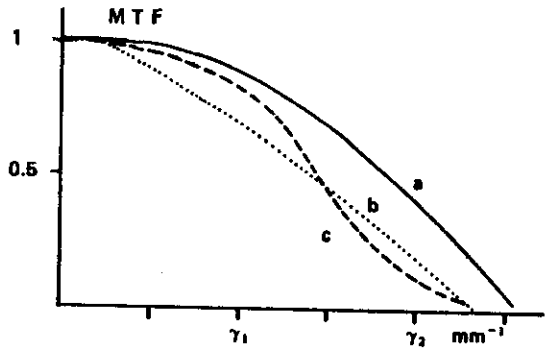


Fig. 7 MTF γ of different imaging Systems

2.1 Visual determination

The most usual way of quantifiying unsharpness is to do this by visual determination by means of images from bar tests, or star patterns. Unsharpness then is figured as resolution by the number of bars or line pairs / mm which can just be detected by an observer as seperated lines.
In the case of star patterns the diameter of the circle on which the total blurring of the pattern occurs is to be measured.
The usefulness of those resolution tests is generally accepted. Especially in non destructive material testing they play a important part and are often imaged together with the sample to assure sufficient image quality. But there the test patterns are strictly standardized; not so in X-ray diagnosis. This leads to difficulties which appear when such values for the resolution are to be compared or interpreted. The results depend on experimental parameters as listed in Tab. 4.

1. This disadvantage of the strong dependence on the experimental parameters, can best be compensated by a exact specification of the test procedure, otherwise the results are of restricted value only.
Arbitrary influences are also introduced by the observer. Practically this determination of resolution is somewhat similar to a detection, experiment, exposed to disturbing influences, which are known from this field.

2. Another type of error can be introduced by parallel superposition of two gratings, like the bar pattern and the gridlines or the bar pattern and the TV monitor lines. Moiree-effects can obscure the resolution provided by the imaging system in such situations.

2.2 Modulation Transfer Curve

Facing all these difficulties, one can understand, that there was a great need for a method to describe unsharpness of a

system more precisely and this leads to Transfer Analysis and the Modulation Transfer Function.
Measurement of MTF is too complicated to be proposed for quality control of installed X-ray facilities, but one aspect of quality is also to assist the proper selection of X-ray diagnostic equipment and the proper choice of physical examination parameters; and in this field MTF can be very helpful.
The determination of MTF is based on the microphotometrical evalution of images of slits, edges or bar patterns (Fig. 6). By calculation, namely the application of Fourier analysis, the MTF of a system can be determined.
The correlation with the visual methods is given by the somewhat arbitarary threshold line; the points where MTF meets the threshold line indicates the highest spacial frequencies detected by an observer.

The benefits provided by the use of MTF are:

1. More information about how structures are imaged; more than given by a single value for resolution.

2. Possibility of combining MTF of subsystems.

3. Application for optimisation of physical parameters of an examination. The still remaining shortcoming of using MTF, however is, that there exists no generally accepted criteria for the interpretation of MTF when e.g. two curves are crossing over (Fig. 7). Unless, the details to be detected are not described in terms of spacial frequency, which is very troublesome and often impossible. MTF are of restricted value for recommending imaging systems for different X-ray examinations.

3 NOISE

3.1 Radiography

In radiography the noise plays a minor part from the stand point of quality control. Once a imaging system is selected, noise can be considered as a constant, system inherent property which does not change in the course of time. In the stage of selecting a system, noise is to be considered, and there is a strong need of specification of its value by the manufacturer. In Radiography, noise results from three sources:

1. Film granininess, which can be neglected, because it is by far the smallest contribution regarding film screen combinations.

2. The quantum mottle caused by the statistical incidence of the photons.
Assuming that 0.1mR is necessary to achieve density 1 only, 5000 photons are absorbed per mm^2 in a high sensitve screen. Thus small, low-contrast details may be mashed or obscured by statistical variations.

3. Structure mottle is caused by the grainy pattern of the screens. In addition inhomogeneities of the screens can give rise to a disturbing background.
Quantitatively noise can be described by the
1) Selwyn measure of granularity

$$G = \sigma \sqrt{F}$$

where σ is the standard deviation of a series of density measurements in a homogenously exposed screen film combination and F is the area of the scanning spot of the densitometer.

2) Wiener spectrum

$$W(\nu) = \frac{G^2 \cdot M(\nu)}{n}$$

G: Gradient, $M(\nu)$: Mod. Transf. Function
n: average number of absorbed photons

3.2 Fluorescopy

By far more important noise can be in fluoroscopy; 20 $\mu R/s$ correspond to 120 photons/mm^2 within 0.2 seconds (assuming 50 % absorption in the entrance screen of a image intensifier). Noise performance of electronical equipment cannot be considered as constant over long periods. There is a great need for quantifying noise better and more reliable then by the visual impression. The most common way is to measure noise by the use of a RMS meter, but this method is not widely accepted outside of the manufacturers laboratories.

4 IMAGE QUALITY AND PHYSICAL IMAGE DESCRIPTORS

The great problem with the physical image descriptors is, that they are somehow correlated with image quality, but do not describe image quality. Unless there are no generally accepted recommendations or criteria, how images are to be in terms of the physical image descriptors, they are only of restricted value for quality control purposes.

4.1 Contrast

It is often stated, that X-ray imaging systems should provide a high contrast. But what is to be understood by a "high contrast"? The problem is not as simple as to say: the higher the contrast, the better the images. Most of the objects contain anyhow details with high subject contrast (like bones), which are therefore imaged with very high contrast. The presence of such high contrast, however hampers the detection of very low contrast, as it is known from detection theory and the

high-contrast details may mask the low-contrast ones. In addition, the range of object thickness which can be imaged simultaniously is decreasing with systems providing higher contrast; but where a compromise is to be made, for the various examinations, there exists no general agreement up to now.

4.2 Unsharpnes

The same holds for unsharpnes. A system is not necessarily better because of its higher resolution. Of course there are examinations like mammography or angiography where high resolution is mandatory, but for other examinations the importance of resolution is not as clear. Highly resolving systems require higher doses (also to the patient) and perhaps longer exposure times causing higher motion unsharpnes. Finally, the sharper an imaging system, the sharper its own distrubing noise is visible; again there is a lack of reliable, generally accepted data in which range the resolution of a system should be to provide optimal or at least acceptable images, for the different X-ray examinations.

4.3 Noise

Considering only the finished image and the details which can be detected in it, a image is the better, the lower its noise level. Low noise systems however are demanding high doses, causing the same troubles as mentioned above.

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WHAT IS A "DIAGNOSTIC QUALITY" IMAGE FORM THE VIEW POINT OF A RADIOLOGIST?

The problem of comparing medical radiographic images is nearly as old as the application of x-rays for diagnostic purposes. The medical profession itself does not want to diagnose a pathological condition, but it also wants to control the success or failure of the treatment and follow up the pathological process involved.
In order to compare radiological images it is necessary to use standardized views produced by so-called standard positions and to produce them under optimal conditions. According to Heinrich Franke's definition in one of his lectures on "the optimal x-ray image and its technical conditions" in 1938, optimization means that optimal conditions exist when motion unsharpness, geometric unsharpness and photographic unsharpness or material unsharpness have equal influence. The other technical parameters - especially the necessary contrast of that part of the body which is of diagnostic interest - should be chosen in order to produce a harmonic image. This is an image which reproduces the parts of the body under examination under optimal viewing conditions. Franke demonstrates the main factors of radiographic image quality in a schematic drawing from Jerman with correct size, definition and contrast. I would like to present this old diagram at the beginning. This is only to demonstrate that the problems of image quality are as old as the radiographic technic itself.
You will find nearly the same wordings in modern books on radiographic quality such as the book of Daniel Donohue.

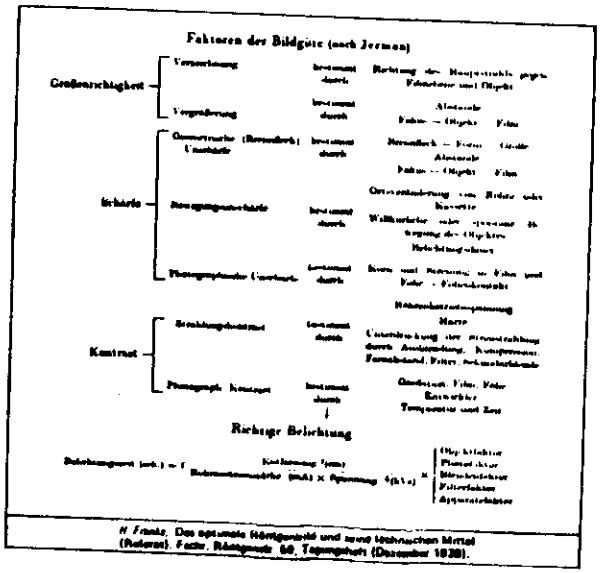


Fig. 1: Factors of image Quality after Jerman

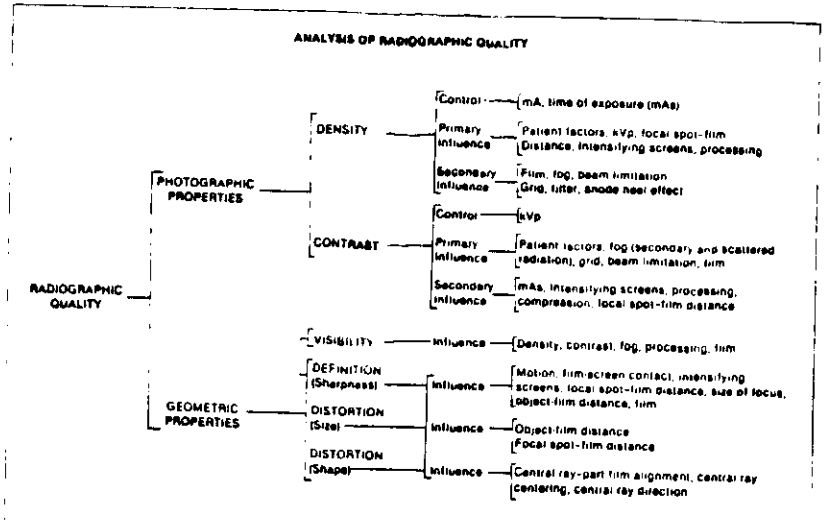


Fig. 2: Analysis of Radiographic Quality after
D.P. Donohue (1980)

In order to produce a radiographic image under optimal conditions the medical profession has to define what "details" it likes to see in order to get a picture that meets the requirements of sufficient quality. This means always a compromise between the possibilities of producing an optimal image and the dose which is necessary to fulfil the recommendations of the International Commission on Radiological Protection. In other words:
How bad can an image be to meet the requirements of the demand: as low as readily achievable.
The radiologists define the concept "detail" as a part of an object which can be recognized by its density, chemical composition, size, form or attenuation. In other words, a part of an organ or tissue which can be defined or sharply be outlined against other parts of the same organ or tissue.

DETAIL =

PART OF AN OBJECT WHICH CAN BE RECOGNIZED BY ITS DENSITY, CHEMICAL COMOPOSITION, SIZE FORM OR ATTENUATION DIE TO X-RAYS.

Fig. 3 DEFINITION OF DETAIL

RADIOGRAPHIC QUALITY =

VISIBILITY OF STRUCTURAL DETAILS WHICH ARE ESSENTIAL FOR THE REQUIRED DIAGNOSIS OF SUSPECTED OR CLINICALLY RECOGNIZED PATHOLOGICAL CONDITIONS OF DISEASES.

Fig. 4 DEFINITION OF RADIOGRAPHIC QUALITY

Therefore, we must answer the following questions:

- Which details are essential for diagnosis?
  (size of the details)
- Which contrast is necessary?
  (necessary detail contrast)
- Which movement is attributed to them?
  (motion unsharpness)
- Which dose is necessary to produce the diagnostic information desired, under optimal conditions?
  (optimization)

Anatomical structures of the body vary considerably in size, shape and thickness. In addition, they overlap each other and are superimposed, while lying at different distances within the exposed part of the body. Some of them are only perceptible through the effect of summation, others are hidden due to the same process. It is therefore essential to measure the size of the parts or details of interest. This is mainly done by means of radiographic images or radiographs of pathological specimen the pathological process of which is known.
Since it is also necessary to evaluate their contrast both conditions are usually summarized in one representation.
It is therefore recommendable to define first the term "contrast". This is the difference in intensity of two neighbouring parts of an image.
Usually the contrast is expressed as radiation contrast, i.e. the relation of the dose of two neighbouring image elements, which can be delineated in front of an imaging system. On the other hand, the image contrast of a radiograph is defined as the relation of light intensities in the visible light.

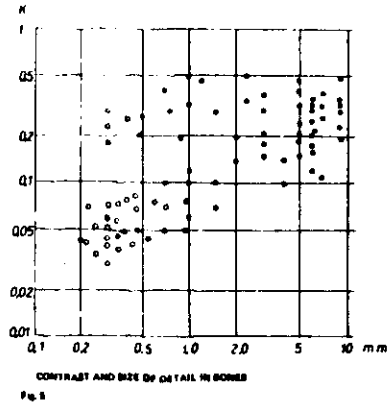
The contrast is usually expressed in the formula:

$$C = \frac{L_1 - L_2}{L_1 + L_2}$$

or if you measure the contrast of an x-ray film as:

$$C = \Delta D\,1 - \Delta D\,2$$

Since the film does not record the contrast linearly, it is better to record the contrast as radiographic contrast, either by measuring the dose or by calculating the dose by analysing the light intensities and transferring the data by considering the part of the density curve of the film.



In Fig. 5 the size and contrast in bone structures are displayed. It can be seen that even in the case of small fractures or structural changes the minimal size of the details is mainly above 1 mm in diameter, while the diameter of the spongiosa lies in the range of 0.1 to 0.6 mm. Nearly the same conditions are found within the lungs, where the normal lung structure shows sizes of about 0.8 to 5.0 mm; chronic proliferative and indurative processes showed sizes of 0.7 and 7.0 mm and nodular changes are in the range of 1 and 6 mm. I have also found such details within the kidney and

the smaller vessels, in the latter case in angiographies. Bigger sizes are usually found in gallbladders. Gallstones mostly have a size of several millimeters. The sizes of details in several important organs are listed in the next table:

organ	min.	max.	mean value
lung	0.25	20.0	2.5
vessels	0.1	20.0	5.0
gallstones	1.5	10.0	5.0
gallvessels	1.0	10.0	7.0
bone	0.2	10.0	1.5

Sizes of details in different organs in radiograms (in mm)

The radiographic contrast of the part of the body under examination is affected by the radiographic density of the details, the tissue thickness of the exposed part, the field size and therefore the exposed volume and the radiation quality of the beam itself. The radiographic property of the contrast is influenced to a great extent by the patient factors. Those are mainly due to the different tissue densities. The higher the effective atomic number and the denser the structure of the organ, the greater is the opacity of the tissue that contains those elements. The highest density and therefore the highest opacity is usually found in bones, the density of muscles corresponds mainly with that of water and the density of fat is lower. Air reduces the opacity to radiation, while other organs which contain fluid have a higher opacity than normal.

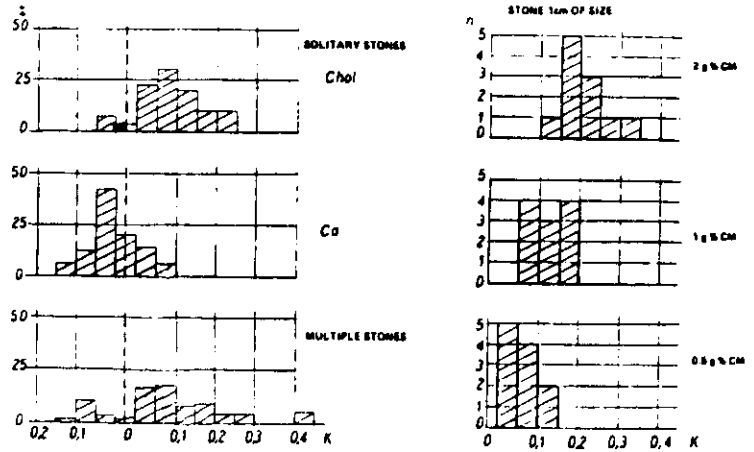


Fig. 6: Contrast of gallbladder stones in a gall bladder filled with contrast media

The effective atomic number per unit of exposed body diameter therefore determines the density of the radiograph. Fig. 6 demonstrates the dependency of the contrast within the gallbladder filled with different concentrations of contrast media.
One can take as a rule of thumb that it is useful for a so called harmonic radiographic image to produce contrasts in the size of 20 to 30 % within the details of interest, as the eye is unable to perceive contrasts lower than 10 %. On the other hand the observer cannot perceive the density gradient in details with high contrast. Therefore it is advisable to use lower radiation qualities, expressed in kilovoltage (60 - 80 kV) for the examination of small bones (hands and feet) and organs filled with iodine contrast media, medium radiation qualities for radiographs of organs with higher contrast such as radiographs of the abdomen, pelvis and the vertebral column and high radiation quality of about 100 - 125 kV for radiographs of the lung and other organs filled with air, eventually together with barium contrast media.

One factor which has a great influence on the radiographic image is the amount of scattered radiation which is contained in the image. In measuring the amount of fog due to the radiation scattered in the body, one can state that there hardly exists a part of the body, except the extremities, where the amount of scattered radiation is lower than 50 % on the exit side of the radiation beam.

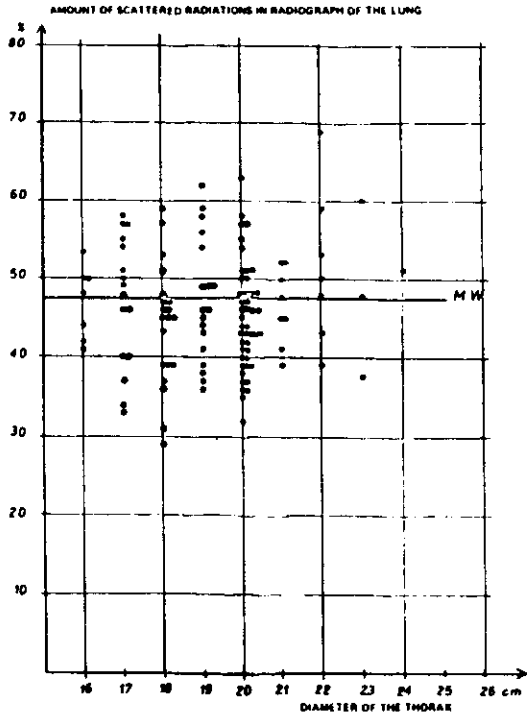


Fig. 7: Scattered radiation in lung images

Fig. 7 demonstrates the amount of scattered radiation in standard lung radiographs. In the lateral view the amount of scattered radiation lies between 65 and 90 percent on the exit side of the radiation beam.

It is therefore necessary to reduce the radiographic fog, which is caused by the scattered radiation, to a minimum since the reduction of scattered radiation is a major aspect in every radiographic procedure not only because of the image quality but also for radiation protection purposes. The reduction of radiographic fog increases the visibility of the recorded image and the radiographic detail contrast, which is extremely necessary to detect small details with low contrast.
The most effective ways to reduce the amount of scattered radiation are:

- beam restriction to the field of interest
- use of grids and, if possible,
- reduction of the tissue thickness.

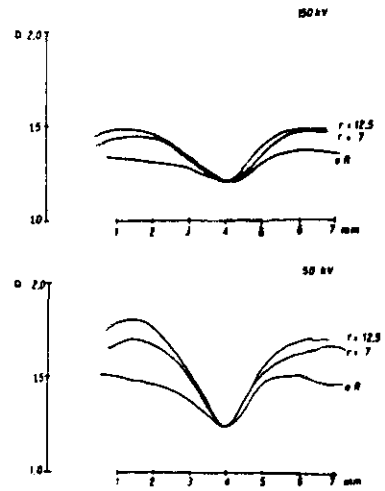


Fig. 8:
Influence of scattered radiation in contrast and resolution

(r = grid ratio,
o.R = without grid)

Fig. 8 demonstrates the influence of fog on the image contrast of small details - the use of radiographic grids is therefore especially useful - when exposure with high radiation quality is used.

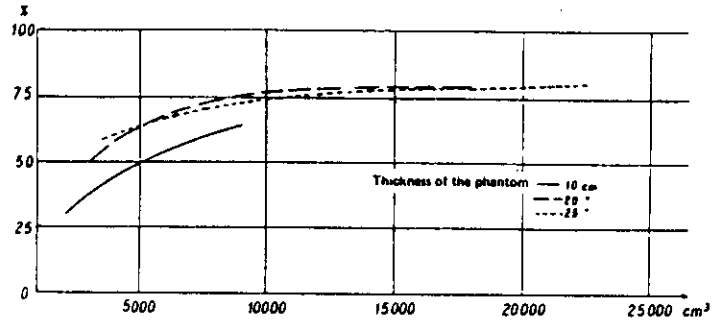


Fig. 9 Scattered radiation behind the Object related to the volume

Fig. 9 demonstrates the influence of field size and thickness of the body on the amount of scattered radiation and Fig. 10 shows the improvement of contrast when using high efficiency grids and reducing the field size.

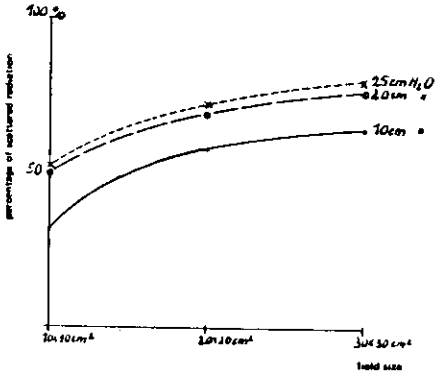


Fig. 10:
Dependency of the amount of scattered radiation on field size and thickness of the phantom

The contrast improving factor increases with the efficiency of the grid, usually expressed as grid ratio, and inverse with the field size. In most cases the radiographic contrast is transferred to the film, where it is recorded as film contrast. Since the characteristic curve of the film has, at its lower end, a curvilinear form and is only linear in the area of densities between density levels of about 0.8

to 2.5 the transfer of the radiographic contrast is recorded in the lower dose range with lower levels than in the higher dose range of the same radiographic image. This means that the contrast-transfer-factor is changing with the dose. In the lower dose range of the radiographic image it is below 1 and in the higher dose range usually above 2 since the gamma of a radiographic film is about 2 to 3 in the linear part of the curve. This effect increases with the amount of scattered radiation.

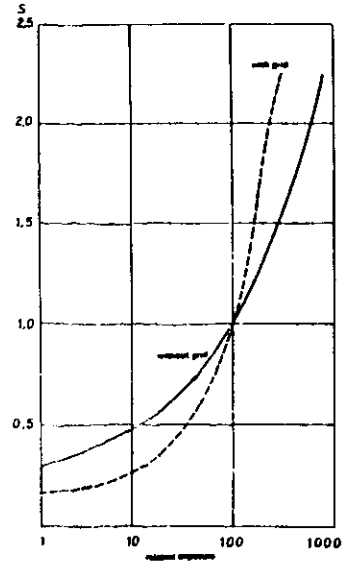


Fig. 11:
Characteristic curve of a radiografic film with and withouth scattered radiation

Fig. 11 demonstrates this effect. As most of the important details which are essential for diagnosis lie in the lower dose range of the radiographic image the reduction of scattered radiation is one of the most effective methods of reducing the amount of unwanted radiation directed towards the detector and does therefore improve the contrast of the recorded image, even in the case of special radiographs such as mammography.
Some physiological conditions characterize the optimal mean density of a good image. Under optimal viewing conditions

the human eye is able to perceive differences in contrast in a range of latitude of about 1 : 30. If one considers this size of the recorded densities in the part of the image which should be used for diagnosis, the density range should be between 0.1 and 0.2 to 1.6 and 1.7. This means that the medium density of a recorded image should be about 0.8 and 1.0 (Fig. 12).

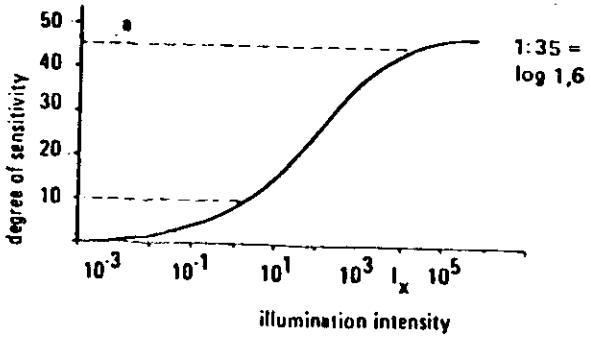


Fig. 12: Sensitivity of the eye

Several examinations of films with different mean densities demonstrate the validity of this observation (Morgan, Franke and others). If the recorded mean density is higher the viewer is usually unable to detect details outside the described physiological range unless he concentrates the viewing field only to those dark areas. This effect is called glare-effect.

The rule that the radiological film should have a mean density of about D = 0.8 to 1.0 is applicable to each radiographic image and is therefore the basis of the automatic exposures of the recorded radiographic image. In all cases the region of interest - the so-called "dominante" should be in the above mentioned range, the perceptible densities in the range of about 0.2 to 1.6 and the percentage of differences higher than 10 %. In a so-called harmonic image the image contrast should not be more than 20 %, as the eye is not able to perceive details between high contrast levels

and therefore the overall distribution of densities should be around the mean value.

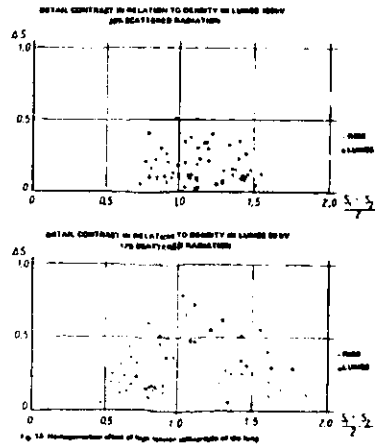


Fig. 13:
Homogenisation effect of high-tension radiographs of the lung

In Fig. 13 the detail-contrast in relation to the area of density demonstrates the harmonisation effects in an x-ray image of the lung with 150 kV in contrast to one image with low kilovoltage. The details within the lung are hidden in the low kilovoltage range behind the structure of the ribs, while the contrasts are nearly homogenously distributed in the high kilovoltage with grids when details in the lung are to be diagnosed while in those cases where questions within the bone part of the thorax are to be considered low kilovoltage should be used. In order to detect details, the zone between two levels of intensity - generally expressed as "unsharpness" - should be small. Otherwise the eye is not able to perceive those differences. It is therefore necessary to relate the image of the structures and the shape unsharpness to the central ray. In reducing this unsharpness to a minimum level it is therefore necessary to center the alignment of the structures of interest to the central beam of radiation. In some cases it is therefore advisable to record the structures in several projections. In this case

the rays should be parallel to the border of the detail and produce a detectable contrast with minimal unsharpness resulting from the shape of the structure. This effect is called tangential effect. Typical examples are fracture lines in the bone and effusions in the interlobar space of the lung. Those pathological conditions can only be detected when the above mentioned conditions are fulfilled.
Motion is one of the most detrimental factors contributing to image unsharpness. In diagnostic radiology certain examinations especially such as performed in children and infants, emergency and operating room patients, examinations in intensive care rooms and with mobile units, are prone to problems of motion.
Motion can be classified into several types:

- voluntary motion
- involuntary motion

By means of positioning and fixation of the patient the main problem of voluntary motion can be overcome. This is known to be very difficult in the case of the examinations of children, unconscious persons and sometimes also elderly patients. Involuntary motion on the other hand cannot be influenced by positioning or other technical methods. This type of motion is attributed to the physiological action of various organs of the body. In analysing the type of motion we must make a distinction between the motion of the organ itself, i.e. peristalsis, pulsation, streaming and active or passive change of organs by conditions of filling and motions which are influenced by movement of neighbouring organs - in this case pulsatoric comovement. Movement of the different organs by breathing and other voluntary and involuntary movements should be mentioned.

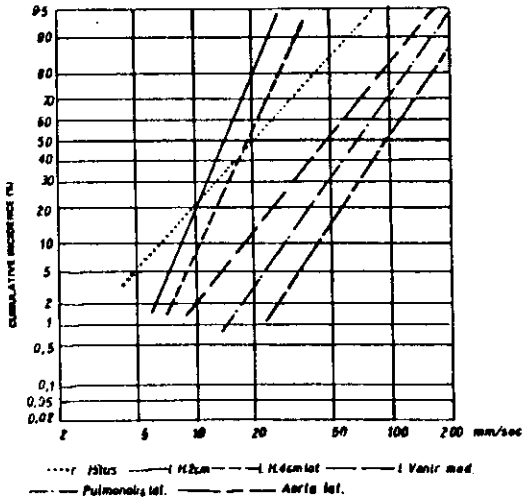


Fig. 14:
Motion velocity of the heart and the hilus observed in radiographs

In all those instances the length of exposure time is the most effective method for controlling the unsharpness. The degree of the unsharpness of the radiograph depends mainly on the velocity of motion and the amplitude of the motion. As probably the velocity remains the greater factor we are measuring the motion velocity in several organs.

In Fig. 14 the different velocities due to the action of the heart are presented in an analytical scheme. The maximal velocity can be found at the border of the heart itself and the large vessels.
In 50 % of the cases it comes to about 100 mm/sec but there are also greater velocities at the border of the arteria pulmonalis and within both hili. The lung as a whole participates in this movement with velocities of about 10 to 20 mm/sec. Similar movements can be recongnized in the upper abdomen, mainly in the kidneys in the different phases of the diastole and systole and, of course, by the peristaltic

movement of the alimentary tract. In the latter case the velocity lies in the range of 2 to 10 mm/sec. Considering the velocity and the amplitude of the motion it is possible to eliminate the motion unsharpness within a radiograph by limiting the exposure time to certain levels. They are presented together with the size of motion in Fig. 15.

organ	motion velocity in mm/sec	optimal exposure time in msec
heart lung vessels	50 – 400 mm/sec	5 msec
oesophagus behind the heart	50 – 200 mm/sec	10 msec
upper abdomen (stomach, spleen, liver gallducts, kidney)	1.5 – 15 mm/sec	100 – 200 msec
organs not immobilised vertebral column	0 – 10 mm/sec	100 – 200 msec

MOTION VELOCITY AND APPROPRIATE TIME OF EXPOSURE IN RADIOGRAPHS OF ORGAN IN MOTION

Fig. 15

The dose is at least mainly a function of the sensitivity of the recording system. The lower the dose required at the detector system either screen/film system or image intensifier system, the lower is the exposure to the patient.
In recent years a number of new chemical compounds containing rare earth elements are used under this term as intensifying screens. The major advantage of those intensifying screens is the higher absorption of ionizing radiation and therefore they have a greater emission of visible light. Analysing such screens several authors state that the sensitivity is about two times higher than that of calcium tungstate screen. It seems therefore desirable to introduce generally those new types of intensifying screens. The advantage of the new screens lies in the reduction of the dose or the improvement of the definition, or both. As in most cases of examination

of the thorax and abdomen the level of unsharpness is mainly due to the motion unsharpness, it is also advisable to use intensifying screens of the parspeed type. In units which can produce only low dose rates it is generally advisable to apply high speed screens.

From the medical point of view the problem of image quality is manifold. It is not only a question of the radiographic image itself but also one of applying the most appropriate examination method (efficiency) and of course of the indication for the most useful method to receive the information and diagnosis desired (efficacy).

INDICATION	SELECTION OF PROCEDURE	PERFORMANCE OF THE RADIOLOGICAL EXAMINATION
EFFICACY	EFFICIENCY	QUALITY
REFERRING PHYSICIAN	RADIOLOGIST	RADIOLOGIST AND MEDICAL RADIOLOGY TECHNICIAN

Fig. 16 ANALYSIS OF RADIOGRAPHIC QUALITY

When analysing the radiographic quality of a recorded image the greatest influence on this multiple factor systems has the malfunctioning of one part of the equipment system. The multiple factors that influence the radiographic system must therefore be identified and examined. Fig. 17 summarizes again those technical factors which mainly contribute to the production of an optimal image. A bad image which has an inadequate contrast or an insufficient or excessive density or does not have the required resolution cannot be used for a proper diagnosis, as the viewer cannot adequately visualize the structures of interest.

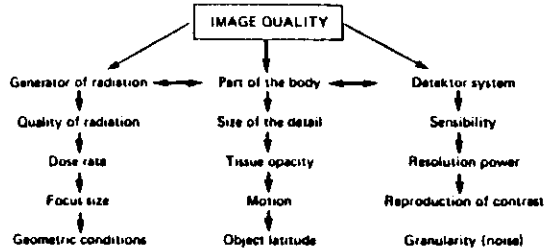


Fig. 17 FACTORS WHICH INFLUENCE THE QUALITY OF A RADIOGRAPHIC IMAGE

Usually each factor influencing the image quality by malfunctioning of one part of the system increases the dose and reduces simultaneously the diagnostic quality.
It seems therefore necessary to identify the major properties of the visible image and the factors that influence it. This is the basic and essential need in order to avoid or overcome the errors inherent in this complicated technical system. The challenge which is again expressed in the recommendations of the International Commission on Radiological Protection and the workshop of the World Health Organization on efficacy and efficiency to develop and adopt programmes of quality control and quality assurance in diagnostic radiology should lead to an improvement of the diagnostic quality and of the diagnostic procedure and to reduction of wastage. This is equally important in industrial as well as in developing countries.

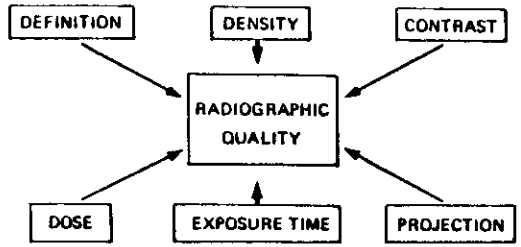


Fig. 18 CONDITIONS INFLUENCING RADIOGRAPHIC QUALITY

Summary:

An image of optimal radiagraphic quality must possess sufficient structural definition, with a minimum of distortion. It must have proper density and contrast in a range which is defined by the physiological conditions of visibility.
To evaluate the quality of the radiographic image the major properties which influence the quality of the recorded image must be identified from the medical point of view. The visibility of the recorded image - this means the reproduction of the information, which is produced in the x-ray beam by interacting with the part of the body penetrated by the ionizing radiation - depends mainly on the factors: definition, contrast, mean density, projection, motion and the required dose. In order to translate the information, carried by the radiation image, into a visible form suitable for interpretation and diagnosis it is necessary to evaluate the properties of the anatomical details which are the basis of the medical diagnosis i.e. detail size, detail contrast, their geometric properties and the properties of the recording system.
Modification of one exposure factor frequently results in change of more than one property of the radiographic image.
Malfunctioning of one part of the system diminishes image quality and increases the dose.

Quality control and quality assurance is therefore the dominant factor to improve the diagnostic quality, reduce dose and wastage.

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X-RAY TUBE AND X-RAY GENERATOR

Before talking about the systems mentioned above, some definitions will be given:

- Tube means an x-ray tube, unless otherwise specified.
- Tube housing assembly means the tube housing with tube installed. It includes high voltage and/or filament transformers and other appropriate elements when they are contained within the tube housing.
- Variable aperture beam limiting device means the beam limiting device which has capacity for stepless adjustment of the x-ray field size at a given source-image receptor distance. - X-ray high voltage generator means a device which transforms electrical energy from the potential supplied by the x-ray control to the tube operating potential.
- X-ray control means a device which controls input power to the x-ray high voltage generator and/or tube. It includes equipment such as timers, phototimers, automatic brightness stabilizers and similar devices which control the technique factors of an x-ray exposure.
- Automatic exposure control means a device which automatically controls one or more technique factors.

Tube Housing Assembly and Tube (Fig. 1 - 10)

The most important parameters influencing image quality are

focal spot size (sharpness)
tube rating (exposure time)
kilovoltage applied to the tube
(contrast and penetration)

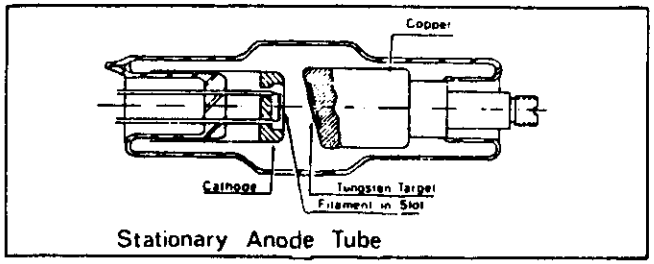


Fig. 1

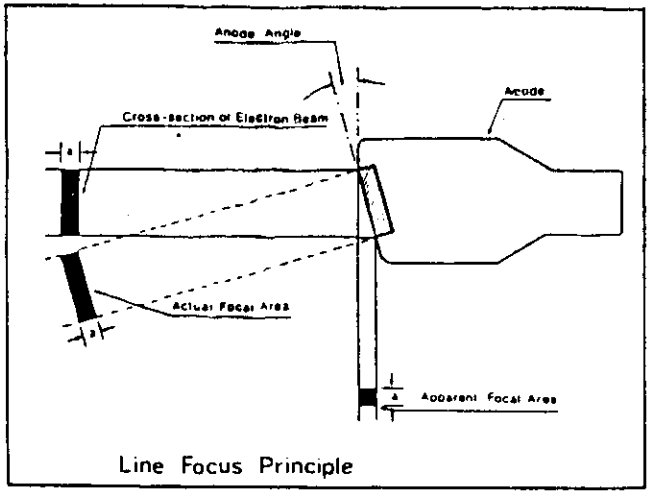


Fig. 2

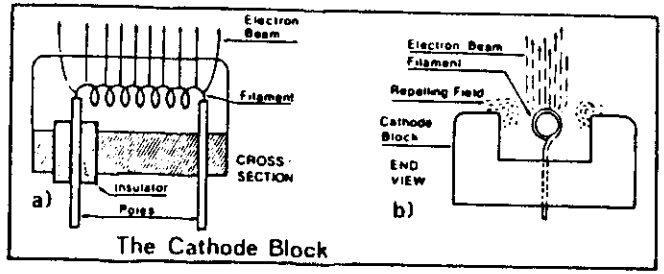


Fig 3

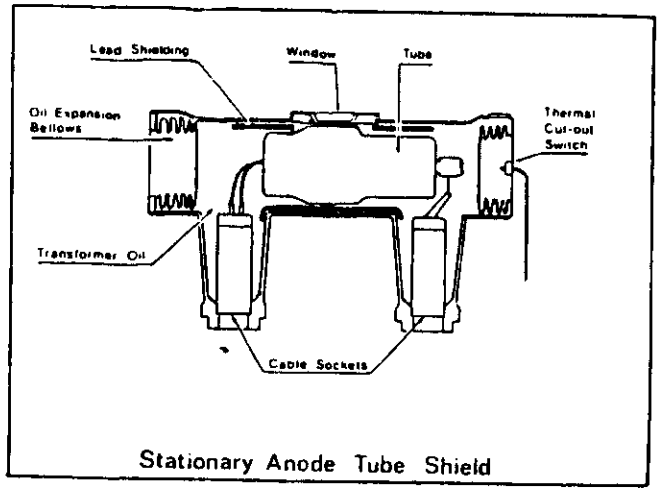


Fig. 4

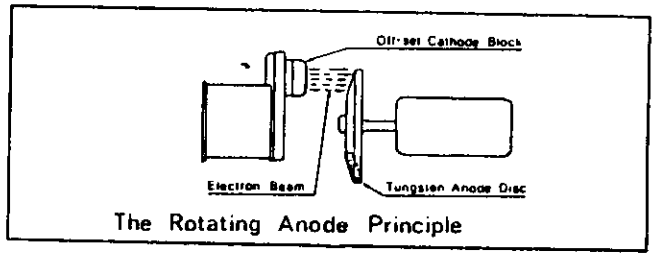


Fig 5

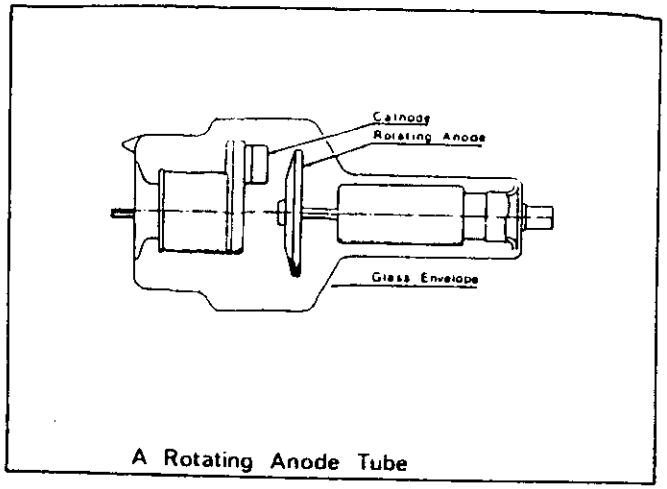


Fig. 6

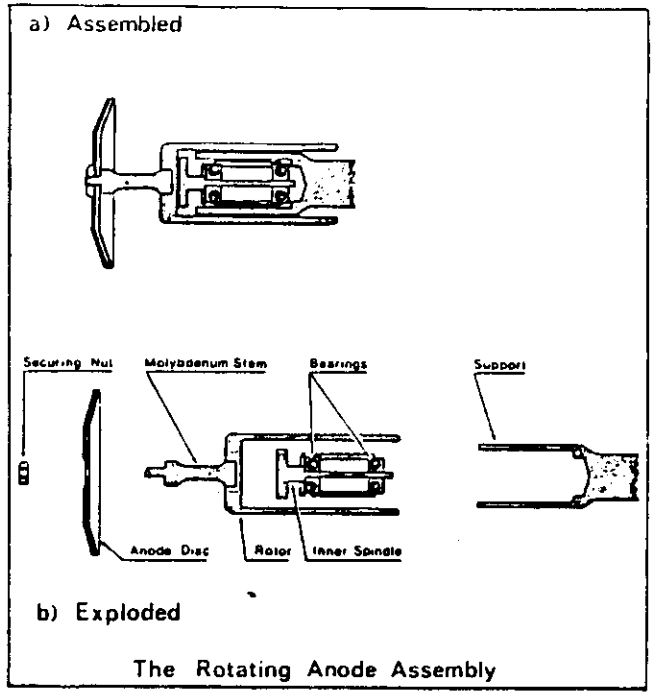


Fig. 7

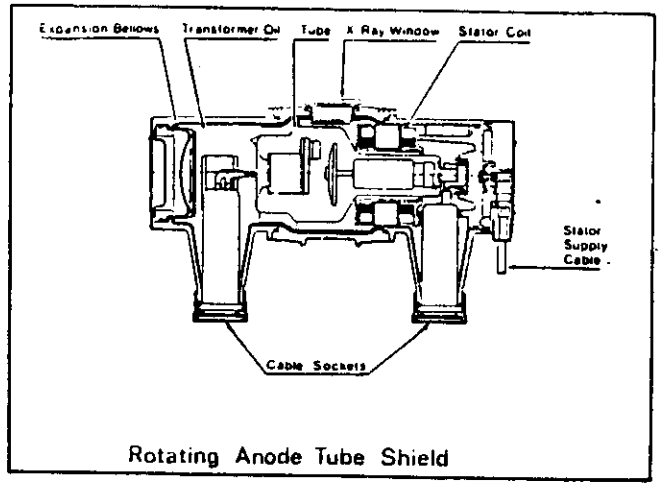


Fig. 8

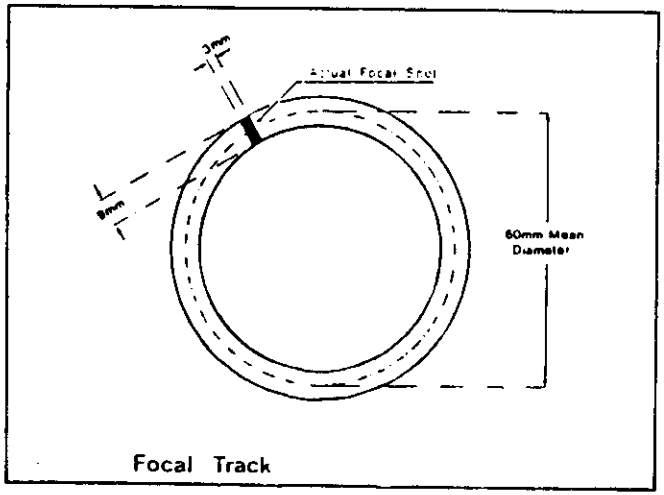


Fig. 9

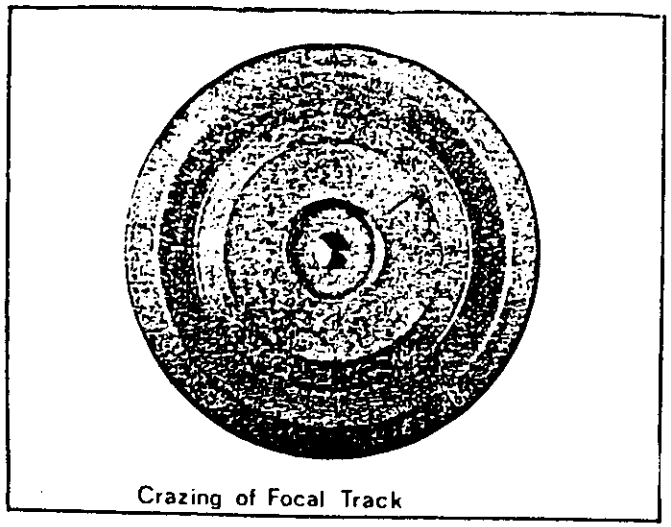


Fig. 10

Other parameters of some influence are extrafocal radiation, anode angle and proper function of the variable aperature beam limiting device.

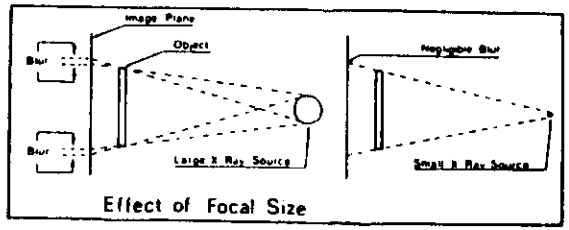


Fig. 11

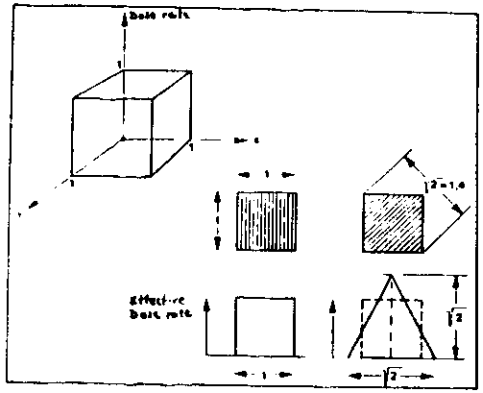


Fig. 12

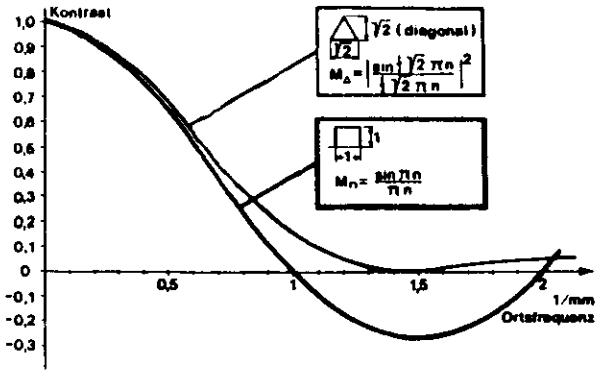


Fig. 13

The focal spot has for practical work a direct relation to the sharpness in the image produced by central projection (Fig. 11). But not only the linear dimensions of a focal spot are of importance. The distribution of the emission centers is relevant. This is shown in Fig. 12 - Fig. 13 for different focal spot sizes.

The modulation transfer function (MTF) has been calculated and one can see that focal spots of different linear dimensions sometimes lead to a less favorable MTF, although their linear dimensions are quite small.

The kilovoltages and spectral distribution of emitted radiation depend on the properties of the tube in certain respects because the construction of the tube and tube housing limits the applicable voltages.
Their setting and the possibilities to set them at a correct absolute value depends strongly on the x-ray control system and structure of the x-ray generator (Fig. 14, Fig. 15).

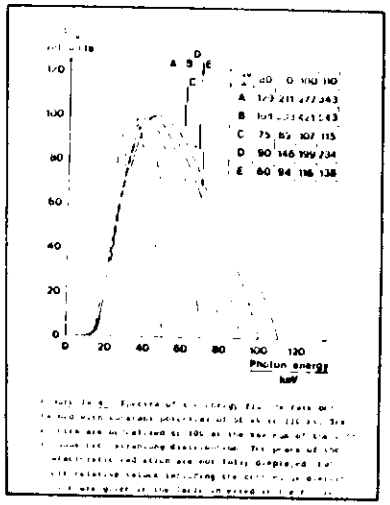


Fig. 14

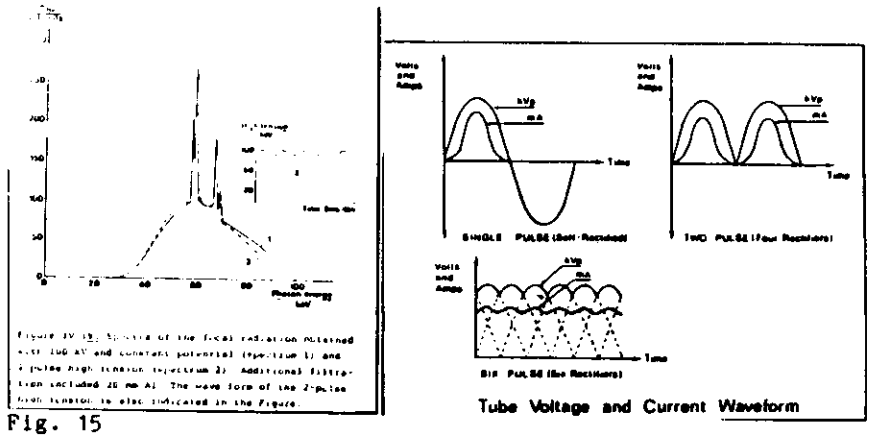


Fig. 15

The tube rating is of importance because a high tube rating means a high output and this again means a short exposure time and little influence of patients motion on the sharpness. The possible tube rating is directly related to the focal spot size. It depends on the high voltage waveform produced by the x-ray generator (Fig. 16, Fig. 17).

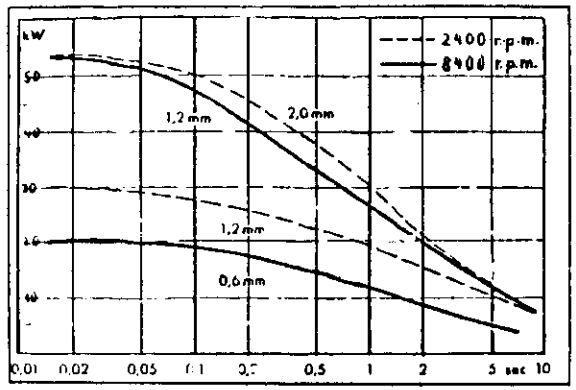


Fig. 16

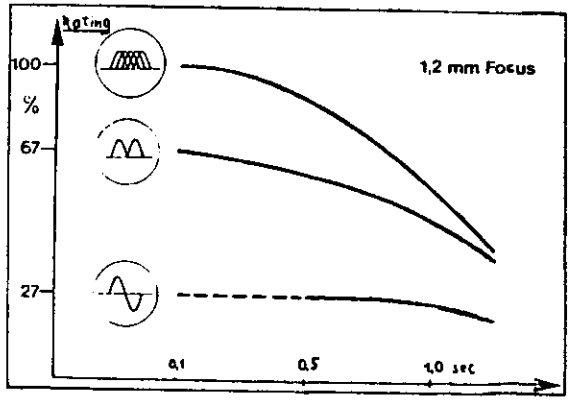


Fig. 17

Extrafocal radiation (off-focal radiation) belongs to the properties of an x-ray tube itself. But its influence depends on the construction of the beam limiting devices, i.e. variable aperture as well as fixed beam limiting devices (Fig. 18).

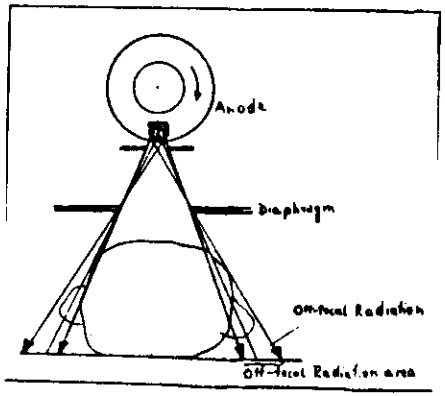


Fig. 18

In principle, such a beam limiting device should consist of two well adjusted limiting diaphragms. One should be as near as possible to the focal spot and the other one should be placed as far as possible away from the focal spot. In practice, there are limits for this requirement and the alignment of the shutter leaf diaphragms in no case is really perfect.

The amount of extrafocal radiation can be estimated in different ways. One way is just to estimate the range within which extrafocal radiation can be seen when the beam limiting device confines the x-ray field to a certain size. This gives an impression of the area covered by the extrafocal radiation. Measurements can be done via photometric evaluation of films exposed to extrafocal radiation and to the total radiation coming from the focal spot. The amount of extrafocal radiation measured as dose rate compared to the total radiation is in the order of magnitude 5 % to 20 %. Modern tubes usually have an amount of 5 % to 10 % of extrafocal radiation. Experience has shown that in the radiographs themselves no significant difference can be observed in the case of 5 %, 10 % or even 20 % of extrafocal radiation.
The spectral distribution of the extrafocal radiation is nearly the same as that of the focal radiation with a slightly reduced high energy portion.
The intensity distribution in the useful beam depends on the anode angle and age of the anode (Fig. 19).

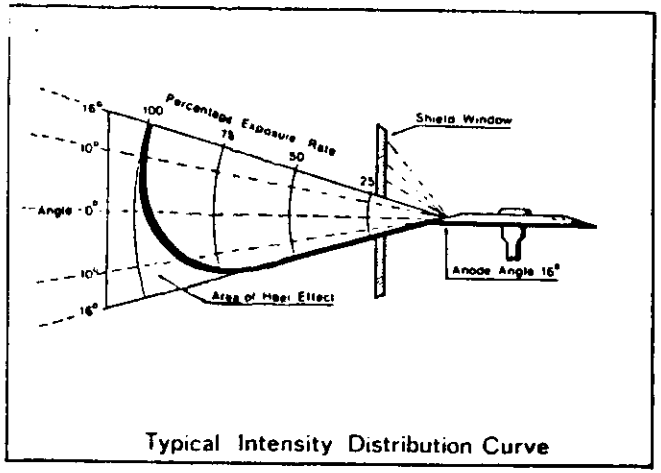


Fig. 19

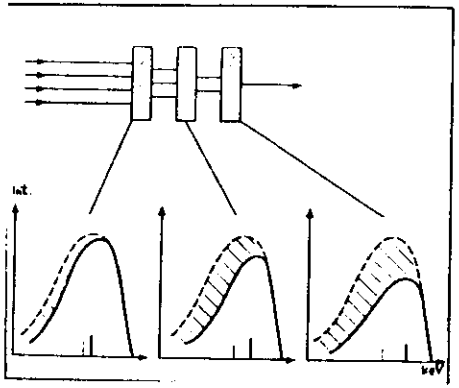


Fig. 20

The total filtration of the tube housing assembly within certain limits serves the purpose of preventing low energy radiation from impinging upon the patients (Fig. 20).

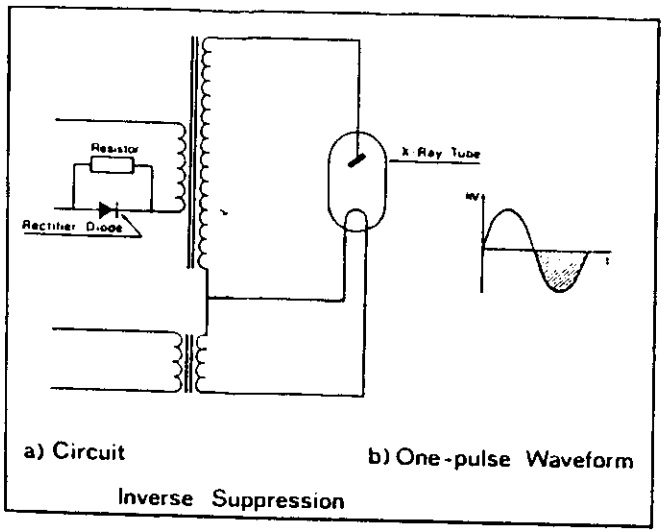


Fig. 21

The X-Ray Generator plus X-Ray Control:

The high voltage is produced by a high voltage transformer and is then rectified by the x-ray tube itself or by rectifiers (Fig. 22 - Fig. 24).
This results in different wave forms of the high voltage applied to the x-ray tube. (Voltages are usually "peak kV" and not RMS-values). The generator controls furnish the power, this means kilovoltage and tube current, to the x-ray tube.

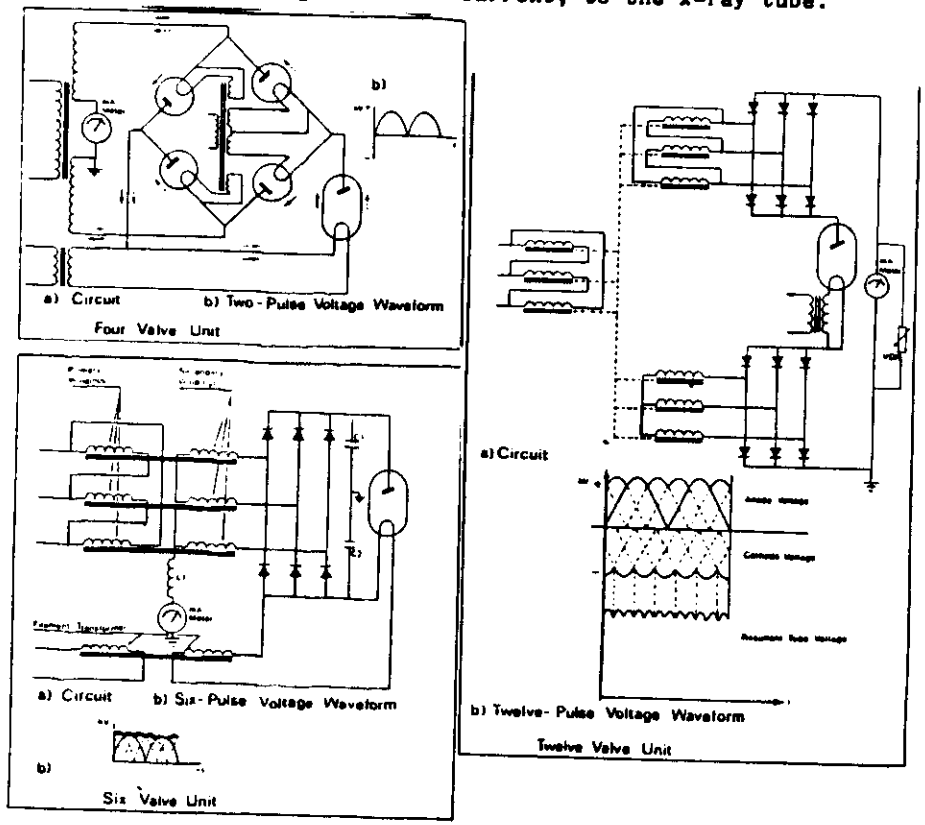
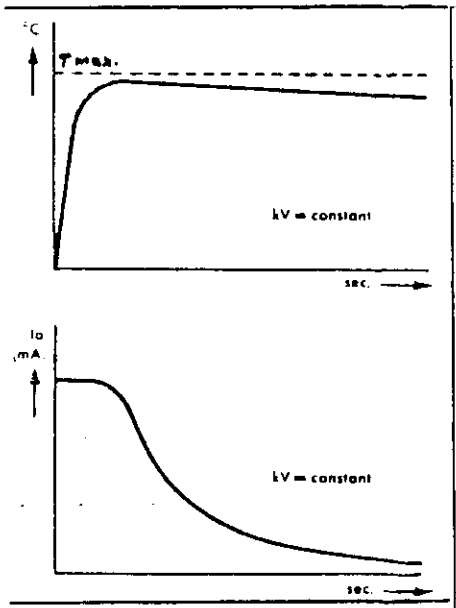


Fig. 22

During exposures there is the possibility to diminish the tube rating depending on maximum anode temperature. The tube rating depends on the high voltage waveform too and is different for instance for 6 pulse generators of full wave rectification (Fig. 17). By definition, the automatic exposure control belongs to the x-ray control. Usually it is an ionisation chamber which is placed in front of the film behind the grid (Fig. 25). It switches off the x-ray generator as soon as the necessary dose has been accumulated. The amount of this dose depends on the film-screen-combination used in each particular case.



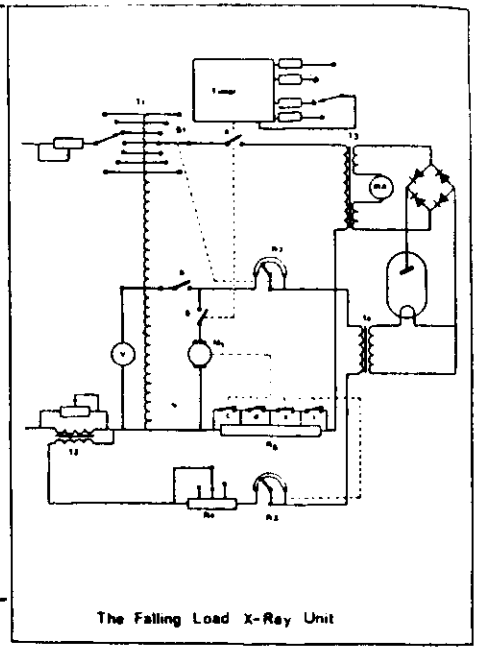
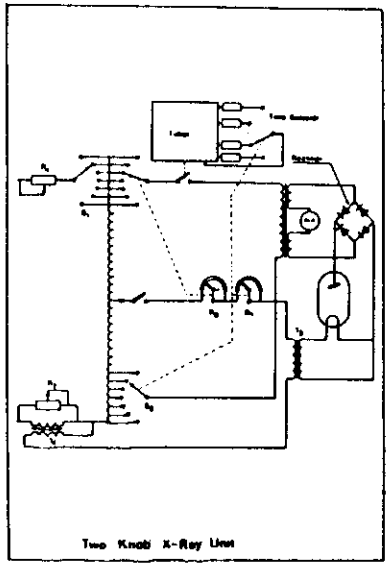

The Falling Load X-Ray Unit

Fig. 23


Two Knob X-Ray Unit

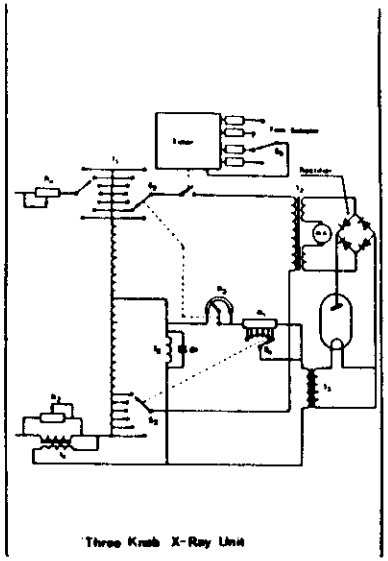
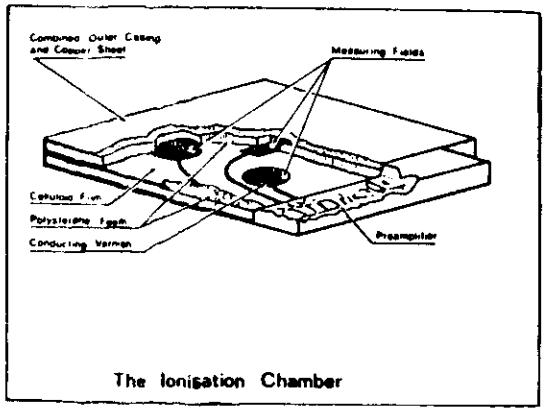

Three Knob X-Ray Unit

Fig. 24



The Ionisation Chamber

Fig. 25

For fluoroscopy the x-ray control controls the high voltage as well as the tube current in a way that is given by experience. Usually the current and high voltage go up and down in the same sense, which means low voltage and low tube current and high voltage and highest possible tube current (Fig. 26).

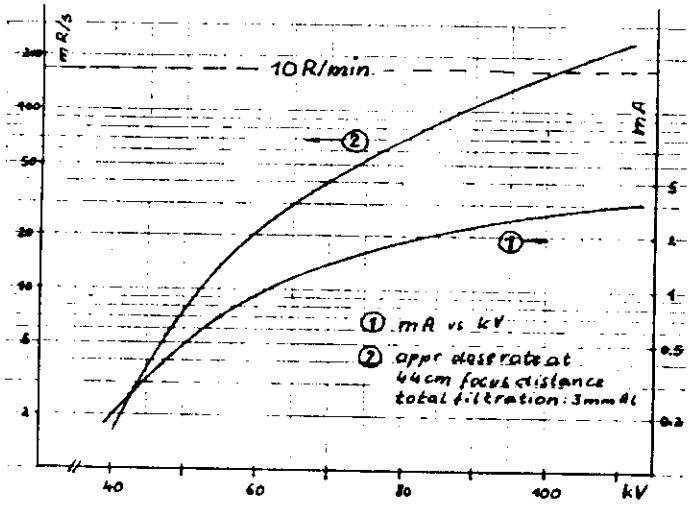


Fig. 26: Automatic dose rate control

During the last years, a new trend in high voltage generation has come up. It is called "converter-inverter-technique" or "Multipulse technique" etc. Its principle means to rectify the low voltage and to produce an alternating voltage of 3000 to 6000 cycles per second by means of an inverter. This alternating power is supplied to a high voltage transformer. The resulting high voltage is rectified and supplied to the x-ray tube.
The advantages of such a system are: Very small dimensions of the high voltage circuit and the possibility to control the high voltage and power via the primary circuit as well as via the secondary circuit, very low ripple althoug small smoothing capacitators are used.
If this trend continues in the coming decade, x-ray generators and x-ray controls of this type will become very popular.

Origin of Pictures.

All pictures belong to publications that are the property of a manufacturer of x-ray systems, except No. 14 and 15. No. 14 and 15 were copied from a Thesis by Gudmund Svahn, "Diagnostic X-ray Spectra" Radiation Physics Department, University of Lund, Sweden, 1977

Dipl. Ing. J. Niepel
Siemens AG, Erlangen

IMAGE RECEPTORS - FILM-SCREEN COMBINATIONS AND IMAGE INTENSIFIERS

The radiation profile behind the patient is a non-visible image with different intensities and energies. It depends on the primary x-ray spectrum and the penetration of the object. The radiation profile has to be converted into visible light. To reduce the necessary dose as much as possible we must look for converters with a high intensification factor.
The first converter was the fluoroscopic screen. It was low in light output and resolution. Good adaptation was necessary. Soon the documentation on film was introduced. Cassettes with different screen-film combinations are also today the basis for diagnosis.
In the 50th the x-ray image intensifier was introduced. In the beginning the output image was viewed directly by a special mirror-optic-system. Later a television-chain was adapted to its output. The next step was to introduce a beam splitter or light distributor. That gave the possibility to adapt a tv-system and a photographic camera. The images were recorded on 70 mm roll-film, later on 100 mm sheet-film or 105 mm roll-film. This medium-size films could be transported rather quickly. So it was possible to do fast series up to 6 frames/second. For heart-studies however this was not fast enough. So the cardiologiststried first took cine pictures from the tv-monitor. The quality was improved by adapting 16 mm cameras directly to the image intensifier. Today only 35 mm cameras are used with a really high image quality. The latest development in conventional radiology is digital imaging. To allow all the possiblilities of manipulating tv images via digitizing it is necessary to have a high quality image intensifier and television chain.

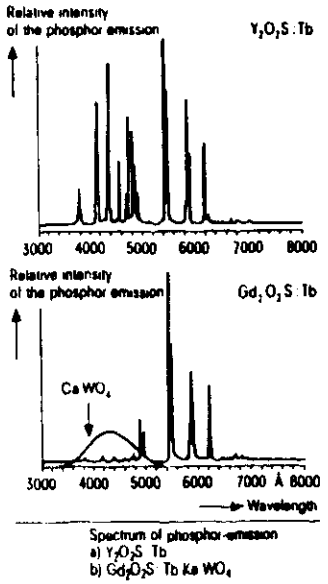
Intensifying screens

The first fluorescent material used for intensifying screens was calcium tungstate, discovered by Edison in 1896. Inspite of discovering also other phosphors as lead barium sulfate, the application of calcium tungstate lasted over 80 years and is used still today.

Year	X-ray phosphor	Short-wave absorption discontinuity	Maximum emission at		Trans formation into light	Density	Crystal system	Index refraction n
1896	$CaWO_4$	69.5 keV	425 nm	blue emission	4%	6.8 g/cm³	tetragonal	1.9
1940	$BaSO_4$:Pb	37.4 keV	350 nm		4%	4.48 g/cm³	orthorhombic	1.6
1969	LaOBr:Tb	38.9 keV	437 nm		13%	6.28 g/cm³	hexagonal	2.3
1972	$(Ba,Sr)SO_4$:Eu	37.4 keV	380 nm		8%	4.48 - 3.91 g/cm³	orthorombic	1.6
1975	BaFCl:Eu	37.4 keV	385 nm		12%	4.56 g/cm³	orthorombic	1.6
1972	Gd_2O_2S:Tb	50.2 keV	545 nm	green emission	15%	7.44 g/cm³	cubic	2.6
1972	La_2O_2S:Tb	38.9 keV	545 nm		12%	5.54 g/cm³	hexagonal	2.2
1972	Y_2O_2S:Tb	17 keV	418 nm 545 nm	blue & green	18%	5.0 g/cm³	cubic	1.8

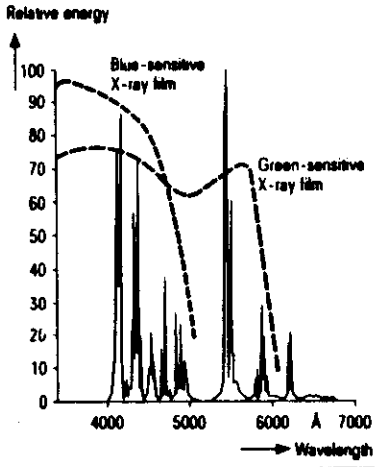
The introduction of the double emulsion film in 1923 brought the first big step for higher intensification by the use of two screens - on each side of the film one. In 1965 Siemens introduced the screen type "Special" which had double the intensification of the "Universal" screen.
In 1972 Buchanan et al proposed the first time the use of rare earth oxisulfides. This was a significant step forwards. At the beginning gadolinium and lanthanum oxisulfide, emitting light in the green range of the spectrum were used. All previously used screens emitted however in the blue range. For the rare earth screens it was now necessary to make new types

of film, especially sensitized to green light. Also the darkroom illumination had to be changed. To avoid these disadvantages, many screen manufacturers used other rare earth phosphors f.i. the blue emitting lanthanum oxibromide. The market was divided into "blue" and "green".



Spectrum of phosphor-emission
a) Y_2O_2S:Tb
b) Gd_2O_2S:Tb Ka WO_4

Fig. 1 Comparison of the spectral emissions of Y_2O_2S:Tb, Gd_2O_2S:Tb and $CaWO_4$



Film-sensitivity and emission of Y_2O_2S:Tb blue and green

Fig. 2 Spectral emission of yttrium oxisulfide phosphor and its adaptation to blue and green-sensitive X-ray films

To understand the next it is necessary to know the fundamental difference for light emission between calcium tungstate and the rare earth substances. The luminescence process in calcium tungstate takes place in the outer electron shells. This gives a wide emission curve with a maximum in the blue range. The luminescence process in the rare earth phosphors occurs within the inner 4 f shell protected by the outer shells. Therefore we have a line spectrum.

For Yttrium-oxisulfide it is possible to activate emission at 418 /um (blue) and at 545 /um (green).

This phosphor is the basis of the Titan 2 screens. They can be used with blue und green sensitive films as well. Also the exposure values for both systems are the same for the same film density.

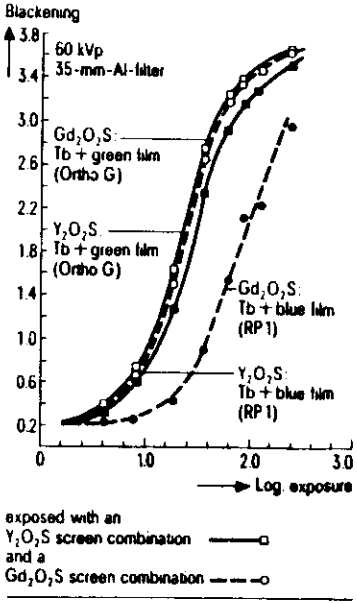


Fig. 3 Gradation of a blue and a green-sensitive X-ray film

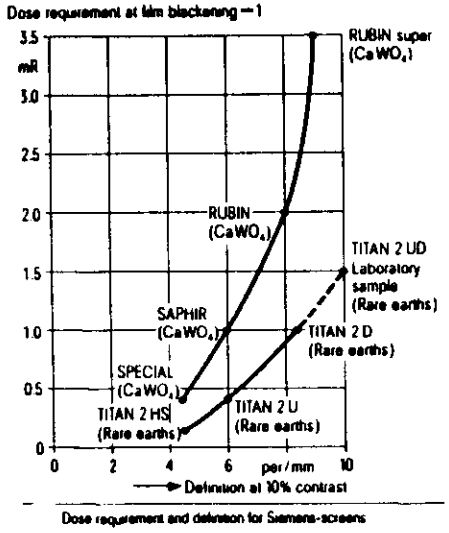


Fig. 4 Dose requirement and definition of Siemens intensifying screens. Radiographs at 77 kV/22 mm Al total filtration

Not only the emission color but also the other characteristics as intensification factor, modulation transfer function or simplier the sharpness or resolution, the voltage response, the lifetime, the mechanical and electrostatical properties are important.

To understand that, we may look at the composition of an intensifying screen. The first layer on the supporting material (paper or plastic material is a reflection or absorption layer. The next is a layer of luminescent material, small crystals bedded into a bonding agent. The thickness of that layer is mainly responsible for the intensification factor

and the resolution. The surface coating is not only a protective layer but is also responsible for the mechanical and electrostatical properties. To give a low friction coefficient for example for the use in cutfilm changers, the surface contains many embedded small plastic balls.

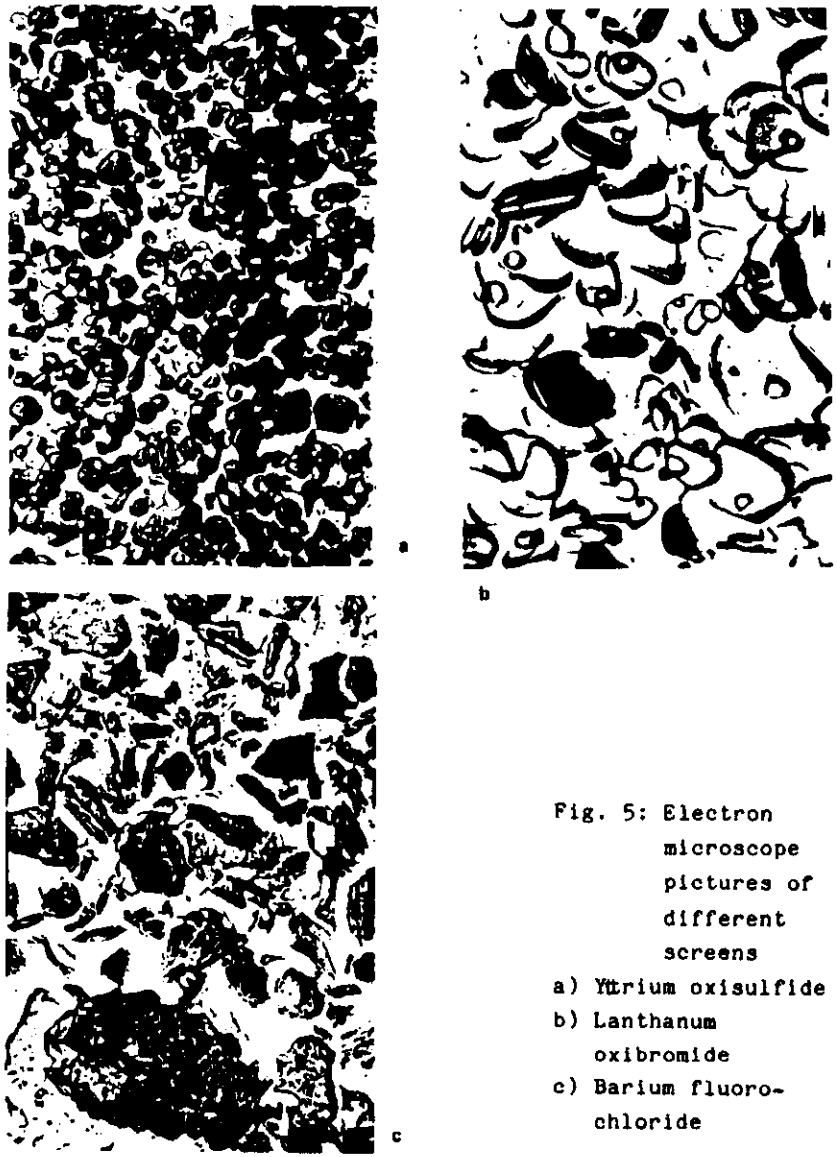
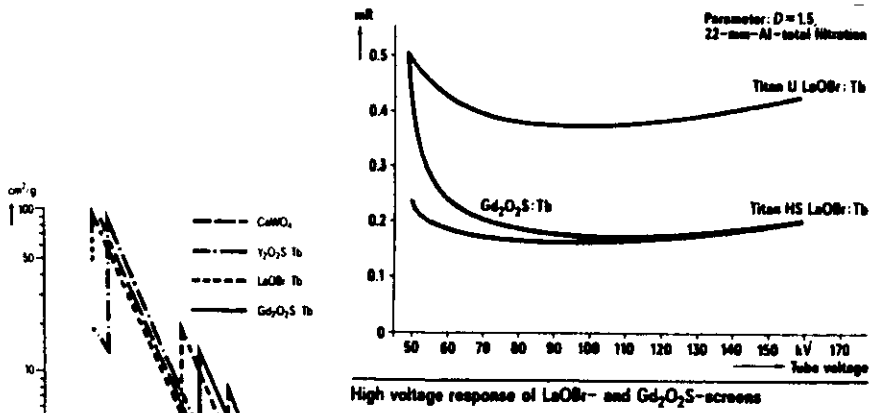


Fig. 5: Electron microscope pictures of different screens
a) Yttrium oxisulfide
b) Lanthanum oxibromide
c) Barium fluoro-chloride

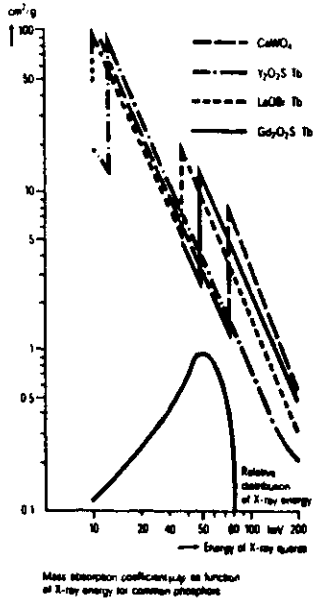
Let us now look to some electron microscopic pictures of different phosphors. The influence on image quality and intensification is obvious. The more close to a spherical shape, the more dense crystal packing is possible. The best in this respect is the yttrium-oxisulfide. Irregularities or even crystal lumps like in the bariumfluorochloride picture give a high granularity, the loose packing a relative low intensification.
The refraction index of the crystals is also important for the image quality. High refraction index as for gadolinium-oxisulfide is responsible for high light scatter which results in optical blurring of crystal inhomogenities. This gives the impression of a flat less grainy image. However it has a little less sharpness.
The best should be a refraction index close to that of the bonding agent, that means about 1.5. This is true for Calcium tungstate and barium-fluorochloride.

The twin-band phosphor yttrium-oxisulfide has a refraction index of 1.8 which gives together with the fine and regular morphology sharp images with low graininess. The resolution of a screen depends - besides the phosphor-type - on the layer thickness. That is the reason for the fact that always a high resolution screen has a low intensification factor and vice versa. On the other hand a part of the rare earth screens has a higher absorption coefficient than calcium tungstate. Also the transformation into light is much higher for the rare earth screens. That results in a generally higher intensification factor for screens of comparable resolution. This can be used to make exposures with lower dose levels (smaller focus, short exposure time, reduction of patients dose) and same sharpness or to apply the same dose as for $CaWO_4$ and to get a better sharpness.



High voltage response of LaOBr- and Gd_2O_2S-screens

Fig. 6: Energy dependent efficiency of different phosphors



Mass absorption coefficient μ/ρ as function of X-ray energy for common phosphors

Fig. 7

The voltage response depends on the absorption curve of the material used. The lower the K-absorption edges the more flat is the voltage response curve for the diagnostic range.

The lifetime of intensifying screens is no more the same problem as it was in the beginning especially for lanthanum oxibromide.

Most intensifying screens have to be replaced when unproper handling causes scratches so that the surface coating is destroyed locally. Besides the mechanical defect to be seen in the image, also humidity can penetrate and destroy the phosphor.

The use of a not recommended screen cleaner can also destroy the screen. Aging of the phosphor itself is not a problem. But we found that at least lanthanum oxibromide shows a significant loss in light output if it is stored in high ambient temperature. Very intensive sunlight has to be avoided.

There is a wide selection of different types of screens and films on the market. Some film companies as 3 M have a large number of different types of screens and film. Every manufacturer produces high sensitive, universal, and high resolution screens. All producers offer a choice of conventional and rare earth types. Also gradual screens, screens for mammography and some special studies are produced.

The film market is not only divided into blue and green. The major film companies offer films for standard application and automatic processing, but also films which ar better for the slow manual processing or with special characteristics f.i. low contrast. My recommendation is, to decide for one filmtype in order to avoid mistakes in the darkroom. Only two or three different screen types should be enough and give more security for correct exposures. Also it is important to use the same type of phosphor in order to have the same spectral response for all screens.

For a normal radiological epartment a rare earth screen of medium intensification as Titan 2 U, Lanex regular or equivalent types for standard application, a high resolution screen as Titan 2 D or UD, Lanex fine or equivalent for the extremities and if small generators with low power are used possibly a high sensitive system with Titan 2 HS, MR 800 or similar may be sufficient. The film should be a standard with normal contrast range for example the RP 1 for automatic processing or Curix MR 4 for manual development or equivalent types from the other film companies. For mammography special films are provided.
Often mammography is done with a grid and a one-screen film combination.

Mammography screens: Kodak: Min-R, Dupont: Low Dose,
3M: Trimax M, Agfa-Gevaert: Mr 50

Tab. 2: Technical data of screens and films

Agfa Screens

Type	Emission Color	Phosphor Type	Intensification factor
Curix Fin	blau	$CaWO_4$	0.5
Curix Universal	blau	$CaWO_4$	1
Curix Special	blau	$CaWO_4$	2
Curix MR 50	blau	LaOBr : Tb	0.5
Curix MR 200	blau	LaOBr : Tb	2
Curix MR 400	blau	LaOBr : Tb	4
Curix MR 800	blau	LaOBr : Tb	7

Agfa Film-Screen Combinations

Screen / Film	Relative exposure factor		
	RP 1	R 4	RP 1 L
Curix Fin	2	4	2
Curix Universal	1	2	1
Curix Special	0.5	1	0.5
Curix MR 50	2	4	2
Curix MR 200	0.5	1	0.5
Curix MR 400	0.25	0.5	0.25
Curix MR 800	0.15	0.3	0.15

Kodak-Screens

Type	Emission Color	Phosphor Type	Intensification factor
X-OMATIC Regular	UV/blau	$BaSrSO_4 : Eu$	1
X-OMATIC Fine	UV/blau	$BaPbSO_4$	0.2
X-OMATIC Rapid*)	UV/blau		2
X-OMATIC Super Rapid*)	UV/blau		4
LANEX Regular	grün	$Gd_2O_2S : Tb$	1
LANEX Medium	grün	$Gd_2O_2S : Tb$	0.5
LANEX Fine	grün	$Gd_2O_2S : Tb$	0.3

*) Only for the european market

Kodak-Films

Type	Sensitized for color	Characteristics
X-OMAT G	UV/blau	High contrast, medium sensitivity
X-OMAT S	UV/blau	Medium contrast, high sensitivity
X-OMAT L	UV/blau	Low contrast, sensitivity equal to X-OMAT S
ORTHO G	grün	Medium contrast, medium sensitivity
ORTHO H	grün	Medium contrast, high sensitivity

DUPONT CRONEX® Screens

Type	Phosphor	Color	Intensification factor
Detail	$CaWO_4$	blue	~0.35
Fast Detail	$CaWO_4$	blue	~0.5
Par Speed	$CaWO_4$	blue	1.0
Hi Plus	$CaWO_4$	blue	~2.0
Lightning Plus	$CaWO_4$	blue	~3.0
Quanta II	$BaFCl : Eu$	UV	~4
Quanta III	$LaOBr : Tb$	blue	~8
Gradient			* *

DUPONT CRONEX® Screens

Type	Phosphor	Color	Intensification factor
Detail	$CaWO_4$	blue	~0.35
Fast Detail	$CaWO_4$	blue	~0.5
Par Speed	$CaWO_4$	blue	1.0
Hi Plus	$CaWO_4$	blue	~2.0
Lightning Plus	$CaWO_4$	blue	~3.0
Quanta II	$BaFCl : Eu$	UV	~4
Quanta III	$LaOBr : Tb$	blue	~8
Gradient			* *

Tab. 2: continued

Siemens-Screens

Type	Emission Color	Phosphor Type	Intensification factor
Rubin super	blue	$CaWO_4$	3.5
Rubin	blue	$CaWO_4$	2.0
Saphir	blue	$CaWO_4$	1.0
Spinell	blue	$CaWO_4$	0.4
Titan 2 UD	blue-green	$Y_2O_2S:Tb$	1.5
Titan 2 D	blue-green	$Y_2O_2S:Tb$	1.0
Titan 2 U	blue-green	$Y_2O_2S:Tb$	0.4
Titan 2 HS	blue-green	$Y_2O_2S:Tb$	0.2

TRIMAX Film/Screen Systems
and Relative Speeds

Trimax Films	Trimax Screens					
	Trimax 2	Trimax 4	Trimax 6/8	Trimax 8	Trimax 12	Trimax 16
XUD	50	100	150	200	300	
XUL	50	100	150	200	300	
XD	100	200	300	400	600	800
XDL	100	200	300	400	600	
XM	200	400	750	800	1200	1600

Image Intensifiers

X-ray image intensifiers were orginally designed for fluoroscopy and introduced in radiology with a direct viewing optic about 30 years ago. Today they are used together with a television-system. That gives the advantage to be more or less independent of the table (the tv-monitor can be mounted anywhere) and also to some extent from he room light. The tv-picture can be stored on magnetic tape or disc, can be digitized and then manipulated. F.i. "Digital subtraction Angiography" is one of the actual methods. Also hard copies can be made from the tv-image. In many cases - via a light distributor - also photofluorography with a 70, 100 oder 105 mm camera is possible. The application in gastro-intestinal studies is almost standard. But also other studies are done with the medium format image-intensifer photography, using the simple spotfilming possibility, the low dose and therefore short exposure time and the easy to handle magazine technique also for fast series up to 6 frames per second. Very important is the cinematography which is used for cardiac studies all over the world.
Thanks to the high image quality of modern image intensifiers and the input field sizes ranging from 5 inches to 22.5 inches there is nearly no limitation for their use. Also tomography and stereo technique are possible.

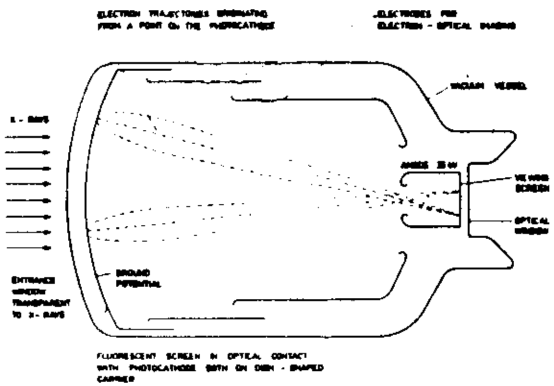
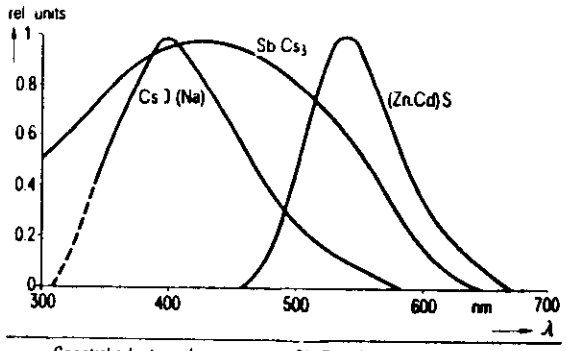


Fig. 8: Cross section of an image intensifier tube

The image intensifier tube is a large vacuum vessel. The radiation converter - the so called input screen is built-in. It is in optical contact with a photo-cathode. The light coming from the entrance screen is converted to electrons. The electrons are focussed and accelerated by an immersion electron optical system to the output or viewing screen. This screen converts the electrons into a light enhanced minified picture. The optical system basis-lens + mirror to plit the beam + camera lens transfers the image to the receptor which is the target of a video-camera-tube or the film.

This image intensifier tube is mounted into a housing which provides magnetic and radiation shielding. Magnetic shielding is necessary for the earth magnetic field alone is strong enough to influence the slow electrons near the cathode. The radiation profile has to pass a very thin coverplate of the housing and the thin Mumetal magnetic shield. The radiation transparency is very high (more than 95 %) and depends on the kV range.
The tube itself has a thin entrance window of about. 0.8 mm aluminium. Only for the very large 57 cm tube, which is designed for lung and vertebral columen examination it is 1.5 mm. The transparency for radiation under ICRU conditions is about 95 % for the 0.8 mm entrance and 92 % for the 1.5 mm. Other tube manufacturers use different radiation windows, f.i. Philips for the 14" tube 0.25 mm titanium which absorbs a little more. The former all-glass tubes had about 2 to 5 mm wall thickness and inspite of using a special glass with high radiation transparency, the absorption was up to 30 %. So the metal input was a big step forwards for better quantum efficiency, lower scattered radiation and higher contrast. This entrance window has to withstand the atmospheric pressure, the respective force for the 57 cm tube is about 3000 kp. Also it must be vacuum-tight. That needs a highly sophisticated technology.



Spectral adaption of u. screens to Sb Cs_3 photokathode

Fig. 9:

This applies also to other parts of the tube, f.i. the entrance screen. Substrate for the phosphor is a thin aluminium plate. The phosphor was in the beginning zinc-cadmium-sulfide (Zn, CdS) and is since 1972 Cesiumiodide (CsJ: Na).
The ZnCd,S was sedimented with a bonding material. The thickness was limited, the light was scattered in this layer and the detection quantum efficiency was relatively low. The maximum packing density was 50 %. The effective absorption was under ICRU conditions about 15 %. The modulation transfer function was lower than today giving a limiting resulution of about two linepairs per mm. Also the contrast of that tubes was poor.

The cesium-iodide in contrary is evaporated on the substrate and grows in upright standing needles. The packing density of crystals is close to 100 %. Also it has higher atomic numbers. Therefore the effective absorption is, epending on thickness of the layer about three times better (45 to 50 %). The light will be piped within the needles. We have nearly no stray-light in the phosphor. For we don't have only ideal crystals but also a certain amount of breakage and other irregularities there is some light scatter. In comparison to the ZnCdS-screens it is very much reduced. The result is a much better modulation transfer function, a reasonable

higher contrast and a very much increased limiting resolution for the i.i., which can reach more than 6 linepairs per mm. That is already in the range of a detail-screen. The higher absorption was not used to reduce the dose but to reduce the signal to noise ratio. Also to image the smaller details more absorbed quantum are necessary.

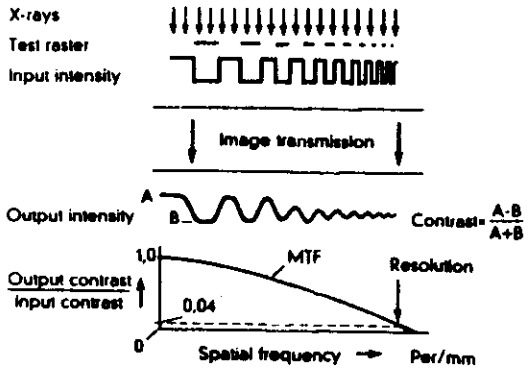


Fig. 10

The input-phosphor is in optical contact to a thin evaporated photocathode layer which is of the S11 type ($SbCs_3$). The spectral response is in the blue part of the spectrum. The blue emitting CsJ:Na is much better adapted to the S11 than the ZnCd,S with green emission had been.

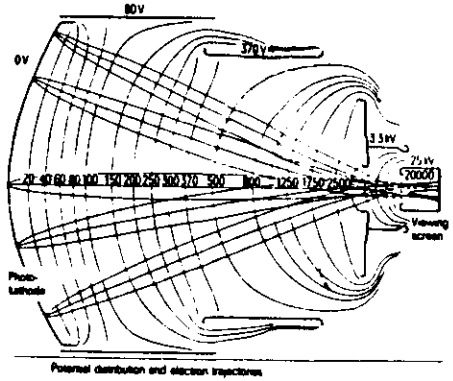


Fig. 11

Behind the photo-cathode (which is on 0 Volt in our tubes) we have an electron image which is a true reproduction of the radiation profile. Every image point generates an electron bundle. If the electron optical system consisting of cylinder and disc electrodes plus anode does the job very well, we will get a reversed minified and light enhanced sharp picture with a homogeneous sharpness over the whole image, a lowest possible distrotion and vignetting. All this must be possible for two or three modes inspite of having a concave input screen and a flat output screen. Therefore the electron bundles have to be focussed so that all electrons coming from one point at the entrance hit the output phosphor on one point. The electrons will be accelerated from 0 to 25 kV. The electron optical system of many tubes has besides the cathode and the beaker-like anode 3 focussing electrodes. The voltages on that electrodes must be adjusted with a tolerance of less than 0.5 %. To make that easier we have normally besides the fixed 0 V on the cathode and the 25 kV on the anode the voltage for two of the focussing electrodes also fixed and for each mode only one voltage variable to allow adjustment for best sharpness. This is the possibility to mention an important point for quality assurance. No power supply in the world is absolutely stable for ever. Small changes especially in he proportionality can occur due to aging of components and temperature changes. Changes of more than .5 % reduce remarkably the visible sharpness. Therefore it is a must to check the image quality and the voltages from time to time, about twice a year.

The already mentioned output screen has a green emitting ZnCdS phosphor. The spectrum is similar to that of a p 20 type phosphor. The quality of this screen has very much influence on the overall image quality. The linear reduction of image size is between 6 and 15. That means that the area for an image detail is factor 36 to 225 smaller on the output than on the input. To get a good sharpness a fine grain phosphor in a very thin layer must be used. Normally the output screen has a sedimented layer of small crystals with a certain amount of bonding agent. Light is emitted in any direction.

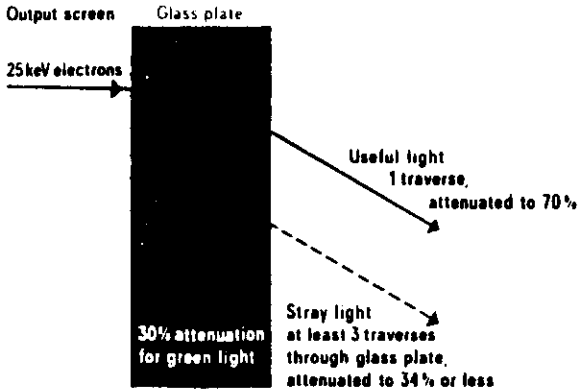


Fig. 12

To improve the contrast it is obvious that the stray-light has to be reduced. This can be done by using a filterglass as carrier for the phosphor. Another possibility would be to use a fiberglass plate. We call an output screen with reduced stray light "Brilliant"-screen.

The most important big steps for the todays high quality image intensifier were:

1. Introduction of metal input instead of glass
2. CsJ:Na input screen instead of Zn,CdS
3. better computer calculated electron optic
4. more precise manufacturing of he tube
5. better fine grain output-screen and
6. contrast enhandement by stray light reduction of the output screen.

Now the conversion chain of an image intensifier is completed. The x-ray beam profile was converted to light, then the light to electrons and the electrons again to visible light. We got a small but bright image on the viewing screen which is sharp and contrasty enough to allow diagnosis via television or mid format or cine-photography.
The physical data of an image intensifier are constant over

many years. Only the conversion factor G_x which ranges between 40 and 300 cd / mR can drop, mostly when image intensifiers are stored at high temperatures - more than 30° C -. The high potential at the output is responsible for electrostatical attration of dust. Dust particles on he output-window, the lenses or mirrors absorb light and lower the contrast as well. To avoid this it is necessary to check and clean the surfaces at least once a year.

The other parameters of the image intensifier tube itself cannot change during the lifetime. As already mentioned the sharpness will not change as long as the potentials don't change. The image size cannot change as long as the voltages are correct. The contrast will be absolutely constant when the optical surfaces are clean. The image intensifier is a high vacuum tube. The vacuum is about 10^{-6} torr. But there is a lot of material built in. Inspite of degassing all the parts and the complete tube under vacuum at high temperature, it can happen that some gas is released. These gas atoms will be ionized by the electrons, focussed to the center of the entrance screen. From here electrons are emitted and occur as a bright "ion spot" in the center of the image. If not gettered, the ions are able to destroy the photocathode locally with the time. Therefore every image intensifier has a gettering device.

From every test protocol of an image intensifier you can read the conversion factor G_x. To know this value is helpful to calculate the diaphragm for the cameras. Sometimes it seems that the G_x has dropped with the time. One possibility is, that dust settled in the optical path. That can be cleaned. The other is storage or use at very high temperature over a long time. If the intensification is no more high enough for practical use the only solution is to change the image intensifier. It will not be helpful to measure the conversion factor in the field. To get the proper conditions it is necessary to measure the tube alone which is somewhat difficult. We have no good experience with field measurements. It is

much easier to check all the other parts of the installation. (So are dose level, tv signal, film blackening). But there is no doubt, the viewing screen will become grey - (less light output). You can see that after a relative short time, if the collimator is always fully open and direct radiation hits the i.i. in the same region. But this is not a proper use of an i.i..
The best image quality you will only have with the smallest possible irradiated field. The conversion factor given in the test protocol is always for the largest format. If you use another mode, the dose will be higher for the same factor as the input field area is smaller compared to the full entrance. For instance if you switch from 10 to 7 inches you need about double the dose. By means of the automatic dose control or exposure control unit via a photomultiplier as a light measuring device the luminance of the output is kept constant or set always to the correct exposure by adapting the dose level. This device compensates also for different absorbing objects. Therefore a dominant area is defined which is a circular field of about one third of image diameter.

In the test protocol you will further find the image size and the electrode voltages for the different modes. That allows - simple check and adjustment.

All the other tube characteristics as contrast factor, sharpness, distortion, vignetting and so on cannot change with the time. They are not listed in the protocol.

Let me give you a few figures to the image intensifier data. The contrast factor for our tubes was in the late 60th about 6 : 1, in the late 70th it was already double the value and since about one year it is three times higher, reaching about 18 : 1. As far as I know also the other manufakturers have about 15 : 1 to 18 : 1. The limiting resolution which corresponds with the 4 % contrast value of the MTF curve was f.i. for the zoom-mode of the 10 inch tube with ZnCd,S input

screen (end of the 60th) about 2.2 lp/mm. The first tubes with CsJ:Na in the early 70th had already 3.5, in the mid 70th it was 4.6 and is now for the most modern image intensifiers for zoom mode between 5 and 6 lp/mm maximum. That means that with photofluorography most of all diagnostic studies can be done.

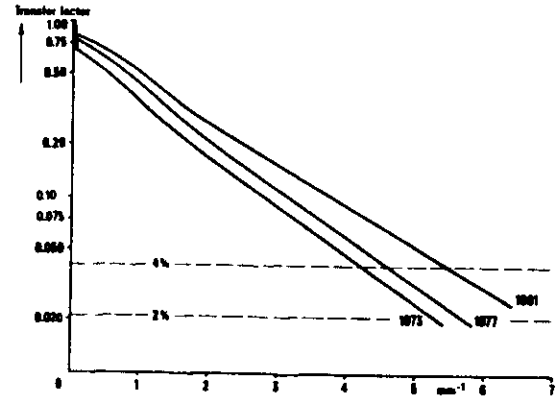


Fig. 13: Improved resolution in image intensifiers

The MTF is the contrast as a function of the spatial frequency. The curves for the same type of i.i. but for different years show the increase in limiting resolution as well as the increase of contrast also for lower frequencies. The high frequencies are important for imaging very small details as bone structure, small vessels and also to get better sharpness at the edges of an object. That is nearly the same difference as between telephone and high fidelity.

From our experience we can recommend certain dose rates for fluoroscopy and exposure dose levels for our image intensifiert. They are based on the fact that lower doses can be produced by the x-ray generator-tube system with lower kV

and shorter exposure time. Also more often the small focus can be used which gives a better image quality especially when geometrical magnification cannot be avoided. Last not least we have a remarkable low patient dose level. On the other hand the signal to noise ratio must be good enough not to loose information by quantum noise.
All recommendations are given for the full input diameter of an image intensifier. If you see the higher figures for the smaller tube type then put into account that the image size on the monitor or film is the same for each i.i. To get the same noise impression it is necessary to adapt to input size.
For fluoroscopy we recommend for the 9 and 10 inch tubes 20 µR/s and for the 7 or 6 inch tube 40 µR/s as normal value for both - standard and high resolution tv-system.
Notice that an increase in dose rate of factor 2 (as recommend for the second dose level for special application) decreases the noise only by $\sqrt{2} = 1.4$ which is rarely to be seen in average pictures. The large 33 cm i.i. which is always triple mode should be adjusted to about 15 µR/s.
For photofluorography we recommend for all tubes the same 50 µR/frame. That is due to the short exposure time which is wanted for oesophageal studies, heart studies and so on. The limit for noisy pictures is somewhere between 30 and 50 µR. So there is no risk to run all i.i. tubes at 50 µR/frame.
Cinematography should be done with 10 µR/frame on the 10 or 9 inch tubes whereas 20 µR/frame are recommended for the 7 or 6 inch tubes. From our experience blurring by quantum mottle was only in a very few cases a problem with that dose levels and I am not sure how correct the dose measurement in that cases had been, as such low level measurements are not easy. But always the advantages of the short exposure time (no motion - unsharpness) and the possibility to use more often a small focus for better Geometry was dominant. If you get noisy pictures with that dose level check first the contrast. In most cases the contrast for the tv-monitor or the gradient of the films was too high.

Television-Systems

Every electron-optical x-ray image intensifier is equipped with a television-system. A tandem optic lens system transfers the image from the output screen fo the i.i. to the receptor, in this case the target of a video camera-tube. The light beam between the i.i. basis lens and the camera lens is parallel (Infinite focussing). The high aperture especially of the i.i. lens requires a precise focussing of the optic. On the other hand - the tandem lens system allows beam splitting which is used for the photomultiplier attachment. The 90 % mirror in the light distributor allows watching a camera exposure or cine run via television. In cardangio-units parallel recording on magnetic tape recorder during a cine-run is quite normal. The normal fluoroscopy is not only a possibility for easy spotfilming, it also allows in many cases to find the diagnosis only from the tv-screen. This is standard f.i. for g.i.-studies.

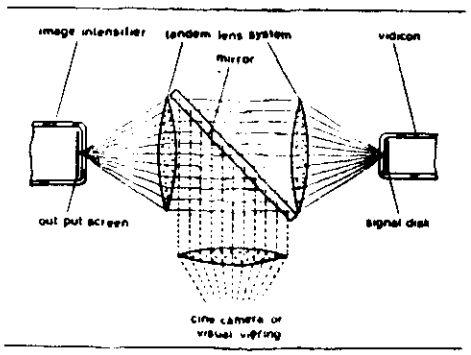


Fig. 14: Beam splitting in the output of an image intensifier

The above mentioned digital subtraction angiography is another application of television, not to forget the surgical application. So we have a wide range of different studies which needs also different characteristics of the tv-image. To adapt

to the different requirements there exist different types of camera tubes, different tv-chains, the standard line system and the high resolution system and last not least a big variability in adjustment for the dark current, the camera or BAS-signal, the dark value, he white limitation, the video amplification (automatic), the plate voltage and possibly some more.
The camera tubes as the first link existend in the past in zwo different versions. The one was the classic vidicon type. It has a gamma-value of γ = 0.7 and a relative slow decay-curve. This tube is used for examinations with not too high object movement when a flat and not to noisy picture is required. The lead-oxide-vidicon or Plumbicon^R type is much more fast, therefore more noisy. It has a γ = 1.0 and has no dark current. It costs much more and has to be gettered during storage. Now much more types with different characteristics as Chalnicon, Pasecon and so on will be introduced.

Recently we found, that the so called slow vidicon or Hivicon^R can also be used for cardiac studies. The heart motion is very high and so everybody expected a bad picture for a tube with a high lag. May be that the noise reduction by that tube in comparison to he lead-oxide type is so much more important. Anyway the heart motion was no problem in the tests. On the other hand it is not good for the oesophagus studies, maybe for the high contrast we have there.

The television system itself is a standard 625 line system with 50 cycles for normal application. Besides that we developed several years ago a high resolution system with increased bandwidth and 1249 lines. The limiting resolution is reasonably better in comparison to the standard system. But also the noise seems to be increased. This is not true. The fact is, that every detail is better imaged as the comparison of the MTF curves shows, and this applies also to the quantum noise. Most people however are able after a certain time to subtract the noise in their brain and to see

the interesting details better. This is a kind of mental training which is for instance normal and fully accepted from doctors who analyze for example the pictures from lung mass studies.

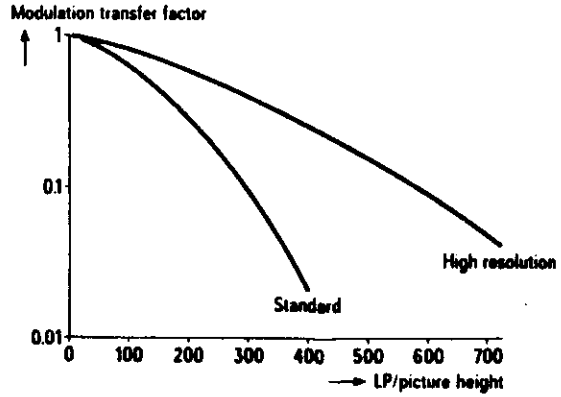


Fig. 15: Improved resolution in special TV-systems

To get the highest information from a tv-system a few facts must be recognized: the vidicon type camera tube give always more information than a leadoxide vidicon, especially on a high resolution system as Videomed H^R; the adjustment of the tv-chain must be done very exact; the viewing distance to the monitor depends on the perceptibility of the observer and should be about 5 times the monitor screen diagonal for a standard system and 1,5 times the diagonal length for the high resolution system; the contrast for the monitor must be adjusted relatively low and the brightness is adapted to the reduced room illumination.
The conversion factor of the individual image intensifiers are different and also the sensitivity of the camera tube. On the other hand we have a certain recommended dose rate. The videosignal however must have a certain value depending on camera tube type. To compensate for too much light a diaphragm is used. It is very important to set the diaphragm

to a value which gives for a homogenous picture a video signal far enough from the maximum not to get saturation in regions of low absorption.

Summary:

There is a big choice in image receptors on the screen-film side, on the image intensifier side and also to some extent on tv. For each application always one system would be the best. Screens and films should be selected carefully always regarding the whole spectrum of examinations and with the aim to have only a few different types in one department in order to avoid mistakes. A medium speed screen from the rare earth type range, a detail screen and possibly a high speed screen from the same type should be enough. The number of films should be reduced to one type medium sensitivity but spectral response adapted to the screen-system. For mammography special screens and films are necessary.

Image intensifiers are much more expensive. It is necessary to take into account all the requirements also for the future because of the lifetime. On the other hand it seems to be useful to change an i.i. tube latest after 5 to 7 years to use the innovations made in the meantime. A dual or triple mode image intensifier of the highest avaiable quality is a good recommendation. The input field size depends on the planned studies. If many projections are necessary or a biplane system is used as for cardiac studies, than the tube should not have more than 10 inch input, otherwise it is difficult to adapt it close to the patient.
If interventional studies are planned, a triple mode can be useful. For digital subtraction angiography also high resolution and high contrast are necessary.

The selection for the tv-system - standard or high resolution - is not only a question of prize but also what it is used for. For any application where the diagnosis can be done

from the tv-picture a high resolution system would be helpful. The choice of the camera tube type depends more on the individual preference. The vidicon type tubes seem to me to be more universal.

References:

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H. Degenhardt, mta praxis 2/88 (1982) 40 - 51
F.W. Hofmann, Radiologische Praxis 2/1976,1, 60 - 65

PRACTICAL EXERCISES

This is a collection of exercises on Quality Control of medical diagnostic X-ray units which has been prepared especially for the WHO Training Workshop on Quality Control and Assurance in Diagnostic Radiology organized by the Institute for Radiation Hygiene of the Federal Health Office. The exercises have been worked out by German medical physicists, by the Agfa-Gevaert Training Center, Munich and a member of an X-ray equipment manufacturing company.

It should be clearly pointed out that we had not the ambition to invent new methods or equipment for testing the performance of X-ray units, nor should the selection of certain methods and test tools be meant to be the optimal ones.

There is a great number of publications on Quality Assurance in diagnostic radiology especially from the U.S.A. and Great Britain, part of which you will find in the reference list of the WHO publication on Quality Assurance in Diagnostic Radiology (Geneva, 1982). The reference list at the end of this "workbook" contains only publications having a direct relation to the text of the exercises.

The material presented here is meant to be a "workbook" which should help to carry out the exercises more effectively and as a basis of discussion in this pilot-course.

PRACTICAL EXERCI

X – RAY GENERATOR AND TUBE

kV_p, HVL, OUTPUT, mAs – REPRODUCIBILITY AND LINEARITY USING AN EAP–METER, EXPOSURE TIME: ACCURACY AND REPRODUCIBILITY, GEOMETRICAL RESOLUTION (FOCAL SPOT) A 1

MATERIAL:

Exposure-area-product meter (Diamentor)
Calibrated dosemeter
kVp test cassette
Timing and mAs-test tool
Focal spot test tool (resolution)
Tape measure

AUTHOR

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A INTRODUCTION

The output is the quantity which can be measured most easily (by means of a calibrated dosemeter or an exposure-area-product meter) and gives an overall impression about the status of the generator and tube.
The output will be measured at a distance from the focus convenient to mount the dosimeter. Using the inverse-square-law, the dose or dose rate measured in a known distance from the focus can be easily converted to a standard distance (e.g. 100 cm or 75 cm). The output is given in mR/mA min or mR/mAs.
The output depends on the tube potential and its wave form, the tube current, the filtration, the exposure time and the distance between the focal spot and dosemeter.
The output is a quantity very well suited for routine tests, in which it is not necessary to use a calibrated dosimeter in general. We will use the exposure-area-product meter (EAM) for this purpose. It will be shown that this instrument can also be calibrated for measuring the dose or dose rate if the dose rate and beam quality used are not too different from the conditions at calibration. If the output is found to be unchanged, one can generally assume that the different parameters influencing the output are also still the same.
The output (and image quality) is very sensitive to changes of the peak tube potential which is, therefore, one of the most important parameters to be checked in the case of output variations.
Changes in the waveform of the high voltage and the filtration can also influence the output to a large extent. They have to be checked individually whenever a change in the normal performance is suspected.

Geometrical resolution is mainly influenced by the size of the focus of the X-ray tube. Controlling this parameter, therefore, provides for information about the status of the tube aging of which would results in reduced output and sometimes lowered resolution.

There are different methods and many tools for the measurements mentioned. The highest accuracy in measurements of both the high voltage and its waveform, as well as the current or charge going through the X-ray tube can be obtained by direct measurement in the high voltage circuit. Reliable information about the peak voltage, waveform and filtration may also be derived from the analysis of the spectra measured for the X-radiation.
However, these two methods are only useful for calibration of test tools for test procedures being less time consuming.

B MEASUREMENTS TO BE PERFORMED

1. PEAK TUBE POTENTIAL AND HALF VALUE LAYER

Test equipment

Calibrated penetrameter, film, lead blockers, densitometer

Description of the test tool

Fig. 1 shows the schematic view of the construction of the kVp cassette.

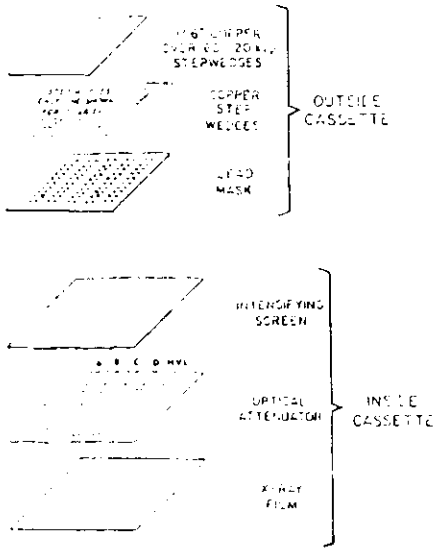


Fig. 1:

Radiation entering the cassette passes a copper filter which reduces mainly the low energy portion of the X-ray spectrum. There are two pathways by which the film is exposed to radiation: one portion first passes copper steps of different thickness, then a lead mask with two rows of holes and finally meets the intensifying screen which directly exposes the film. The other portion of radiation passes at first the lead mask and the intensifying screen; subsequently the light emitted there is optically attenuated by a known reduction factor (referent culumn). By comparing the two rows of differently exposed spots on the film, the attenuation effected by the copper steps can be estimated to determine the maximum energy of the radiation spectrum.

OPERATION

- Load the cassette, place it on the X-ray table (facing the tube and the long sides of the cassette so as to be situated parallelly to the anode-cathode axis).
  Center the region of the cassette to be exposed in the radiation field, shield the others with the lead blockers.

- Set the kV-control to the desired value.

- Select both the distance between the tube and cassette and the setting for mAs (or: mA and sec) so as to obtain a density of about 1 in the reference column.

- Expose the different regions of the cassette and develop the film.

EVALUATION

The resulting image will consist of 10 columns of dots in five pairs. The right hand column (reference column) will consist of dots of nearly uniform density; the other column (under the copper stepwedge) will show a density gradient.

Determine for each pair of columns those pairs of dots that most closely match in density (accuracy by eye: 4 kV, densitometer: 2 kV).

If the "match step" falls between two pairs, the linear interpolation is recommended.

Once the number for the match-up is known, the thickness of the copper step that will result in the same intensity reduction as the optical attenuator may be calculated. By means of the calibration curve (fig. 2) it is easy to find the corresponding value of kVp.

If possible, these measurements should be repeated for different mA-settings to check whether changes of mA do result in different kVp.

kVp CASSETTE CALIBRATION FORM

Serial No. 101-3169

3 ø = ____ S = Step No.
1 ø = ____ r = Correlation Coefficient

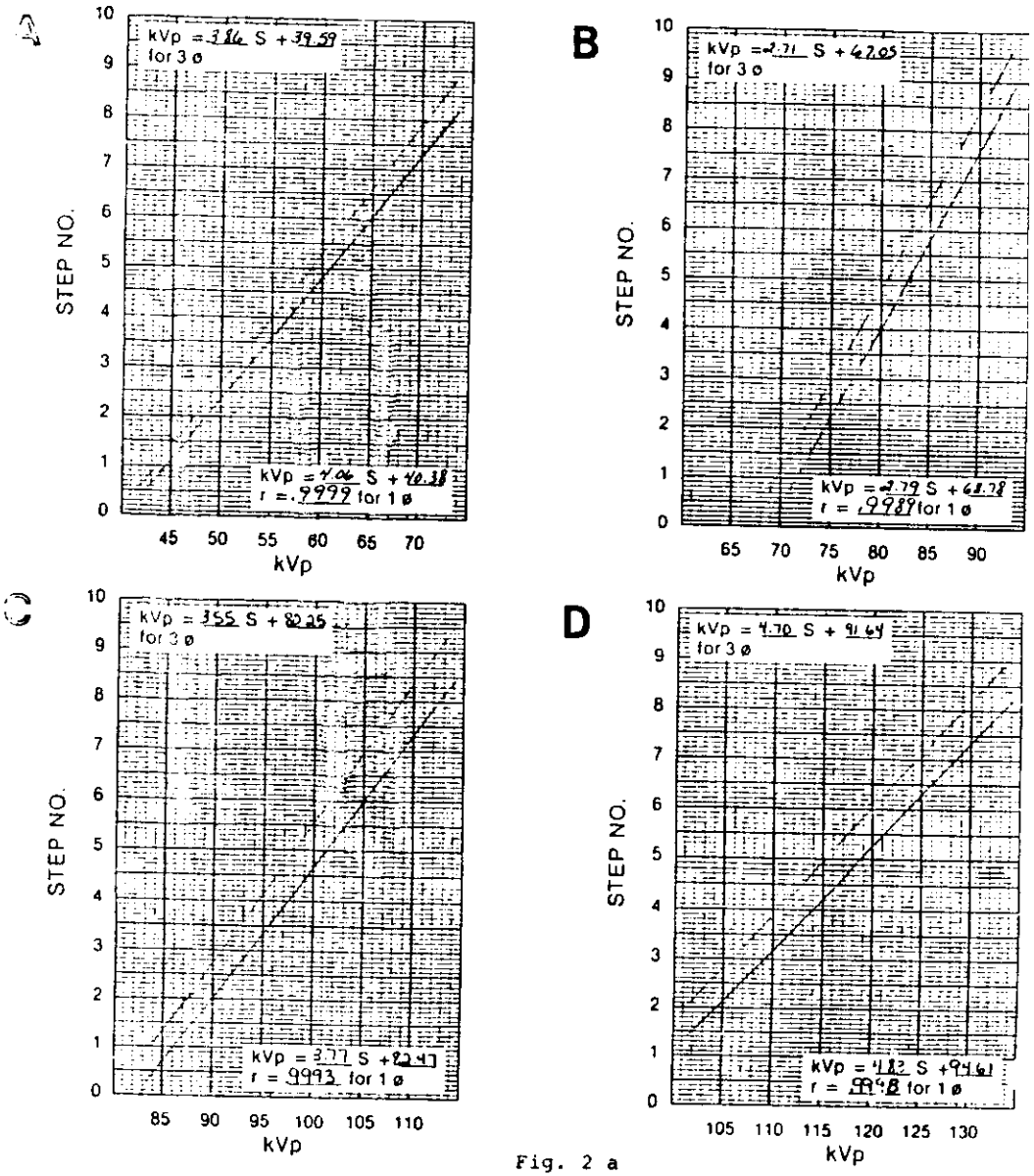
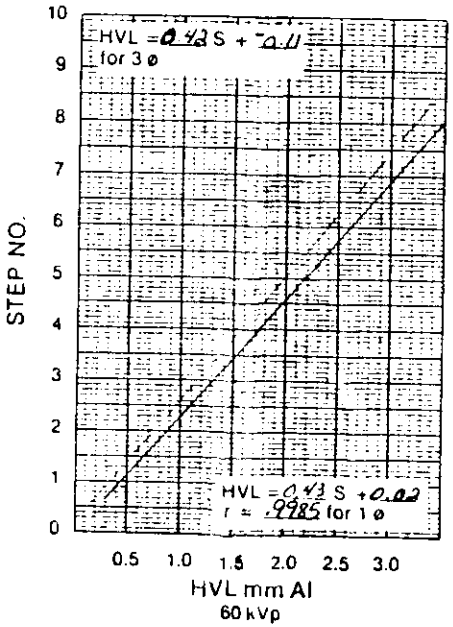


Fig. 2 a

RMI Quality assurance in Radiology

HVL REGION

3ø = _____
1ø = _____
S = Step No.
r = Correlation Coefficient



Calibrated By M L Cashman Date 9-4-81

RMI
RADIATION MEASUREMENTS INCORPORATED
P.O. Box 327
Middleton, Wisconsin 53562
Telephone (608) 831-1188
TWX 910-280-2524

Fig. 2 b

tube potential (results):

tube: generator: date:

kVp (set)	distance	mAs	match step	kVp (measured	difference	acceptable yes no
60	cm					
80	cm					
100	cm					
120	cm					
HVL (60)	cm			(mm Al)		

Surveyor:

Calibration of the EAM (results)

tube potential: kV charge: mAs

	1	2	3	4
distance	cm	cm	cm	75 cm
Area A	cm^2	cm^2	cm^2	collimator open
exposure D	R	R	R	R
A D	Rcm^2	Rcm^2	Rcm^2	———
digits of EAM				
calibration-factor	$\frac{Rcm^2}{digit}$	$\frac{Rcm^2}{digit}$	$\frac{Rcm^2}{digit}$	$\frac{R}{digit}$

Surveyor:

2. CALIBRATION OF THE EAM

Test equipment

dosemeter, film, tape measure

Measure the exposure (D) at a fixed distance to the tube (focus) by means of a calibrated dosemeter; measure the area (A) exposed at the same distance (by exposing a film):

n digits of EAM $\hat{=}$ A x D (Rcm^2)

Go on accordingly measuring several different areas to check the proportionality of the EAM measurement. If the EAM is used for a routine check of the tube output, this calibration will have to be performed with open collimator:

n digits of EAM $\hat{=}$ D (R at distance x)

A pocket dosemeter may be used for this calibration.

3. OUTPUT

Test equipment

Dosemeter, tape meter, EAM

3.1 Using an ionizing chamber

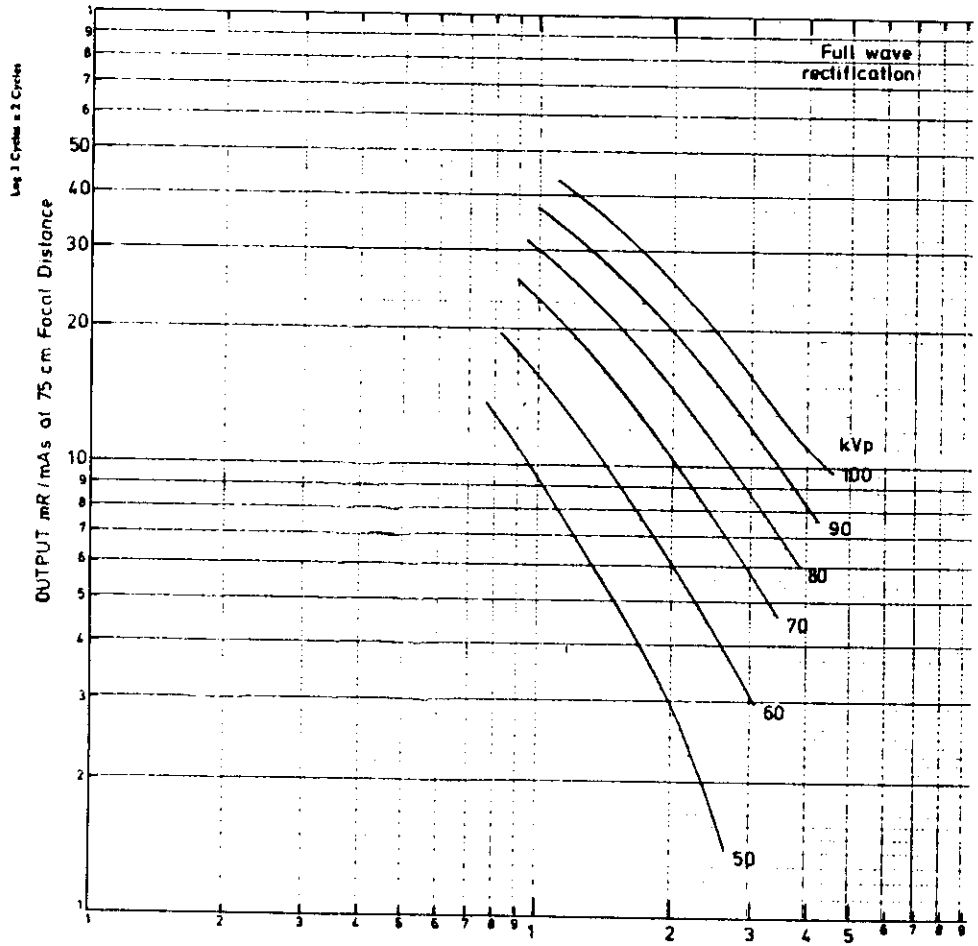
- Measure the exposure D(x) (mR) at a known distance x between the focus and an ionization chamber at different mAs-settings;
- Calculate D for x = 75 cm and compare to tabulated values (fig. 3).

3.2 Using the calibrated EAM:

- Check constancy of exposure output with the mAs setting and kV value unchanged but differing focal spot sizes (i.e. differing mA value);

- Check recproducibility and linearity at different mAs settings.

Fig. 3



From

The Hospital Physicists' Association

The Physics of Radiodiagnosis (1977)

output (results)

tube: generator: date:

tube potential: kVp, focus: small o large o

distance x: cm, charge: mAs

exposure at x: mR, exposure at 75 cm: mR

output (measured) $\frac{mR}{mAs}$

output (tabulated): $\frac{mR}{mAs}$

constancy of output

mAs	output* (EAM digits) small focus	large focus (mR at 75 cm)

* Collimator open

output (results, continued)

linearity and reproducibility of mAs-setting

output* (EAM-digits)

mAs	1st measurement	2nd measurement	3rd measurement

* collimator open

Surveyor:

4. EXPOSURE TIME

Test equipment

Timing and mAs test tool, protacor, (densitometer), film cassette.

Description of the test tool

The instrument case of the timing test tool contains a rotating brass disc (8,25 cm in diameter, 1 rps, driven by a synchronous motor) with a slit cut into it.

Radiation passing this slit exposes the film cassette on which the tool is placed. Measuring the angle of the arc, visible after processing the film, gives information about the exposure time. A copper step wedge incorporated into the test tool permits to check the constancy of mAs (or output) at different mA and time settings selected appropriately.

OPERATION

- Position the timer tool on top of a loaded cassette with a distance between source and film of about 1 m; collimate to the tool and shield the unused area of the cassette with lead.
- Perform three exposures on three different areas of the cassette at 70 kVp; keep mAs constant but choose different mA and time settings (recommended density: 1 - 2).
- Develop the film as usual.

EVALUATION

- Measure the exposed arc by means of the transparent protractor.

- If the timing is acceptable ($\pm$ 10 %), the constancy of the mA stations can be checked by inspecting the density of the stepwedge pattern images. If the corresponding steps of each of the patterns appear to be of the same density, the mA setting is sufficiently accurate. The densities can be checked with a densitometer for greater accuracy. An error (differing density) may be due to either the wrong kVp or the wrong mA.

Exposure time (results):

tube: generator: date:

tube potential: 70 kVp

settings			timer				mAs reciprosity	
mA	mAs	time (s)	time measured	% variance	acceptable yes	acceptable no	% variance	acceptable yes	acceptable no

Surveyor:

table:

Smallest Group Resolved	Number of line pairs/mm	Dimension of Effective Focal Spot with M=4/3 (mm)
1	0.84	4.3
2	1.00	3.7
3	1.19	3.1
4	1.41	2.6
5	1.68	2.2
6	2.00	1.8
7	2.38	1.5
8	2.83	1.3
9	3.36	1.1
10	4.00	0.9
11	4.76	0.8
12	5.66	0.7

Geometrical resolutions (results):

tube: generator: date:

tube potential: kVp; current: mA

	small focus	large focus
magnification M		
smallest group resolved		
number N of line pairs/mm (see table)		
geometrical resolution N/M:		
measured focal spot size		
acceptable yes		
no		

Surveyor:

5. GEOMETRICAL RESOLUTION (FOCUS)

Test equipment

Focal spot test tool, magnifying glass

Description of the test tool

Geometrical resolution is determined by the size and shape of the focal spot. Because of the irregular shape of the focus, the specification of the focus size is controversial.
The test tool used here consists of a heavy metal target with 12 bar pattern groups of different sizes. Each group consists of six bars, three of which are arranged perpendicular to the other three slots. There is a decrease in size and spacing of the slots by steps of 16 % from 0.84 line pairs/mm to 5.66 line pairs/mm. The test pattern is mounted in the center of a plexiglass disc (7.6 cm in diameter). It contains a lead shield with two small holes 6 cm apart from one another to check the magnification and thus the distance from the film (the pattern is 15.2 cm above the base of the tool).

OPERATION

- Position the test tool directly on a cardboard cassette, arrange the tool so that the printing of the label is parallel to the long axis of the tube. For focal spot size of more than 0,8 mm, a magnification of 4/3 is recommended, i.e. the distance between the bar pattern and the tube focal spot should be 46 cm. For smaller focal size the magnification must be higher. This can be obtained by placing a spacer of known height under the tool.

- Perform two exposures (at the most commonly used kVp and mA station) with both the small and large focal spots. A fine grain X-ray film should be used without intensifying screen.

- Develop the film.

EVALUATION

To check the magnification, measure the distance d (cm) between the centers of the image of the two holes on the film. The magnification M is calculated by d/6 (4/3 magnification corresponds to d = 8 cm).

Use a magnifying glass to examine the groups in the image parallel to the cathode-anode axis. Find the image of the smallest group where all three bars are clearly to be seen (a "double" peak focal spot may produce an image with four bars; this false resolution should not be confused with proper resolution which would result in a three bar image). The perpendicular groups may be used independently to estimate two dimensions of a focal spot, or all six bars in a group may be used together to find the largest dimension of the spot.

The geometrical resolution is then calculated by means of the following table which gives the numbers of line pairs per mm for the different groups; this number N for the smallest group resolved has to be divided by the magnification M:

Geometrical resolution $\hat{=}$ N/M line pairs/mm

Once the geometrical resolution is known, the dimensions f_s of the so-called effective focal spot may be calculated which are defined as the dimensions of a uniformly emitting focal spot with the same resolution as the focal spot under study:

$$f_s = \frac{M}{M-1} \cdot \frac{1}{N}$$

IMAGE – RECEPTORS: RADIOGRAPHY – FLUOROSCOPY

1) FILM – SCREEN SYSTEMS: SENSITIVITY, RESOLUTION, FILM – SCREEN CONTACT
2) FLUOROSCOPY: CONVERSION FACTOR, RESOLUTION, LOW CONTRAST VISIBILITY, SENSITIVITY (AEC)

A 2

MATERIAL:

Films
Intensifying screens
Film-screen combination
Cassettes
Fluoroscope
X-ray image intensifier

AUTHOR

Dr. R. Müller

1. RADIOGRAPHY

Test equipment

3 cassettes with different screen combinations, densitometer, lead shield (2mm), a phantom of 30 to 40 mm Al or 15 to 20 cm water (or equivalent material), high contrast resolution test tool.

1.1. Inspection of the film cassette:
Does it show mechanical damage?
Does the lock fit well?
Does the screen show dust, shadows or any mechanical damage?

1.2. Does the spectral sensitivity of the film fit the spectral emission of the screen?

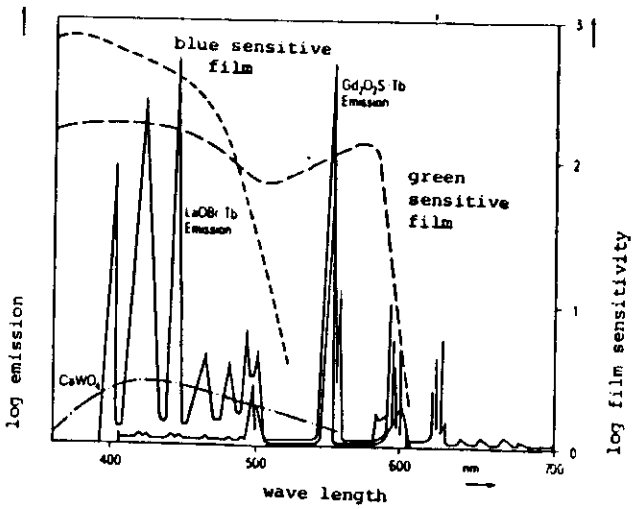


Fig. 1: Spectral emission of Ca WO_4, LaOB:Tb, Gd_2O_2S:Tb and film sensitivity (Krestel)

1.3. Measurement of the characteristic curve of the film with reference screen

Use 70 kV; phantom of 30 to 40 mm Al or 15 to 20 cm water. Set mAs stepwise in arbitrary units $2,4,8,.....2^n$. Expose the film-screen combination by stepwise retraction of the lead shield (e.g.20 mm for one exposure). Make densitometry with the processed film. Draw density versus logarithm of relative exposure (drawing 1, data page 1)

Repeat this procedure with the other two cassettes using different film-screen combinations but only three different exposure values. Insert these points in the above drawing.

What is to say about screen speed and patient exposure?

1.4. Evaluation of high contrast resolution

Expose all three film-screen combinations with the resolution test tool on the cassette.

Find resolution of the different screens. Insert relative speed versus resolution into drawing No.2.

1.5. Check of film-screen contact

Line-spread is a function of screen speed (fig. 2) but also of screen-film distance (fig. 3).

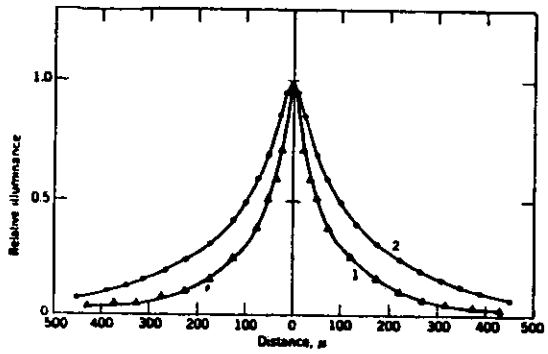


Fig. 2: Normalized line-spread function of two radiographic systems containing calcium tungstate screens: curve 1, two medium speed screens; curve 2, two fast screens (Seemann)

Therefore, an equal good contact of the film to screen is necessary.

Demonstration of failures of film-screen contact using a special test tool.

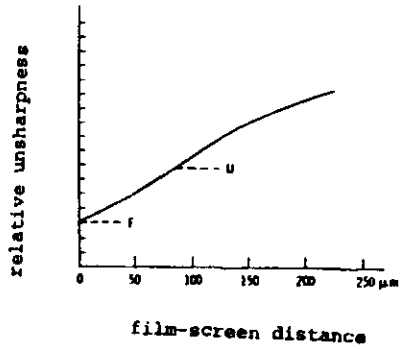


Fig. 3: Unsharpness as a result of film-screen distance (Frommhold et.al.)

2. FLUOROSCOPY

2.1 Fluoroscope

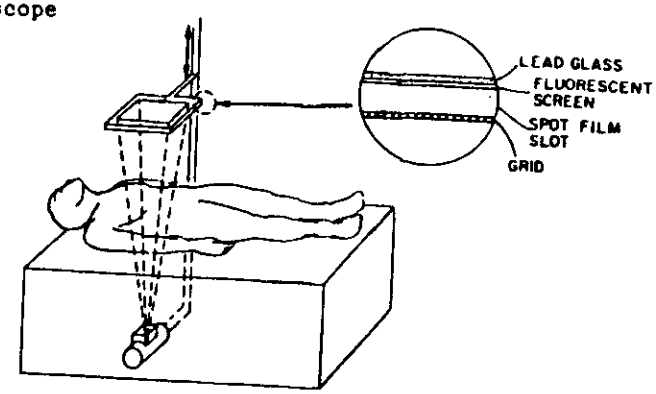


Fig. 4: Fluoroscope (Cristenson et.al.)

2.1.1 Check the fluoroscopic screen for mechanical damage.

2.1.2 Conversion factor

Fluoroscopy does work particularly by the extraordinary ability of the human eye to adapt to low level illumination (Christensen et.al.)

The conversion factor is defined as the ratio of luminance versus imput exposure rate. The conversion factor for modern screens ranges from 0.006 to 0.013 $\frac{cd \cdot s}{m^2 \cdot mR}$ for 70 to 85 kV X-rays. Image intensifiers attain conversion factors from 60 up to 250 $\frac{cd \cdot S}{m^2 \cdot mR}$ (see below).
Measurements of the conversion factor can be done by synchronous detection of exposure rate and luminance. This is a large-scale procedure. A less complicated method is to check the luminance of the specimen against a well fitted reference screen under defined conditions.

Some different fluoroscopy screens will be demonstrated.

2.2. X-Ray Image Intensifiers

Fig. 5 shows the image intensifying chain.

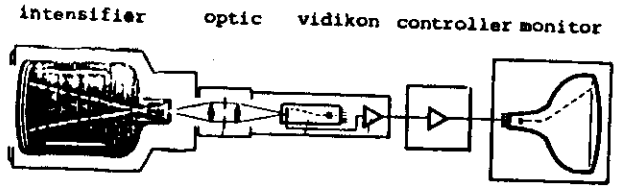


Fig. 5: The X-ray intensifying chain (Krestel)

When discussing the resolution of the whole system it is best to investigate the modulation transfer function (MTF) of everly link.

In fig.6 the single MFT's are seen for a high resolution (-) and a lower resolution (---) system.

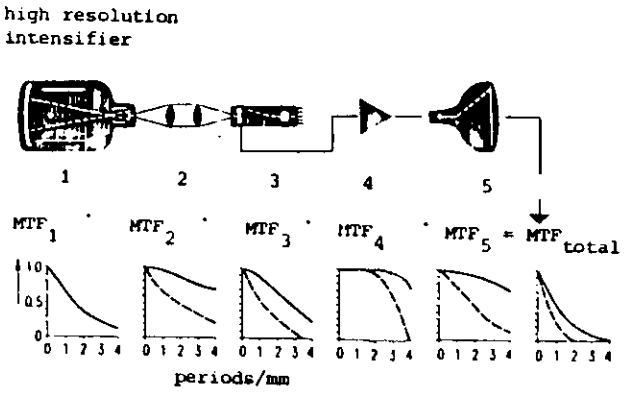


Fig. 6: Total MTF of the X-ray intensifying system (Krestel)

For a quick check it is not possible to measure the MTF. However, to determine the status of the image intensifier it is sufficient to test the high and low contrast resolution.

2.2.1 High contrast resolution

Test equipment

High contrast resolution test tool.

Try to fix the high resolution test tool directly on the image intensifier. Set lowest kV and record resolution as line pairs per mm (lp/mm) versus tube current (mA) parallel and perpendicular to the monitor lines (data page No. 2, drawing No. 3)

2.2.2 Low contrast resolution

Test equipment

Low contrast resolution test tool, 0.8 mm Al plate with bore holes from 1 to 20 mm diameter (1; 1.5; 2; 3; 4; 6; 10; 20). Additional filters of 20 mm Al, 0.5 mm Cu and two plates of 1 mm Cu.

Place the bore hole plate with additional filter on the patient's table and irradiate by defined geometry in the automatic mode. Record additional filtration, current, voltage and low contrast resolution (data page No. 3).

If there is time enough, this measurement may be repeated for a second focus-intensifier distance (FID). The focus-test plate distance has to be constant. It is sufficient to do this measurement for only one combination (e.g. bore hole plate + 0.5 mm Cu).

2.2.3 Dose Rate Imput

Test equipment

The same as in 2.2.2., dose rate meter.

High and low contrast tests give a good finger print of the image intensifying system. But the magnitude of dose rate at the intensifier input plane is also of great interest.

Use the set up as under 2.2.2. Only the Al bore hole plate and 0.5 mm Cu are applied. Fix the ionization chamber near the intensifier entrance plane. If necessary, make a correction for the focus distance ($1/r^2$).

Use all possible automatic steps. Record these data on data page No. 4, drawing No. 4.

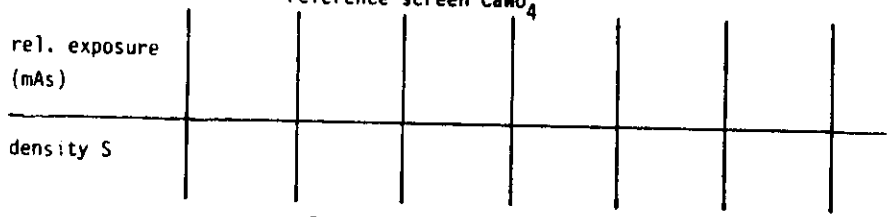
The exposure rate of the intensifier should be lower than 40 /uR/s for the lowest automatic step and lower than 80 /uR/s for the highest step.

Is the dose rate influencing the low contrast resolution (quantum mottle)?
Measurement with the low contrast phantom is essentially a test of the automatic brightness stabilizer system (ABS). The importance of radiation protection for patients and workers may be discussed here.

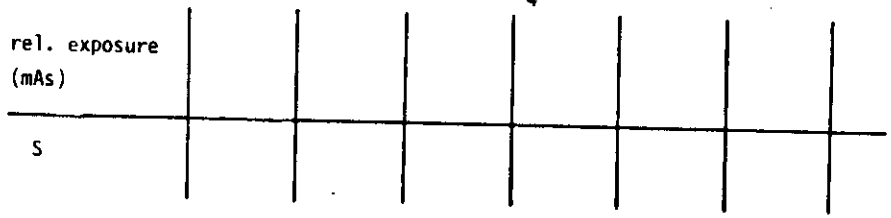
DATA PAGE NO. 1

voltage: ..... kV
filtration: ..... Al
FFD: ..... cm
phantom: .....
film: .....
screen: .....
cassette: .....
coach: yes/no

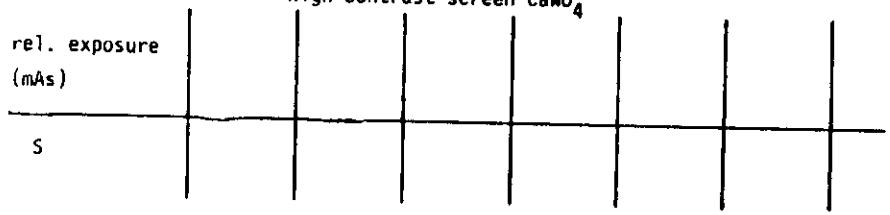
reference screen $CaWO_4$



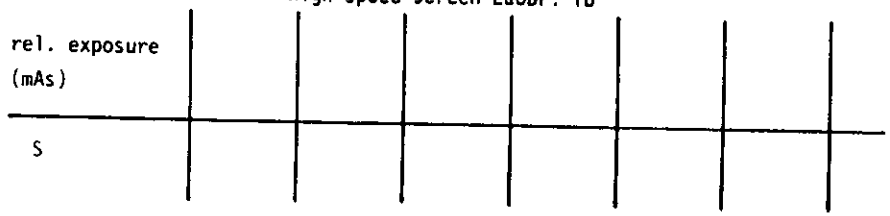
reference screen $CaWO_4$



high contrast screen $CaWO_4$



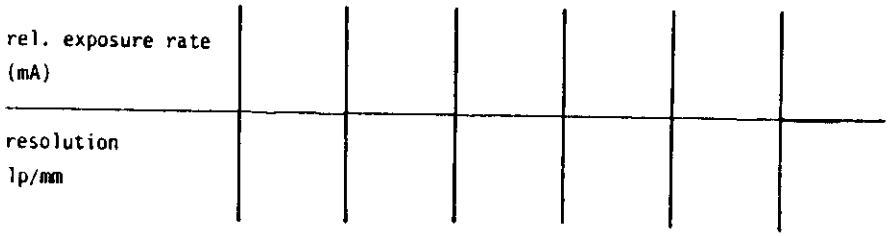
high speed screen LaOBr: Tb



DATA PAGE NO. 2

High Contrast Resolution Test of Image Intensifier

voltage: ..... kV
filtration: ..... Al
FID: ..... cm (focus intensifier distance)
phantom: yes/no
tube: .....
intensifier: .....
coach: yes/no



DATA PAGE NO. 3

Low Contrast Resolution Test of Image Intensifier

fluoroscopic unit: ..... if automatic: step .....
automatic: yes/no c: .....($\frac{\mu R}{s}$ / $\frac{nC}{min}$) (calibration fact
filtration:.....mm Al grid: yes/no
FID:..... cm
FCD:..... cm (focus chamber distance)
$(FCD/FID)^2$ = k: ..... (correction factor)

add. filter (mm Al/Cu)	--	20 mm Al	0.5 mm Cu	1 mm Cu	2 mm Cu	20 mm Al 2.5 mm Cu
voltage (kV)						
current (mA)						
low contrast diameter (mm)						
high contrast (lp/mm)						
intensifier exposure (nC)						
dto. times k · c (μR/s)						

DATA PAGE No. 4

Resolution Versus Dose Rate Input

fluoroscopic unit ..... $(\frac{FCD}{FID})^2$ = k: .....

filtration: ..... mm Al

FID:..... cm c: ..... $(\frac{\mu R}{s} / \frac{nC}{min})$

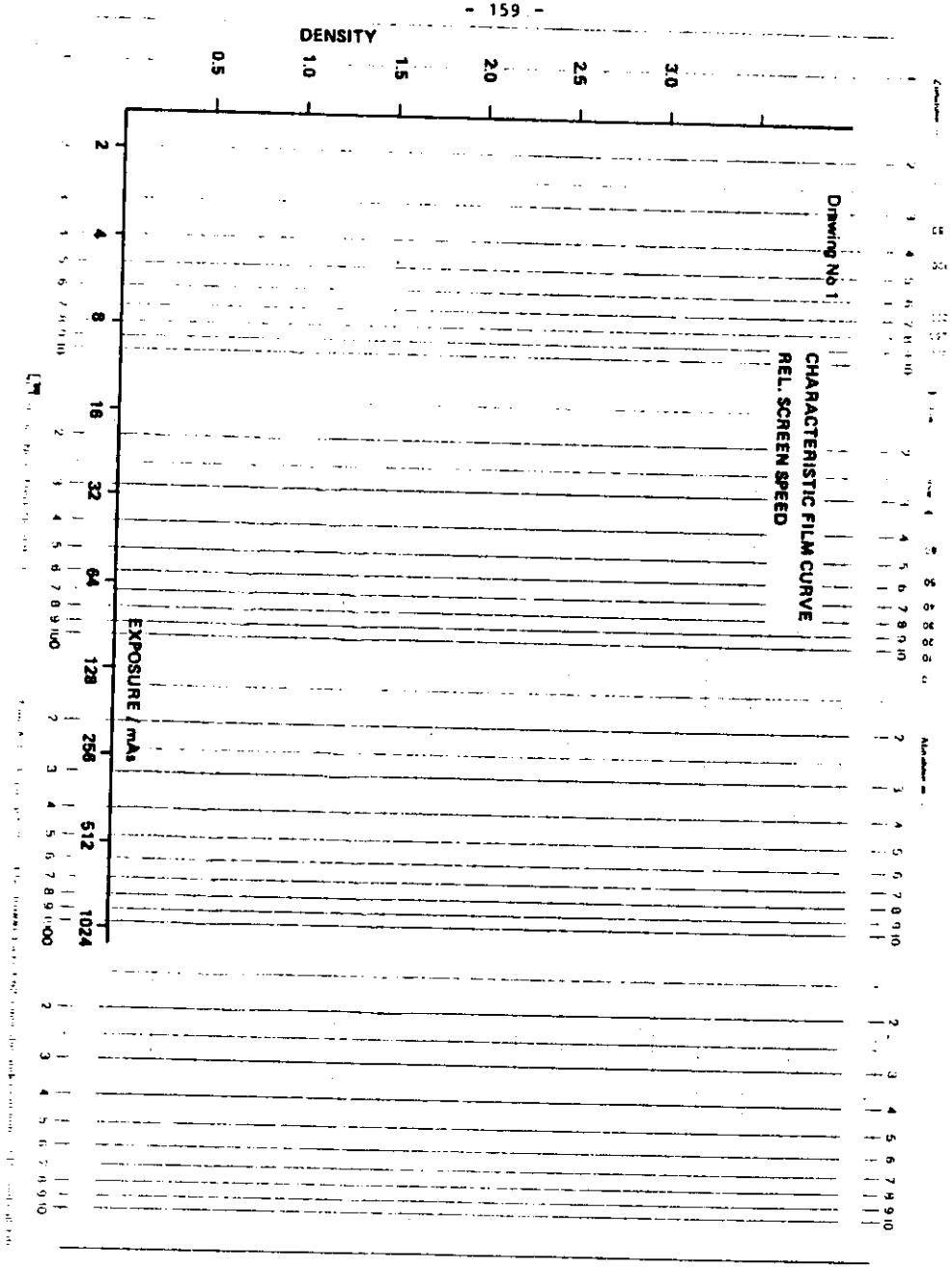
FCD:..... cm

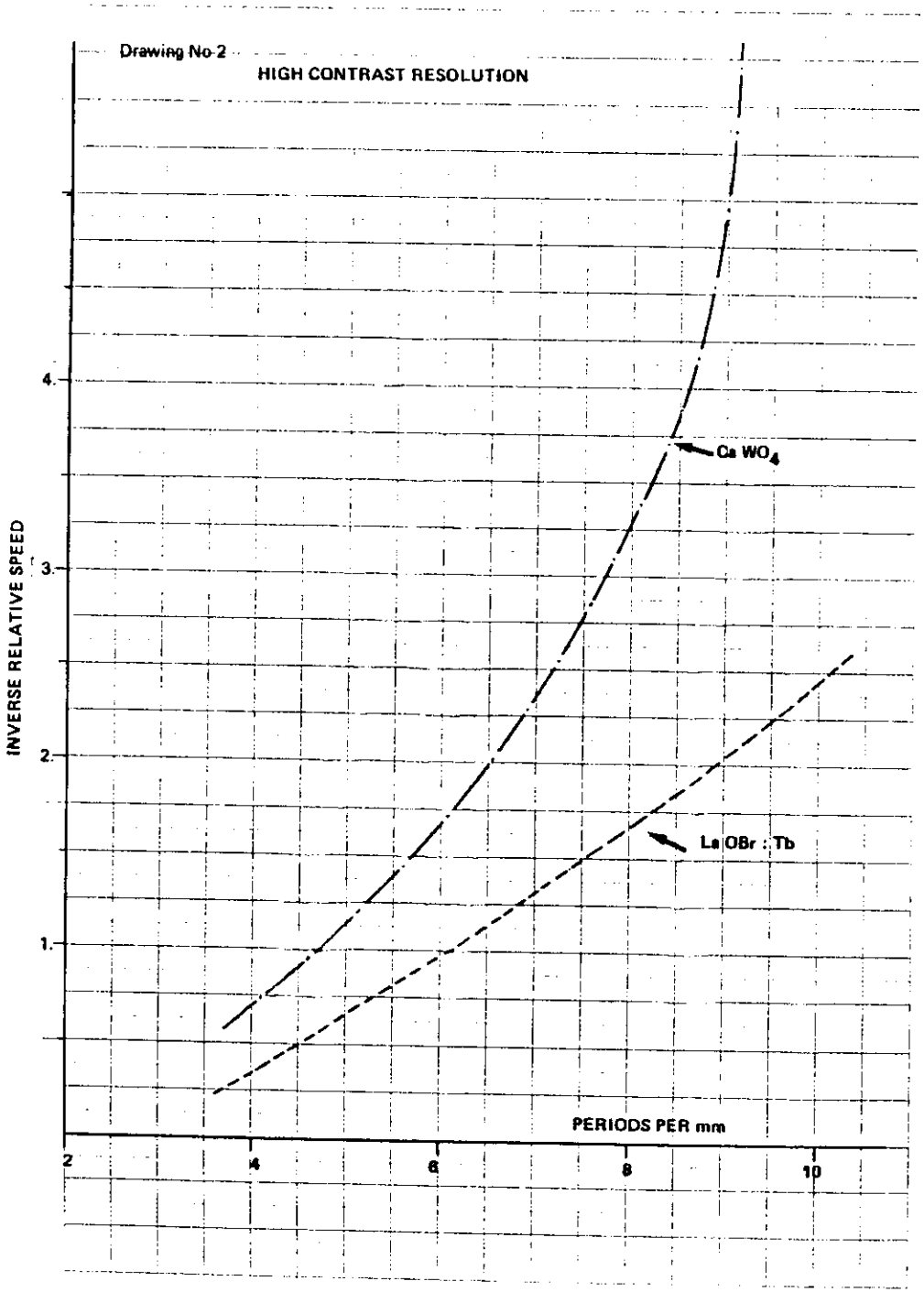
additional filter: 0.8 mm Al bore hole

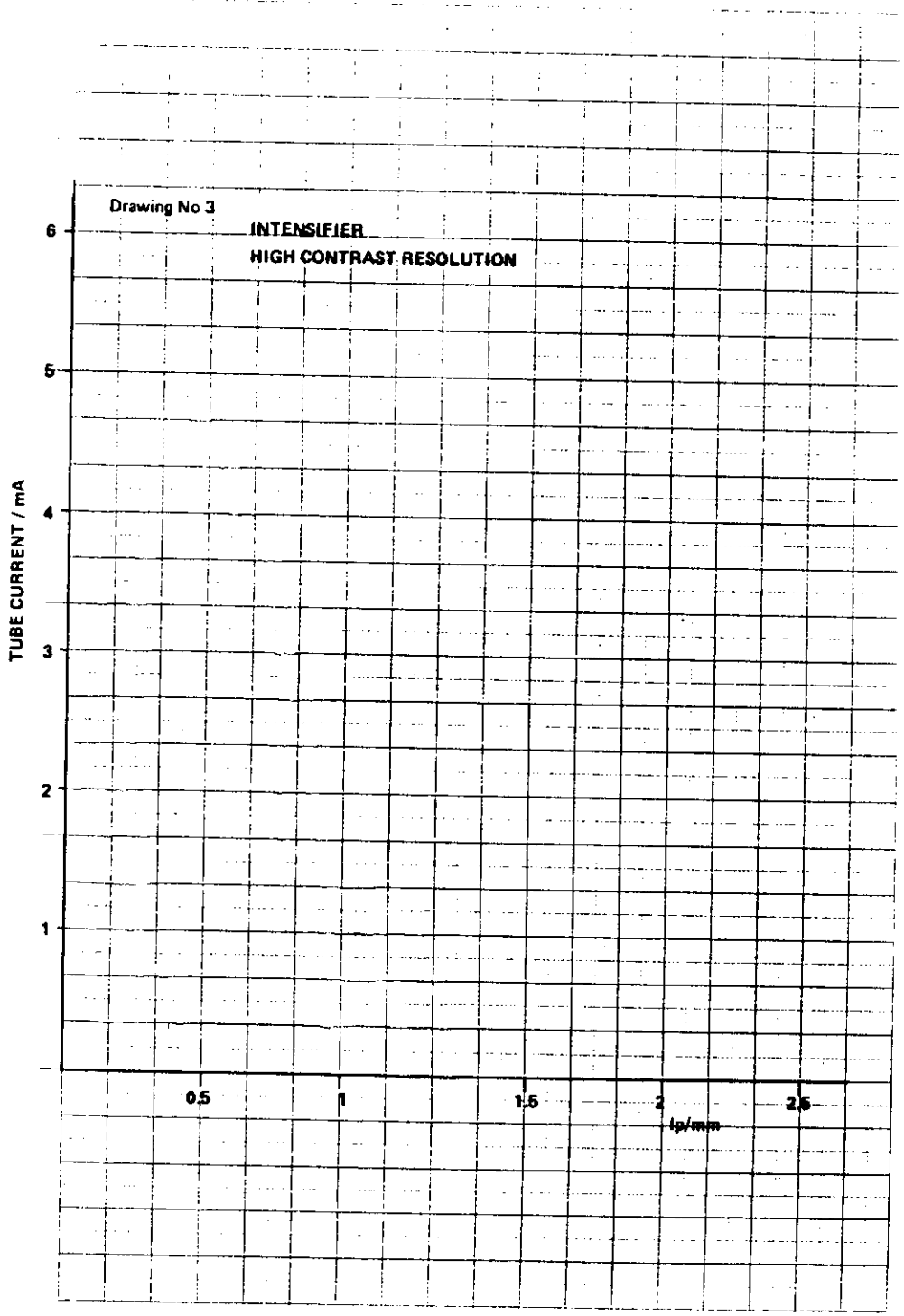
2 mm Cu

high contrast resolution test tool

step	voltage (kV)	current (mA)	low contrast Ø (mm)	high contrast (lp/mm)	exposure (nC/min)	corrected exposure (µR/s)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
aut. I						
aut. II						

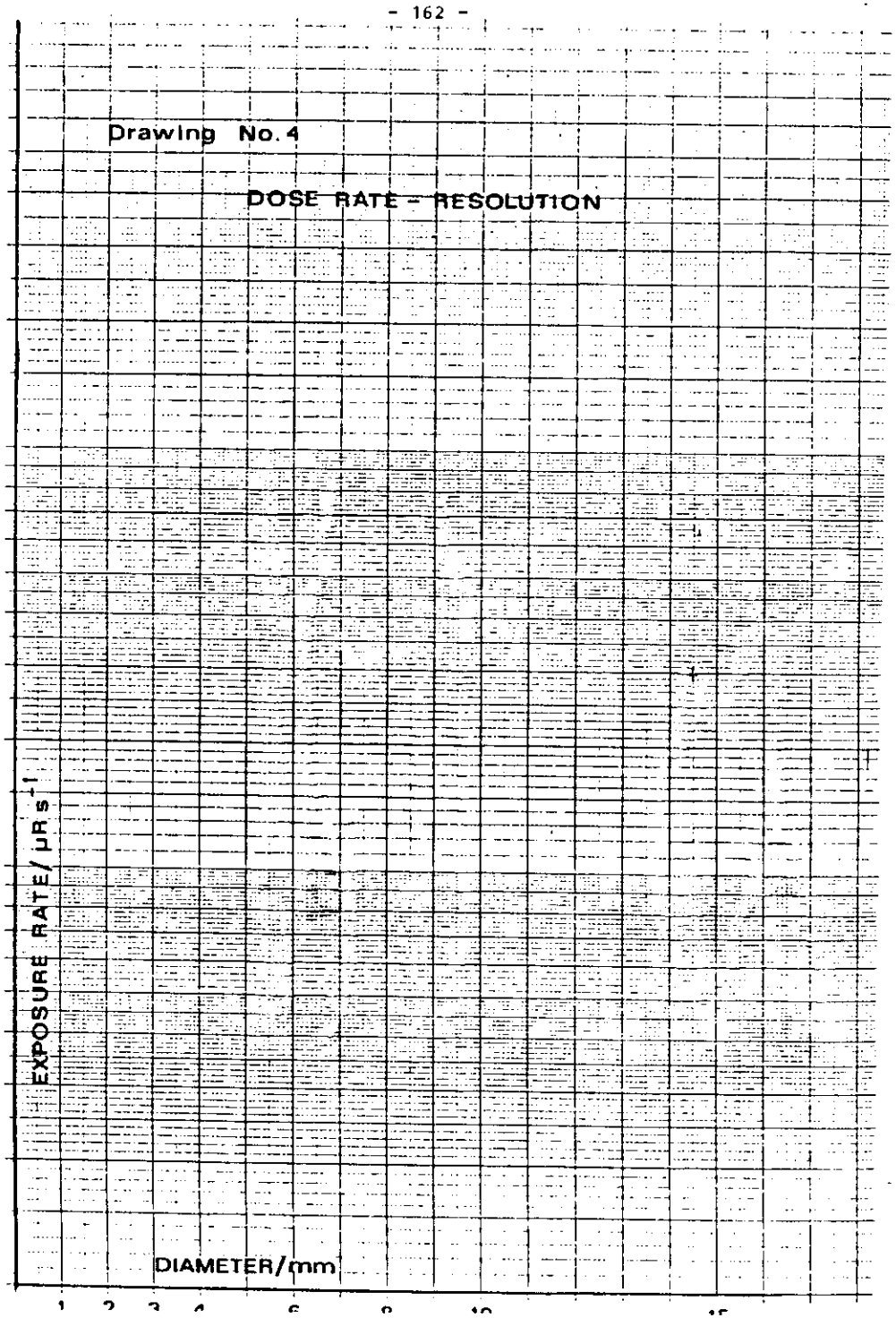



Drawing No 2
HIGH CONTRAST RESOLUTION
INVERSE RELATIVE SPEED
4.
3.
2.
1.
Ca WO4
La OBr : Tb
PERIODS PER mm
2
4
6
8
10


Drawing No 3
INTENSIFIER
HIGH CONTRAST RESOLUTION
TUBE CURRENT / mA
6
5
4
3
2
1
0.5
1
1.5
2
2.5
lp/mm

Drawing No. 4

DOSE RATE - RESOLUTION



DATA PAGE NO. 5

Resolution Versus Dose Rate Input

fluoroscopic unit .....

filtration: ..... mm Al

FID: ..... cm

FCD: ..... cm

$(\frac{FCD}{FID})^2$ = k: .....

c: ..... $(\frac{\mu R}{s} / \frac{nC}{min})$

additional filter: 0.8 mm Al bore hole

2.0 mm Cu

high contrast resolution test tool

current / kV \ mA												
exposure (nC/min)												
exposure corrected (µR/s)												
resolution diameter (mm)												

current / kV \ mA												
exposure (nC/min)												
exposure corrected (µR/s)												
resolution diameter (mm)												

kV \ current / mA												
exposure (nC/min)												
exposure corrected (µR/s)												
resolution diameter (mm)												

DATA PAGE NO. 5

LINEARITY of TUBECHARGE versus FILMEXPOSURE

Radiographic unit: .....

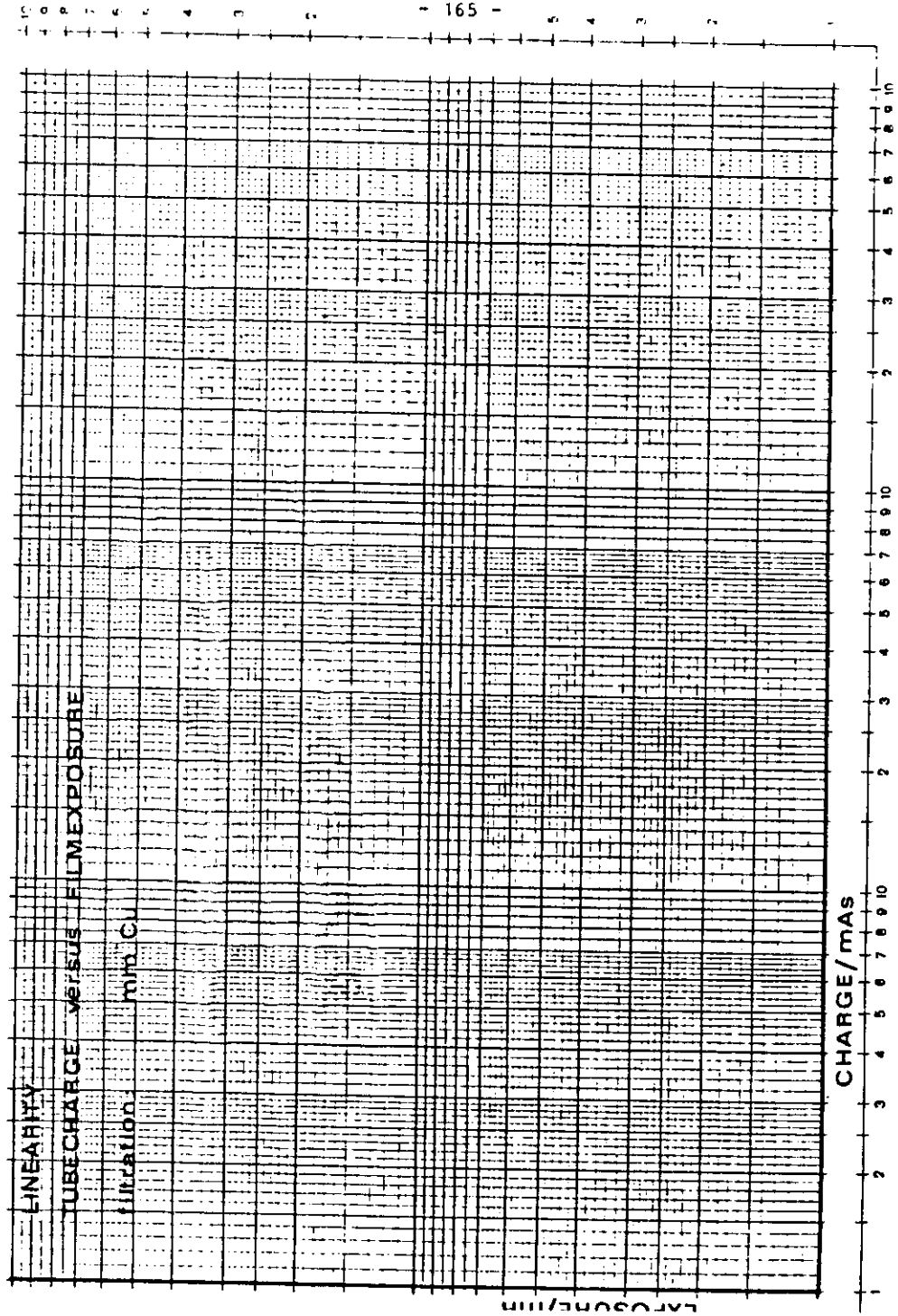
voltage: .....kV c: ..... $\frac{mR}{nC}$ (chamber calibration)

current:.....mA

add. filtration: .....mm Cu

FCD:.....cm (focus chamber distance)

tube charge (mAs)	film exposure (nC)	film exposure (mR)	$\frac{\text{exposure}}{\text{charge}}$ (mR/mAs)
2			
4			
8			
16			
32			
64			
125			
250			
500			
1000			



FILM PROCESSING AND VIEWING EQUIPMENT

SENSITOMETRY: TEMPERATURE DEPENDENCE OF "SPEED", AVERAGE GRADIENT, FOG. DARKROOM SAFELIGHTS DEMONSTRATIONS AT A LIGHT BOX

A3

MATERIAL:

Sensitometer
Densitometer
Step-wedge

AUTHOR

Dr. E. Borcke
W. Merkle

A PROCESSING OF X-RAY FILM

INTRODUCTION

It is assumed that the reader is already well informed about the characteristics of X-ray films. The following is, therefore, only a very brief summary of the most important facts.

The halides (e.g. silverbromide) within an X-ray film are sensitive to high energy irradiation (e.g. X-rays), invisible ultraviolet radiation and to the blue speck of visible light exposure.

When enough energy has been absorbed by the halides, a reduction to very small traces of metallic silver is initiated by photolysis. An image is formed thereby which is called the "latent image". Thus the sensitivity centres (halides) change into development centres where development can take place. As a result of development the film darkens in these exposed areas, depending on the absorbed energy.

PROCESSING

There are two basic means to process exposed or irradiated X-ray films:

(a) manual processing, involving:

development, intermediat rinse, fixing, final wash, wetting agent, drying.

(b) machine (automatic) processing, involving:

development, fixing, final wash, drying.

DEVELOPMENT

During development the invisible "latent image" (exposed or irradiated silver halides) is converted into a visible image. The quality of the developed image is influenced by many factors such as:

temperature, time, agitation, condition of developer, pH-value, replenishment rate.

The 5 most important components of an X-ray machine developer are:

(a) Developing agents (mostly hydroquinone and phenidone).

The task of the developing agent is to reduce the halide (e.g. silverbromide) to pure silver, depending on the absorbed energy (dose). In simple words: it darkens the film in those areas concerned.

(b) Accelerator.

Since the developing agents will not act by themselves, an activator (alkaline) has to be added to speed up the development process.

(c) Restrainer.

Although, in general, the developer only acts with exposed silver halide grains, a development fog is formed depending on the film speed and the developer's condition.
The restrainer slows down formation of such unwanted development fog.

(d) Preservative.

The developer agents tend to oxidate quickly when exposed to oxygen, thus reducing the activity enormously. To prevent this from happening, a preservative (sodium sulphite) is added which engages the oxygen faster than the developing agents.

(e) Hardener (only required for automatic processing)

During processing (development, fixing, washing) the gelatine of the photographic emulsion might swell up to seven times of its initial volume. This makes the emulsion vulnerable to scratches and damages. If a hardener is used, the emulsion will be prevented from swelling and the risk of damage will be reduced.

Apart from the chemicals just mentioned, several other chemical substances may be added to the developer for specific purposes.

Intermediate Rinse or Stop Bath (only for manual processing)

To prevent the developer from reacting with the exposed silver halides after the desired density of the image has been obtained, an intermediate rinse or stop bath is required for manual processing.

Running water of 20°C and one immersion (shorter time at higher temperature) will reduce the quantity of developer adhering to the emulsion and, thereby, the possibilities of unwanted further darkening of the emulsion. If development has to be interrupted immediately after a certain time, an acid stop bath of an acidity between pH 3 and pH 5 can be used. Both the intermediate rinse and stop bath prevent the acid fixer from being spoiled by those amounts of alkaline developer that adhere to the emulsion of the film.

During automatic processing the intermediate rinse is replaced by squeegee-rollers (last set of rollers of the developer rack). Excess developer is removed and the film leaves the developing rack only damp.

If intermediate rinse or stop bath in manual processing is inadequate or squeegee action of the developer rack in machine processing is inefficient, streaks might occur on the film and the fixing bath might be spoiled more easily. Appropriate intermediate rinse for manual processing or proper squeegee action during automatic processing are, therefore, very important details when processing X-ray films.

FIXING

Silver halide which could not be reduced to metallic silver during development, since it lacked sufficient exposure, still appears milky opaque in the emulsion. Therefore, the X-ray image has not yet received its wanted contrast and the still present silver bromide may darken at a later date, decreasing contrast even more.

The fixing solutions:
(a) sodium thiosulphate for regular fixing
(b) ammonium thiosulphate for rapid fixing
convert the not developable silver halides into water-soluble complexes. Thus the film will become clear in these areas.

An acid is added to the fixing agent in order to stop further development and to prevent formation of dichroic fog which might occur when used developer comes into contact with fixing solution. For machine processing a hardener must be added to prevent the film from swelling too much in final wash, to cut down the drying temperature or/and to shorten drying time.

The quality of the fixing is influenced by:

temperature, time, agitation, condition of fixer, pH-value, replenishment rate, silver content in fixer.

FINAL WASH

After fixing, the films must be washed under running water to remove the adhering chemicals, - in particular fixing solution. It is very important to pay attention to an adequate final wash. Otherwise the image might be ruined by the remaining fixing agent which may attack the silver that originally formed the image. This would prevent the radiograph from persisting as a dependable document.

The final wash is influenced by:

temperature, time, agitation, quality of water used, water flow.

Wetting agent (only for manual processing)

When the films are taken out of the final wash, they should be immersed into a wetting agent and hung up for drying (always on one corner diagonally only) to ensure that the water drains off evenly with the drying time being reduced and drying marks being prevented from occuring.

DRYING

After the final wash, the films are soaked with water und must be dried. Excess water is taken off by a pair of squeegee rollers (automatic process) installed at the end of the water rack. Still damp, the film enters the drying compartment of the processor where it must be dried in a given time and at a certain temperature.

An adequate drying is influenced by:

temperature, time, air ventilation (exchange of air), relative air humidity, film hardening (added to fixer)

CONCLUSION

What important facts influence X-ray films in automatic processors?

Parameters	Development	Fixing	Final Wash	Drying

B SENSITOMETRY

Introduction

With the tools needed, sensitometry can be conducted to evaluate the interactions of exposure and processing of X-ray films. It is particularly utilized to maintain standard processing conditions to ensure good quality radiographs.

In order to conduct an adequate sensitometry, appropriate tools such as a sensitometer (or suitable pre-exposed step wedges), a densitometer and sensitometric sheets should be at the user's disposal.

When to conduct Sensitometry?

The frequency recommended for sensitometric evaluations depends on several facts. As a general rule, it should be done as often as necessary.

In X-ray cineradiography it is mandatory to do the evaluation at least once a day, best before processing the first patient film.

In regular processing, once or twice a week may be sufficient if the results do not vary considerably and do not exceed given limits.

How to conduct Sensitometry?

If a sensitometer is available, it should be available with a blue emitting light source of approximately 465 nm (for blue sensitive emulsions) and green emitting light source of approximately 520 nm (for orthochromatic emulsions). A sample of the film in use should be exposed with the appropriate light source blue or green on the sensitometer (watch for proper safelight in darkroom) and be processed immediately thereafter.

Note

If a sensitometer is not available, a suitable pre-exposed-step wedge on the same film type as the one in use might be utilized to check the processing conditions. In this case the user must be sure that these pre-exposed step wedges have been stored properly and that the latent image is still intact.

The exposed and processed step wedge should be marked immediately with the following important parameters:

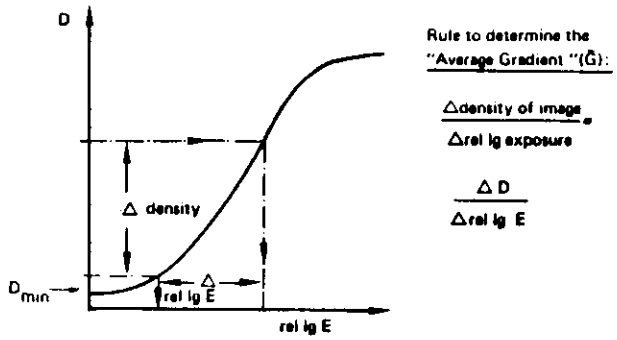
type of film, emulsion number, type of processor, type of developer, temperature, processing time.

The processed step wedge's density modulation (for the original step wedge it should not exceed D = 0,15 per step) is then measured on a densitometer and plotted down on a sensitometric paper, basic fog (D_{min}) as well. From the plotted curve the "relative speed" of the system (exposure and processing conditions) and the contrast factor become available.

The "relative speed" is determined via D = 1.0 plus "basic fog" D_{min} at the ordinate of the graph. Results are expressed in "logarithm relative exposure" (lg rel E) at the abscissa of the graph.

The contrast factor, mostly expressed as "average gradient" ($\bar{G}$), is determined between two given points as indicated below, depending on the X-ray technique applied:

- cinefluorography D = (0.25 and 1.25)+D_{min}
- image intensifier technique D = (0.25 and 1.75)+D_{min}
- monitor photography D = (0.25 and 1.75)+D_{min}
- photofluorography D = (0.25 and 2.0)+D_{min}
- film-/screen-technique D = (0.25 and 2.0)+D_{min}



The results obtained from the sensitometric paper should be plotted in a graph daily or whenever they have been calculated. Thus the following parameters may be recorded:

- basic fog (D_{min})
- index for exposure
- index for contrast
  (see "quality check chart")

Note

It is not necessarily hazardous if the data entered are close to a limit at a certain time while the results seem to be correct again one day thereafter.

It is more hazardous if the plotted lines move steadily in one direction towards either limit line. This should be watched closely, and proper actions should be taken on time.

Exercises on Sensitometry

E x e r c i s e I

a) Expose 3 samples of film on sensitometer

b) Process one of the samples with the standard temperature of the processor, one sample with + 4°C and the last one with - 4,°C

c) Measure all three step wedges and plot them on the same sensitometric paper

d) Determine "rel lg E" and the "average gradient" ($\bar{G}$) for each of the three curves

e) Record the data of the three step wedges:

step wedge	temperature	rel lg E	$\bar{G}$	D_{min}
A	+ 4 C			
B	standard			
C	- 4 C			

f) Draw conclusions from results:

E x e r c i s e II

a) Expose 4 samples of the film on sensitometer

b) - Process 3 samples with standard temperature and change processing speed to 1, 2 and 3 m/min per sample

- Process last sample with processing speed 2 m/min, lower temperature by 2 to 3°C to match standard processing (standard temperature/Processing speed: 3 m/min)

c) Measure all four step wedges and plot on sensitometric paper

d) Determine "rel lg E" and the "average gradient" ($\bar{G}$) for all these curves

e) Record the data obteined for the four step wedges:

step wedge	tempera-ture	proc. speed	rel lg E	$\bar{G}$	D_{min}
D (ref.)	standard	3m/min			
E	standard	2m/min			
F	standard	1m/min			
G	2 to 3°C	2m/min			

f) Draw conclusion from results

Exercises on Sensitometry

E x e r c i s e III

a) Measure the following parameters from each supplied processed step wedge:

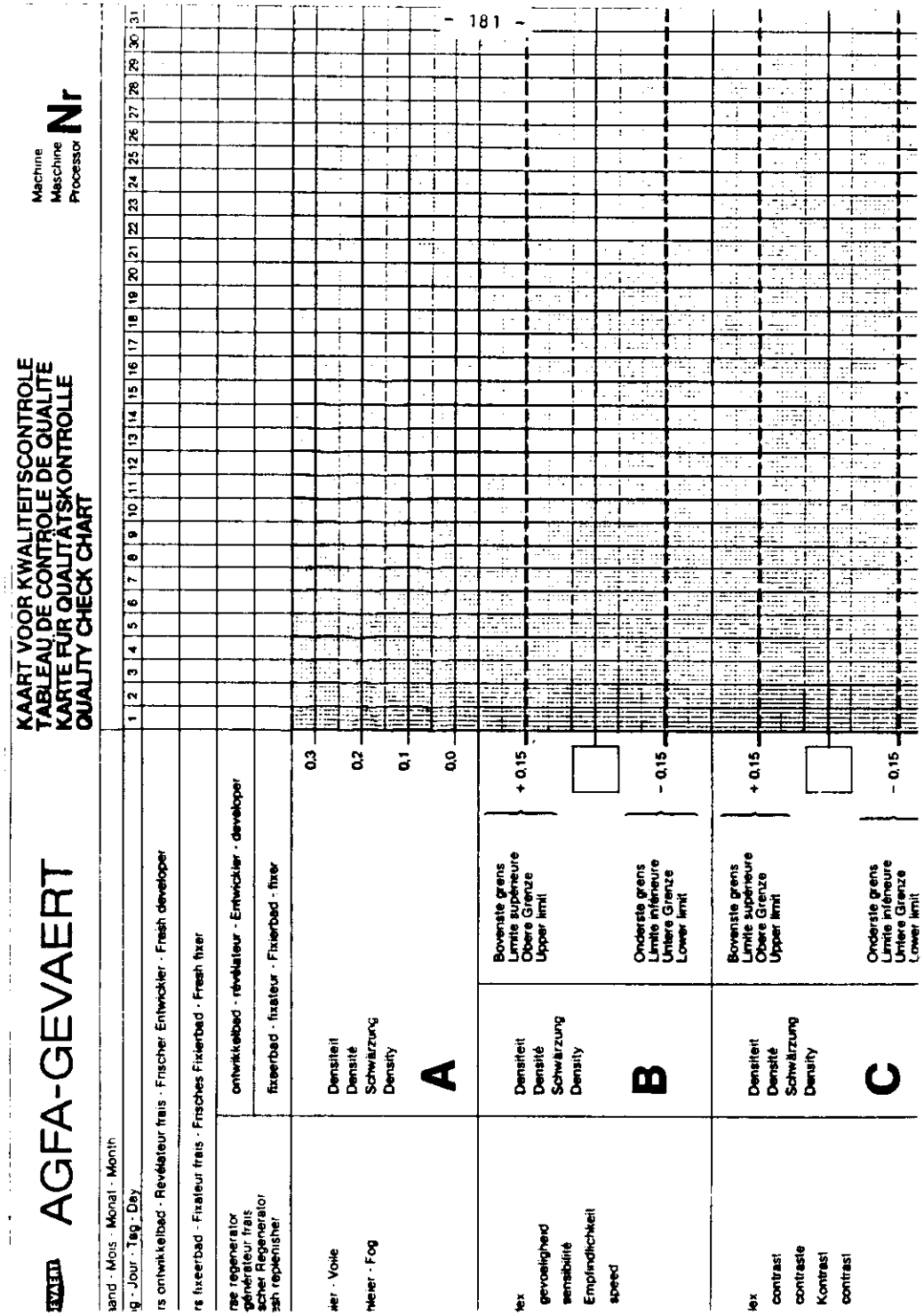
- Basic fog (D_{min})
- Index for speed (= rel lg E)
  (step closest to D = 1.0 without D_{min})
- Index for contrast
  use step "index for speed" + 4 steps
  (= $\triangle$rel lg E + D = 0.6, if there is $\triangle$D = 0.15 per step)

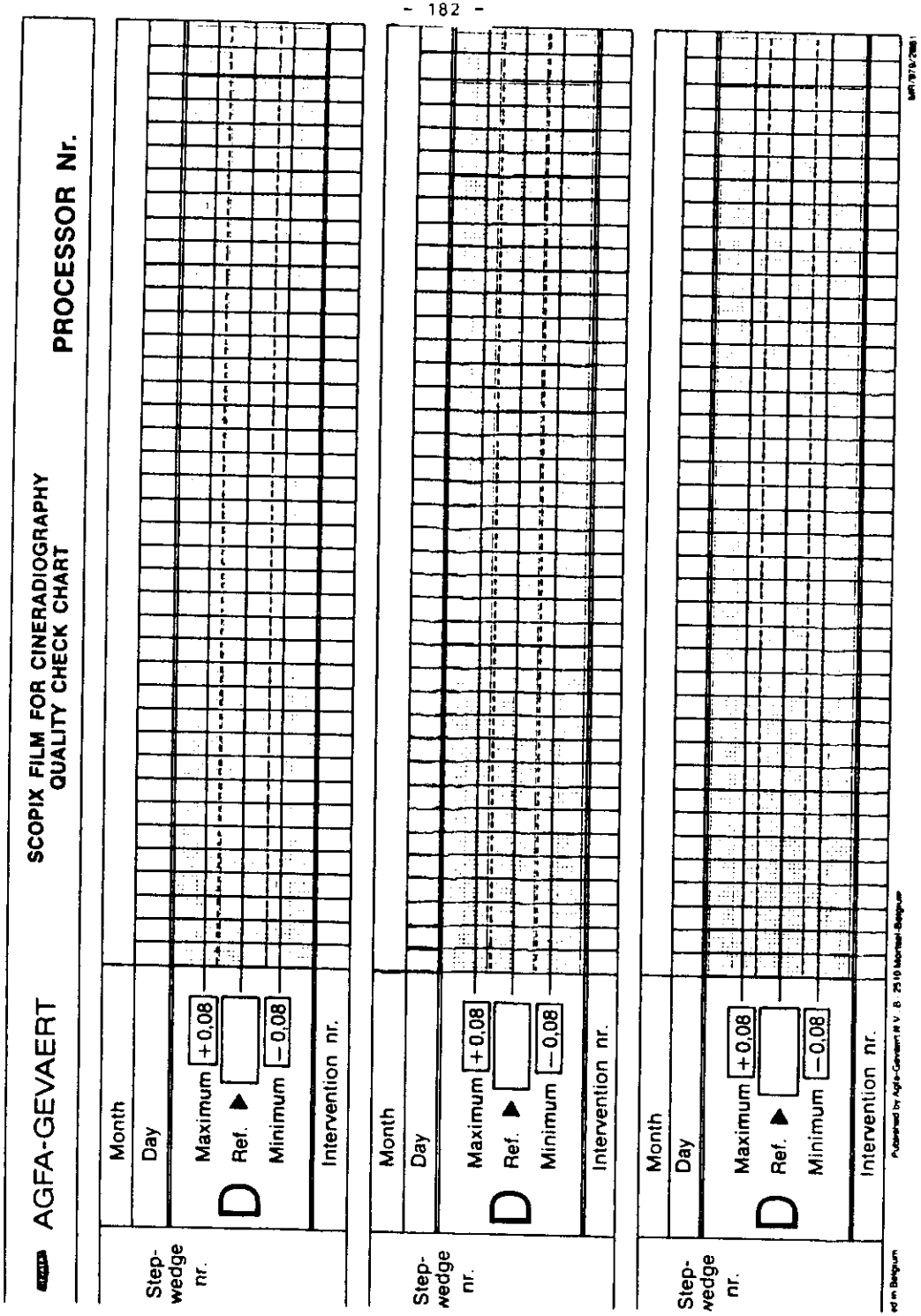
b) Record these three parameters in the "Quality Check Chart" for each step wedge and day

c) Draw a continous line from the points marked

d) Compare lines with given limits

e) Draw conclusions





C DARKROOM SAFELIGHT

(Maintaining secure filmhandling in darkroom)

In general, the fact is disregarded that inproper safelight conditions may fog the X-ray film and/or decrease the contrast of the radiograph. Mostly the error is blamed upon the X-ray film or processing.

Whenever safelight conditions have changed and/or a new type of film is introduced for use with new techniques, testing the safelight and/or film is recommended. It is very important that an appropriate safelight test be always conducted with a pre-exposed X-ray film since this is the easiest way to ensure adequate safelight conditions.

Exercise I
(use un-exposed film)

This exercise is intended to show that testing an un-exposed film does not necessarily provide for reliable results as to whether the tested film and safelight are safe in practice (see results of exercise II).

a) Use an X-ray film, but do not pre-expose it and put under safelight for testing

b) - Cover 1/6 of film immediately before ex- posing it to safelight
- Expose uncovered 5/6 of total film to safelight for 15 sec.
- Again cover another 1/6 of film and go on accordingly. Each time expose the remainder uncovered film to safelight for 15 sec. and gradually increase exposure to 30 sec., 60 sec. and 120 sec.

c) If the film is fogged by safelight, measure the density in each of the 6 steps

d) Record details of test such as:
Date of test .....
Film used for test .....
Emulsion number of film .....
Type of safelight .....
Filter of safelight .....
Distance safelight/tested film.....
Time of safelight exposure of the film.....
(0 - 15 - 30 - 60 - 120 - 240 sec.)
Density in all 6 steps .....

e) Draw conclusions from results, considering that an increase in fog to more than D=0.05 is not tolerable.

Exercise II
(use pre-exposed film)

This exercise is intended to prove that a pre-exposed film will fog faster than a fresh one (see results of exercise I). This should be taken into consideration when testing safelight conditions.

a) Put an X-ray film (same type as used for exercise I) into cassette with parspeed (universal) screens

b) Expose the loaded cassette on X-ray unit with approximately 40 kV and 12 mAs at FFD: 5 ft (1.7 m)

c) Take pre-exposed film from cassette and place it under safelight for testing.

d) - Cover 1/6 of film immediately before exposing it to safelight

- Expose uncovered 5/6 of total film to safelight for 15 sec.

- Again cover another 1/6 of film and go on accordingly. Each time expose the remainder uncovered film to safelight for 15 sec. and gradually increase exposure time to 30 sec., 60 sec.and 120 sec.

e) If the film is fogged by safelight, measure the density in each of the 6 steps

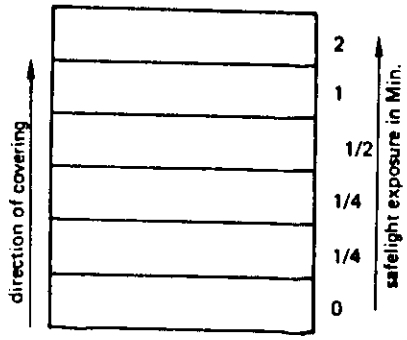
f) Record details of test such as:

Date of test .....
Film used for test .....
Emulsion number of film .....
Pre-exposure data .....
Type of safelight .....
Filter of safelight .....
Distance safelight/tested film .....
Record safelight-exposure on film
(0 - 15 - 30 - 60 - 120 - 240 sec.)
Record density in all 6 steps .....

g) Draw conclusion from results considering that an increase in fog to more than D=0.05 is not tolerable.

This page refers to exercise I and II:

Graph to show how the film to be tested is exposed to safelight.



actual exposure (accumulated):

1/4 + 1/4 + 1/2 + 1 + 2 = 4 Min.
1/4 + 1/4 + 1/2 + 1 = 2 Min.
1/4 + 1/4 + 1/2 = 1 Min.
1/4 + 1/4 = 1/2 Min.
1/4 = 1/4 Min.
0 = 0 Min.

Compare results of the two exercises:

Compare results of the two exercises:

seconds exposed to safelight	un-exposed film (measure density of step .....only)	pre-exposed film (measure density of step..... only)	increase of density
0 reference	D =	D =	+ D =
15	D =	D =	+ D =
30	D =	D =	+ D =
60	D =	D =	+ D =
120	D =	D =	+ D =
240	D =	D =	+ D =

Conclusion

Exercise III

(use pre-exposed step wedges)

This exercise is intended to prove that inadequate safelight conditions do not only fog the film but also decrease the contrast.

a) Expose 4 samples of film on a sensitometer

b) Process one of the samples immediately after exposure (reference)

c) Expose 2nd sample to the tested safelight for 60 sec, next sample for 120 sec, last sample for 240 sec.

d) Record important details

e) Measure all 4 step wedges and plot curves

f) Determine the "average gradient" ($\bar{G}$)

g) Draw conclusion from results

Measuring of Illuminator Brightness

Important Rule: When evaluating radiographs avoid dazzling by illuminator, use collimation whenever possible.

Procedure for measuring

Use lightmeter without diffusor.
Set speed at 100 ASA = 21 DIN. Measure vertically in direct contact with illuminated area.

Exposure Value EV [1]	Brightness [2] in cd/m^2
18	25 000
17	12 000
16	6 000
15	3 000
14	1 500
13	750
12	400
11	200
10	100
9	50

Very bright illuminators require a subduction with a grey filter D = 200 (N 200). In this case the resulting exposure value EV has to be multiplied with 100.

1) EV readings are used instead of f-stop data
2) physical exact: luminance

The use of Lux-values is not permissable, as the relevant factor is not light intensity, but luminance which is given in candela per square meter (cd/m^2).

Brightness Recommendation

For illuminators without collimation, a brightness of 1 500 to 3 000 cd/m^2 (EV 14 - 15) is considered as optimum. However, the radiologist must keep in mind that densities of more than D 2.3 cannot be evaluated properly (dazzling!). When the radiograph is properly collimated the optimum brightness is 3 000 to 6 000 cd/m^2 (EV 15 - 16). In this case the total range of the radiograph can be evaluated. In case of very high densities (D 3.0 or more) the luminance level of the relevant image area should have at least 10 cd/m^2 (DIN 54 111), to prevent loss of perception.

The required brightness is figured out from

$$\lg H_o = 1 + D \text{ or } H_o = 10^{1+D}$$

Dazzling has to be prevented in every case!
The ambient light in the room has to be kept low. It is measured near the illuminator in Lux-values (light intensity). To do this a lightmeter with diffusor can be used. The light of the illuminator has to be shut off for this purpose. Only after the roomlight has been subdued to 50 Lux or less there is no more impairment of perception.

When setting the lightmeter at 100 ASA (= 21 DIN) there is the following context between EV and light intensity Lux:

2 EV/10 Lux - 3 EV/25 Lux - 4 EV/50 Lux - 5 EV/100 Lux - 6 EV/200 Lux (Lux: approcimate values)

RADIOGRAPHIC EQUIPMENT

COLLIMATOR, BEAM ALIGNMENT, FILM– SCREEN – TESTS.
OUTPUT: REPRODUCIBILITY AND LINEARITY, BEAM QUALITY
GRID ALIGNMENT

B 1

MATERIAL

Pen dosimeter
Collimator test tool
Beam alignment test tool
Attenuator set (AL)
Film screen contact test tool
Lead blockers
Densitometer

AUTHOR

Dr. M. Goßrau

Parameters and components to be tested

1. Collimator
2. Beam alignment
3. Film - screen
4. Output: reproducibility
5. Output: linearity
6. Output: quality (HVL)
7. Grid alignment

General remarks

In the following exercises the test equipment from Radiation Measurements Inc., PO Box 44, Middleton, Wisconsin 53562 (RMI) will be used. This does, however, not mean any preference of this manufacturer.
Among the numerous publications on Quality Assurance for radiographic X-ray units there is one containing a detailed list of manufacturers and suppliers of test tools (AAPM Report No 4: Basic Quality Control in Diagnostic Radiology, 1978).

Except for the tests concerning the output of the X-ray unit, consideration will be given exclusively to parameters relateded to the mechanical components.
Thereby emphasis is laid on the fact that it is mandatory for the mechanical components of a radiographic X-ray unit to be in a good condition. Any quality assurance programme should therefore include a general survey of mechanical stability and integrity.
All tests are feasible with rather simple tools which in most cases can be constructed by the user himself. The tests are suited for routine checks. However, no general recommendation can be made as to how often such checks should be performed because this should be decided individually according to the situation in the X-ray department concerned.

Exercises

1. Collimator

1.1. Introduction

The light field provides for simulation of the X-ray field in size and location. These two fields should therefore be congruent within reasonable limits. Although the collimator test can be done conveniently using the collimator test tool RMI 161 A, there are several other possibilities to do this test without a commercial tool, e.g. using coins or metal strips in a defined position.

1.2. Test procedure

At first, bring the tube in a position with the tube axis perpendicular to the table and center it so to the table that the focus-table distance is 1 m.

Place the collimator test tool in the center of the light field and adjust the light field to the lines marked on the test tool. Load a 24 x 30 cm cassette and perform an exposure with 60 kV and 2 mAs.

1.3. Evaluation and discussion of results

There is a good congruence between the light and X-ray beam when the image is within the lines marked on the test tool. If any side of the image falls on the first or second spot, inside or outside the borderlines, there will be a misalignment of $\pm$ 1 cm or 2 cm corresponding to 1% or 2 % of the chosen focus-table distance of 1 m. The results can be noted in the following form:

Congruence of light and X-ray field

Department: Room No.
X-ray unit, modell: Manufacturer:
Focus-film distance: m; field size: x cm^2
Film and exposure data used: kV, mAs

Date	Deviation in cm				Total dev. %		Remarks, Sign.
	left	right	top	bottom	horizontal	vertical	

Remark:

In addition to the alignment of the X-ray and light field, the alignment of the X-ray field and image receptor, in our case the film, is required.

To check this condition, the center of the film may be marked by drawing diagonal lines on it and may be compared with the center of the imaged X-ray field. The deviation should not exceed 2% of the focus-film distance.

Question:

What are the main causes of deviations between the light and X-ray field?

2. Beam alignment

2.1. Introduction

This test is recommended to be combined with the collimator test (1). The additional tool (RMI 162 A) required for this purpose consists of a plastic cylinder containing two steel balls. These are situated exactly one above the other when the cylinder is placed on a level table.

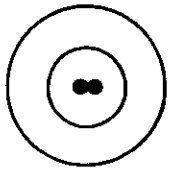
2.2. Test procedure

Make the same arrangement as described under 1.2. and place the alignment tool into the center of the collimator tool. Perform an exposure (60 kV, 2 mAs, focus-table distance 1 m), develop the film and evaluate the image. The film should be kept as a document and for comparison with future tests.

2.3. Evaluation and discussion of results

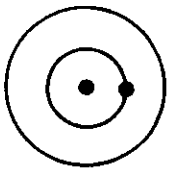
The used tools enable for direct evaluation if the focus-table distance is 1 m. The images of the steel balls may be interpreted as follows:

1. The images of the two balls overlap within the inner circle:



the central axis beam is perpendicular to the table within 0,5°

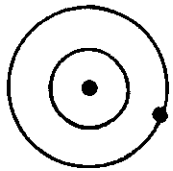
2. The image of the top ball lies on the first circle line:



misalignment of about 1,5°

3. The image of the top ball lies on the second circle line:

misalignment of about 3°



Remark

The measurements are performed on the table and not in the plane of the image receptor (cassette). The results are, therefore, only meaningful when the plane of the image receptor is parallel to the table plane. This must be checked before.

3. Film - screen

3.1. Introduction

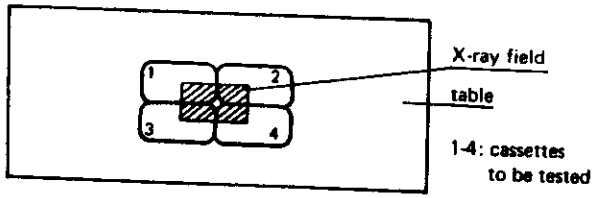
To ensure constant quality of radiographs, it is important to use only cassettes in a good condition. These should, therefore, be inspected for mechanical damage in regular intervals (e.g. 1 year) in order to eliminate cassettes with faults due to stained or yellowing areas, dirt, light leaks etc.
When the screens have been cleaned, the material recommended by the manufacturer should be used exclusively.

There is a simple possibility to test film screen contact and screen integrity with a test tool (RMI 142) consisting of a wire mash (3 lines per cm) embedded in plastic. In lack of this tool, a normal wire mash may be used as well.

3.2. Test procedure

Load the cassette to be tested, put it on the table and place the test tool on it. Adjust the light field to cover the whole cassette and perform an exposure of approx. 50 kV and 2 mAs at 1 m focus-table distance.

To check the speed of screens, another test can be done with a radiograph using 4 cassettes simultaneously, one of which is a master cassette with known speed. The geometric agrrangement on the table would be as indicated in the following figure:



3.3 Evaluation and discussion of results

The image obtained by means of the wire mesh tool should be inspected on a view box from a distance of about 2 m where areas of bad contact will show a slight increase in density. When inspected from a shorter distance, such areas will show a slightly blurred image of the wire mesh.

The result of the speed test should be equal visual densities; when a densitometer is used, the variation should not exceed $\pm$ 0.2 OD.

The results of the film screen contact test may be recorded in a data form like the following:

Survey of film screen contact

X-ray unit used:

Cassette			Test date	Good cassette		Remarks
No.	Screen type	Size		Yes	No	

4. Output: Reproducibility

4.1. Introduction

The output is one of the most important parameters of an X-ray unit. The general output measurement procedure has been discussed in part 1 of these exercises. In the following, one special aspect will be considered, viz. the reproducibility of the output which is expressed as the coefficient of variation of several output measurements.

4.2. Test procedure

Place a pen dosimeter on the table and adjust the light field to this dosimeter. In order to obtain well defined conditions and a minimized backscatter, it is recommended to place a piece of lead under the pen dosimeter.

The exposure parameters should be equal to those of normal clinical use and produce a reading approximating the full scale of the dosimeter. Example: focus-table distance 1 m; 70 kV; 30 mAs.

Remark on pen dosimeters:

This simple instrument may be used often to measure exposure for QA-purposes. The following advices should be observed then:

1) There are different types of pen dosimeters depending on the radiation quality to be measured

2) There is a great variety of measuring ranges, the most common one for personnel monitoring is 0 - 200 mR.

3) A typical value for accuracy (measured with Co 60, midscale) is $\pm$ 10 %.

4) There is an electrical leak of about 1 - 2% from full scale per day.

4.3. Evaluation and discussion of results

The measured values may be recorded using the following form:

Output reproducibility survey

Department: Room No.:
X-ray unit, model: Manufacturer:
Date: Dosimeter No.:
Exposure parameters: kV, mAs, m focus-table distance

Reading No.	Exposure X_i (mR)	$X_i - \bar{X}$	$(X_i - \bar{X})^2$
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
	$\bar{X} = \frac{1}{10}\sum_{i=1}^{10} X_i$		$\sum_{1}^{10} (X_i - \bar{X})^2 =$
			$\sigma =$

The coefficient of variation for these measurements is calculated from

$$\sigma = \frac{1}{\bar{X}} \sqrt{\frac{\sum_{1}^{10} (X_i - \bar{X})^2}{n-1}}$$

where n = 10 is the number of measurements.

The value of σ should not exceed 0.05 = 5 %.

Reference: Quality Assurance Handbook, RMI, 1981

5. Output: Linearity

5.1. Introduction

When using a unit that permits selection of kV, mA and sec., it is important to be sure that the output of mR/mA is independent from the mA station used. This may be checked, in regular intervals (e.g. 3 months),by measuring the exposure.

5.2. Test procedure

The arrangement is the same as in section 4.2.; a lead blocker is used for analogous reasons. The exposure parameters should be those of general clinical use (e.g. focus-table distance 1 m, 70 kV and 30 mAs). They may be slightly changed in order to obtain a reading approaching the full scale of the pen dosimeter. During the measurements, kV and distance must be kept constant. To avoid statistical errors, 10 measurements are made for every station and the average values are taken. When testing the linearity of 5 stations, the following form may be used.

5.3. Evaluation and discussion of results

The coefficient of linearity between two stations, e.g. station 1 and station 2, is defined as

$$c_{1,2} = \frac{|\bar{X}_1 - \bar{X}_2|}{\bar{X}_1 + \bar{X}_2}$$

with X_1 and X_2 as the corresponding values of the output mR/mAs.

When the stations considered are adjacent to one another, c should not exceed 0.1 (that means a difference of 22% between the values of X).

Some authors require this criterion to be fulfilled for the stations with maximal and minimal values of mR/mAs as well.

Remark:

The absolute value of the difference $X_A - X_B$ is used in order to avoid negative numbers for c.

	remarks
$c_{1,2} = \frac{-}{+} =$	
$c_{2,3} = \frac{-}{+} =$	
$c_{3,4} = \frac{-}{+} =$	
$c_{4,5} = \frac{-}{+} =$	
$c_{max,min} = \frac{-}{+} =$	

Output linearity survey

Department: Room nr.:
X-ray unit, model: manufacturer:
Date: dosimeter nr.:
kV: focus table distance: m

Reading Nr.	Station 1			Station 2			Station 3			Station 4			Station 5		
	mA	s	mAs	mA	s	mAs	mA	s	mAs	mA	s	mAs	mA	s	mAs
	Exposure (mR)														
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
$\bar{X}$															

6. Output: HVL

6.1. Introduction

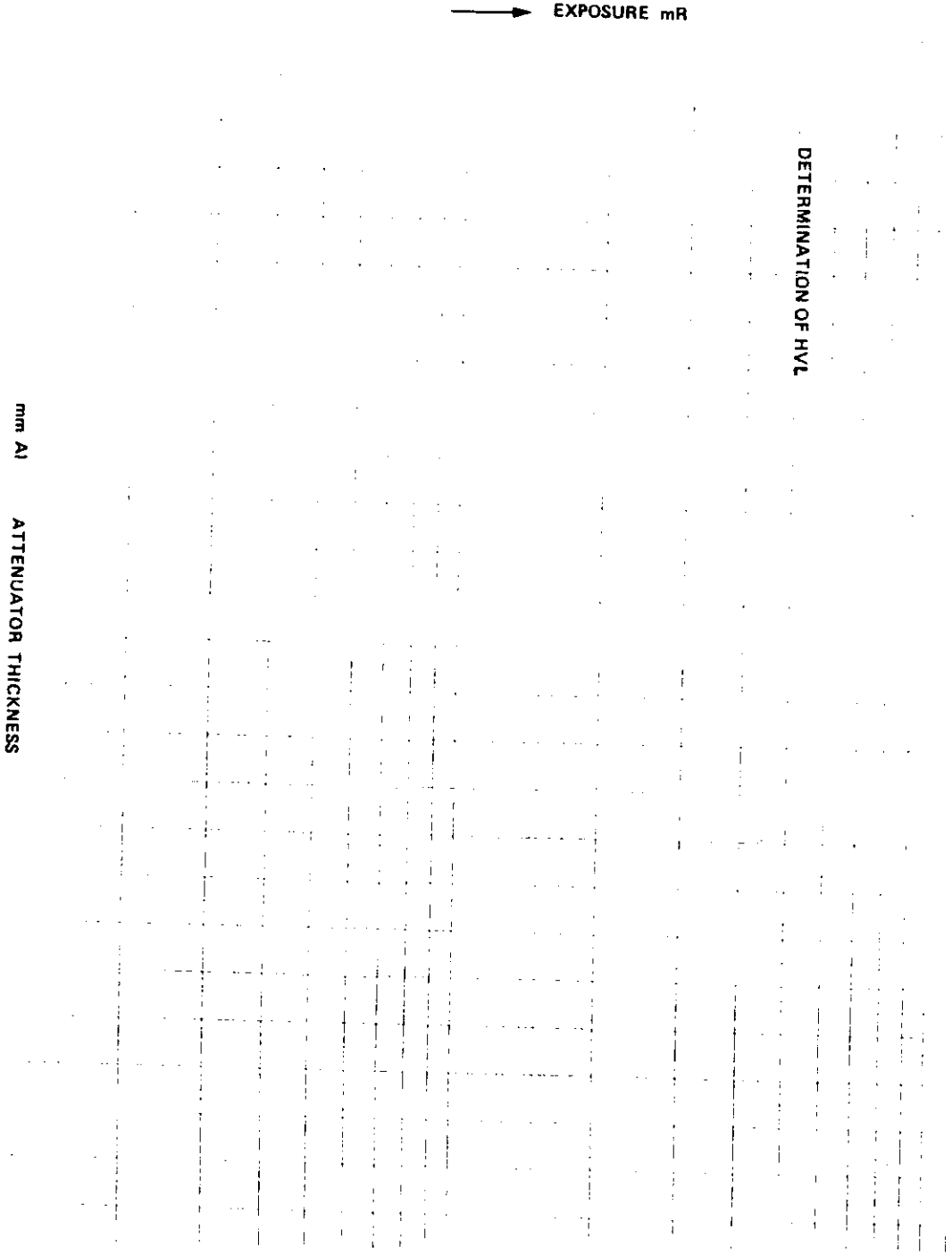
In addition to the two parameters for reproducibility and linearity describing the output quantity, it is common to measure the HVL of the X-ray beam in order to obtain an indicator for its quality. Normally Al is used and care should be taken to use material of high purity, since working with alloys might produce false results.

6.2. Test procedure

To determine the HVL the same set-up is used as that indicated in part 4.2., i.e. the dose measurements are done with a pen dosimeter placed on the table. The attenuators, varying from 0.5mm up to 5.0 mm Al, are fixed at the collimator housing with a tape. As an initial test, the measurements should be done at several kV settings within the clinically used range. As a routine test, it is common to use 80 kV for comparison with former results.

The focus-table distance and the mAs setting have to be selected in a way that the dosimeter reading approaches the full scale. To ensure consistency, 3 readings are done and the average value is used.

For documentation of results, the form shown below may be used.



Department: Room No.:

X-ray unit, model: Manufacturer:

Date: Dosimeter No.:

Exposure parameters: kV, mAs, m focus-table distance

Inherent filter: Added filter:

Attenuator thickness (mm Al)	mR reading No. 1	2	3	average
0				
0.5				
1.0				
1.5				
2.0				
2.5				
3.0				
3.5				
4.0				
4.5				
5.0				

6.3. Evaluation and discussion of results

To determine the HVL, the dosimeter reading is plotted versus the attenuator thickness. The plot is usually done on semi-log graph paper. For initial testing, the whole curve should be plotted, whereas routine tests may be done by plotting only a few points near the expected HVL value.

Compare the measured values with the recommended values you know.

What may be the reason if HVL is
- too low?.....
- too high?....

What may be the consequence if HVL is
- too low?.....
- too high?.....

7. Grid alignment

7.1. Introduction

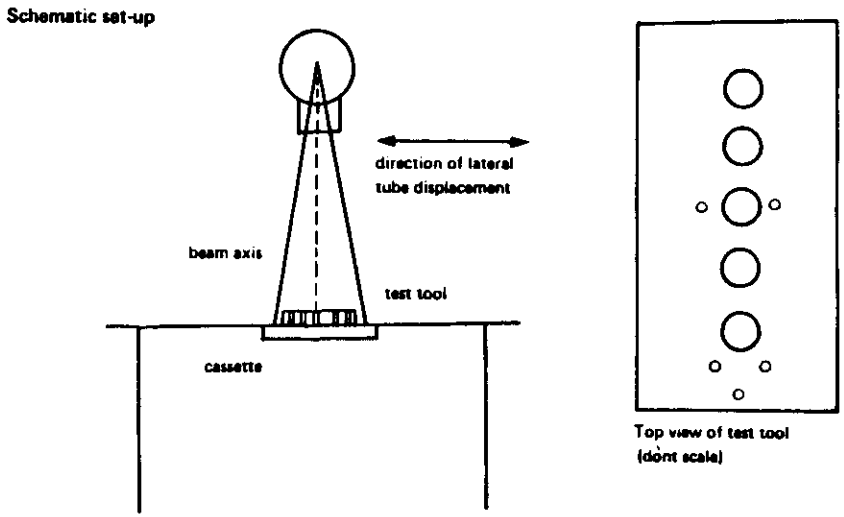
The proper alignment of the radiographic grid should be controlled because in the case of misalignment two parameters will be influenced:

- patient dose is increased
- image quality is decreased.

Grid cut-off caused by incorrect source-grid distance (i.e. grid not used within the focal range usually marked on it) or upside-down focussing may be detected very easily. The following test is designed to find out any lateral displacement of the grid.

7.2. Test procedure

The used test tool RMI No. 144 consists of a lead blocker (plastic covered, 0.2 cm x 9 cm x 23 cm) with 5 holes (diameter: 0,9 cm) spaced at a distance of 2.5 cm from one another (see diagram). The additional small holes are for orientation purposes only.



Place the tool on the table, load a cassette (20 cm x 25 cm or larger) and center the tube on the middle hole. Cover the other holes with two small lead blockers and perform an exposure (60 kV, 5 mAs) resulting in a density between 1 and 2.
Subsequently, move the tube in a perpendicular direction to the grid lines (see diagram), centering it to the additional 4 holes and performing exposures in the same way as described before.

Process the film, measure the optical density and record results in a form like the following:

Grid alignment survey

Department: Room No.:
X-ray unit, model: Manufacturer:
Grid ratio: Focal distance:
Exposure data: kV, mAs, m(focus-table distance)

Date	Measured optical densities hole nr. 2	1	0	1	2	Remarks	Sign.

If there is proper alignment, the density of the center hole should be maximum and the density values of the adjacent holes should fall off symmetrically.

In this case an adequate alignment within 1.25 cm (the holes are spaced 2.5 cm) will be found which is an acceptable tolerance for routine use of most grids.

To avoid any misinterpretation, the collimator and the centering of the beam should be checked before this test.

Question:
What may be the cause of grid misalignment?

FLUOROSCOPIC EQUIPMENT

IMAGE QUALITY: RESOLUTION, CONTRAST. ALIGNMENT, ACCURACY OF READING INSTRUMENTS,AEC – FUNCTION TEST, DOSE RATE LEVELS

B 2

MATERIAL:

Test body having the properties and structures needed to measure the six parameters of image quality as identified below. (Description of Al-Testbody see p. 224 f.)

Tape measure (150 cm)

Tube (peak) voltage measuring device (60 kV to 150 kV)

Pen dosimeter (200 mR)

Exposure rate meter (50 R/s to 2500 R/s)

AUTHOR:

Dr. T. Bronder

1. Introduction:

The task of quality control is to measure characteristic parameters and to compare the measured values with those identified using the same x-ray equipment earlier or at other equipments under the same measurement conditions. Values given by a manufacturer, a national or an international commission can be compared with these quality control data. There are two classes of parameters:

a) parameters describing the relative image quality under special conditions (i.e. test patterns)
b) parameters describing the absolute properties of the components of the x-ray equipment.

to a): In this exercise, the relative quality of the fluoroscopic image will be evaluated by the following six parameters:

1. limiting resolution
2. threshold contrast
3. visible object field size (scale, operating mode)
4. image distortion (radial and tangential)
5. brightness homogenity
6. "afterglow"

to b): In addition, the quality of the following important components of the fluoroscopic equipment will be assessed:

- diaphragm system (alignment)
- reading instruments (accuracy of "kV" and EAP)
- automatic exposure control (AEC-function, variable quantities: "kV" and/or "mA", controlled levels of exposure rate, alignment of the useful beam.)
- size and alignment for the sensitive area of AEC

Therefore, the following parameters will be measured for different working conditions of the components mentioned:

1. tube peak voltage
2. distances (lateral and parallel to the central beam)
3. field sizes
4. exposure at the entrance of testbody
5. exposure rate or dose rate (behind the testbody) at the entrance to the image intensifier.

2. Checking procedure

Before starting the quality control measurements, record the following date (see "Record of measurements" Sec. 3)

- room and date
- decription of the x-ray equipment
- description of the test equipment used

Now you can perform the quality assurance measurements and comparisons

2.1. Image Quality

- place the test body next to the imaging system, align the image to the center and adjust the useful beam to the size of the monitor.
- vary the combinations of operating modes and observe the resulting image structures. The most important image parameters are the limiting resolution and the threshold contrast.
- for quality control, the date must be compared with earlier measurements or the absolute values of tolerances given by the manufacturer.
  You can also compare your measurements with the data measured using the same test equipment with other X-ray equipments.

2.2. Alignment of diaphragm-imaging system

- Center test body and collimate the diaphragm-pairs of each direction to its center.
- A deviation of 1 cm may be acceptable.

2.3. Accuracy of reading instruments

a) Tube voltage reading
   - introduce the probe of the tube voltage measuring instrument into the x-ray field and vary the tube voltage control.
   - compare the measured values with the reading at the x-ray equipment. The acceptable tolerance is given by the manufacturer's indications (or IEC).

b) Exposure area product reading (EAP)
   - collimate to a defined area in the plane of the dosimeter (with the help of the test body) and perform an exposure for about 1 minute.
   - calculate the exposure area product using the measured values and compare it with the EAP meter reading of the X-ray equipment. The tolerance is given by the manufacturer (or IEC).

2.4. The automatic exposure rate control (AEC)

a) Range of automatically adjusted quantities ("kV" and/or "mA")
   - Vary the combinations of operating modes and read the tube voltage and the tube current (without the test body) at opened and closed diaphragm.
   - The AEC must work according to the manufacturer's indications

b) Type of controlled exposure area (CEA)
   - Center the test body in the image field, gradually close the diaphragm and observe the instruments indicating tube voltage and tube current
   - An "average value" - control will work as soon as the diameter falls short of about 1/2 of image diameter. A "peak value" controll will not work until the field is very close to about 4 cm^2. Compare with data given by the manufacturer.

c) Size and alignment of the controlled exposure area
   - Center to the "absorption hole" of the test body and close only one pair of diaphragm (horizontal or vertical) to 1 cm. Move the image intensifier (lateral) in the horizontal or vertical direction. With the "absorption hole" at the border of the controlled exposure area, the AEC will work strongly (look for instruments or intensity). Measure four distances to the image border for different directions.
   - Compare the size and alignment with earlier measurements, data measured with other x-ray equipments or the manufacturer's indications.

d) Values of exposure rate or dose rate in the plane of image intensifier (IMI)
   - Place an absorption plate (Water phantom, Copper or the Aluminium testbody) into the X-ray field next to the focus, and a dosemeter probe next to the image intensifier. Adjust a great distance and collimate to the diameter of the dosemeter. Select the two settings of dose rate levels and read each time the values of tube current, tube voltage and measured dose rate.

- If the anti-scatter grid was between the dosemeter probe and the image intensifier, correct the dose rate J_1 with the formula:

$J_2 = f_{grid} \times (d_1/d_2)^2 \times J_1$ with $f_{grid} = 0,6$

f_{grid}: transmission factor of the grid

d_1 : focus - probe distance

d_2 : focus - image intensifier distance

For transforming the values from old to new SI - units use the relation:

100 /uR/s 1 /uGy/s (in air)

- Compare the values of both dose rate levels (key 1 and key 2) with the data given by the manufacturer. At 80 kV they should not exceed:

40 /uR/s (lower level)
100 /uR/s (high level). (see "WHO-Workshop on QA" paper 1980)

Record of measurements

Room: Date:

A. Description of x-ray equipment

Type of (imaging) systems:
Geometric data

- Focus-table top distance: cm
- Spotfilm-device - imaging system distance:
  a) Film cassette = cm
  b) Image intensifier (or fluoroscopic screen) = cm
- Diameter of image intensifier (IMI): cm
- Field of fluoroscopic screen (FLS): cm x cm

- Type of generator:

- Operating knobs, switches and keys for
  - tube voltage: from kV up to kV
  - tube current: from mA up to mA
    or: level 1: mA
    level 2: mA
    level 3: mA
  - automatic control type: control key : (mA)
    control key : (kV)
    control key : (mA+kV)
  - dose rate level (at automatic control)
    DR level 1: /uR/s /uGy/s
    DR level 2: /uR/s /uGy/s

Reading instruments for
- O tube voltage
- O tube current
- O exposure area product (EAP)
- O exposure time
- O.....

B. Measurements

1. Image Quality

Focus - IMI (FLS) distance : cm

Focus - test body distance : cm

Image area in the plane of test body : cm ⌀ for IMI

(visible object size) (cm x cm) for FLS

selected automatic control type	(key) :	
selected dose rate level	(key) :	
tube current (selected)	(mA) :	
tube voltage	(kV) :	
limiting resolution	(Lp/mm) :	
threshold contrast	(Step No.) :	

2. Alignment of the tube assembly to the imaging system

Focus-IMI (FLS) distance : cm

Focus-test body distance : cm

Diaphragma center in the plane of test body:

... cm left/right from image center

... cm over/under the image center

3. Accuracy of reading instruments

a) "kV"-meter

selected tube voltage (kV) _____

measured tube voltage (kV) _____

b) EAP-meter

field size at dosemeter distance: cm x cm = cm^2

measured exposure dose: R = Gy

reading of EAP meter: R x cm^2 = Gy x cm^2

computed EAP : R x cm^2 = Gy x cm^2

4. The automatic exposure rate control (AEC)

a) range of automatically regulated quantities (kV and mA)

automatic control type	(key):
dose rate level	(key):
tube voltage at opened collimator	(kV):
tube current at opened collimator	(mA):
tube voltage at closed collimator	(kV):
tube current at closed collimator	(mA):

b) type of controled exposure area (CEA)

lenght of quadratic field size (cm): 4,0 2,5 2,0 1,5

Brightness:

results: average value control O peak value control O

c) Size and alignment of controlled exposure area

Focus - IMI distance: cm

Focus - Test body distance: cm

Image diameter in the plane of the test body: cm

border of controlled exposure area, measured distance:

cm from the upper image border
cm from the lower image border
cm from the left image border
cm from the right image border

d) Controlled dose rate at image intensifier

focus - dosemeter chamber distance: d_1 = cm

focus - image intensifier distance: d_2 = cm

anti-scatter grid between chamber and IMI no O,
O yes calculatete the dose rate at d_2 with
$f_{grid} = 0,6$

dose rate level (key) : _____
tube voltage (kV) : _____
tube current (mA) : _____
measured dose rate (/uR/s): _____
corrected dose rate (/uR/s) _____
(if necessary)

C. Results and consequences of the qualitiy control

(Are the measured data in agreement with absolute tolerance values or with data you measured at the same x-ray equipment earlier?)

Discussion of measurement results

1.1 Describe the variation of image quality ("limiting resolution" an "threshold contrast") depending on different tube voltages if the dose rate at imaging system is constant.

1.2 Describe the variation of image quality depending on different dose rate if the voltage is constant.

2.1 Which components of the x-ray-equipment must be aligned on the central beam?

2.2 To what extent do the patient exposure and the image quality vary if the anti-scatter grid is misaligned?

3.1 Which tolerance do you think to be acceptable for accuracy of the tube voltage and the exposure area product reading? (1 %, 5 %, 10 %, 30 %)

3.2 Which quantitaties should be read at the x-ray-equipment with instruments built in and why do you need these readings?

4.1 What advantages has an automatic exposure rate control with

a) automatic regulation of both the tube voltage and the tube current?
b) automatic regulation of the tube voltage only?

4.2 Describe a simple method for testing the function of the automatic exposure rate control and the equipment used for the check.

Integrated Test Body for Quality Assurance in Diagnostic Radiology

A) Description of the integrated Al-test body for radiography and fluoroscopy

Material:

250 mm x 250 mm x 25 mm Aluminium (Type: Al Mg 3)
Al with Si and Mg (no Cu, etc.)

Tests (built in, see Fig. 1)

1. Line-Group-Test Nr. 38/0,05
   (Price: DM 90,--,
   Fa. Hüttner
   An der Schwedenschanze 1
   D - 8551 Heroldsbach/Thurn)

   0,6 Lp/mm to 5,0 Lp/mm
   50 mm x 50 mm (0,05 mm Pb)

2. Contrast-Step-Test
   7 steps: 8 mm Ø
   0,9 mm ... 0,3 mm deep in Al-test body

   For numbering:
   7 lead-numbers in holes,
   3 mm deep, 8 mm Ø

3. Only for fluoroscopy with TV-monitor: Two Contrast-Fields
   a) Brigth-contrast-field (right position)
      25 mm x 25 mm x 2 mm deep in Al-test body
      with a centric circle 8 mm Ø,
      4 mm deep in Al test body

   b) Dark-contrast-field (left position)
      25 mm x 25 mm x 4 mm deep in Al-test body,
      with a 25 mm x 25 mm x 1 mm thick copper and
      a centric circle of copper 0,2 mm thick, 8 mm Ø

4. Only for fluoroscopy with TV and automatic exposure rate control: Bright hole (absorption hole)
   10 mm 0, 15 mm deep with a fastener at the opposite plane of the test body.

Grid of lines:

For measuring of lateral distances in the picture and for positioning of the test body and the diaphragm under fluoroscopy.

Two central lines 3 mm deep (vertical and horizontal) and parallel lines 1 mm deep in distances of 10 mm.
Two quadratic field-lines
100 mm x 100 mm and 200 mm x 200 mm,
3 mm deep in Al-test body.
All lines are 1,5 mm or 2,0 mm wide.
All lines must not be at the positions of the 4 tests.

Markers for radiographic pictures:

For positioning of the test body with respect to the light-field of the collimator there are some markers:

4 Centering markers
25 mm x 2 mm and 1 mm deep
4 field-edge-markers (or more for other fields)
25 mm x 2 mm in each direction and 1 mm deep.

4 bases:

Distance-bases for different positioning of the test body.

Clamp for pen dosimeter:

Holder for pen dosimeter at the side of the test body to the focus facing.

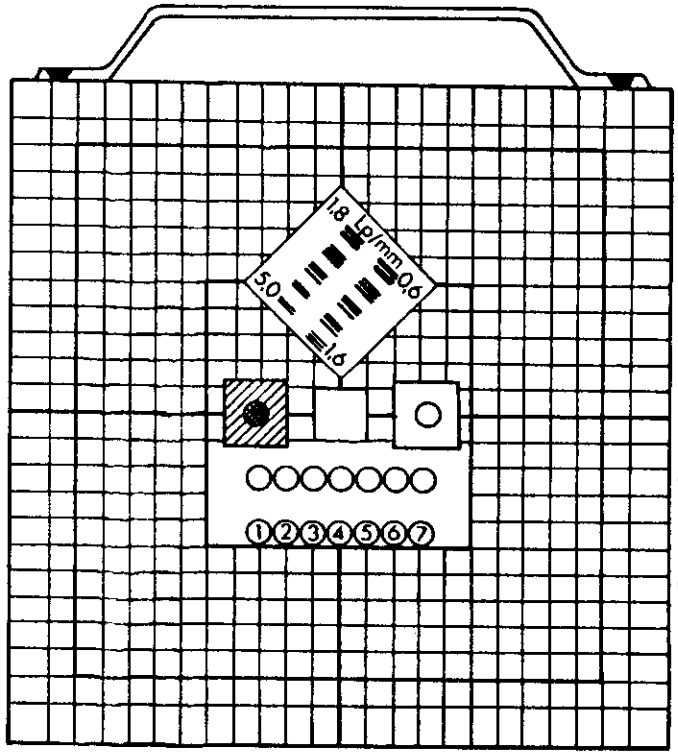


Figure 1: Integrated testbody - View of the plane of test-structures

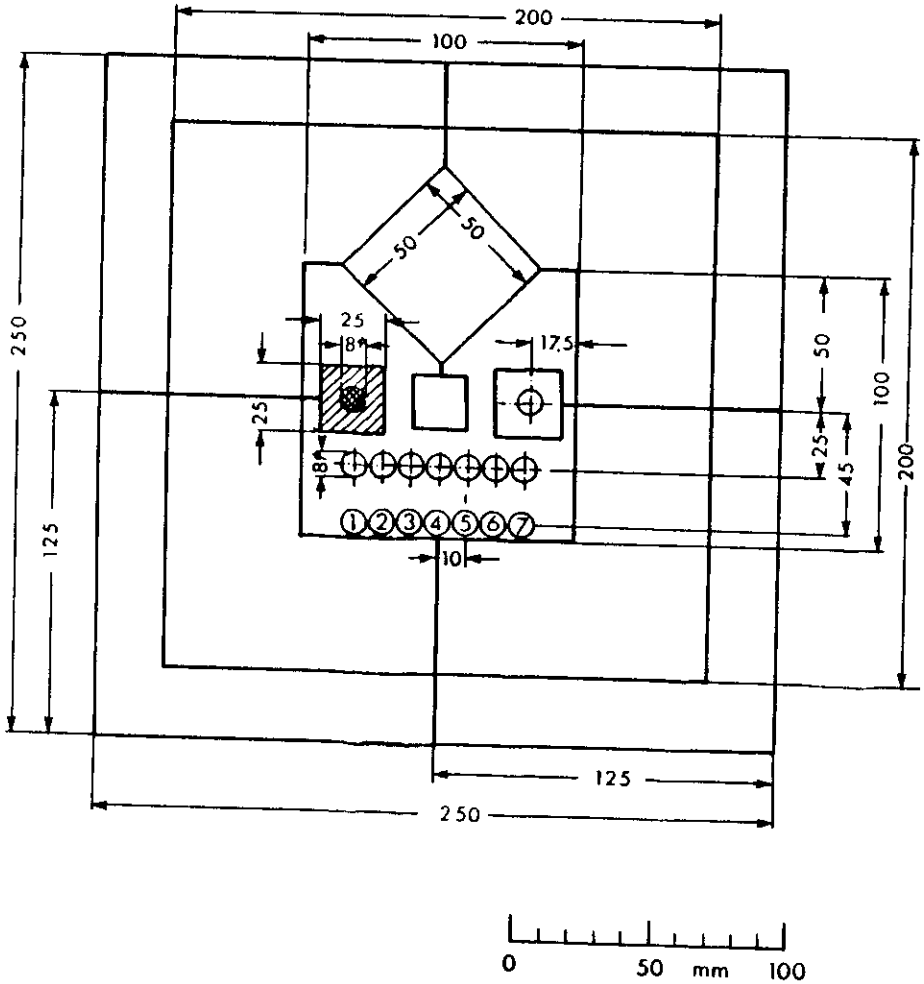


Figure 2: Integrated testbody - Positions of the test-structures

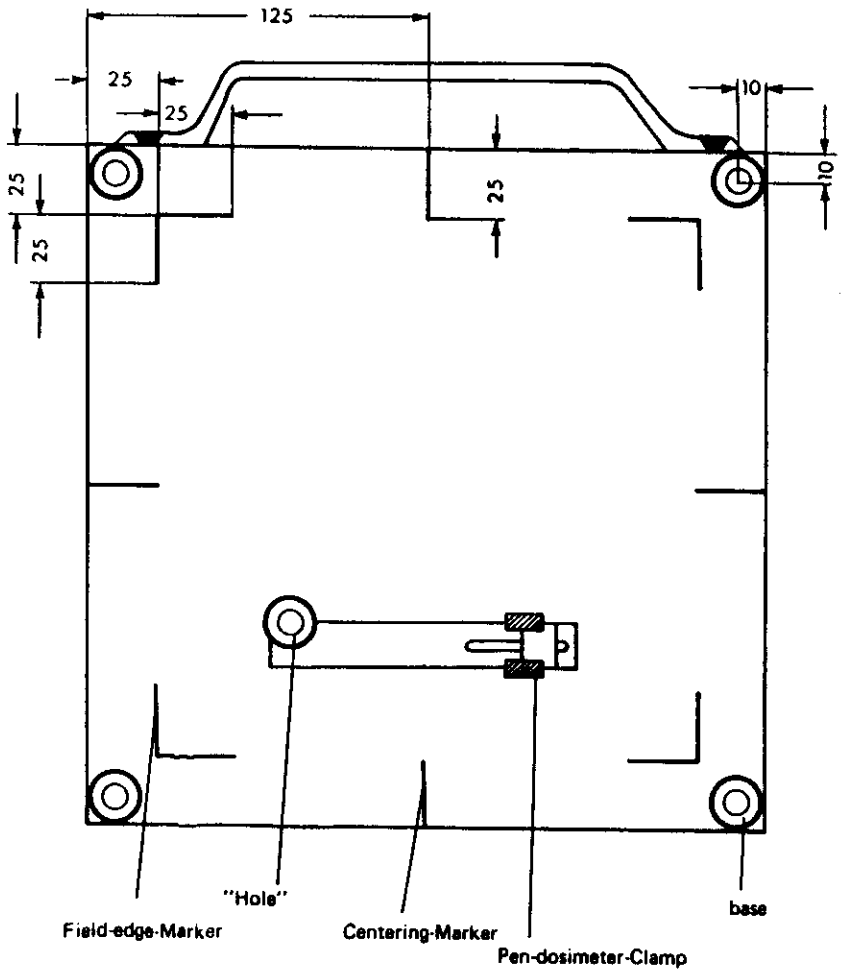


Figure 3: Integrated testbody - View of the plane directed to the focus (in normal testbody position) - Positions of markers and bases

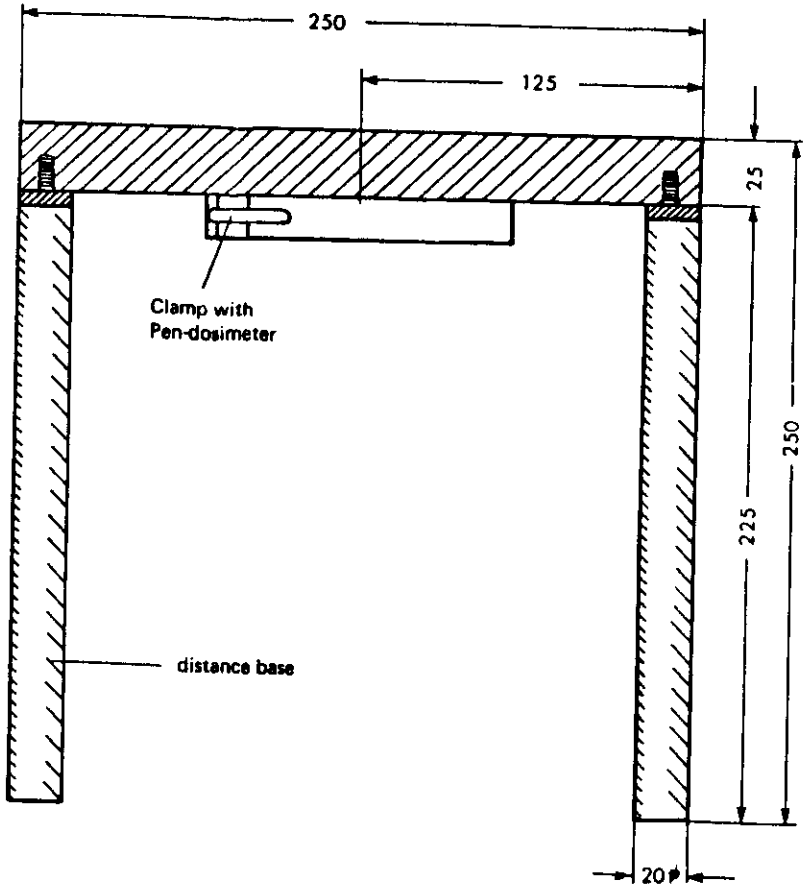


Figure 4: Integrated testbody - Side - view of the testbody on the bases

B) Measurements with the Integrated Test Body

This integrated test body is very useful for
- checks of the long time constancy of the x-ray equipment
- comparing different x-ray equipments or components
- measuring of some x-ray equipment parameters which influence the quality of the x-ray image
- demonstrating or testing the different image quality under different conditions of the x-ray equipment parameters

Some measurements are listed in the following tabel.

Remark: For all measurements the
- description of the x-ray equipment components
- adjusted values of geometric parameters (focus size, distances, field sizes)
- values of electrically controlled parameters (kV, mA, mAs, s, position of control knobs)

must be recorded together with results of the measurements in a protocol.

1. Aliqument of the x-ray equipment components

   - light field - x-ray field
   - x-ray field - patient table (if it is fixed)
   - x-ray field - film cassette holder
   - x-ray field - fluoroscopic screen or image intensifier entrance screen

2. Deviations of the field size between different x-ray equipment components

- light field	- x-ray field
- indicated collimator setting	- x-ray field
- indicated image intensifier diameter	- visible diameter
- automatically controlled x-ray field size	- film dimensions

3. Deviations of the dose or dose rate

- of indicating instruments (exposure area product meter)
- in the test body entrance plane depending on the time (after some months)
- behind the test body, compared with international patient protection limits or depending on the dose value, which is needed for a picture. For measurements of the dose (rate) behind the test body there must be a great distance between the test body (nearer to the focus) and the dosemeter chamber (position with distance bases).

4. Deviations of the optical density

- depending on the time (every week)
- of different x-ray equipments (at the same conditions for field size, distance, kV, mAs)

5. Deviations of the focus size (with the line-group test)

- depending on the time (after some months)
- different x-ray tubes (at the same measuring conditions) For that measurement the test body must have a shorter distance to the focus but a greater one to the film cassette (position with distance bases)

6. Deviations of the resolution in the x-ray image

- depending on different types of intensifying screens
- depending on time (after some months) at fluoroscopy (the same TV-monitor brightness and contrast must be adjusted)

7. Deviation of the contrast in the x-ray image

- depending on different types of radiographic films
- depending on different kV
- depending on time (after some months) at fluoroscopy (the same TV-monitor brightness and contrast must be adjusted)

8. Deviation of the TV-monitor contrast

- depending on the individual setting of the knobs for TV-brightness and TV-contrast

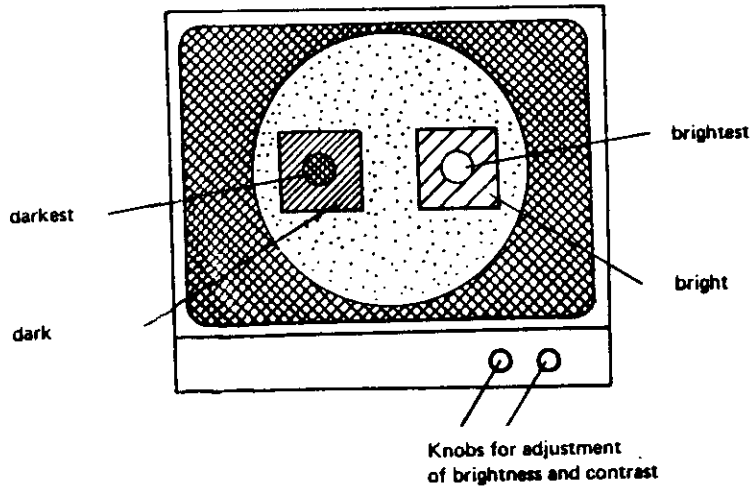


Figure 5

This schematic picture shows only the TV-x-ray-image of the two monitor contrast fields (the scale and relative distances are not correct).

Adjust a correct TV-monitor contrast and brightness for reproducible measurements of the image quality. (This adjustment is near the optimal conditions for practical fluoroscopy.)

SPECIALIZED X – RAY SYSTEMS

DENTAL UNIT: USEFUL BEAM DIAMETER, EXTRAFOCAL RADIATION, OUTPUT, TIMER
SURGICAL X – RAY UNIT: MECHANICAL STABILITY, DOSE RATE AT THE ENTRANCE OF A PHANTOM, RESOLUTION AND CONTRAST IN THE "DIRECT" AND "STORED" IMAGE. RADIOGRAPHIC UNIT WITH A MEDIUM FREQUENCY GENERATOR

B 3

MATERIAL:

- Pen dosimeter 0.5 R
  Charging device
- Low-dose dosimeter DIAMENTOR DALI
- Film cassettes with screens and films
  Size 13 x 18 cm^2 and 35 x 35 cm^2
- Copper sheets
  35 x 35 cm^2, thickness 1.0 mm and 0.5 mm
- Copper step wedge with 0.2 mm steps
- Polyethylene water can
  25 x 30 x 30 cm^3
- X-ray test patterns
  (calibrated in line pairs per mm)
- X-ray wire test patterns/Aluminium DIN 54109
- Mammographic Phantom, KODAK
- Low absorption sheet with holes of different diameters
- Lead sheet
  50 x 50 cm^2, thickness 2 mm
- Lead screens
  30 x 40 cm^2, thickness 0.1 mm

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A Measurement with the "Multi-Pulse-Unit"(BRS)

1.0. Checking mechanical stability of the device

1.1. Perform two exposures with the size of the fields smaller than that of the used film-screen combination. Exposure (a) to be made with vertical axis of the useful beam. Exposure (b) to be made with horizontal axis of the useful beam. Set the field size using the light beam diaphragm or by observing the X-ray field using a fluoroscent screen. In the latter case, adequate radiation protection measures must be taken. Determine the interdependence of beam direction and field center.

Expected results:
The center of the X-ray field may deviate depending on the direction of the useful beam.

1.2. Actuate all possible motions of the unit. Repeat the exposures according to 1.1.. Establish the variations of the values found for the deviation as indicated under 1.1.

1.3. Assess the significance of results for practical work.

Expected results:
Deviations from the center of the X-ray field will occur. These might be irrelevant for practical work.

2.0. Measurement of the dose output using the pen dosimeter

2.1. Plot the dose rate at 1 m focal-spot distance as a function of kVp (measurements at 60, 70, 80, 90, 100 kVp). Measure the dose rate at three exposure levels.

Prior to the measurements, establish the standard deviations under the conditions given at a setting of 80 kV and at one of the three exposure levels. Check the influence of backscatter (lead, copper, plexiglass).

Expected results:
Dose rate output as a function of kVp, assessment of the accuracy of dose rate measurements.

3.0. Test exposures

3.1. Perform 3 exposures with the 15 cm water phantom at 65, 70 und 75 kV. Plot the optical density as a function of kVp.

3.2 Perform 3 exposures with the 1,5 mm copper phantom at 65, 70 and 75 kV. Plot the optical density as a function of kVp.

Expected results:
Different slopes of the plots.

4.0 Qualitative checking of pulsation of X-ray output

4.1. Cover the X-ray tube assembly with a lead shield of 2 mm thickness. In the center of the X-ray field there is a 2 mm hole, enabling a 2 mm diameter beam to come out of the tube assembly. Perform an exposure of at least 0.2 sec. at 60 kVp at lowest tube current. During exposure move a loaded film-screen cassette behind the hole of the lead cover at a speed of about 60 cm/sec. Observe the radiation protection measures to be taken.

Expected results:
Viewing both the relatively high frequency of the X-ray pulses and the low ripple, the beam path on the film should not have a marked periodical density structure.

5.0 Qualitative checking of the extrafocal radiation

5.1. Using the configuration under 4.1., a "pinhole" radiograph of the area emitting extrafocal radiation is made. Stop the central beam emitted by the focal spot by means of a circular piece of lead (diameter approx. 5 mm). Exposure time to be established by experiments. The distance between the film and pinhole must be two times that between the pinhole and focal spot. Two additional pinholes in the lead cover will serve as a means to calculate the exact scale of enlargement.

Choose a cassette of the size 13 x 18 cm^2, the 13 cms side should be parallel to the direction from the cathode to the anode.

Expected results:
The area emitting extrafocal radiation will be depicted. The linear dimensions (e.g. diameter, if circularly shaped or side length if square shaped) may be assessed.

B Measurements with the Dental Unit

6.0 Assessment of pulsation

6.1. Perform the simple test procedure (4.1.) using the dental unit.

Expected results:
Pulsation of 50 cycles/sec. leads to density periods of beam path on the film.

7.0 Dose rate measurements

7.1. Measure the dose rate as a function of line voltage. Plot the dose rate at a focal spot distance of 1 m.

Expected results:
Influence of line voltage on dose output.

8.0 Test exposures with dental film

8.1. Use a phantom corresponding to a molar to perform exposures at line voltages of 200 V, 220 V and 240 V.

Expected results:
Slightly differing film density. Slightly differing image contrast.

9.0 Qualitative check of the extrafocal radiation

9.1. Perform the first exposure with the 10 cm FSD dental collimator using a film screen combination of 13 x 18 cm^2. Keep exposure time very short (e.g. 0.2 sec). Go on with a second exposure under the same

geometrical conditions but with very long exposure times (e.g. 3 sec). Compare the two exposures to show the area irradiated by extrafocal radiation.

Expected results:
Extrafocal radiation may lead to wrong interpretations of the collimator function, if the exposure time is too long.

9.21 Assess the dose rates of the extrafocal radiation by exposing a set of at least 3 films to the penumbra of the extrafocal radiation. The penumbra is generated by a circular lead beam stopper placed as near as possible to the focal spot. Its diameter has to be about 3 mm. Plot the densities of the three films as function of exposure time. Allow for a density of D 1.0 and correlate with the dose.

9.22 Perform another set of exposures with the direct beam. Plot the densities of these exposures, allowing for a density of D≈1.
To obtain the proper dose rate range, the exposure time must be low and the FFD enlarged, if necessary. Correlate the density D≈1.0 with the dose rate. The doses at which approximately equal density (e.g. D≈1.0) is found enable the percentage of extrafocal radiation to be estimated as compared with the total radiation.

Expected results:
Assessment of percentage of extrafocal radiation.

C Measurements with a Surgical X-ray Unit

10.0 Checking the mechanical stability of the device

10.1. Principally, this check is done in the same way as described under 1.1, but no exposures are performed. Instead of this, the central beam is marked by a 2 mm diameter lead piece attached to the collimator. The deviation of its fluoroscopic shadow is taken as a measure for mechanical stability. (The TV camera of the unit is flanged firmly to the image intensifier via its housing and fiber optics. Therefore no unwanted deviations of pictures may be expected from this side).

Expected results:
Negligible deviations of the lead piece shadow for different directions of the useful beam.

11.0 Repeat experiment 4.1 using the surgical X-ray unit.

Expected results:
See under 6.1

12.0 Measure the dose rate as a function of kVp settings with different exposure rates.
See under 2.1 for method and expected results.

13.0 Measurements with fluoroscopic mode

13.1 Set the dose rate at the image intensifier entrance window at 20 µR/sec using a DALI dosimeter. Use a 15 cm water phantom at 80 kVp.

13.2. Measure the dose rate at the beam entrance side of a water phantom as a function of the penetrated water thickness. Perform the measurements with the pen dosimeters of 10 cm, 15 cm, 20 cm and 25 cm water tickness.
Check the entrance dose rate simultaneously according to 13.1.

Expected results:
Increase of "skin doses" with increasing thickness.
Deviations of image intensifier entrance dose rate from the value according to 13.1.

13.3. Assess the resolution and contrast of the fluoroscopic images by visually estimating the fluoroscopic images, line pair structures, holes with different diameters in low absorption sheets, etc. Do the assessments for different thickness of penetrated water. Use normal fluoroscopic images and stored images. Plot the minimum sizes of perceptible details (line pairs, holes,wires of different diameters, etc.) as a function of water thickness.

Expected results:
Decrease of perceptible details with increasing thickness. Slight differences between stored and direct fluoroscopic images.

APPENDI

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Krestel, Erich: Bildgebende Systeme für die medizinische Diagnostik, Siemens AG 1980, Berlin/München

Quality Assurance Handbook, RMI 1981

Seemann, Herman E.: Physical and Photographic Principles of Medical Radiography, John Wiley & Sons, Inc., New York 1968

World Health Organization: Quality Assurance in Diagnostic Radiology. A guide prepared following a workshop held in Neuherberg, FRG, October 20-24, 1980, Geneva 1982

Time-table *for the WHO-training workshop on Quality Assurance*

Time	9 a.m.	10	11	12	1 p.m.	2	3	4	5
Wednesday 27.10.	Opening (Kaul)		Introductory lectures* (Schoknecht) (Panzer) (Stieve)		Lunch	← Introductory lectures (Lang) (Niepel) (Borcke)		organizational arrangements	Informal get together
Thursday 28.10.	← a 1	Practical exercises part A b 2	c 3		Lunch	← a 3	Practical exercises part A b 1		c 2
Friday 29.10.	← a 2	Practical exercises part A b 3	c 1		Lunch	Discussion part A		Organizational arrangements	
Saturday 30.10.	Clinical aspects of quality control (University Clinics)				*LUNCH AT HOFBRAUKELLER*	← Optional: Demonstration of radiological techniques (University Clinics)			
Monday 1.11.	← a 1	Practical exercises part B b 2	c 3		Lunch	← a 3	Exercises part B b 1		c 2
Tuesday 2.11.	← a 2	Practical exercises part B b 3	c 1		Lunch	← Discussion of part B general discussion			
Wednesday 3.11.	Lecture (Henshaw)	Practical value of test equipment – demonstrations and exercises			Lunch	Demonstration exercises continued		Final discussion	
Thursday 4.11.	Optional: Visit to the university clinics to see the routine work in the radiological departments								

* Lecture to be given by Dr.Racowanu will be scheduled later

Schedule of events

Wednesday, 27 October, 1982

9.30 - 17.00

9.30 Kaul
Welcome and Introduction

10.00 Schoknecht
Aims of the quality assurance in the medical care

10.45 Racoveanu
The significance of quality assurance in diagnostic radiology

11.30 Panzer
What is a "diagnostic quality" image from the viewpoint of a medical physicist

12.15 Stieve
What is a "diagnostic quality image from the view point of a radiologist

12.30 Lunch

13.30 Lang
X-ray machine parameters influencing the image quality:
X-ray generator and X-ray tube

14.15 Niepel
Image receptors
- Film-screen combinations and image intensifiers

15.00 Borcke
Film processing

16.15 Discussion
Organizational arrangements for the practical exercises of the following days.

17.00 Informal get together

Thursday, 28 October, 1982

9.00 - 17.00

9.00 Practical exercises part A +)
a 1, b 2, c 3,

13.00 Lunch

14.00 Practical exercises part A +)
a 3, b 1, c 2,

17.00 Plenary discussion of the exercises

Friday, 29 October, 1982

9.00 - 16.00

9.00 Practical exercises part A +)
a 2, b 3, c 1,

13.00 Lunch

14.00 Discussion

16.00 Organizational arragements for the visit of the university clinics

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+)
The practical exercise part A comprise the following topics:

1) X-ray generator and X-ray tube
2) Image receptors
3) Film processing

The three groups are denoted by a, b, and c

a 2 means: group a is doing exercise 2.

Saturday, 30 October, 1982

Visit of the radiological departments of the two University clinics:

Klinikum Großhadern (Director Prof.Dr.med.J.Lissner)

Klinikum rechts der Isar (Director Prof.Dr.med.H.Anacker)

Klinikum Großhadern:

9.30 Welcome and Introduction
Quality control performance at a radiographic and radioscopic equipment: beam geometry parameters, physical beam parameters, cassettes, film-processing.

11.00 Coffee break

11.20 Quality control perfomance at a special equipment for breast radiographs: phantom, surface dose measurement, checking of AEC

14.00 Optional:
a) Demonstration of the results of a "field study" concerning X-ray diagnostic quality assurance which was performed in Bavaria by measurements in many radiological hospital departments and individual offices

b) Demonstration of radiographs showing the influence of various conditions on image quality

Klinikum rechts der Isar:

9.00 Welcome and Introduction

9.30 Demonstration of quality control procedures, tools and methods at a radiographic unit:
deviation of various parameters, quality improvement of the radiographs

10.30 Coffee break

Sensitometric control equipment and measurements, daylight processing machine

11.00 Demonstration and discussion of quality control performance at a fluoroscopic unit

14.00 Optional:

Demonstration of special diagnostic radiology equipment and techniques as

grid/film-screen mammography,
mammo-sonographic scanner,
xeroradiography system,
radiographic subtraction procedure etc,

Sunday, 31 October, 1982

free

Monday, 1 November, 1982

9.00 - 17.00

9.00 Practical exercises part B [+)]
a 1, b 2, c 3,

13.00 Lunch

14.00 Practical exercises part B [+)]
a 3, b 1, c 2

17.00 Discussion

[+)] Topics of the exercises part B:

1) Radiographic Equipment
2) Fluoroscopic Equipment
3) Specialized Equipment

b 3 means: group b is doing exercise 3

Tuesday, 2 November, 1982

9.00 - 16.00

9.00 Practical exercises part B
a 2, b 3, c 1

12.30 Lunch

13.30 Discussion of the part B and

16.00 general discussion

Wednesday, 3November, 1982

9.00 - 15.00

9.00 Henshaw
Instruments and Methods for testing diagnostic radiology equipment - a critical review (lecture)

10.00 Practical work with test equipment demonstration of performance and discussion

12.30 Lunch

13.30 Practical exercises continued

15.00 Final discussion

Thursday, 4 November, 1982

Optional:

Informational visit of the radiological departments of the two University clinics to see the routine work

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