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QUALITY ASSURANCE IN X-RAY DIAGNOSTIC RADIOLOGY

Report II

Results

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STATENS INSTITUTT FOR STRÅLEHYGIENE

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PREFACE

There is at the moment a widespread interest in quality assurance in medical X-ray diagnosis, and several international bodies like WHO, ICRP and IEC are considering its role and organisation. In 1984, as a part of the efforts to implement quality assurance in X-ray diagnostic radiology in Norway, the National Institute of Radiation Hygiene performed a technical control in four representative departments.

The authors would like to thank the staff of the different hospitals where measurements were made for their kind cooperation.

SUMMARY

In the context of an analysis of technical quality assurance in Norwegian X-ray departments, a survey has been carried out in 21 laboratories in 4 hospitals. The tests were restricted to equipment used in general radiography, and the parameters analysed were of kV (using an electronic penetrameter), exposure time, waveform, output and automatic exposure control systems. In addition, a trial to compare overall performance in radiography and fluoroscopy was performed with a PMMP test phantom (SPRI).

The survey is presented in two reports, the first one covers details of procedures and equipment, in the second results are given and discussed. The results show that most of the equipment does function satisfactorily, but also demonstrate the need to introduce quality assurance in X-ray departements.

CONTENTS

1. INTRODUCTION

This paper is the second of two reports describing a quality assurance control survey in four X-ray diagnostic departments in Norway. A series of measurements have been made on generators and tubes. Presented here are the results of the tests followed by a discussion section. Details of the methods are described in report I. (Ref.9)

The proceedings of a Scientific Seminar on Criteria and Methods for Quality Assurance in Medical X-ray Diagnosis which was organized by the Commission of the European Communities in 1984, illustrate the diversity of quality assurance programmes in different countries (Ref.1). In Sweden, for instance, a statutory regulation, which states that several technical parameters have to be tested regularly came into effect in 1983 (Ref.4). Testing of generator (kV, timer, mAs, automatic exposure), image intensifier/TV systems (resolution, exposure/exposure rate), cassettes, screens etc. have to be done least once a year and constancy testing of the film processing once a week. The regulation is supported by a recommendation (Ref.8) covering aspects of organisation, groups involved, control methods, electrical and mechanical safety and guidance for in-house maintenance. The quality assurance efforts which, in our opinion, are very ambitious, have resulted in many new physicists employed in radiodiagnostic departments. However, the benefits to be gained, image quality, lower doses, maintenance costs etc. have not been analyzed further.

In England and USA we find voluntarily programmes and series of manuals giving information on parameters to be tested and technical standards for image quality (Ref.2,7). Reports of cost-effective programmes in USA appear in the literature (Ref.1,p.77).

In Denmark a regulation states annual technical control of mechanical stability and function, filtration and labelling,

beam collimation and alignment, tube potential, indication of technique factors, beam and tube current limitation in the fluoroscopy mode, and exposure rate limitation at the image intensifier input plane (Ref.1). The controls are normally carried out by the manufactures.

German regulations from 1974 for medical X-ray diagnostic equipment ask for checking records which allow reconstruction of an X-ray examination at any time. The most important aspects of the German approach are acceptance test at installation, requirement of measurement once a year of the exposure delivered by the automatic exposure device and the exposure rate at the entrance of the image intensifier and data of the setting of the developer. In addition a German standard, Din 6868, divided into different parts is in preparation where quality assurance of different parameters is reduced to constancy tests which is to be carried out by the radiographer at regular intervals. For instance, Din 6868 part 3 proposes a test object of PMMP and copper, including a step wedge, and in combination with an ionization chamber one film has to be exposed once a month. The test object is used with two qualities of the X-ray beam, near 70 kV and near 100 kV.

In 1977 a working group of the Norwegian Association of Medical Radiation Physics started to prepare a catalogue of quality assurance methods, and the catalogue was presented in 1980 (Ref.3). During the last years several groups, organizations and persons, have been involved in spesific parts of quality assurance, and seminars and training courses have been arranged.

In Norway, there are no national regulations which directly specify regular control of medical X-ray diagnostic units. An important step, however, concerning quality assurance has been taken by the Regulation No 15 of March 30, 1984 which demands that health authorities in each county shall ensure that health services in general are supervised in such a way that failures can be prevented.

In 1986 the Ministry of Health and Social Affairs nominated a private company, the Norwegian Veritas, to prepare and organize a general quality assurance programme in hospitals. The content of the programmes is not ready.

In 1984 the National Institute of Radiation Hygiene set up a working group with the following task (Ref.8).

1. Give a proposal on how quality assurance can be organized in X-ray departments and recommend quality control methods suitable in an quality assurance program for X-ray equipment.

2. Test these proposals in four to five hospitals in X-ray departments of different sizes.

3. Sort out problems connected with quality assurance and quality control in diagnostic radiology, and give final recommendations on how quality assurance should be organized and performed nation-wide.

Details of the programme are still in draft form, and some of the issues remain unresolved, but the intention is to test the complete programme in a few hospitals during 1987, 1988.

The survey presented here will provide some guidelines for setting up local quality assurance programmes in Norway. But further work is required to establish the most efficient methods in such a national programme.

2. CHARACTERISTICS OF INVESTIGATED X-RAY UNITS

The control measurements were limited to 4 middle sized hospitals. The units varied in age from relatively new ones to about 10 years old.

The tests were restricted to the equipment used in general radiography, like bucky tables, chest stands and universal examination tables. Specialized equipment like angiographic and tomographic units were not examined. The X-ray units investigated are shown in Table I.

Table I. X-ray units investigated

Types of generators	Number of generators	Number of tubes
Siemens Tridoros 5S	5	7
Siemens Triomat 2	1	2
Siemens Garantix 1000	1	1
Siemens Tridoros 512MP	2	3
Siemens Tridoros Optimatic 800	5	8
General Electric Telemax 1050	1	2
Philips Maximus CM80	1	2
Philips Super M100	3	5
Philips Maximus C850	1	1
Total	20	31

A typical room for routine radiography may contain two over-couch tubes with corresponding buckytables or a universal fluoroscopic system with undercouch tube and an image intensifier/TV-system. A chest stand is often also included.

The generators normally have the following exposure functions:

MANUAL MODE

Free manual selection of all exposure parameters (kV, mA, exposure time) together with focus spot size. With some modern units only kV and mAs can be selected.

AUTOMATIC MODE

The automatic control exposure (AEC)systems examined were either equipped with an organ programme or kV was selected with an automatic exposure for a certain preselected density, or some combinations of these systems. All the AEC were equipped with three detectors (ionization chambers). For older systems normally a single detector technique was available, but on modern generators usually any combination of the three detectors could be selected.

With most AEC there were three course density settings and several fine adjustments to each of these. The course density settings were normally used to adjust the system to different screen-film combinations.

3. CONTROL PROGRAMME

The details of control programme and equipment used are described in report I (Ref.9)

Table 2 lists the examined parameters and in the following a few basic items of the programme are given:

Table II Control programme

I	Generator and control system	Kilovoltage Exposure time Waveform X-ray output Automatic exposure control system
II	Overall performance control with a phantom	
	A. Radiography	Image quality parameters Alignment Coincidence between light field and X-ray field
	B. Television fluoroscopy	Image quality parameters

Peak kilovoltage and exposure time were recorded simultanously with an electronic penetrameter (Digi-X). Measurements were obtained for several kilovoltage values in the range 60 - 130 kV for representative generator settings. Repeatability of kVp and exposure time were calculated on the basis of two series of 5 measurements at 75 kV, 100 mA, 100 ms.

Waveform was normally examined for two kV stations and for both foci. Ripple and effective kilovoltage were calculated from the oscilloscope pictures.

Output in air was measured in terms of air Kerma at 75, 100 and 120 kV. Repeatability and linearity in output have been determined.

Phototimers were checked for repeatability, conformity between detectors, consistency with change in phantom thickness, minimum response time etc..

In addition to generator and control system testing, an attempt to compare overall performance was made with a test phantom (SPRI-phantom). Details about the phantom are given in report I. The obtained radiographs were analysed in terms of resolution (LP/cm) and detail resolution (number of holes in Cu strips).

Evaluation of fluoroscopic equipment was performed under two standard conditions, one in "clinical" geometry using the SPRI phantom and one in "traditional" geometry using a lead bar test pattern placed close to the image intensifier.

4. GENERATORS AND ASSOCIATED EQUIPMENT. RESULTS

4.1 KILOVOLTAGE AND EXPOSURE TIME

4.1.1 REPEATABILITY OF kVp AND EXPOSURE TIME

Measurements of kVp and exposure time were performed simultaneously. The calculated variation repeatability is shown in Table III.

Table III. Repeatability of kilovoltage and exposure time

	Variation in repeatability %	Number of generators
Kilovoltage	< 3	20
	20 generators and 21 X-ray tubes tested	
Exposure time	< 5	17
	5-10	0
	> 10	1
	18 generators and 19 X-ray tubes tested	

Repeatability in kVp was excellent, variation was less than 3% for all the generators tested. In tubes operated by the same generator, we did not find any significant difference in repeatability (repeatability of Digi-X is better than 1 %).

On generators where kV is selected with dials (continously variable scales) two series of measurements were done, one without changing the factors, the other where the kVp knob was moved away from the chosen value and back again between measurements. We did not observe any differences in repeatability for these two series.

Variation in repeatability in exposure time was less than 5% except in one case where the variation was calculated to about 12%. For this generator analyses of the waveform revealed errors in the tube current circuitry. This behavior was later confirmed by the manufacturer, and has now been corrected.

Repeatability in kVp and exposure time have only been measured near 100 ms. Thus the results may only be correct at this point. It is well known, that some generators give inconsistent kV and exposure times for short exposure times, even though they are very consistent for longer times.

4.1.2 ACCURACY OF KVP AND EXPOSURE TIME

The accuracy of measured kVp and exposure time against dial values in the manual mode are shown in Table IV.

Table IV. Accuracy of kVp and exposure time against dial values of kVp, time, current and focus

Parameter	Deviation %	Number of generators No.	Number of generators %
Kilovoltage	< 5	1	5,0
	5 - 10	11	55,0
	10 - 20	8	40,0
	Total	20	100
		30 X-ray tubes tested	
Exposure time (entire range)	< 10	0	0
	10 - 20	2	15.4
	20 - 40	6	46,2
	> 40	5	38,4
Exposure time (above 20 ms)	< 10	5	38.4
	10 - 20	4	30.8
	20 - 40	4	30,8
	Total	13	100
		20 X-ray tubes tested	

The deviation of the kVp against dial values was found between 5-10% for 55% of the generators, only one generator had accuracy better than 5%. The highest deviation obtained was 15% (one generator). The variations in kVp were normally assymetric, only 3 generators had deviations in one direction (plus or minus). Maximum deviations for boundary values of mA and exposure times were also typical. In tubes operated by the same generator the accuracy often differed. Sometimes the generator functioned better in the manual mode than in the automatic mode and vice versa.

It is seen that the deviation between measured and dial exposure time was rather large. None of the tested generators had accuracy better than 10%. 5 generators had deviations above 40%. These high deviation, derive usually from the shortest exposure times. Thus, if to eliminate exposure times below 20 ms, 5 out of 13 generators were within 10%. On the other hand, the repeatability in exposure time was very good (100 ms), and this is more important than the accuracy of the exposure time. Typical survey data obtained are illustrated in Appendix (Table I).

4.2. WAVEFORM

The heavily filtered radiation waveform and the corresponding calculated kilovoltage waveform memorized in Digi-x at the same exposure provide a considerable amount of information about a generator/tube system. In this survey the waveforms were recorded for each tube for both foci, for two kV stations and for different exposure times. From the calculated kV-curves ripple was assessed.

Ripple was of the order of 10% and 5% for the examined three phase, six pulse and twelve pulse generators, respectively, which corresponds to the theory (Ref.5). The corresponding average kVp as read from the oscilloscope pictures was about 1-6% lower than the peak kilovoltage measured in the kVp mode.

One example of a generator contactor problem is given in Fig. 1 for an old three-phase, six pulse generator.

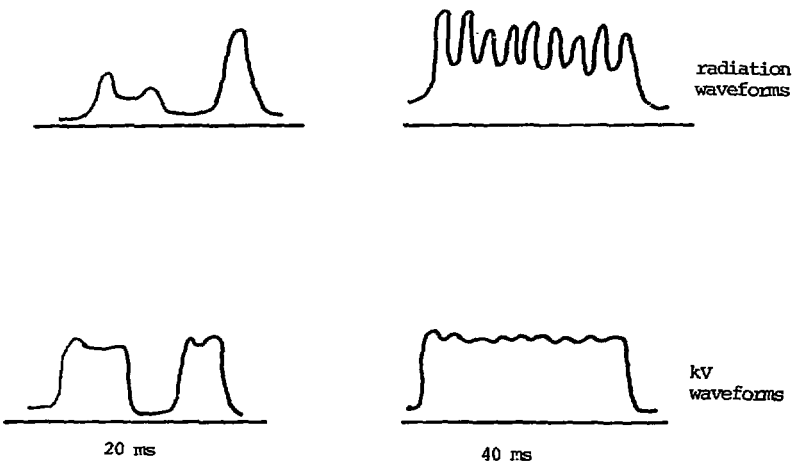

Fig. 1 Drawings from oscilloscope photograps. Radiation waveforms and kV-waveforms for a three phase, six pulse generator. Dial settings 75 kV, 200 mA, 20 and 40 ms (curves are not in scale).

The waveforms on the right are normal. The waveforms on the left start with a small pulse, and the main exposure is too short. This generator had been given up as hopeless for exposure times below 30 ms.

4.3. X-RAY OUTPUT

4.3.1 LINEARITY AND REPEATABILITY

Repeatability and linearity of output were normally evaluated for several mAs stations at one kV. The measurements were performed under conditions of heavy filtration (1,5 mm Cu) and therefore represent the attenuation in the patient (by means of Digi-x).

The calculated linearity - the constancy of exposure pr mAs at a given kV for various mA and time combinations is shown in Table V.

Table V. Linearity of output

Variation in linearity	Number of generators	
%	No.	%
< 10	2	10
10 - 20	7	35
20 - 30	2	10
> 30	9	45
Total	20	100

Only 45 % of the tested generators met the often demanded tolerance of 20 % in linearity. The highest linearity calculated w i 43.9 % . These high values were normally found for boundary values of mAs. For example, one generator had variation in linearity of 34.7 % , but without 1.25 mAs and 56 mAs stations variation was 10.3 %.

Typical data obtained are given in the Appendix I.

Exposure repeatability was determined for several mAs stations, and the highest value calculated for each generator is shown in Table VI.

Table VI. Repeatability of output

Variation in repeatability %	Number of generators No.	%
< 5	4	20
5 - 10	7	35
10 - 20	7	35
> 20	2	10
Total	20	100

It is seen that for two units the variation in repeatability is higher than 20%, and only 4 generators had variation less than 5%. The highest values derive normally from the lowest mAs stations. If we eliminate the lowest station, a setting very seldom met in routine radiography, only 4 out of 20 generators have variation repeatability higher than 10% .

4.3.2 TUBE OUTPUT

Output measurements provide an additional tool in evaluating the status of a generator/tube system. Tube output in air Kerma for different generator/tube combinations is given in Table VII.

Table VII. Output in air Kerma in (mGy /100 mAs) for different generator/tube combinations (distance 100 cm)

Dial kV	75 - 77	100 - 102	117 -120
No.of tubes	25	19	17
Variation in output	2,8-5,9	5,0-9,7	7,0-13,0
Mean output	4,6	7,3	9,7

Total filtration as read from the manufacturer label was normally near 3 mm Al.

Variations in tube output are well known (Ref.2), and this is reflected in the measured output values in Table VII, with a ratio of 2 between the highest and lowest value. The output measurements have not been analysed further.

4.4 AUTOMATIC EXPOSURE CONTROL SYSTEMS

Automatic exposure control systems (AEC) are very common in Norway, and one of the most important elements to test in a quality assurance programme is the AEC system.

The number of tested single AEC detectors and / or combinations of detectors are presented in Table VIII.

Table VIII. No of tested AEC detector/detector combinations

Detector combinations						Total
No.of tested combinations	31	31	31	14	14	121

4.4.1 REPEATABILITY

The variation in repeatability of the tested AEC systems is shown in Table IX. The center detector was always selected in these measurements.

Table IX. Variation in repeatability of AEC systems

Variation in repeatability %	Number of AEC systems No.	%
< 5	28	90,3
5 - 10	3	9,7
Total	31	100

The repeatability of the examined AEC systems was very good, variation was less than 5% for 28 systems. The highest calculated value was about 7 % .

4.4.2 DETECTOR CONFORMITY

The conformity of different individual detectors or combinations of detectors referred to the average exposure are given in Table X.

Table X. Variation for conformity of AEC systems

Variation in detector conformity %	Number of AEC system No.	%
< 5	9	29,0
5 - 10	10	32,3
10 - 20	9	29,0
> 20	3	9,7
Total	31	100

19 out of 31 tested AEC systems (about 60 %) had variation in detector matching less than 10 % . In one case the exposure of each single detector was a factor of two lower than the combination of all the detectors together indicating that either the AEC system was not functioning correctly or had not been set up properly. The system should be retested prior to further action.

4.4.3 PATIENT ADJUSTMENT

All the examined AEC systems were equipped with a manual density regulator which could increase or decrease the film density (exposure time) by a certain percentage from that at the middle density.

In Table XI the fractional changes in exposure (measured with a plate chamber in the cassette tray) for different density settings relative to middle density (N) are presented. The measurements were limited to the fine control setting.

Table XI. Fractional change in exposure relative to normal (N)

	Fine density setting								
Ref.no	-4	-3	-2	-1	N	+1	+2	+3	+4
1	0.61	0.69	0.71	0.87	1	1.20	1.37	1.58	1.75
2	0.60	0.68	0.78	0.81	1	1.17	1.26	1.43	1.64
3	0.61	0.68	0.75	0.86	1	1.16	1.27	1.49	1.74
4	0.57	0.68	0.72	0.81	1	1.19	1.46	1.59	1.84
5	0.53	0.66	0.66	0.71	1	1.24	1.46	1.73	1.99
6	0.46				1	1.31			1.52
7	0.56	0.56	0.67	0.89	1	1.22	1.44	1.78	2.11
8	0.48	0.56	0.65	0.181	1	1.21	1.53	1.94	2.34
9	0.47	0.53	0.67	0.80	1	1.20	1.40	1.83	2.27
10	0.47	0.58	0.68	0.83	1	1.22	1.51	1.87	2.37
11	0.38	0.48	0.62	0.79	1	1.28	1.61	2.05	2.58
12		0.58	0.67	0.88	1	1.33	1.67	2.00	
13	0.44	0.54	0.67	0.78	1	1.08	1.54	1.83	1.92
14			0.53	0.78	1		1.38		1.60

When examining Table XI it appears in generator 5 that the differences between station -1, -2 and -3 seem too small, and similar in generator 10 for station -3 and -4. This may indicate AEC malfunctions. Further analyses of generator 10 showed that the minimum response time (5 ms) was reached at station -3 for a setting 117 kV and 20 cm PMMP which corresponds to a colon examination at this unit.

4.4.4 kVp AND MIMIMUM EXPOSURE TIME

The minimum exposure time for the generator/AEC systems was examined by measuring the exposure/ exposure time for different PMMP thicknesses. As expected, the minimum response time varied from about 20 ms for the older systems to about 2-5 ms for modern systems.

In our opinion, the AEC-systems sometimes were too near the minimum response time even for normal patients, indicating that the resultant density of the films, occasionally, might be too high.

The kV checking of AEC systems and the measurements on the patient compensation ("thick" and "thin" patient) were carried out in a very limited way and are not included in this report.

5. OVERALL PERFORMANCE CONTROLL WITH A PHANTOM

5.1 RADIOGRAPHY

Image quality parameters were assessed subjectively using a test phantom. Parameters studied were resolution (number of line pair resolvable) and detail contrast (number of holes resolvable in strips of Cu). The ratings of the observers (the authors) have been averaged. Only those radiographs which had density within 1,0 $\pm$ 0,2 were included in the evaluation. The image quality parameters determined are shown in Table XII. The distribution of resolution is presented in Table XIII.

Table XII. *Image quality parameters determined*

Ref No		Examination	Focus	kV	Screen	Resolution LP/cm	Total No of holes resolvable
1		chest	large	115	Agfa MR200	32	35
2		"	small*	125	Curix univ.	40	32
3		"	"	120	Agfa MR400	32	28
4		"	"	120	Kodak Lanex Regular	32	33
5		"	"	120	"	32	30
6	**	"	large	125	Curix spes.	28	29
7		urography	"	73	Agfa MR200	19	32
8		"	"	73	"	19	35
9		"	"	73	"	19	34
10		"	"	77	Agfa MR400	12,5	26
11		"	"	77	"	21	29
12		"	small	77	"	26	28
13		"	"	75	"	32	34
14		"	large	70	"	21	32
15		"	small	70	"	29	33
16		"	large	70	"	21	34
17		"	small	70	"	29	34
18		"	"	77	"	32	34
19		"	"	77	"	32	31
20		"	"	75	"	32	34
21		"	"	75	"	32	34
22		"	"	75	Kodak Lanex Regular	26	34
23		"	"	70	"	29	32
24		"	"	77	"	23	33
25		"	"	75	Agfa MR400	32	33
26		colon	"	120	"	17	25
27		"	"	85	Agfa MR200	14	33

* Some photographs were produced with the small focal spot instead of the large one.

** Photographs taken with the same unit but with different kV, focus etc. are listed in brackets.

Table XIII. The distribution of visual resolution

Resolution LP/cm	No of units						
	Examination/focus					Total	
	Urography etc.		Chest		Colon		
	Small (10)	*Large (6)	Small (5)	Large (2)	Large (2)	Small	Large
10							
11							
12,5							
14					1		1
15,5							
17					1		1
19		3					3
21		3					3
23	1					1	
26	1			1		1	1
29	2					2	
32	6		3	1		9	1
36							
40			2			2	
45							
50							
Total No of units	10	6	5	2	2	15	10

*Nominal focal spot sizes were normally 1,2 mm^2 and 0,6 mm^2 for large and small focus, respectively.

The resolution ranges from 14 LP/cm to 32 LP/cm for large focal spots , and from 23 LP/cm to 40 LP/cm for small focal spots. The variation in unsharpness because of different source-to-film/source-to-phantom distances contributes mainly to this wide range of resolution (typical 100 cm SFD for urography, 150-200 cm for chest and 70-80 for colon). The variation in screen/film combinations will also contribute to the measured differences.

The lowest resolution recorded for a urography examination (small focus) was 23 LP/cm which is marked lower than for the other units. This tube had been used for a long time and was already suspected of a damaged target. The total number of holes, however, was not affected.

Small differences were found in the number of holes resolvable for different radiographic settings and geometries. This appears in Table XV. The detail contrast test object consists of 6 strips of different thicknesses (Cu) and with 7 holes of different diameter as shown in Table XIV.

Table XIV. Thickness of Cu strips and diameters of holes in the SPRI-phantom

Strip No	1	2	3	4	5	6	
Strip thickness (mm)	0,15	0,100	0,075	0,050	0,038	0,020	
Hole No	1	2	3	4	5	6	7
Hole diam. (mm)	3,0	2,0	1,5	1,0	0,75	0,50	0,25

Table XV. Distribution of detail contrast

Strip No	Smallest holes visible	Examination/number of units			
		Urography (16)	Chest (7)	Colon (2)	Total (25)
1	6	15	6	2	23
	7	1	1		2
	4				
2	5				
	6	16	6	2	24
	7		1		1
	4			1	1
3	5		1		1
	6	16	6	1	23
4	4	2		1	3
	5		2		2
	6	14	5	1	20
	3	1	1	1	3
5	4	2	3		5
	5	3			3
	6	10	3	1	14
	1		1		1
6	2	2	2	1	5
	3	6	2	1	9
	4	7	2		9
	5	1			1

The general number of units examined are given in brackets.

For the units examined the total number of resolvable holes range from 28-35 (total score 42). The results indicate that only in the best units (2) the smallest holes of diameter 0,25 mm are visible in the first strips (0.015 mm). Holes of diameter 0,5 mm are imaged provided that there is an adequate contrast (thickness), usually in 5 strips. In the last strip (0,02 mm)a hole of diameter 1 mm is normally seen.

Rather little variation was found in the appearance of the step wedge. In 90 % of the listed radiographs 10-12 steps were visible, the lowest number visible was 8 (2 radiographs).

The size of the X-ray field relative to the light field was examined in most units, except for some units with automatic collimation. The X-ray field was close to the light field in 17 out of 22 units. In some units a rather large penumbra (3-5 cm) was observed usually at one side. Alignment was found satisfactory, except for two units.

There were 5 different screen/film combinations with markedly different speeds, in use in the departments. One department used Agfa MR200 and Curix special screens, the second Agfa MR400 and Curix universal, the third Agfa MR400 and the last department used Kodak Lanex regular. The entrance phantom doses obtained are given in Table XVI.

Table XVI. Entrance phantom doses per radiograph referred to a density level 1,0 ± 0,2

Examination	No. of measurements	Screen	Phantom doses mGy
Urography, abdomen etc.	11	Kodak Lanex regular, Agfa MR400, Curix spezial	2 - 4
"	2	Agfa MR200	14
Chest	5	Agfa MR400, Curix special, Curix universal, Kodak Lanex regular	0,2-0,6

As expected, there is a considerable spread in the entrance doses for one and the same examination. The main contribution to the range of doses observed is the different screen/film combinations in use. It should be stressed that the measurements were very limited.

5.2. FLUOROSCOPIC EQUIPMENT

The number of examined fluoroscopic systems was only seven. The image quality parameters recorded, holes in the last visible strip, steps in the wedge and resolution using both the SPRI-phantom and a traditional line pair pattern are presented in Table XVII.

Table XVII. Image quality parameters imaged in television fluoroscopy

Ref. No	Resolution(LP/cm)		No. of holes visible		No.of steps visible
	Line pattern	SPRI phantom	Strip No 4	5	
1	9	11	2		3
2	12(20)*	14(15,5)		4	7 (5)
3	7(14)	11(14)		3	6 (5)
4	9(12)	10(15,5)		2	10(11)
5	12(18)	11(15,5)		2	6 (9)
6	10(18)	10(12,5)		1	5(0)
7		12,5		1	5

*Parameters obtained with electric amplification are given in brackets.

The results of the television fluoroscopy control which are shown in Table XVII must be considered tentative because of the very small number of data. The resolution determined visually by the line test pattern and the SPRI-phantom were 7 - 12 LP/cm and 10 -14 LP/cm, respectively. The resolution was generally higher with electric amplification.

It was impossible to visualize holes in strip no.6 in the investigated systems. The contrast was usually adequate to observe holes in strip no. 5 and the number of holes varied from none to 4 as shown above. Regarding the visualization of holes we found very little difference between the normal and amplified mode.

The steps in the wedge ranged from 3 to 10 (0-11 with electronic amplification). The large variation in the appearance of the wedge probably indicates that the TV-monitors have not been set up to optimum conditions.

6. DISCUSSION AND CONCLUSIONS

This survey presents a technical assurance control in four Norwegian hospitals. Details of the procedures followed and equipment used is shown in Report I. (Ref. 9). The classification between good and poor performance was similar to that identified in SPRI 6.27 (Ref.2)(Table XVIII). The evaluation of the measurements are given in Table XVIV.

Table XVIII. Criteria for evaluation of generator/tube/ AEC systems performance

Parameter	Criteria (%) Good	Poor
kVp accuracy	< 10	> 10
kVp repeatability	< 5	> 5
Exposure time accuracy	< 10	> 10
Exposure time repeatability	< 5	> 5
Radiation output repeatability	< 5	> 5
Radiation output variation with mAs	< 20	> 20
AEC repeatability	< 10	> 10
AEC conformity	< 10	> 10
Collimation	< 1	> 1

Table XVIV. Evaluation of measured generator/tube/ AEC systems

Parameter	No of systems			Proportion of good systems
	Good	Poor	Total	%
kV accuracy	12	8	20	60
kV repeatability	20	0	20	100
Exposure time accuracy (full range)		13	13	0
Exposure times below 20 mS excluded	5	8	13	4
Exposure time repeatability	17	1	18	94
Radiation output linearity	9	11	20	45
Radiation output repeatability	4	16	20	20
AEC repeatability	31	0	31	100
AEC conformity	19	12	31	61
Collimation	17	5	22	77

Comparisons of the measurement data in Table XVIII with the results of other surveys are difficult because of different classification criteria and measurement procedures. Recalculation of the measurement data of the present survey, however, indicates that accuracy and repeatability of X-ray parameters in some cases are in agreement with other publications on the subject, for example surveys in England and Ireland (Ref.1).

All the examined X-ray units showed deviations outside the tolerance of 10 % in the exposure time setting. Five out of 13 generators had deviations above 40 % . The highest deviations were always at the lowest time settings (below 20 ms).

Abnormalities in the X-ray waveform, electromechanical contactors or simply wrong calibration of the timing circuit may explain the differences. Similarly, it was found corresponding deviations in output linearity at the same time stations.

Repeatability of output which is of importance to assure that the same film density will be produced for the same setting for each generator showed the highest variation at the lowest mA values. Including the lowest mAs values, only 4 out of 20 generators had variation in repeatability bigger than 5 % .

Whether the lowest mAs stations are in use in normal radiography or not, has not been analyzed further. On the other hand, one cannot achieve an accuracy better than the one which an X-ray generator has been designed to achieve, some of the generators simply are not better !

Summarizing the above, neglecting deviations in the smallest exposure times and mAs values, the performance of the examined X-ray units was found reasonably satisfactory.

Most of the X-ray units examined were considered locally to be acceptable, and radiologist/radiographer were usually quite satisfied with the image quality they got. In some cases, variations in parameter accuracy and/or repeatability were compensated with a chart of suitable factors for some examinations.

Some abnormalities were unknown before our control, for example analyses of the waveform in one case showed that instead of falling load in mA, the mA increased during the exposure !

A few units had been given up as hopeless because of unacceptable variations in film density. For instance, further testing of one generator with a homogeneous perspex phantom revealed that with constant kV and mAs for different

mA and time combinations, net density varied between 0,47 and 1,73. A service representative should of cource be contacted under such circumstances.

It is our experience that changes in mean density often pass undetected by radiologist/radiographer. Maybe they are used to accepting such variations or it reflects the radiologist's considerable capacsity for adaptation to quite wide variations of density.

It is unfortunate that no international accepted guidelines/ criteria for image quality of X-ray systems exist. X-ray systems can, of course be evaluated in physical terms of resolution, contrast, noise etc., but the transformation of these physical parameters into clinically meaningful image quality is not well understood. At present, a great number of phantoms and test objects have been developed (Ref.1) some with physical parameters describing resolution etc., others intended to be used in constance testing of X-ray systems (Ref.1.p.87).

The SPRI-phantom described in Report I (Ref.9) is primarily intended to be used in constance testing by comparing photographs with a reference. In this work we have tried to use the phantom in comparing physical imaging properties of different X-ray units under conditions simulating the situation during some common examinations.

The number of examined X-ray units were limited, but the results of this study indicate that most of the holes are seen on all films for different radiographic settings and geometries. The wide variation in the resolution (LP/cm) is mainly introduced by the focal spot/imaging geometry.

In conclusion, it seems relatively clear that the SPRI-phantom can answer very few questions raised when comparing imaging properties of X-ray systems. Of course, large changes in the focal spot size, which often may not be detectable in every day practice, will appear. But other and more effe-cient methods are available when measuring focal spot size (IEC).

Various electronic penetrameters for noninvasive measurements in X-ray units are now marketed. The penetrameter, Digi-X is very useful when checking X-ray units in the way we have done. On the other hand, it must be stressed that one has to be familiar with the instrument to take advantage of the different possibilities. For instance incorrect positioning of the detector or wrong interpretation can easily lead to serious mistakes. In our opinion it is not cost effective to provide such an instrument in a small hospital because the instrument probably is too complex for the average radiographer.

To sum up, the main aim of this survey has been a sort of critical analysis of the Norwegian situation before introduction of quality assurance in medical radiology. The survey demonstrated, as expected, that in spite of the satisfactory condition of most X-ray units, the situation regarding performance of equipment, patient doses and economy is by no means optimized. Therefore, a justification for introducing quality assurance into radiological practice should be no longer necessary. This is, of course, not a new idea, quality assurance in itself is generally accepted in the medical field all over the world.

Realizing the considerable variety of publications and handbooks giving test proposals, and that quality assurance programmes in X-ray departments already are present in many countries, we have found it useful to concentrate our conclusions to a few points relevant to implementation of quality assurance in Norway rather than just another set of proposals to be produced or duplicated.

The first point we want to make is a word of warning, checking of the very wide range of parameters in a radiographic system is very time consuming. Even this limited survey, required a working day to check out a room for routine radiography and more if discrepancies occured.

This is a very strong argument to consider whether or not some tests really have effects on image quality and dose reduction, or what is really necessary regarding quality assurance in every day practice in radiological departments.

Our second point is, realizing that checking of single parameters to characterize a radiographic system is very time consuming, we assume that system and/or constancy testing of radiographic systems with suitable test objects are the best way to go. It will, in our opinion be necessary to have several test objects to cover different situations. On the other hand, we look at the existing phantoms and test objects as first generation objects and hopefully more efficient test objects will appear in the future.

Another approach on quality assurance is the system adopted in IEC which is a collection of constancy tests (in preparation Ref.1.p.22).

The third point is which personell category should perform quality assurance testing? In Norway, there are very few physicists familiar with quality assurance in X-ray departments. This means probably that staff within the hospitals have to play an important role in this work. For instance, a quality assurance radiographer could be designated within each department with scientific and technical support on a district or regional basis. This will obviously require an education process.

Prior to use of new equipment, according to the traditional view, acceptance or installation testing should ensure that all physical parameters are performing to specification. Comprehensive initial testing require sophisticated test equipment and interpretation, and we assume that it is only cost effective to provide such equipment and competance on a Region or National basis. Considering a cost-benefit-analysis of new and sophisticated equipment we want to ask what is really necessary regarding acceptance testing after installation, when the end product (image quality) is accepted by the department and safety (patient dose) is satisfactory?

The last point we want to make is to express very clearly that technical quality assurance alone is by no means sufficient. When implementing a quality assurance programme one has to include each phase of operation of the X-ray department, beginning with the request for an examination and ending with transmitting the diagnoses to the referring physician. When examining the content of quality assurance programmes in the literature it is evident that the programmes tend to concentrate on the performance of equipment, little mention has been made of comprehensive programmes. An example of such a programme can be found in reference (Ref.6)

7. REFERENCES

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(HF/ut"tad2)

Table I

Example of measurements with Digi-x, kV and exposure time accuracy from two rooms sharing one generator. Numbers marked - are read from oscilloscope pictures (memory option in Digi-x). Generator: Philips Maximus CM 80

kV dial	focus	kVp meas.	t dial ms	t meas. ms	mA	mAs	ΔkV	ΔkV kV dial %	Δt ms	Δt t dial %	Lab. A
75	□	75	100	102	50	5	0	0	-2	+2	
		74	100	101	500	50	-1	-1,3	+2	+2	
		72	1	-1,5	667max	0,7	-3	-4,0	+0,5	+50	
		-70	2	-3,1	667	1,3	-5	-6,7	+1,2	+57	
		-70	3	-3,8	667	2,0	-5	-6,7	+0,8	+25	
		-70	4	4,8	667	2,7	-5	-6,7	+0,8	+20	
		-70	10	10,8	667	6,7	-5	-6,7	+0,8	+8	
		70	10	11,1	667	6,7	-5	-6,7	+1,1	+11	
		72	20	21,3	500	10,0	-2,5	-3,3	+1,3	+6,5	
		75,5	500	500	100	50,0	-2,5	-3,3	0	0	
75	■	75,5	100	100	200	20	+0,5	+0,7	0	0	
		74,5	100	100	333	33	-0,5	-0,7	0	0	
		75,5	100	100	100	10	+0,5	+0,7	0	0	
		75,5	100	-103	50	5	+0,5	+0,7	+3	+3	
		72,0	10	10,3	333	3,3	-3	+4,0	+0,3	+30	
		70,5	3	3,5	333	1,0	+4,5	+6,0	+0,5	+16,7	
		-70	5	-4,8	333	1,7	-5	-6,7	-0,2	-4,0	
60	□	60	100	98,7	200	20	0	0	-1,3	-1,3	
100		100	100	100	200	20	0	0	0	0	
115		114	100	100,1	200	20	-1	-0,9	+1	+1	
120		120	100	102,0	100	10	0	0	+2	+2	
120		119	100	101,1	200	20	-1	-0,8	+1	+1	
120		117	10	11,8	200	2	-3	-2,5	+1,8	+18	
120		118	5	6,7	200	1	-2	-1,7	+1,7	+34	
120		120	20	22	50	1	0	0	+2	+10	
75	□	71	2	3,5 -3,4			-4	-5,3	+1,34	+67,5	Lab. B
75		75,5	100	100	200	20	+0,5	+0,7	0	0	
120		121	50	52,5	150	7,5	+1	+0,8	+2,5	+5	
100		107	10	10,5	150	1,5	+7	+5,8	+0,5	+5	
65		54	100	100	300	30	-1	-1,5	0	0	
65		64	10	10,5	300	3	-1	-1,5	+0,5	+5	

The lowest exposure times are probably not used clinically.

8. APPENDIX

Table II Representative results of linearity measurements. General Electric Telemax 1050, 75 kV, large focus.

Dial			Measured		Calculated	
mA	t(ms)	mAs*	mA	mAs	$\overline{\text{mAs}}$	$\overline{\text{mAs}}$/mAs**
290	32	9,6	301	9,63	9,58	1,0
			301	9,59		
			298	9,51		
300	10	3,2	300	3,12	3,12	0,98
			303	3,15		
			298	3,10		
500	10	5,4	515	5,36	5,35	0,99
			507	5,27		
			520	5,41		
500	3	1,35		1,06	1,05	0,78
				1,08		
				1,01		
500	4	1,2		2,17	2,14	0,97
				2,07		
				2,18		
600	20	13	637	12,9	12,87	0,99
			627	12,7		
			642	13,0		
580	50	30	691	35,2	35,47	1,18
			697	35,5		
			700	35,7		
550	100	56	624	63,9	63,43	1,13
			615	63,0		
			620	63,4		
690	10	7,4	720	7,56	7,56	1,02
			713	7,49		
			727	7,63		

* Dial values as read on the generator panel

** Ratios of measured $\overline{\text{mAs}}$ and dial mAs

Calculated linearity with extremal values 20 %

without 1,35 mAs and 56 mAs 10,3 %