UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4.SMR/773-12

College on Medical Physics:
Radiation Protection and Imaging Techniques

5 - 23 September 1994

Quality Control in Nuclear Medicine

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Malmö University Hospital
Malmo, Sweden

MAIN BUILDING STRADA COSTIERA, 11 TEL. 22401 TELEFAX 224163 TELEX 460392 ADRIATICO GUEST HOUSE VIA GRIGNANO, 9 TEL.224241 TELEFAX 224531 TELEX 460449
MICROPROCESSOR LAB. VIA BEIRUT, 31 TEL. 224471 TELEFAX 224600 TELEX 460392 GALILEO GUEST HOUSE VIA BEIRUT, 7 TEL. 22401 TELEFAX 2240310 TELEX 460392

Quality Control in Nuclear Medicine

Mario De Denaro
Trieste
and
Sören Mattsson
Malmö

Quality Assurance QA

all aspects of a procedure which contribute to the quality of the results obtained

eg in nuclear medicine

- staff training
- testing of radiopharmaceuticals
- assessment of equipment performance
- reporting of clinical studies
- radiation protection is a part of all QA programs

Quality Control QC

specification, assessment, optimization and maintainance of a particular aspect

eg in nuclear medicine

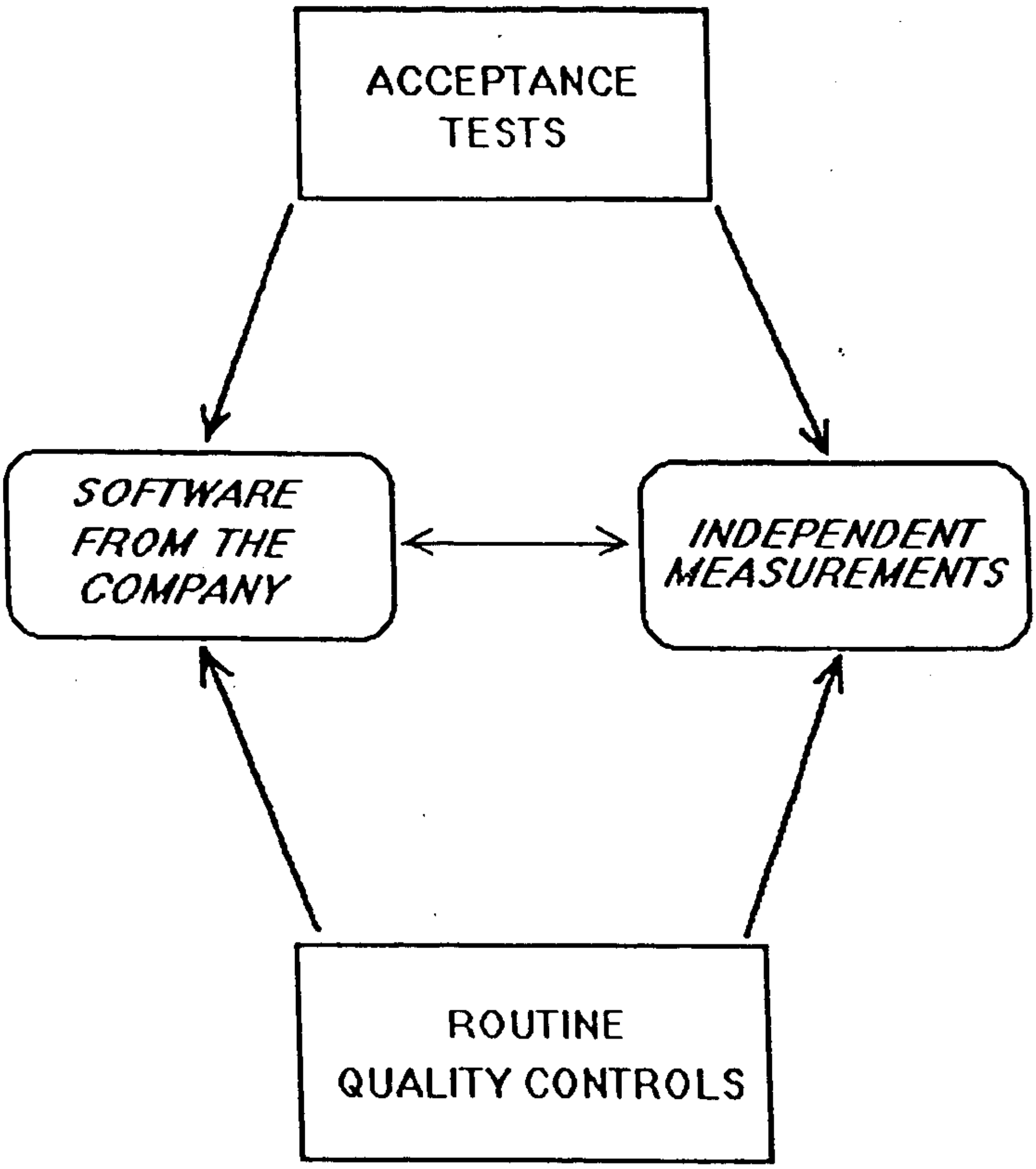
- performance of the gamma cameras
- " " " activity meters

"a chain is only as strong as its weakest link"

Acceptance testing – NEMA

Regular checks

- must be much simpler ($^{99}Tc^m$ or ^{57}Co, ±10% window, good phantoms . . .
- the results must be understandable for those who make the tests.


ACCEPTANCE TESTS
SOFTWARE FROM THE COMPANY
INDEPENDENT MEASUREMENTS
ROUTINE QUALITY CONTROLS

PERFORMANCE MEASUREMENTS OF SCINTILLATION CAMERAS

RACCOMANDATIONS FOR QUALITY CONTROL AND PERFORMANCE ASSESMENT OF GAMMA CAMERAS

For the manufacturer

British Standard Institution (BSI)
National Electrical Manufacturers' Association (NEMA)
International Electrotechnical Commission (IEC)

For routine hopital use

International Atomic Energy Agency (IAEA)
Hospital Physicists' Association (HPA)
Department of Health and Social Security (DHSS)
Bureau of Radiological Health (BRH)
World Health Organisation (WHO)

NEMA NU 1-1986

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

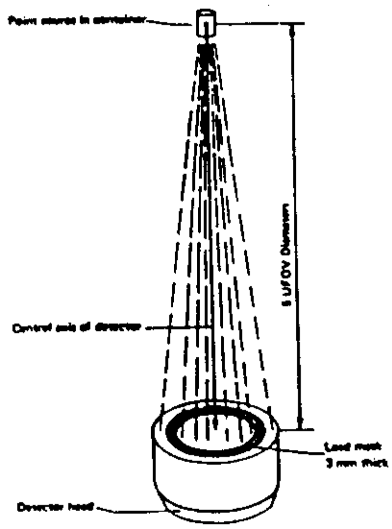
PARAMETERS

1. *- INTRINSIC FLOOD FIELD UNIFORMITY*
2. *- INTRINSIC SPATIAL RESOLUTION*
3. *- SPATIAL DISTORTION*
4. *- SYSTEM SPATIAL RESOLUTION WITH AND WITHOUT SCATTER*
5. *- INTRINSIC COUNT RATE PERFORMANCE*
6. *- SYSTEM SENSIBILITY*
7. *- INTRINSIC ENERGY RESOLUTION*
8. *- DETECTOR HEAD SHIELDING LEAKAGE*
9. *- TOMOGRAPHIC SYSTEM RESOLUTION*
10. *- TOMOGRAPHIC CENTRE OF ROTATION*

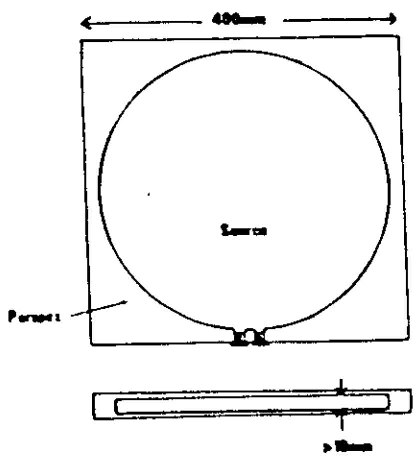
• INTRINSIC FLOOD-FIELD UNIFORMITY

– ACQUISITION –

POINT SOURCE GEOMETRY



FLOOD PHANTOM

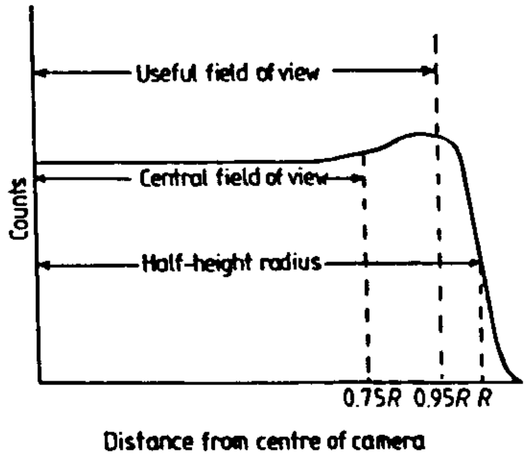


ACQUISITION :

- 20% PHA window on the photopeak
- 64X64 Matrix
- Total counts 3 milion counts (central pixel > 4,000 counts)
- Count rate < 20,000 cps

• INTRINSIC FLOOD-FIELD UNIFORMITY

– DATA ANALYSIS –



UFOV : Uniform Field Of View
CFOV : Central Field Of View

Smoothing by convolution with a 9 points filter function

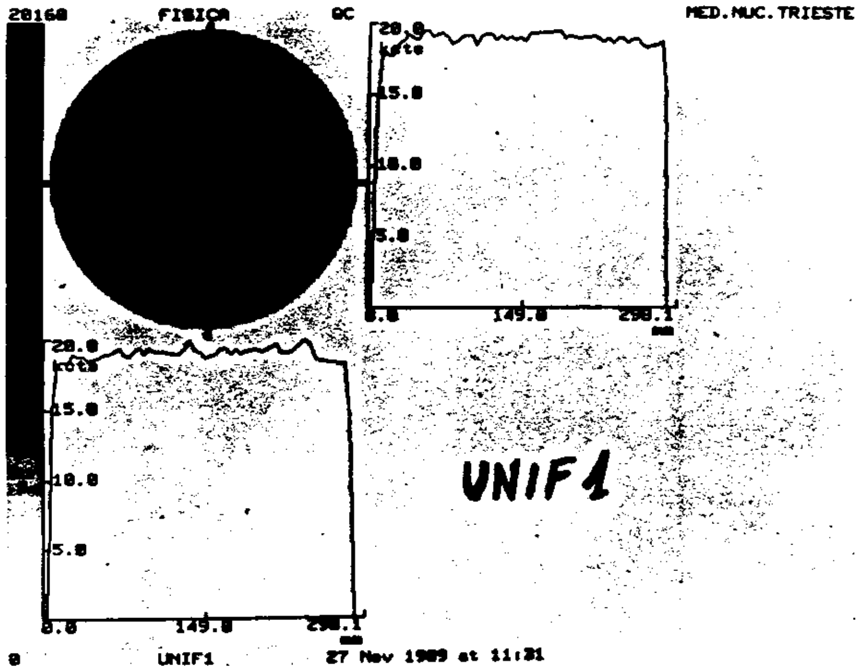
1	2	1
2	4	2
1	2	1

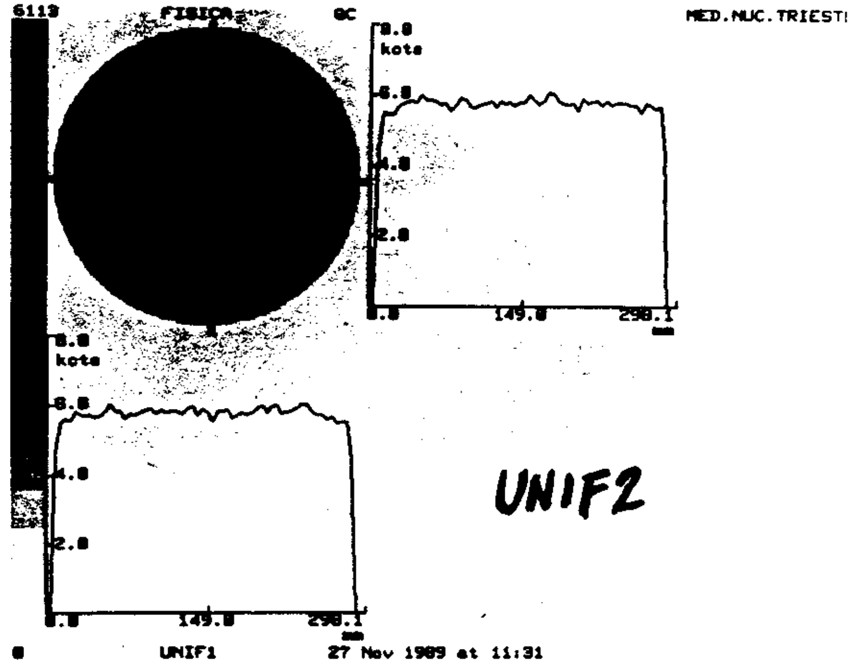
INTEGRAL UNIFORMITY
(OVER WHOLE FIELD OF VIEW)

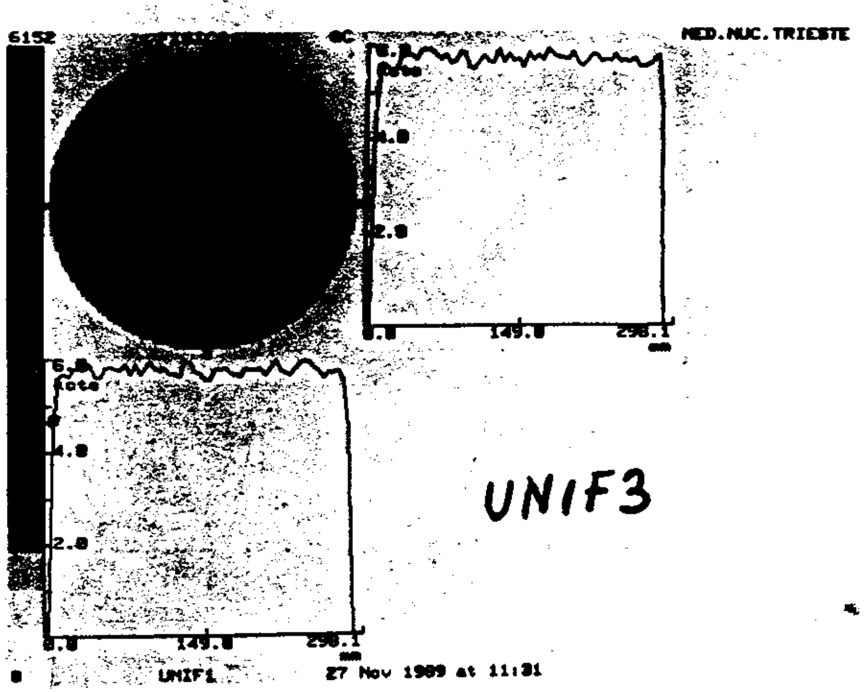
$U_I \% = [(MAX - MIN) / (MAX + MIN)] * 100$

DIFFERENTIAL UNIFORMITY
(OVER A 5-PIXEL DISTANCE)

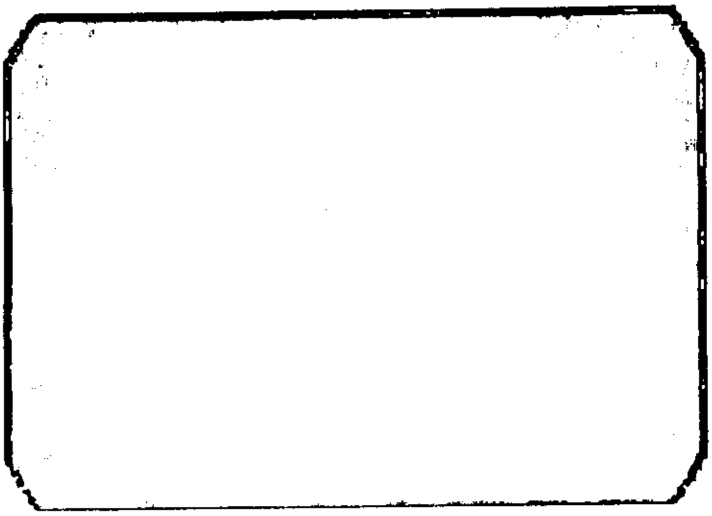
$U_D \% = [(HI - LOW) / (HI + LOW)] * 100$


20160
FIBICA
QC
MED.NUC.TRIESTE
20.0
kcts
15.0
10.0
5.0
0.0
149.0
298.1
mm
0
UNIF1
27 Nov 1989 at 11:31
UNIF1

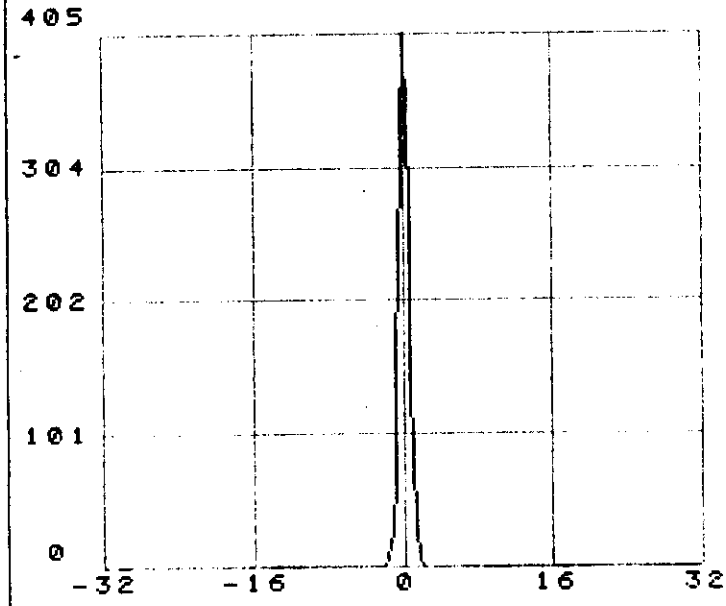

6113
FISICA
QC
MED.NUC.TRIESTE
8.0
kcts
6.0
4.0
2.0
0.0
149.0
298.1
mm
0
UNIF1
27 Nov 1989 at 11:31
UNIF2

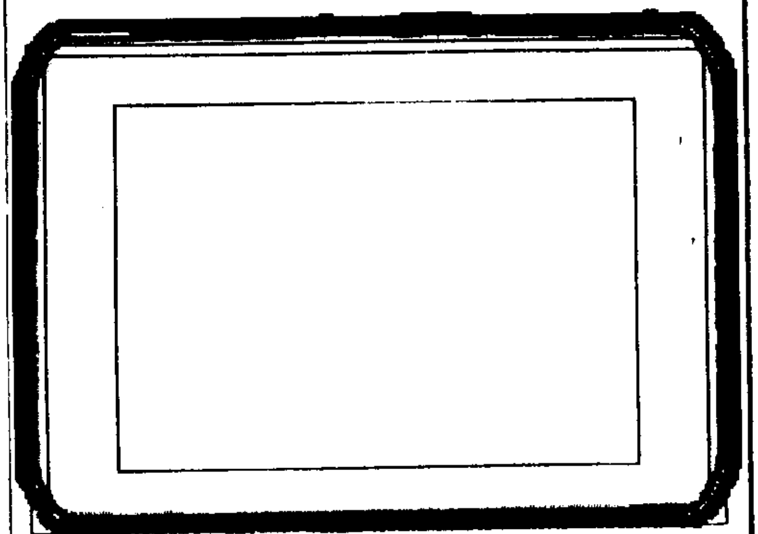

6152
QC
MED.NUC.TRIESTE
kcts
6.0
4.0
2.0
0.0
149.0
298.1
mm
0
UNIF1
27 Nov 1989 at 11:31
UNIF3

27/11/89



UNIFORMITY HISTOGRAM





UNIFORMITY %

	UFOV	CFOV
Integral	1.89	1.67
Differential	1.30	1.30
Standard dev	0.56	

X center(pix) = 31.67
Y center(pix) = 31.40
Horiz Width = 59.91
Verti Width = 44.05

7

UNIFORMITY MATRIX

ON LINE CORRECTION FACTORS

If the intrinsic flood-field uniformity test is over the limit of acceptability then

PM GAIN SOFTWARE CALIBRATION

EXAMPLE

APM GAIN VARIATION SINCE LAST CALIBRATION IN % :

PM 1 = 9.3	PM 2 = 5.5	PM 3 = 3.2	PM 4 = 4.6	PM 5 = 3.2
PM 6 = -0.5	PM 7 = -1.3	PM 8 = -1.7	PM 9 = -2.0	PM 10 = 2.8
PM 11 = -2.3	PM 12 = -1.8	PM 13 = -3.9	PM 14 = 2.5	PM 15 = -1.4
PM 16 = 0.0	PM 17 = -1.4	PM 18 = -0.9	PM 19 = -1.9	PM 20 = -0.5
PM 21 = -1.4	PM 22 = -2.7	PM 23 = 0.5	PM 24 = -0.4	PM 25 = -2.3
PM 26 = -1.8	PM 27 = -0.9	PM 28 = -5.5	PM 29 = -1.4	PM 30 = 0.0
PM 31 = 0.5	PM 32 = -0.4	PM 33 = -0.4	PM 34 = 1.0	PM 35 = -2.7
PM 36 = 0.5	PM 37 = -4.4	PM 38 = -1.8	PM 39 = -0.9	PM 40 = -3.1
PM 41 = 3.8	PM 42 = -1.7	PM 43 = -1.4	PM 44 = -1.3	PM 45 = 1.4
PM 46 = -1.5	PM 47 = 0.5	PM 48 = -2.3	PM 49 = -3.8	PM 50 = 3.5
PM 51 = 1.8	PM 52 = -2.6	PM 53 = -5.2	PM 54 = -0.5	PM 55 = -3.5
PM 56 = -3.1	PM 57 = -2.6	PM 58 = -3.7	PM 59 = 7.3	PM 60 = -0.9
PM 61 = -3.8	PM 62 = -1.7	PM 63 = -0.4	PM 64 = 2.3	PM 65 = -0.9
PM 66 = -3.3	PM 67 = -2.5	PM 68 = -2.4	PM 69 = -2.3	PM 70 = -3.9
PM 71 = -3.0	PM 72 = -0.9	PM 73 = -4.0	PM 74 = -3.4	PM 75 = -3.0
PM 76 = -3.1	PM 77 = -0.4	PM 78 = -1.3	PM 79 = -0.5	PM 80 = -3.6
PM 81 = 0.5	PM 82 = -3.3	PM 83 = -3.4	PM 84 = -3.0	PM 85 = -3.7
PM 86 = -2.1	PM 87 = -1.7	PM 88 = 0.9	PM 89 = -2.2	PM 90 = 3.9
PM 91 = 6.5	PM 92 = 6.3	PM 93 = 4.5	PM 94 = 7.1	

CALIBRATION DATE : 4 11 1994

POSITION # (deg) : 269

APM TABLE # : 48

CONVERGENCE CODE : TUNING HAS CONVERGED

CONTROL DATE : 7 25 1994

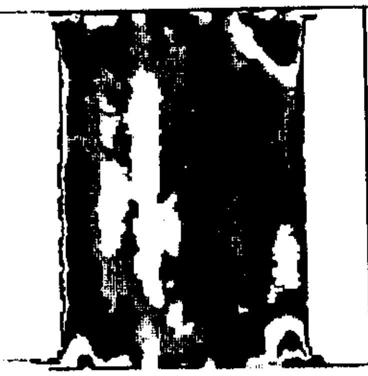
NEW UNIFORMITY MATRIX

ONE FOR EACH RADIOISOTOPE

CORRECTIONS CURRENTLY USED :

HORIZONTAL
LINEARITY

Displacement
(pixels 1024)



6
4
2
0
-2
-4
-6
-8

VERTICAL
LINEARITY

Displacement
(pixels 1024)

6
4
2
0
-2
-4
-6
-8

ENERGY

Peak adjustment
(%)

12
8
4
13 4 92
-4
-8
-12
-16

UNIFORMITY

Rejection rate
(%)

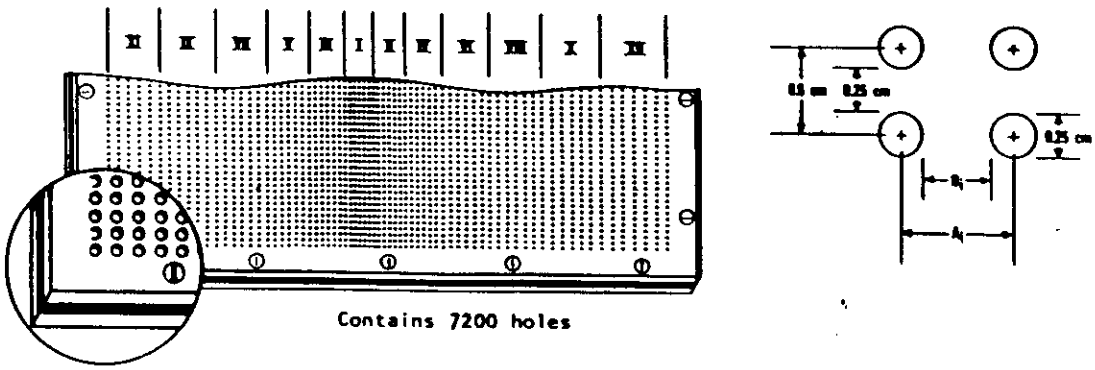
14
12
10
8
6
4
2
0

Uniformity Matrix:
MAPPA DI COR. UNIFORMIT

INTRINSIC SPATIAL RESOLUTION

– *QUALITATIVE TEST* –

BRH PHANTOM

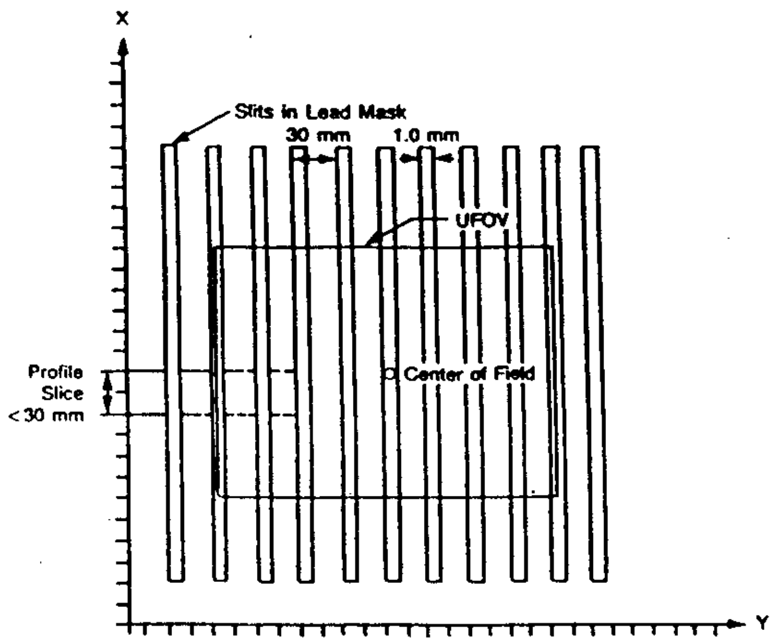


Schematic section of test pattern. Hole separation (A_i) and minimal lead spacing between the holes (B_i) vary in the X direction in groups of six holes, as follows:

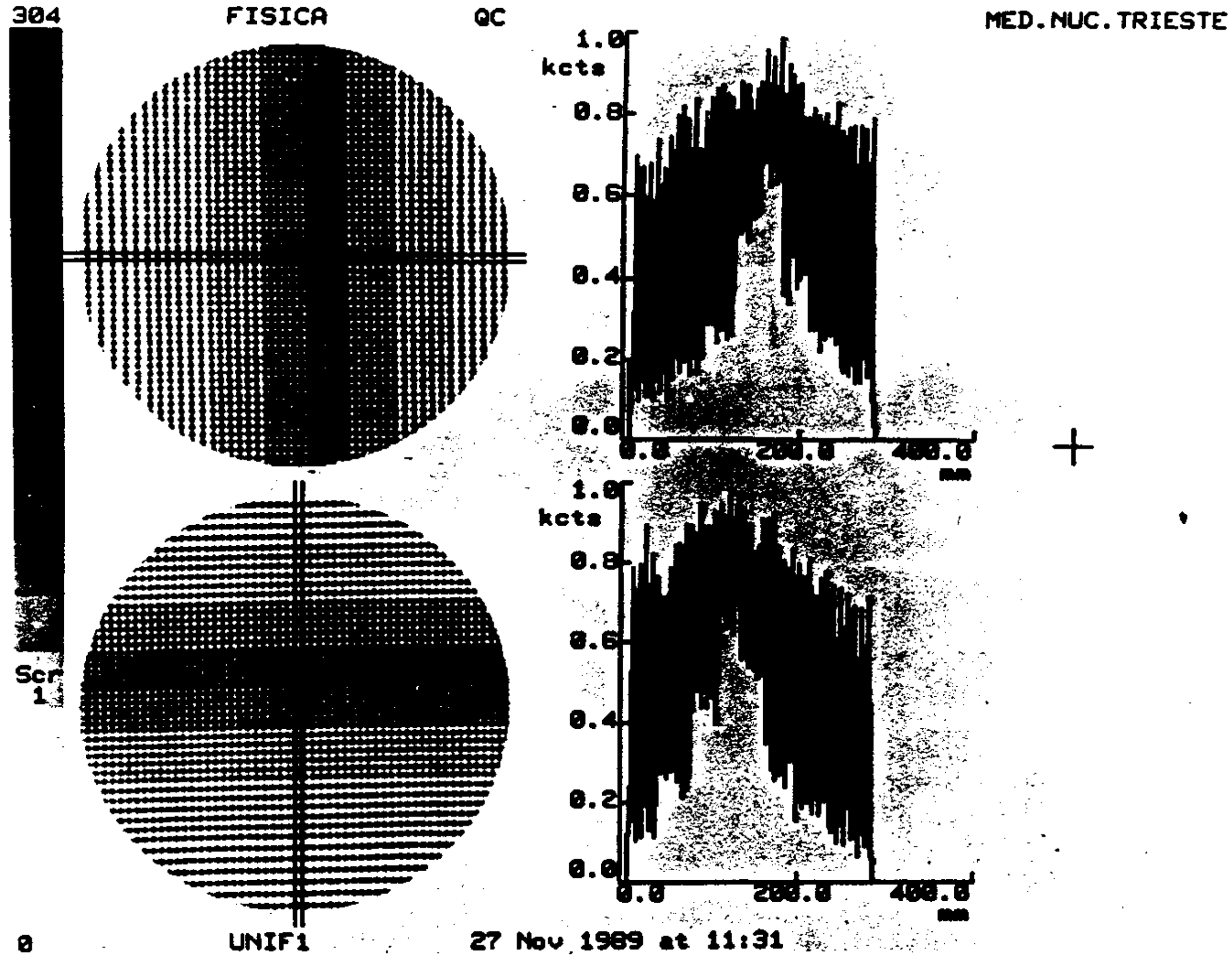
Group	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
A_i (cm)	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95
B_i (cm)	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7

– *QUANTITATIVE TEST* –

SLIT MASK



27/11/89

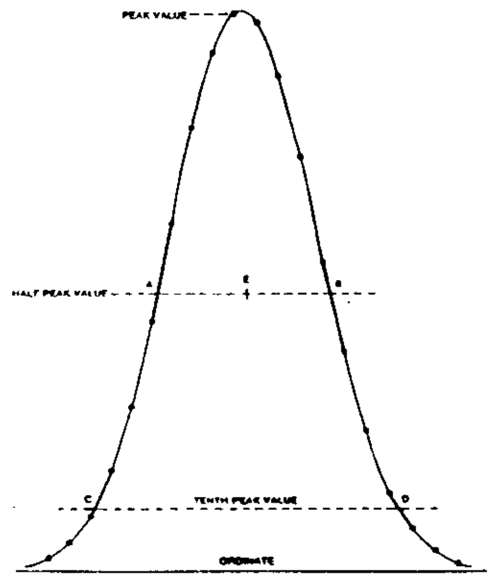

304
FISICA
QC
MED.NUC.TRIESTE
1.0
kcts
0.8
0.6
0.4
0.2
0.0
0.0
200.0
400.0
mm
Scr
1
0
UNIF1
27 Nov 1989 at 11:31

INTRINSIC SPATIAL RESOLUTION

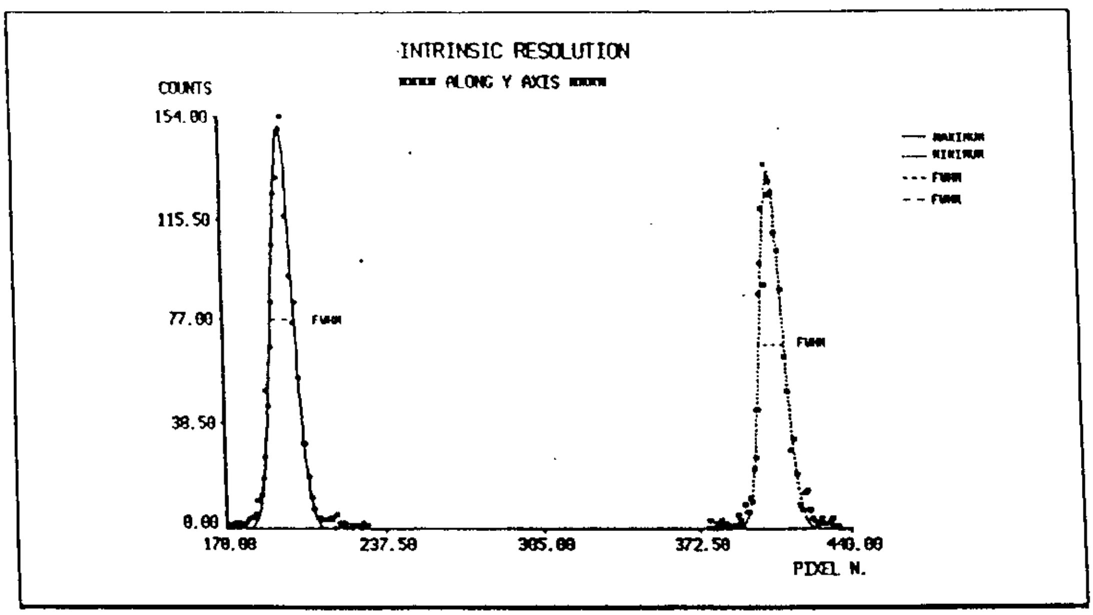
– QUANTITATIVE TEST –

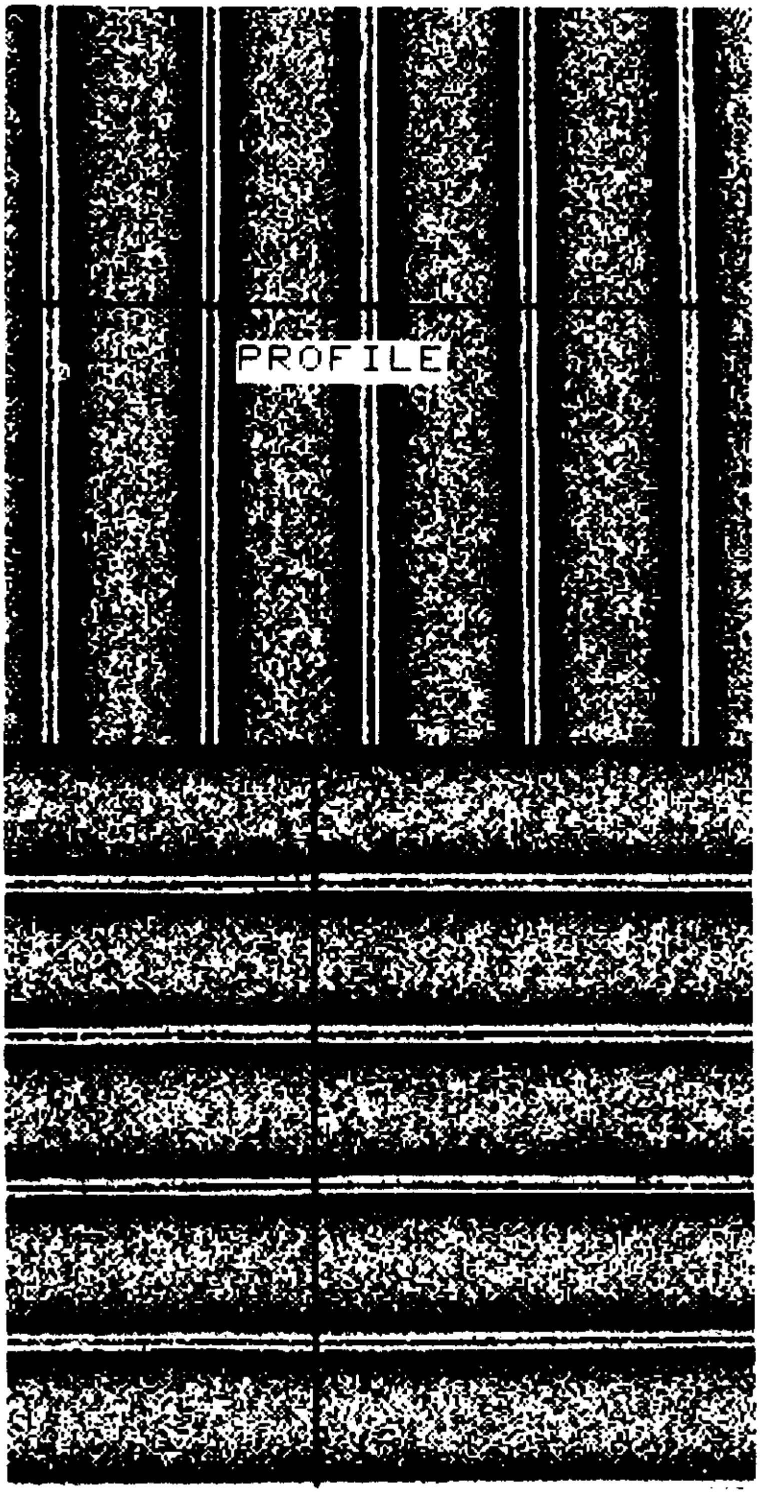
LINE SPREAD FUNCTION

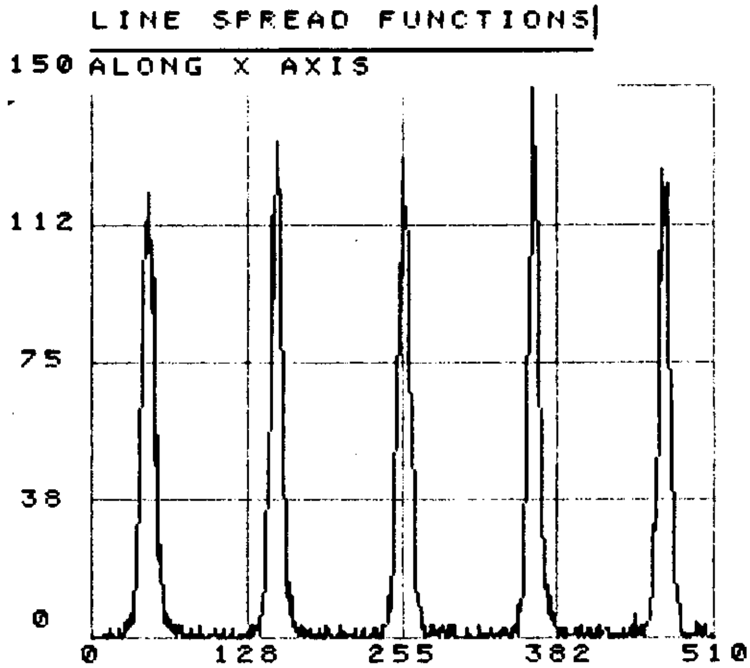
FWHM : Full Width at Half Maximum   FWTM : Full Width at Tenth Maximum

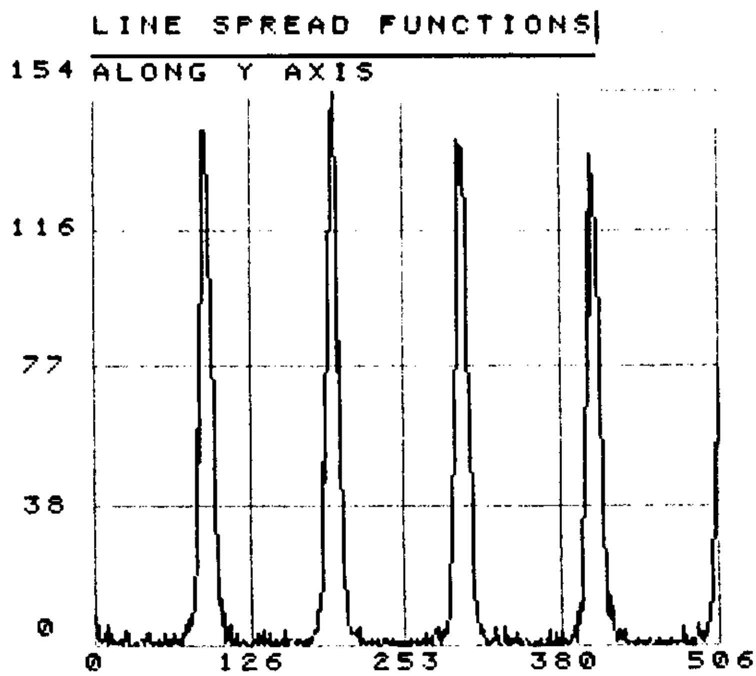


EXPERIMENTAL DATA




PROFILE

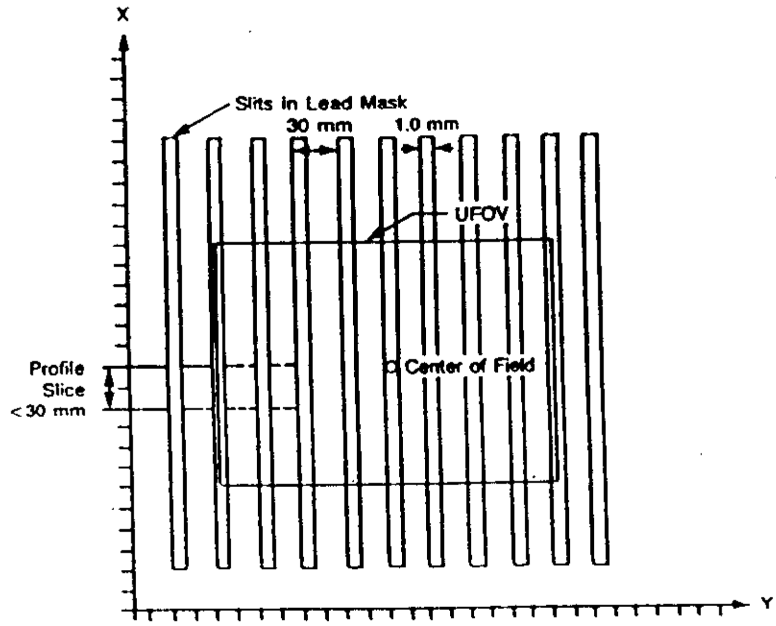

LINE SPREAD FUNCTIONS
ALONG X AXIS
150
112
75
38
0
0
128
255
382
510

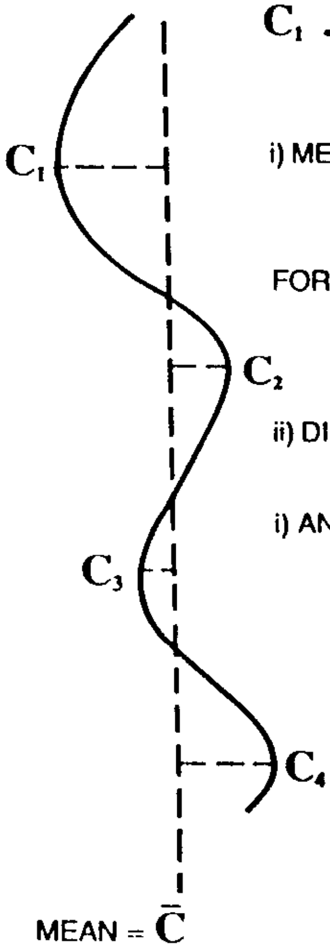

LINE SPREAD FUNCTIONS
ALONG Y AXIS
154
116
77
38
0
0
126
253
380
506

SPATIAL DISTORTION

MEASUREMENT OF SPATIAL DISPLACEMENT

— SLIT MASK PHANTOM —





$C_1 \; . \; . \; . \; . \; . \; C_i$ = FITTED PEAK CHANNELS FOR i PROFILES

i) MEAN DEVIATION = $\sum_{\text{ALL LINES}}^{i} \left| \bar{C} - C_i \right| / N$

FOR BOTH X AND Y (N VALUES)

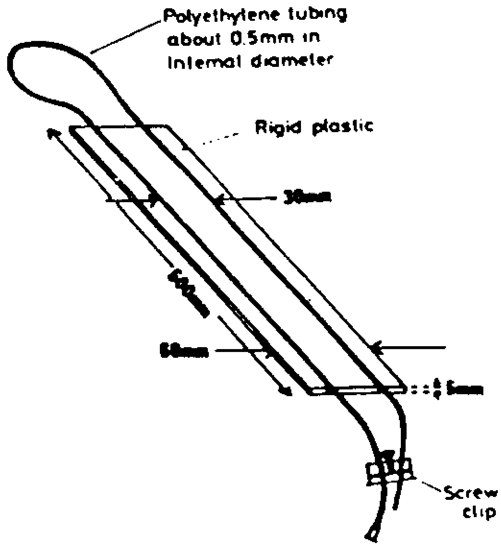
ii) DIFFERENTIAL = MAX $\left| C_i - C_{i+1} \right|$

i) AND ii) EXPRESSED AS % OF GFOV.

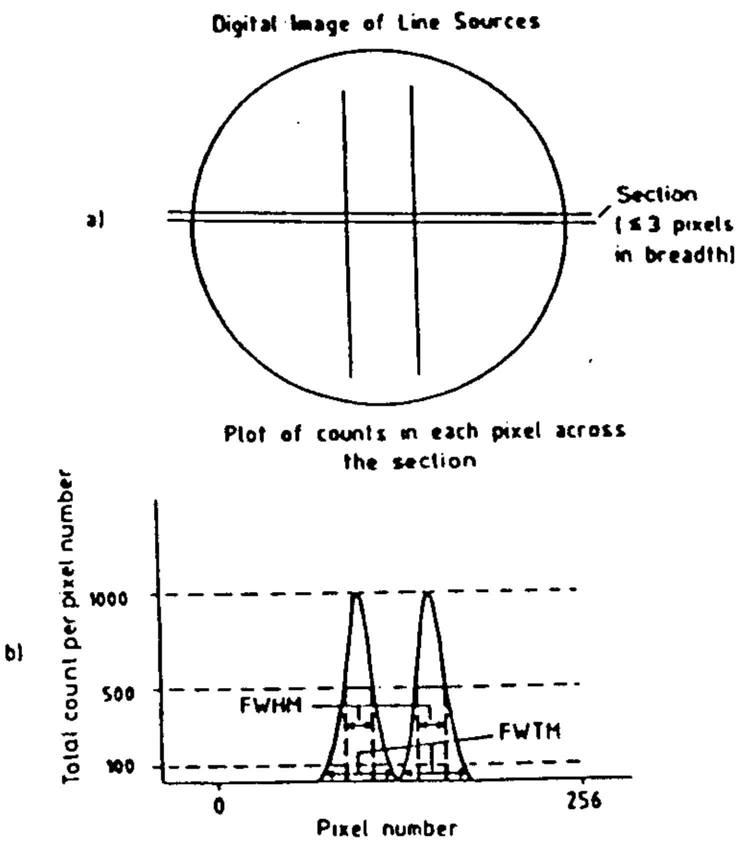
15

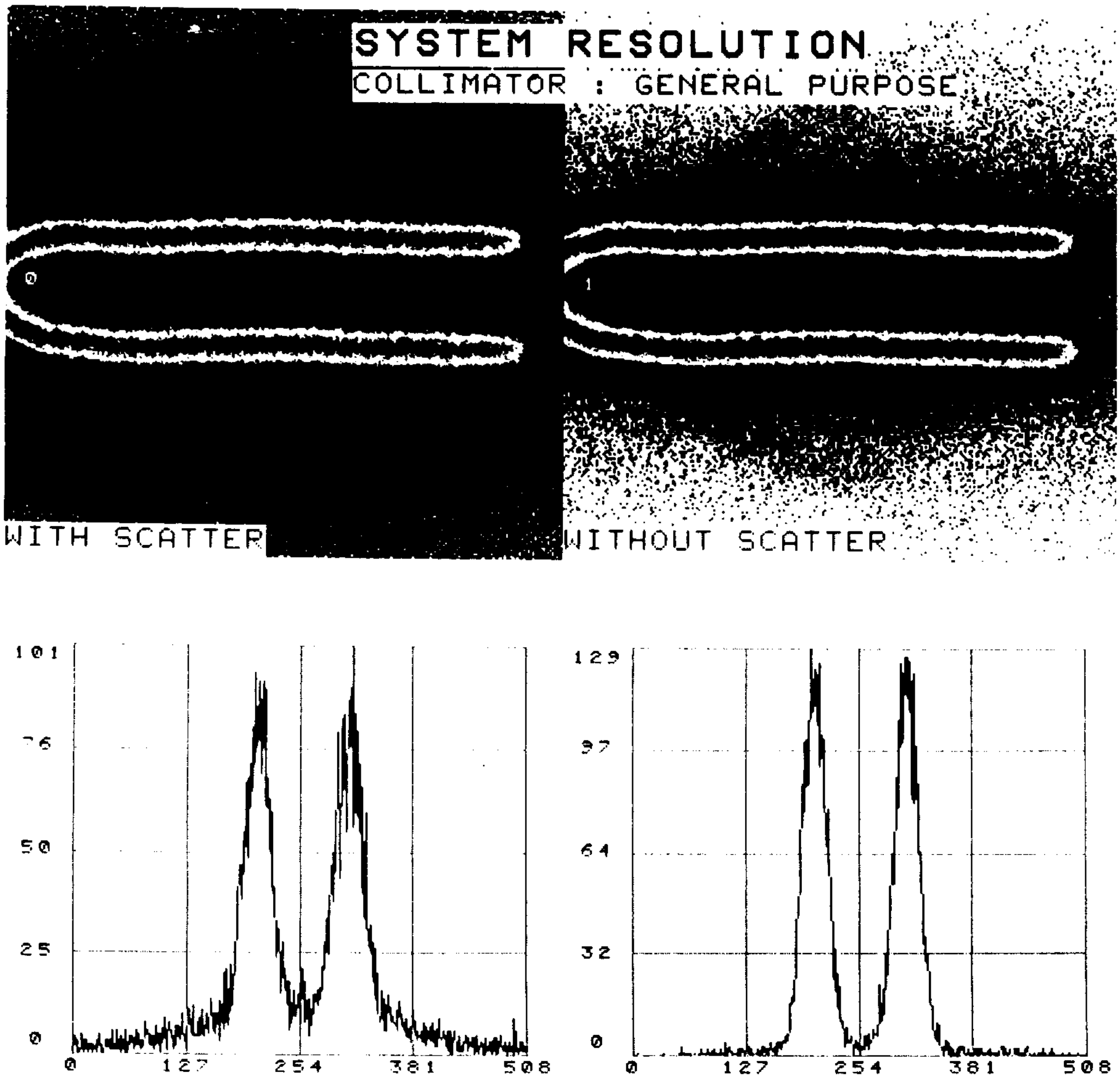
SYSTEM SPATIAL RESOLUTION WITH AND WITHOUT SCATTER

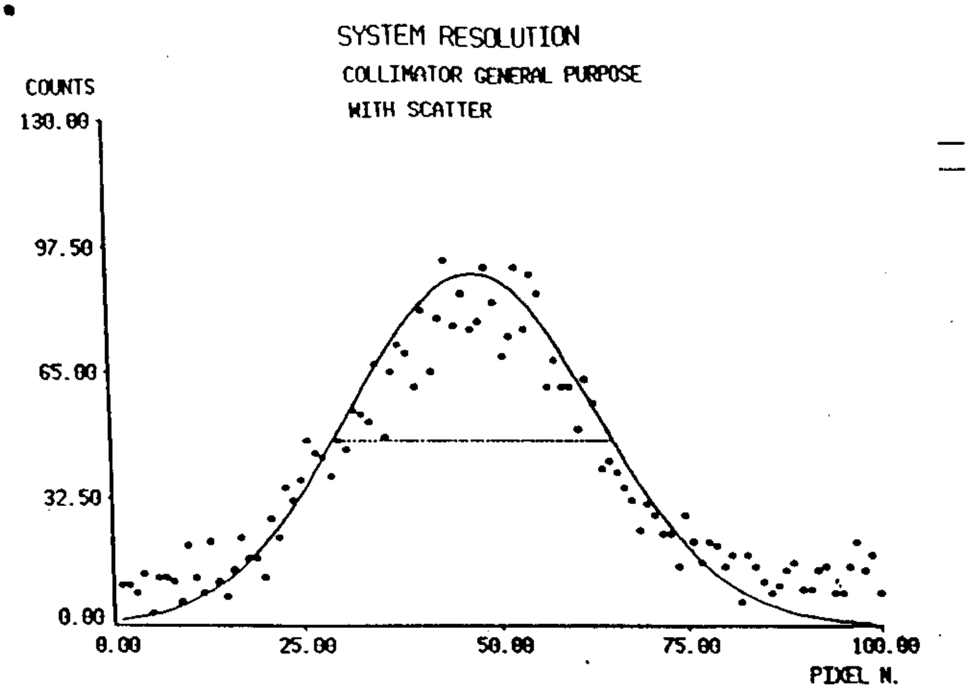
PARALLEL LINE SOURCE PHAMTOM



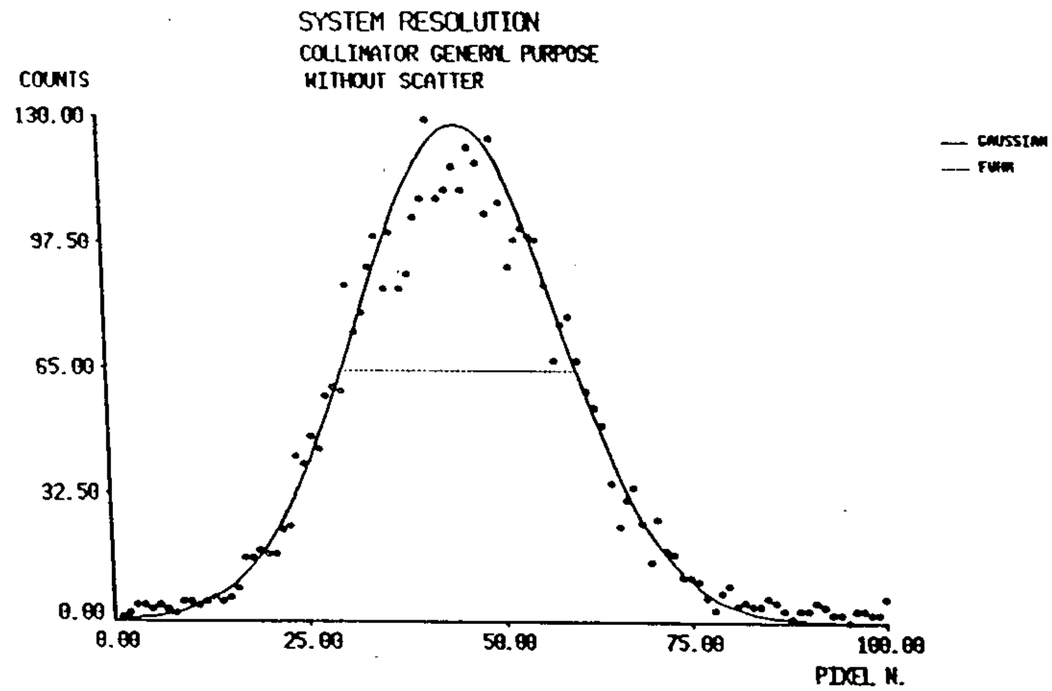
PROFILE VALUES



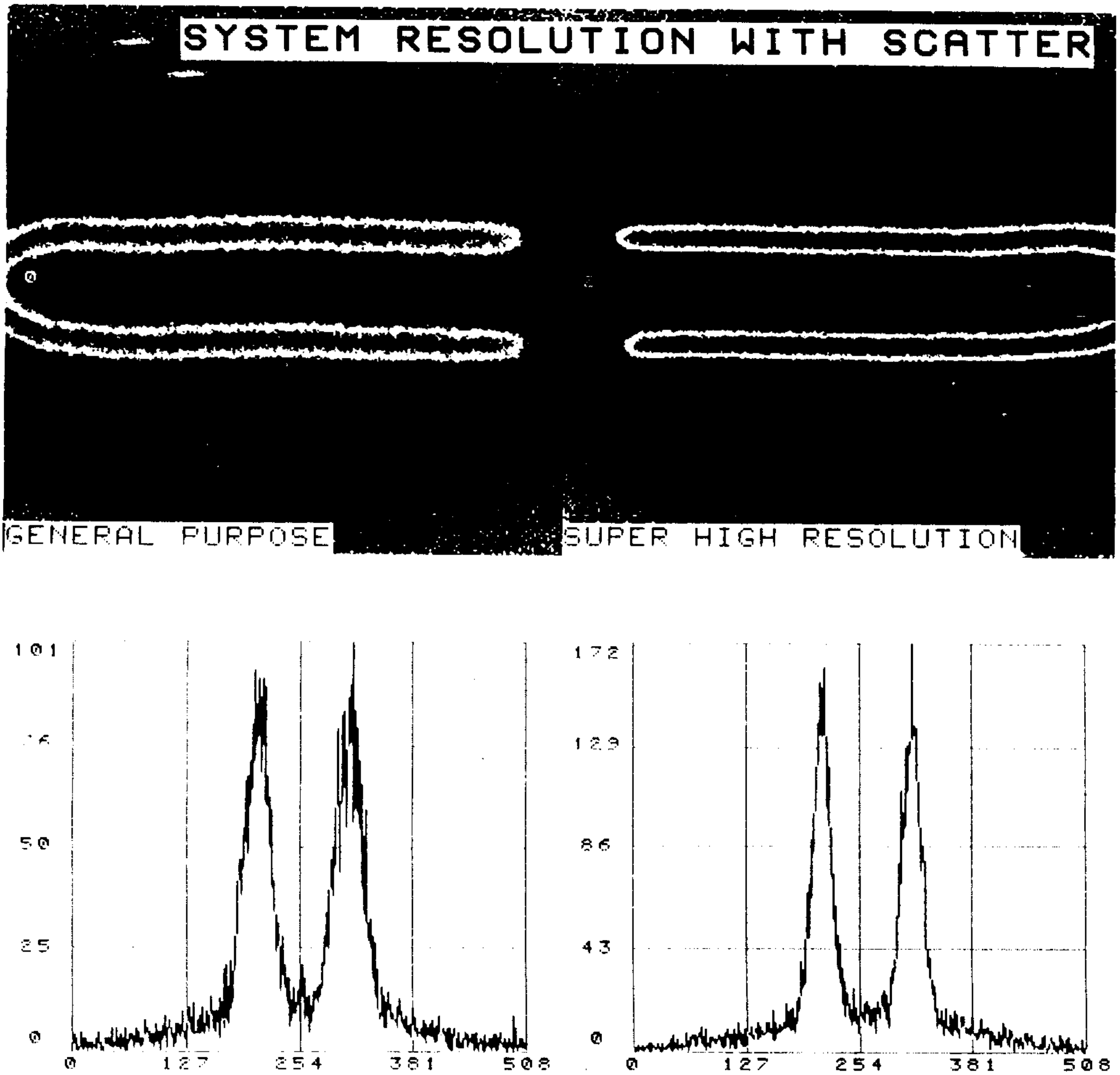

SYSTEM RESOLUTION
COLLIMATOR : GENERAL PURPOSE
WITH SCATTER
WITHOUT SCATTER
101
50
25
0
0
127
254
381
508
129
97
64
32
0
0
127
254
381
508


SYSTEM RESOLUTION
COLLIMATOR GENERAL PURPOSE
WITH SCATTER
COUNTS
130.00
97.50
65.00
32.50
0.00
0.00
25.00
50.00
75.00
100.00
PIXEL N.

a)

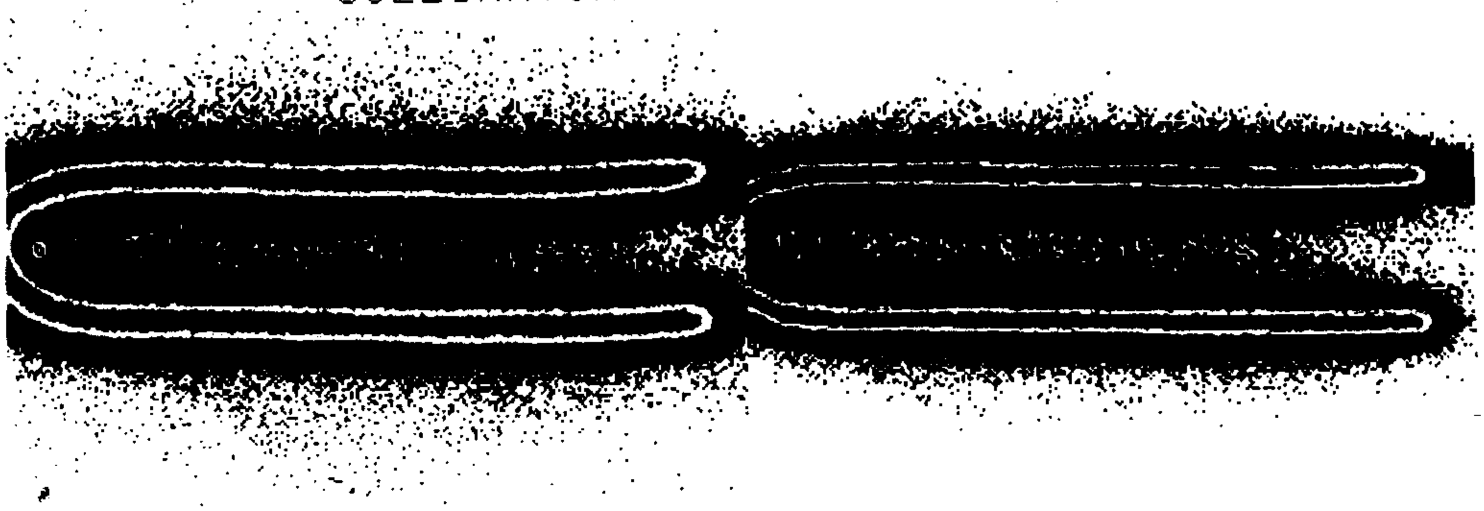

SYSTEM RESOLUTION
COLLIMATOR GENERAL PURPOSE
WITHOUT SCATTER
COUNTS
130.00
97.50
65.00
32.50
0.00
0.00
25.00
50.00
75.00
100.00
PIXEL N.

b)


SYSTEM RESOLUTION WITH SCATTER
GENERAL PURPOSE
SUPER HIGH RESOLUTION
101
50
25
0
0 127 254 381 508
172
129
86
43
0
0 127 254 381 508

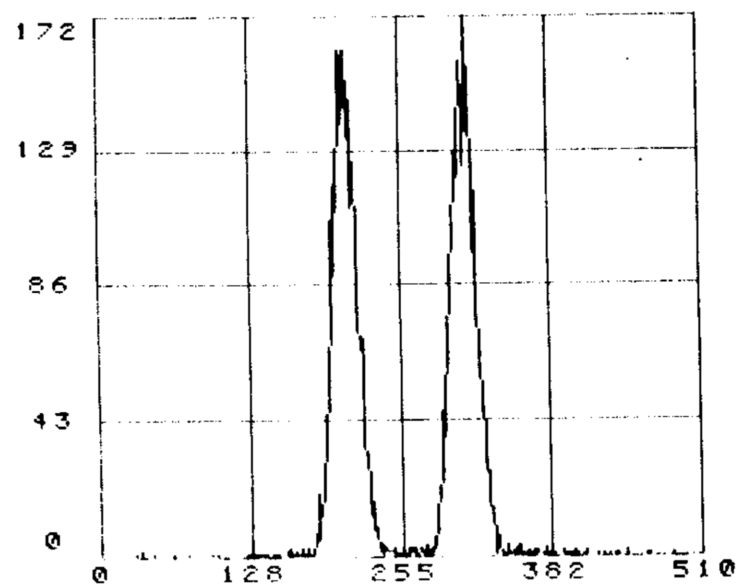
SYSTEM RESOLUTION

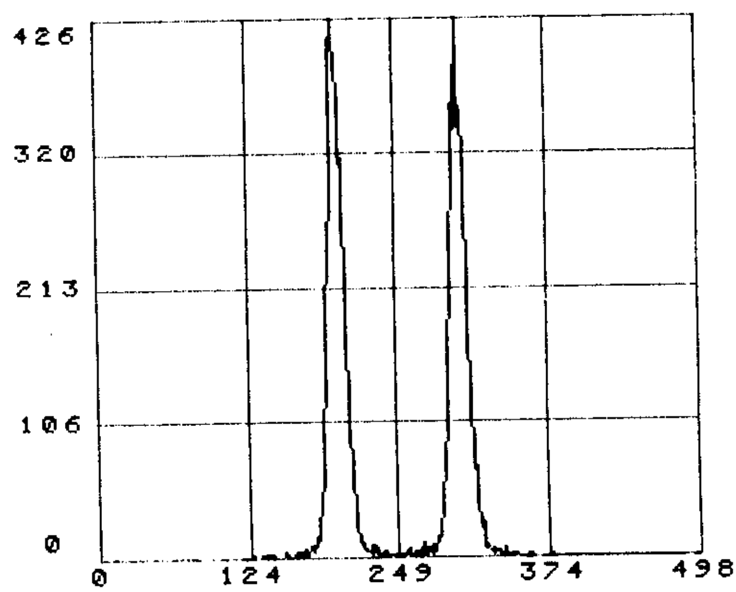
COLLIMATOR : SUPER HIGH RESOLUTION

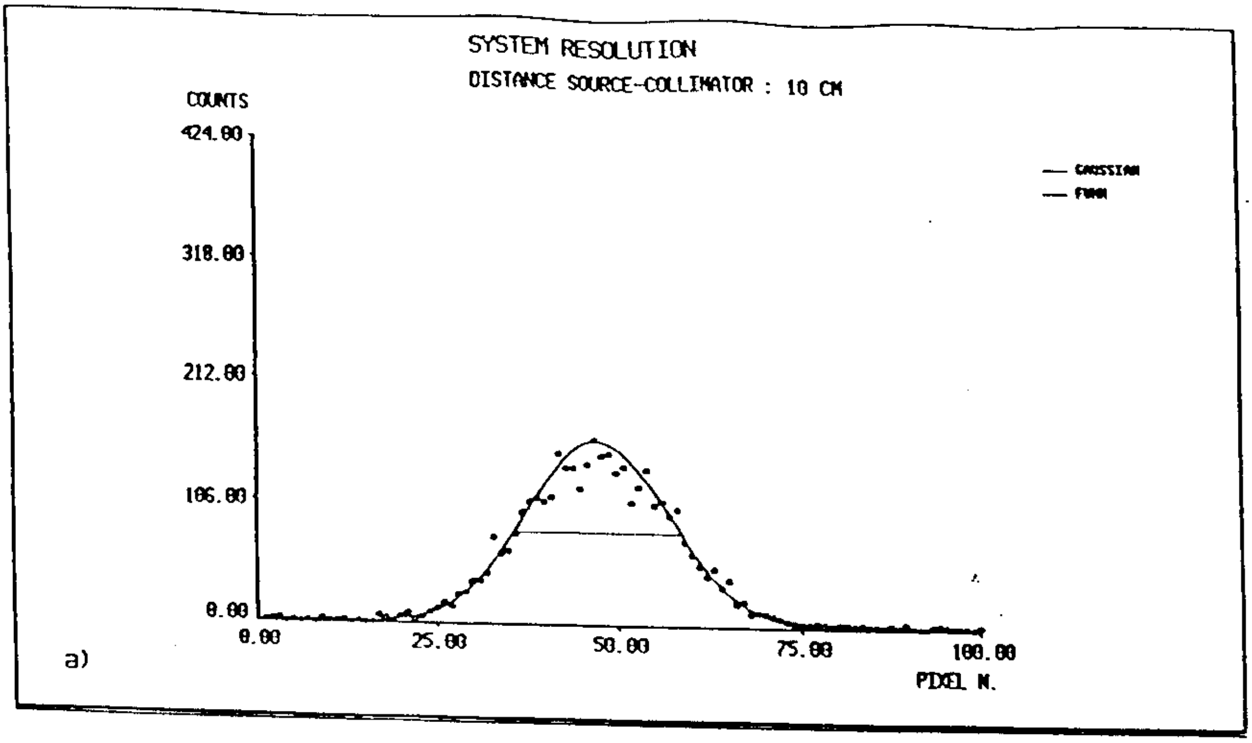


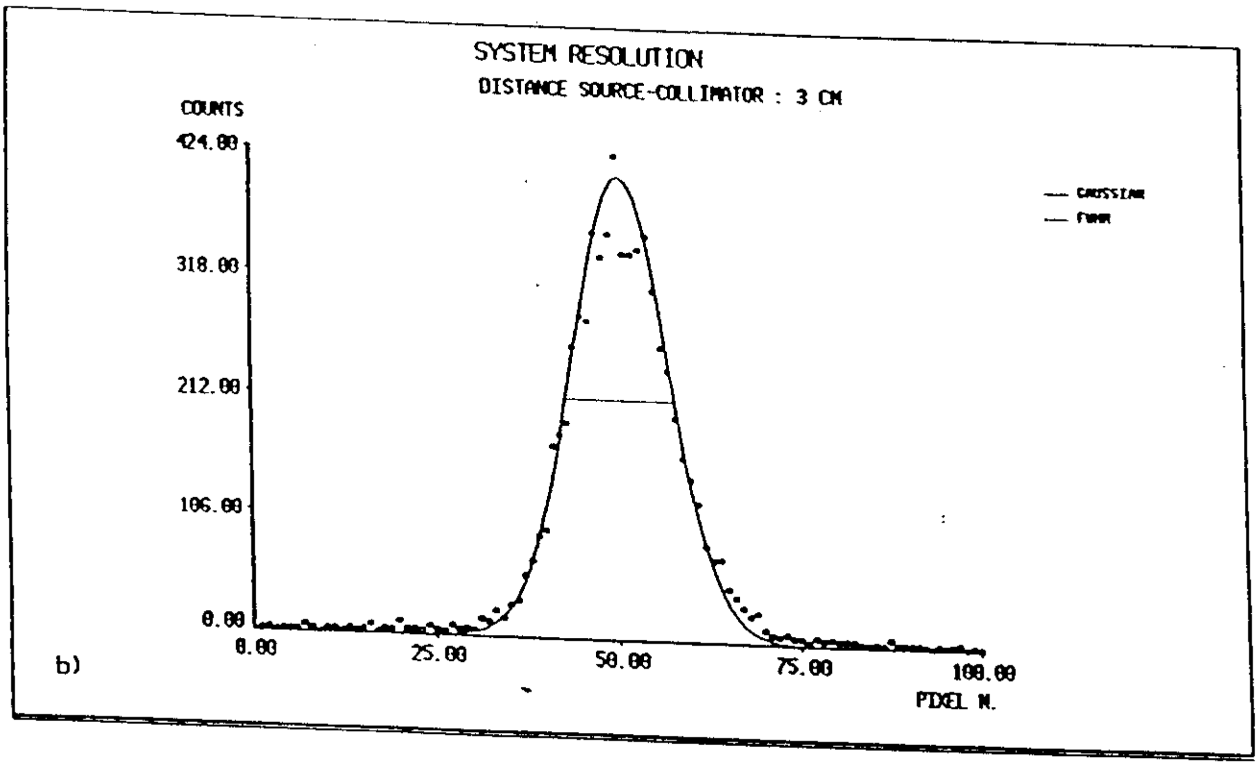
DISTANCE SOURCE-COLL.
10 CM

DISTANCE SOURCE-COLL.
3 CM



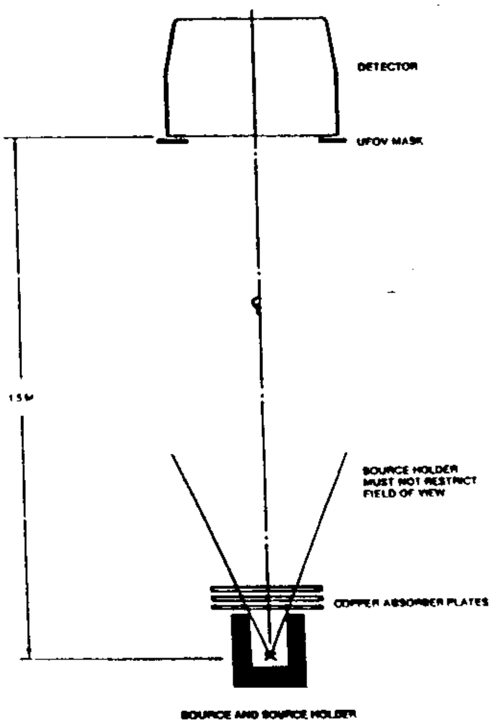



SYSTEM RESOLUTION
DISTANCE SOURCE-COLLIMATOR : 10 CM
COUNTS
424.00
318.00
212.00
106.00
0.00
0.00
25.00
50.00
75.00
100.00
PIXEL N.
GAUSSIAN
FWHM
a)

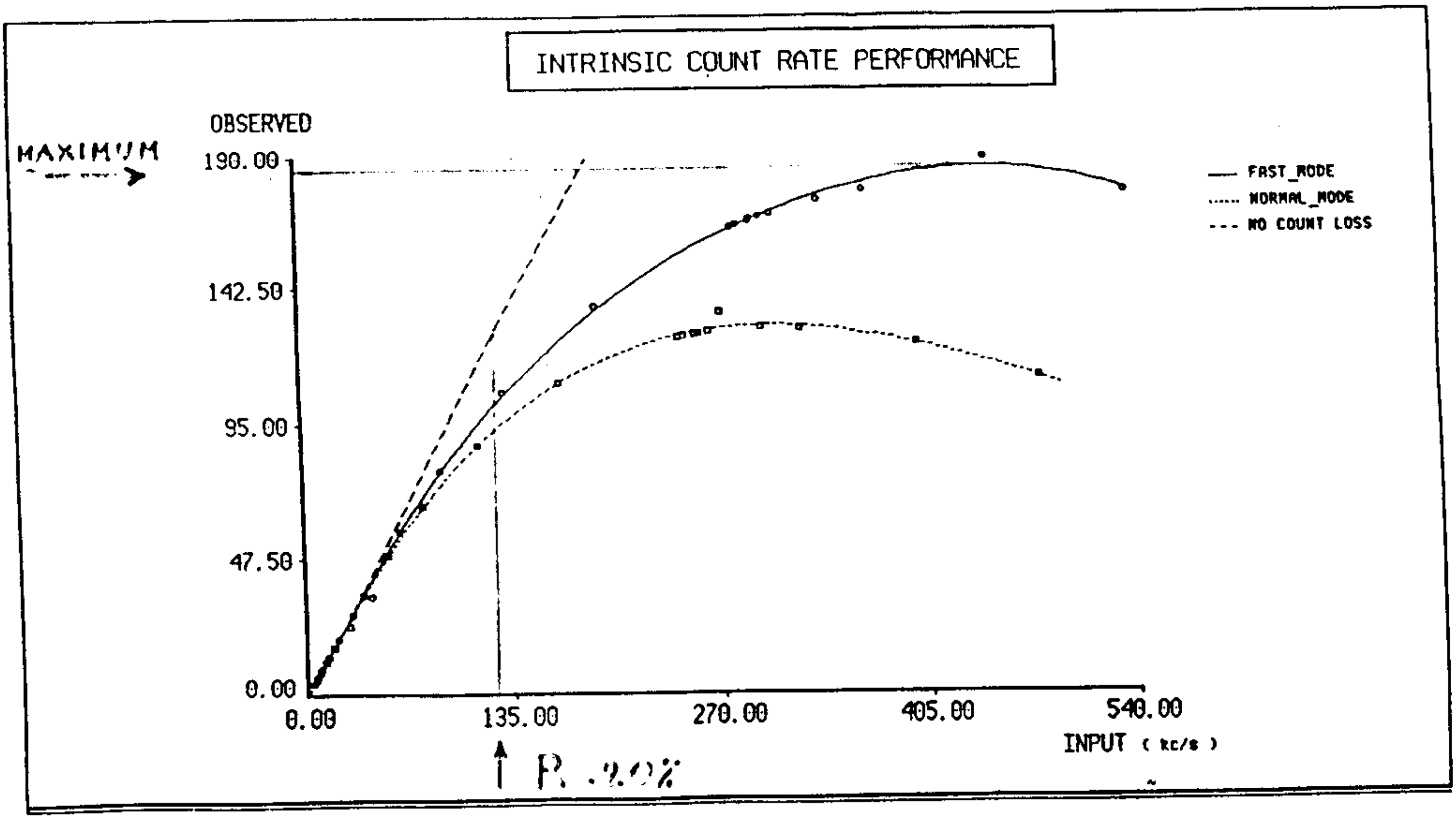

SYSTEM RESOLUTION
DISTANCE SOURCE-COLLIMATOR : 3 CM
COUNTS
424.00
318.00
212.00
106.00
0.00
0.00
25.00
50.00
75.00
100.00
PIXEL N.
GAUSSIAN
FWHM
b)

•INTRINSIC COUNT RATE PERFORMANCE

GEOMETRY FOR COUNT RATE CURVE

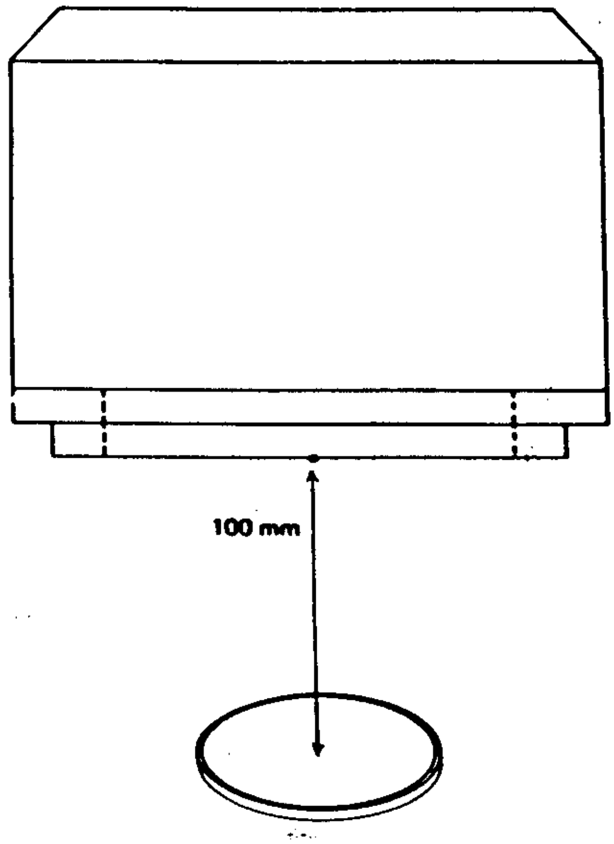


EXPERIMENTAL DATA



SYSTEM SENSIBILITY

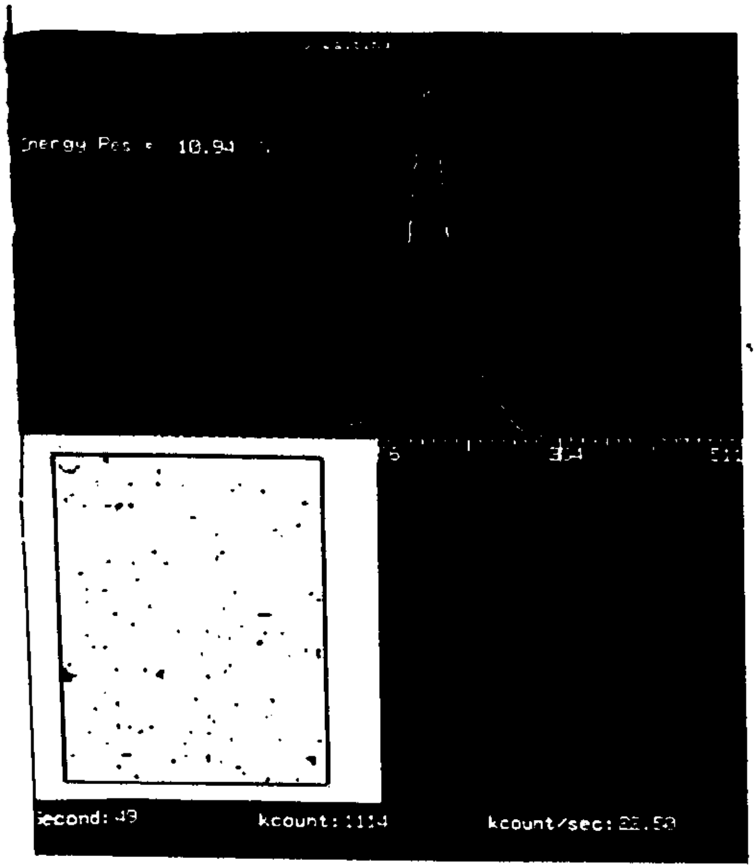
PLANAR SOURCE PHAMTOM

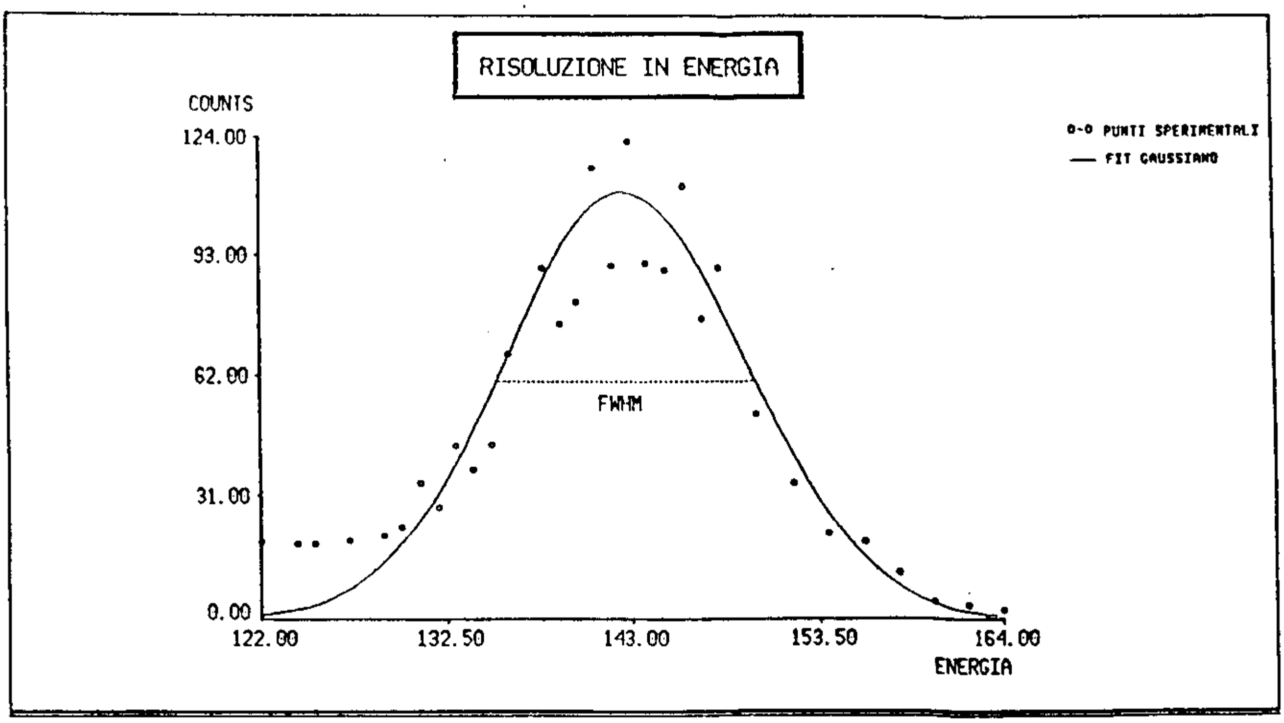


$$S = \text{counts} / \text{MBq} \cdot \text{sec}$$

• INTRINSIC ENERGY RESOLUTION

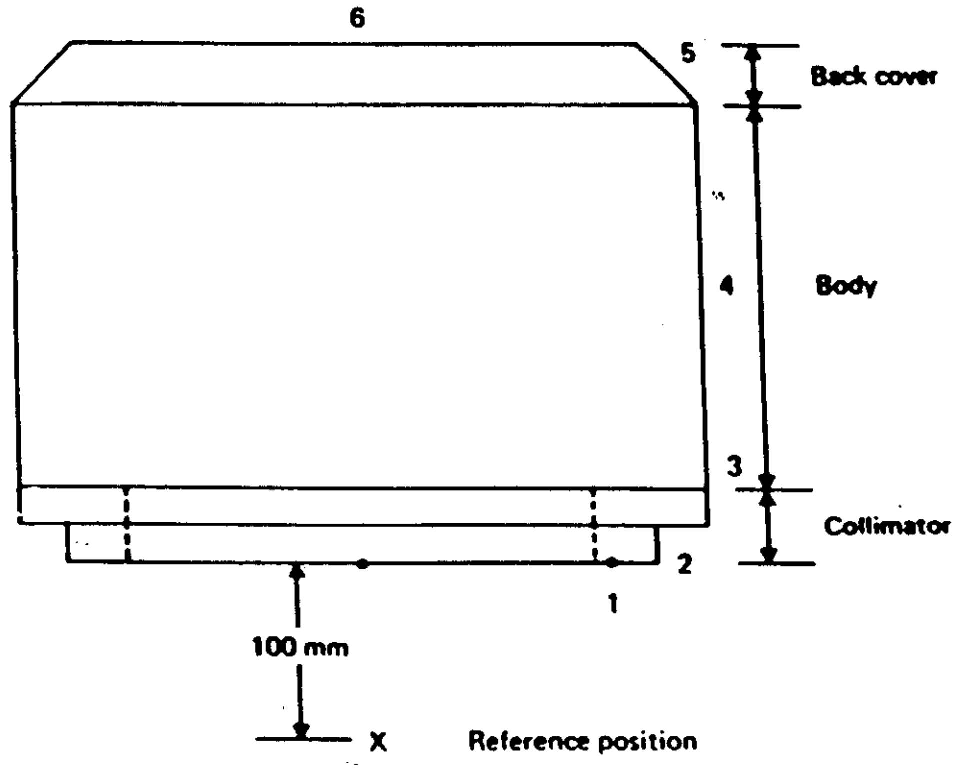
RES % = FWHM / PHOTOPEAK ENERGY





DETECTOR HEAD SHIELDING LEAKAGE

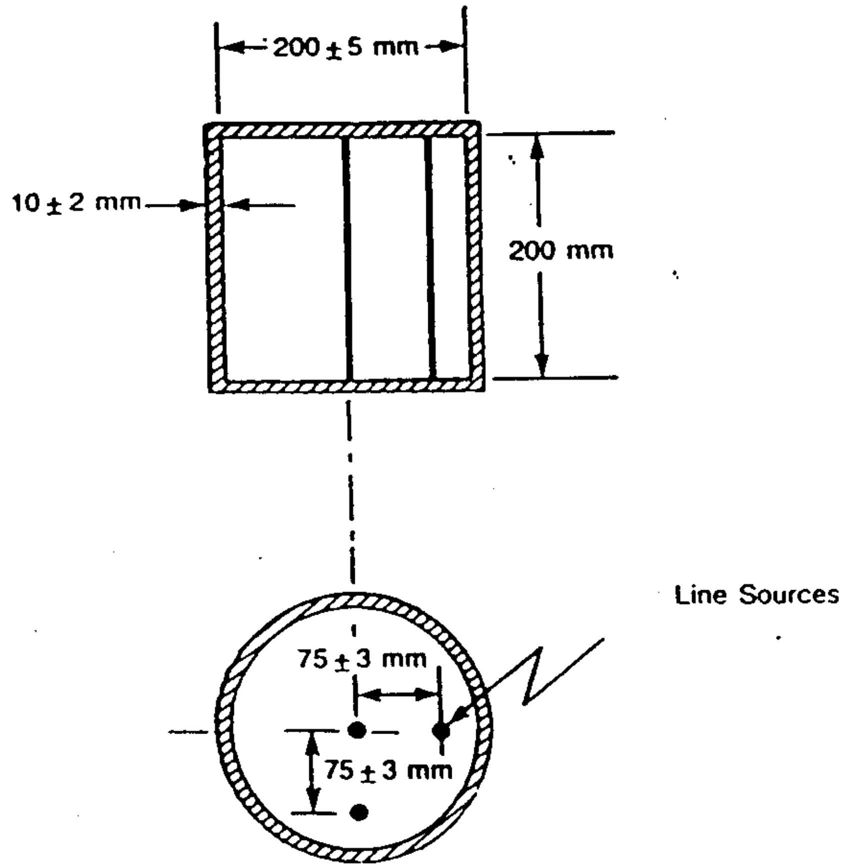
SMALL CUBIC SOURCE



$$L\ (\%) = \frac{\text{observed count rate}}{\text{reference count rate}} * 100$$

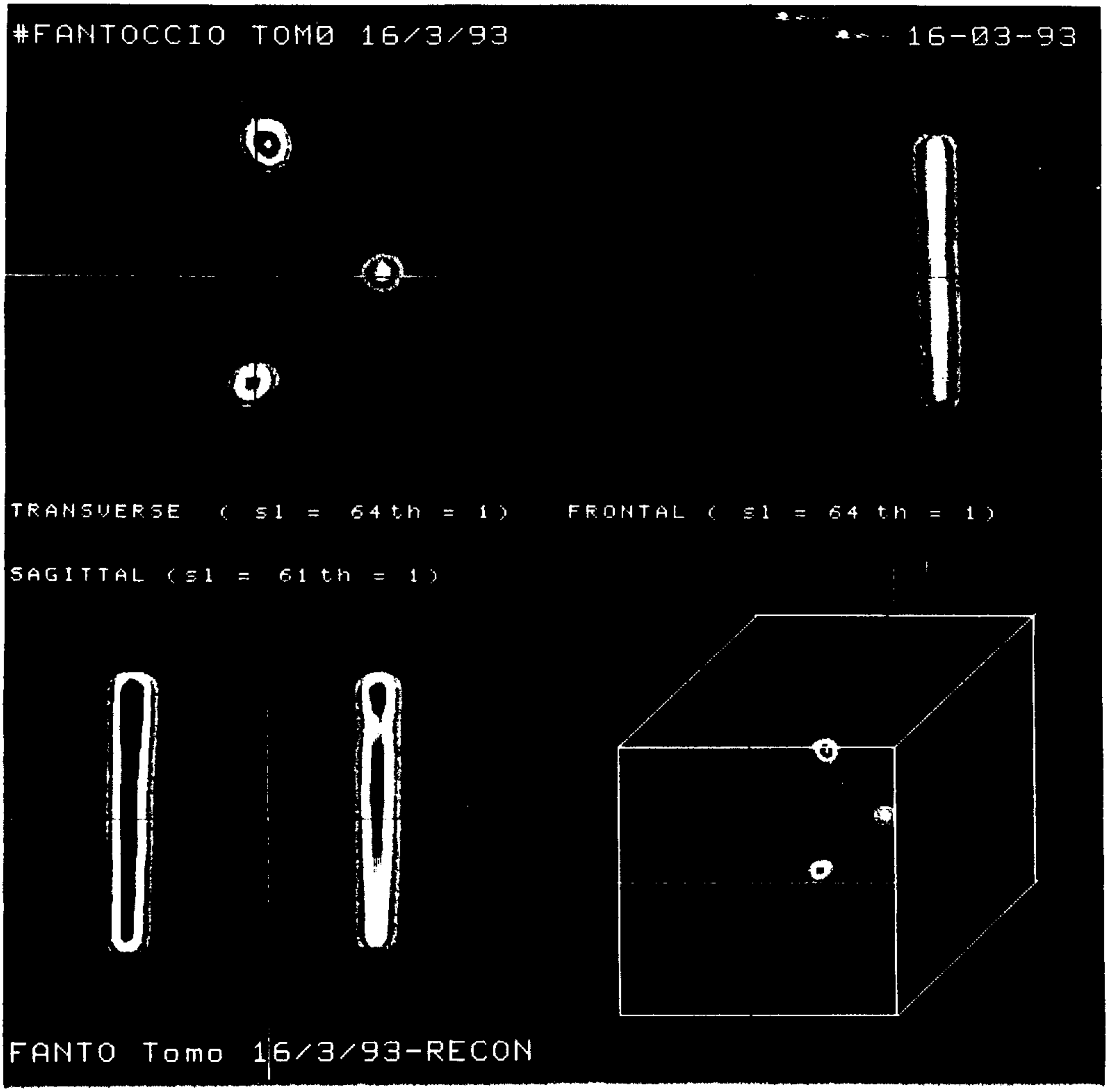
TOMOGRAPHIC SYSTEM RESOLUTION

TOMOGRAPHIC PHANTOM



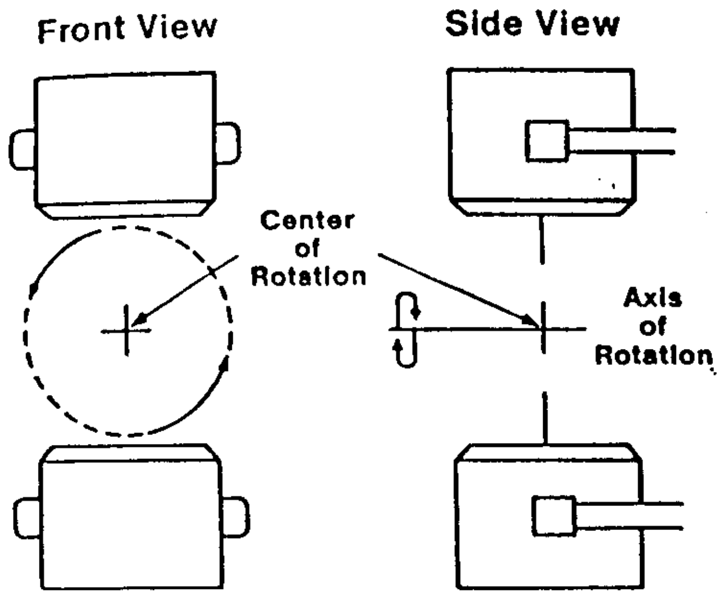
ACQUISITION PARAMETERS:

- 20% PHA window on the photopeak
- 128x128 Matrix
- x2 preprocess zoom
- Radius of rotation 150±5 mm
- Transverse slice 10±3 mm thick ≥ 250,000 counts

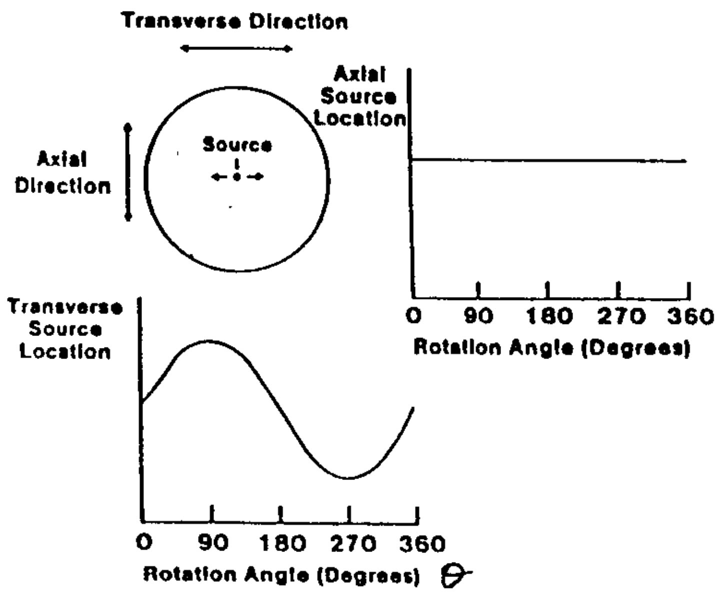

#FANTOCCIO TOMØ 16/3/93
16-Ø3-93
TRANSVERSE (sl = 64th = 1)
FRONTAL (sl = 64 th = 1)
SAGITTAL (sl = 61th = 1)
FANTO Tomo 16/3/93-RECON

TOMOGRAPHIC CENTRE OF ROTATION

POINT SOURCE
(5 cm from the axis of rotation)



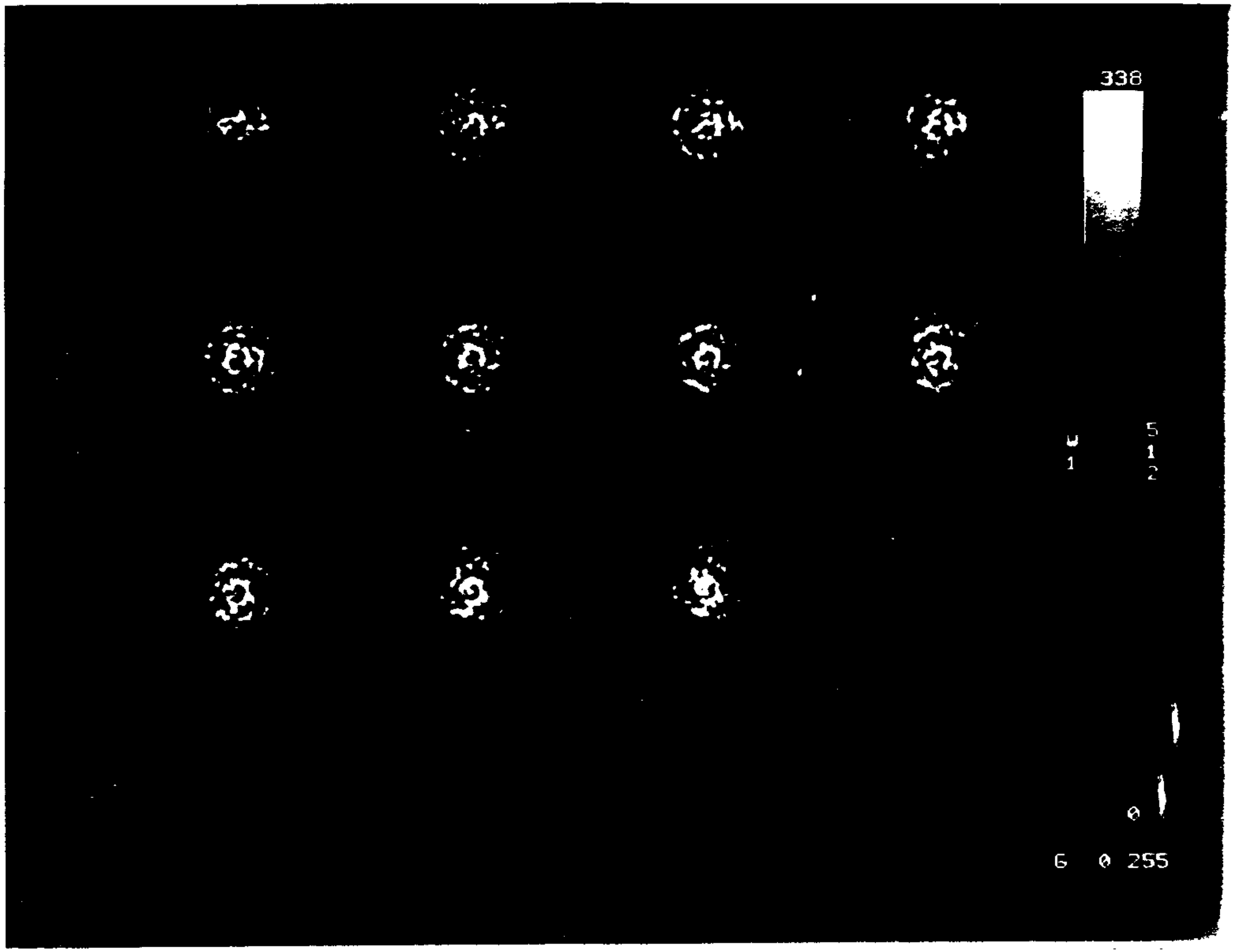
SINOGRAM



FITTING $\Longrightarrow$ $A \sin (\vartheta + \phi) + B$

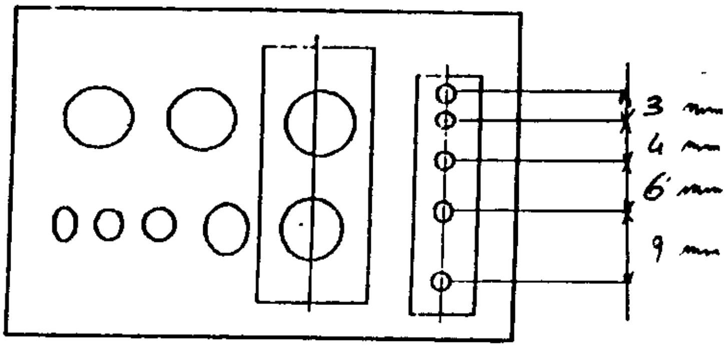
Expected COR : (martix size + 1) / 2

offset $\Longrightarrow$ $R = ECOR - B$ **R (ϑ) : sinogram - fitted curve**

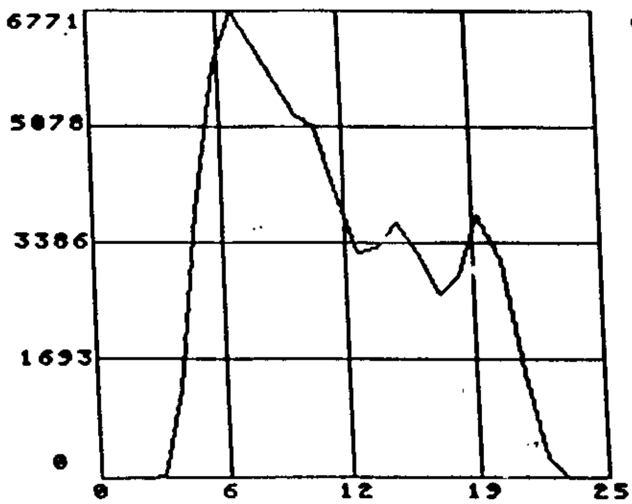

338
G 0 255

RECONSTRUCTION FILTERS

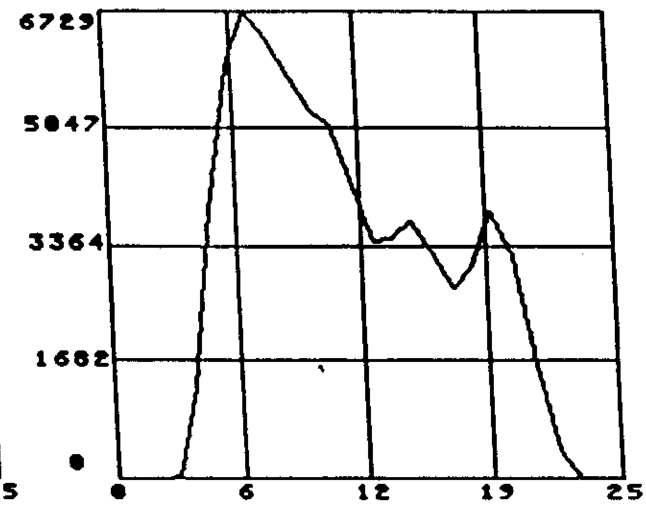
— SPATIAL RESOLUTION —



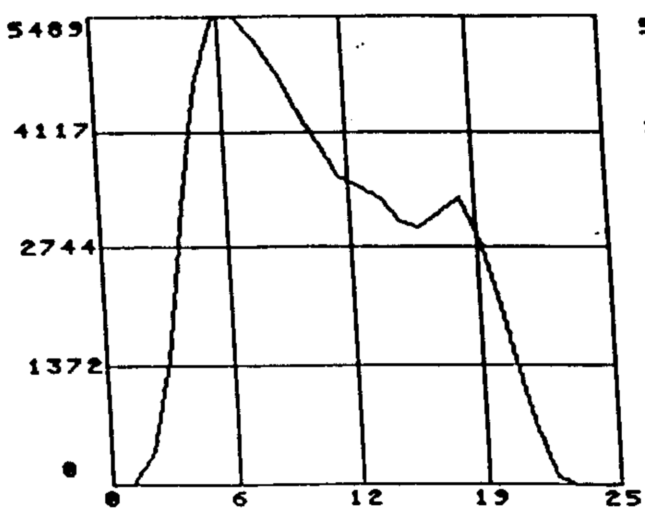
NESSUN FILTRO



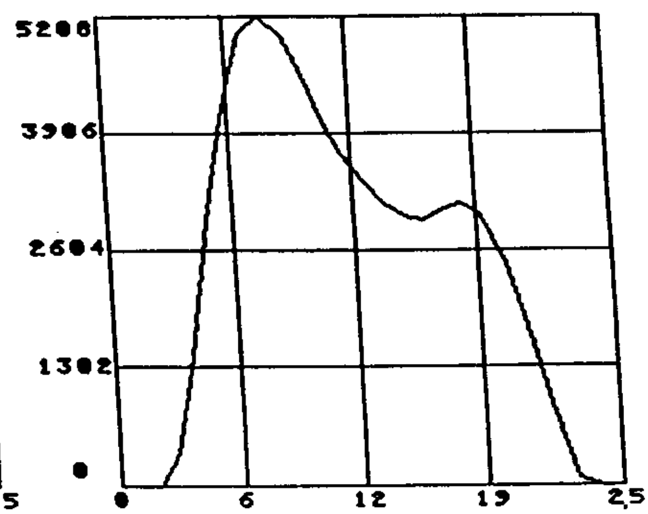
FILTRO SHEPP-LOGAN



FILTRO PARZEN



FILTRO WIENER



Quality Control of Gamma Cameras

(all results are registered in protocols)

Daily:
- Energy window $^{99}Tc^{m}$
- Background
- Uniformity } ^{57}Co planar source, 2000 kcounts
- Sensitivity }

Every 2nd week:
- Uniformity $^{99}Tc^{m}$ flood source test and uniformity matrix collection
- Sensitivity (cps/MBq) same source
- Spatial resolution same source + bar quadrant phantom
- Position linearity (mm/pixel) —"— —"—

SPECT:
- Uniformity test and uniformity matrix collection $^{99}Tc^{m}$ cylindrical phantom (other radionuclides if needed)
- Center of rotation $^{99}Tc^{m}$ point source

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PHYSICAL SCIENCES
IN MEDICINE

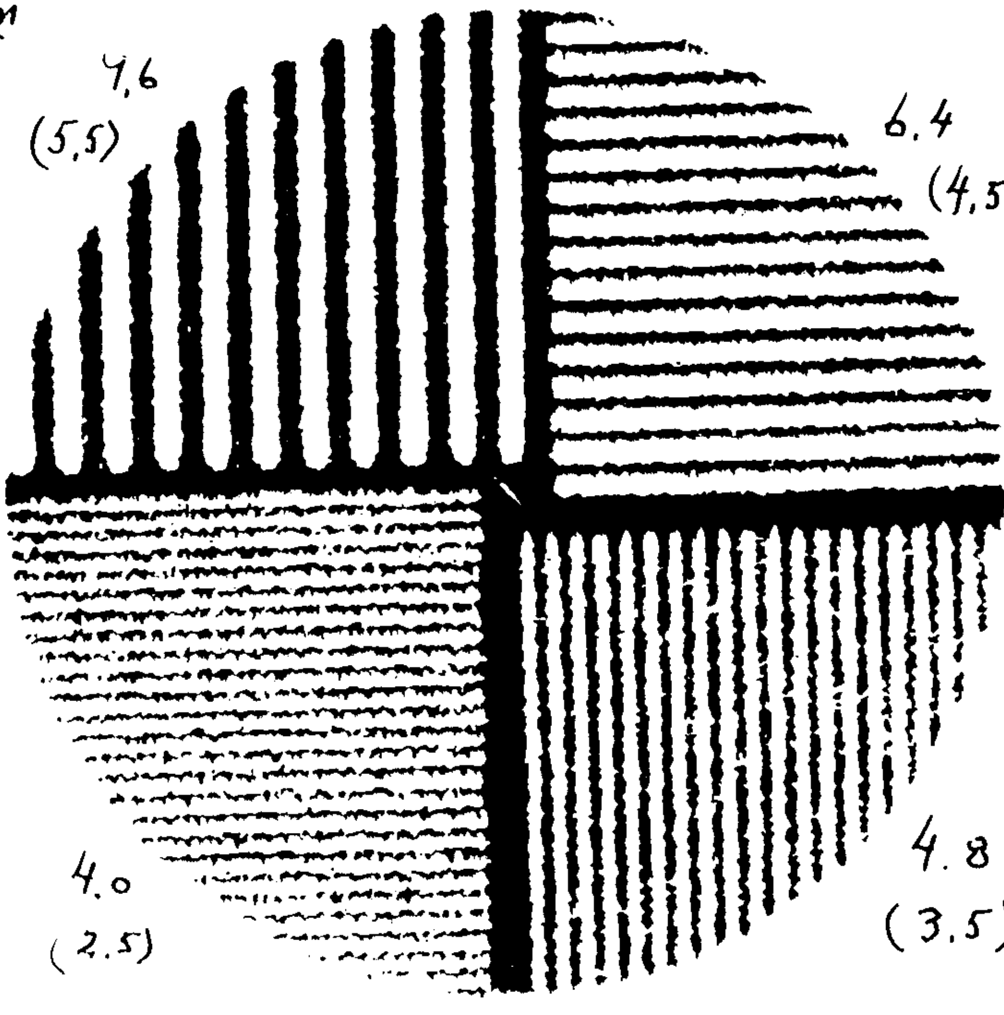
Report No. 66

Quality Control of Gamma Cameras and Associated Computer Systems

mm

7,6
(5,5)

6,4
(4,5)



4,0
(2,5)

4.8
(3,5)

Bar-quadrant phantom

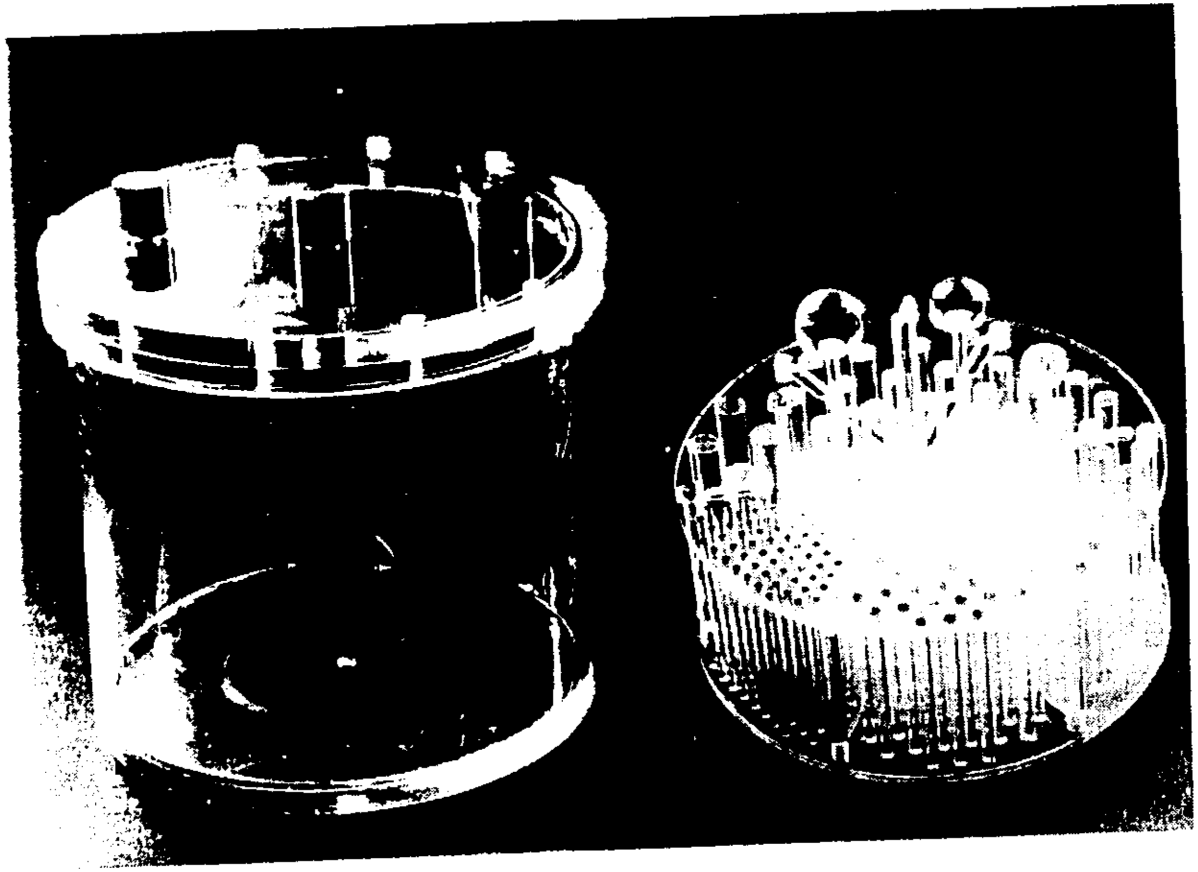
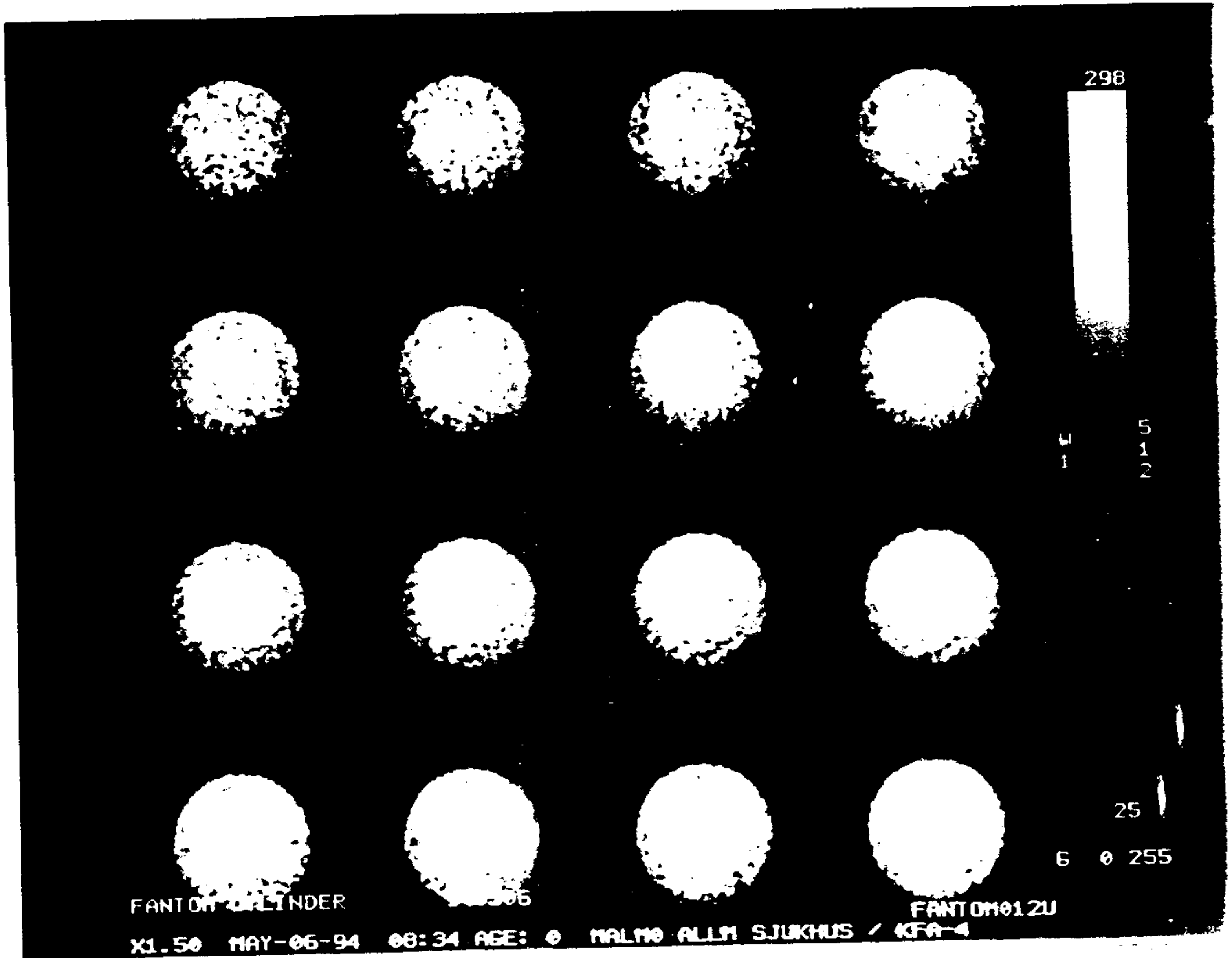


Figure 4.1 A typical SPECT phantom


298
5
1
2
25
6 0 255
FANTOM012U
X1.50 MAY-06-94 08:34 AGE: 0 MALMO ALLM SJUKHUS / KFA-4

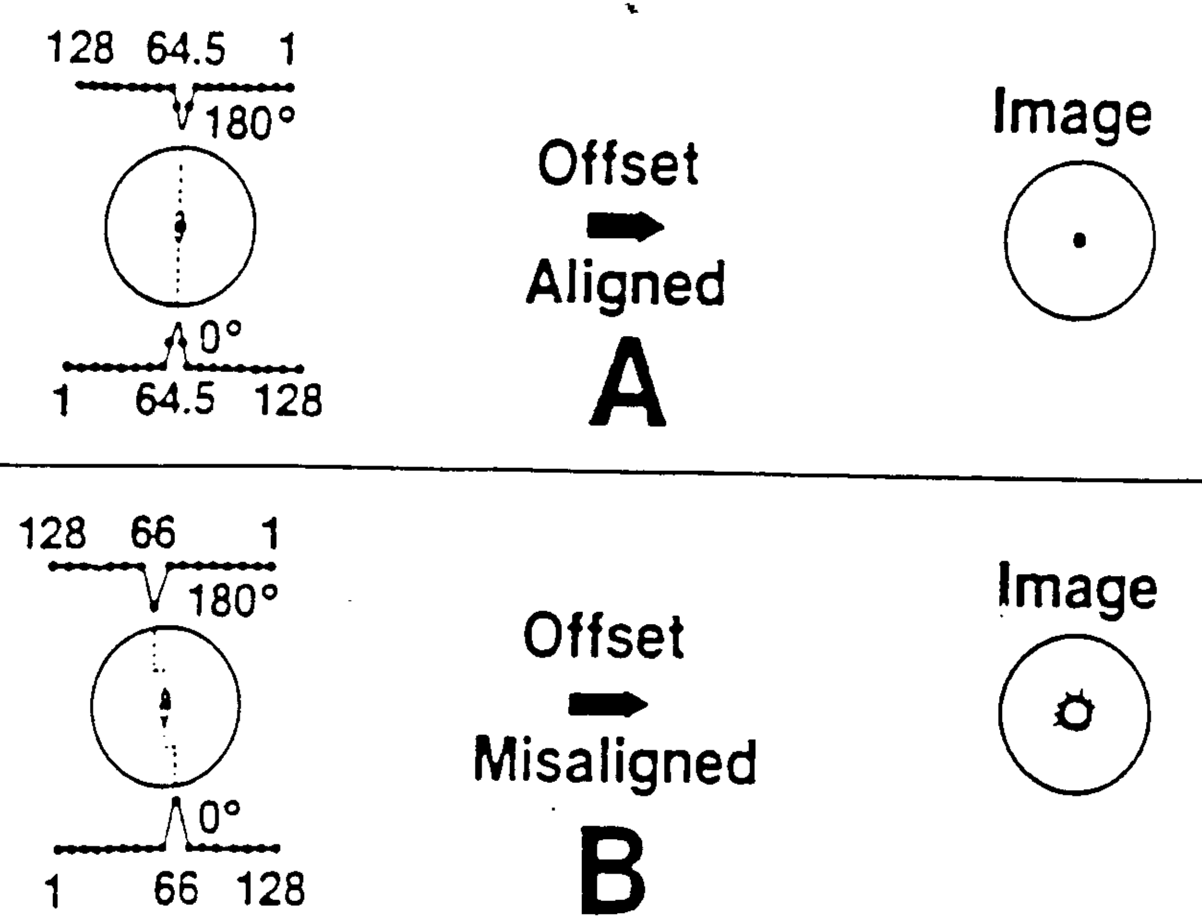


Figure 2. Reconstruction of a point source A) with no centre of rotation offset and B) when centre of rotation offset exists - note the image becomes a circle in the latter case (from IAEA TECDOC-317).

Activity meter ("Dose calibrator")

Before each measurement:
Background

Daily:
Measurement of a standard source (Cs-137)

Monthly:
Battery test
Zero test. Adjusted if necessary.
Background test. -"-
Measurements of three standard sources (Co-57, Cs-137 and Ra-226)

Documentation in protocols and in graphs placed close to the instrument

NaI(Tl)-detector for thyroid uptake measurements

Daily:

Energy window
Standard source of I-131
Background

NaI(Tl)-detectors for measurements on samples ("gamma counters, well detectors etc"

Before each measurement:
Energy window
Background
Standard source (Na-22)

Every 6 months:
Absolute calibration (all radionuclides measured)
Volume correction
Deadtime correction

Quality Control of Radiopharmaceuticals

Radiation considerations

- Radionuclide purity
- Radiochemical purity
- Activity

Pharmaceutical considerations

- Visual inspection
- Chemical purity
- pH

Biologic considerations

- Sterility
- Pyrogens

Radionuclide purity.

^{99}Mo in $^{99}Tc^{m}$ Activity meter Sample with and without Pb-shielding

^{126}I in ^{125}I Ge ($NaI(Tl)$)

^{200}Tl, ^{202}Tl in ^{201}Tl — " —

$^{114}In^{m}$ in ^{111}In

TABLE 3

Standards for BP radiopharmaceuticals

Preparation	Radioactivity Limits	Radionuclidic purity	Radiochemical purity	Details of method
Iodinated [^{125}I] Albumin injection	85.0 to 115.0%	nmt 1% ^{126}I	nlt 95% HSA	ep on paper at [illegible]00V for 60 min using barbitone + acetate + octanoate + HCl buffer
Chromium [^{51}Cr] Edetate injection	90.0 to 110.0%	gamma spectrum same as std ^{51}Cr	nlt 95% Cr edetate	ep on paper at 30V/cm for 30 min using barbitone + nitrate buffer
Cyanocobalamin [^{57}Co] solution	85.0 to 115.0%	nmt 1% ^{60}Co and other nuclides	nlt 90% activity in the material purified by column and paper chromatography	cc on carboxymethylcellulose with water, extract with CCl_4 + o-cresol, then ppt with Me_2CO, dissolve in water, then pc in with butanol:acetic acid:water, elute and assay
Cyanocobalamin [^{58}Co] Solution	90.0 to 110.0%	nmt 1% ^{60}Co and other nuclides	nlt 90% activity in the material purified by column and paper chromatography	as above
Ferric Citrate [^{59}Fe] Solution	90.0 to 110.0%	gamma spectrum same as std ^{59}Fe	no test specified	complies with limit test for iron
Gallium [^{67}Ga] Citrate injection	90.0 to 110.0%	nmt 0.2% ^{66}Ga	no test specified	limit test for Zinc (5 ppm)
Colloidal Gold [^{198}Au] injection	90.0 to 110.0%	gamma spectrum same as ^{198}Au except that up to 10% ^{199}Au may be present	nlt 98% colloidal Au	ascending pc using acetone:water:HCl (70:20:10); colloidal Au stays at origin $R_f = 0$; soluble Au moves to sf and visualised by Sn(II) iodide spray
L-Selenomethionine [^{75}Se] injection	90.0 to 110.0%	gamma spectrum same as std ^{75}Se	nlt 90% in the principal spot	descending pc using butanol:water:glacial acetic acid (60:25:15); add L-methionine as carrier
Sodium chromate [^{51}Cr] Sterile solution	90.0 to 110.0%	gamma spectrum same as std ^{51}Cr	nlt 90%	ascending pc using water:ethanol:10M ammonia (125:50:25) for 2.5 hr. Cr(III) ions remain at origin

Sodium iodide [^{131}I] Solution	90.0 to 110.0%	gamma spectrum same as std ^{131}I specific activity nlt 185Gnq/mg I^-	nlt 95% as iodide with R_f within 5% of std spot	ascending pc using methanol:water (75:25) and stds of 1% I^- and 2% IO_3^- for 2 hrs; stds visualised;
Sodium iodohippurate [^{131}I] Injection	90.0 to 110.0%	gamma spectrum same as std ^{131}I	nlt 96% as 2-iodohippuric acid nmt 2% as 2-iodobenzoic acid and/or iodide	tlc on silica gel GF254 using toluene:butanol:glacial acetic acid:water (80:20:4:1) for 75 min or 12 cm and stds of 2-iodohippuric acids and a mixture of 2-iodobenzoic
Sodium pertechnetate [^{99m}Tc] injection (fission)	90.0 to 110.0%	^{99}Mo nmt 1×10^{-1}% ^{131}I nmt 5×10^{-3}% ^{103}Ru nmt 5×10^{-3}% ^{89}Sr nmt 6×10^{-5}% ^{90}Sr nmt 6×10^{-6}% alpha emitters nmt 1×10^{-7}%	nlt 95%	descending pc using methanol:water (80:20) for 2 hrs. TcO_4^- has R_f about 0.6
Sodium pertechnetate [^{99m}Tc] Injection (non-fission)	90.0 to 110.0%	^{99}Mo nmt 0.1% nmt 0.01% other radionuclides	nlt 95%	descending pc as above
Sodium phosphate [^{32}P] Injection	90.0 to 110.0%	beta spectrum same as standard ^{32}P solution	nlt 95% nmt 0.0033% PO_4^- per 37MBq	ascending pc using propanol:water: (75:25) with trichloracetic acid and ammonia for 16 hrs and stds of H_3PO_4
Technetium [^{99m}Tc] colloidal antimony sulphide injection	90.0 to 110.0%	as for Na $^{99m}TcO_4^-$	nlt 95%	Itlc on silica gel using 0.9% NaCl over 10–15 cm in 10 min. Plate heated at 110° for 10 min before use.
Technetium [^{99m}Tc] colloidal sulphur injection	90.0 to 110.0%	as for Na $^{99m}TcO_4^-$	nlt 92%	10–15 cm, colloid remains at origin TcO_4^- $R_f = 0.6$, other spots at $R_f = 0.8$–0.9

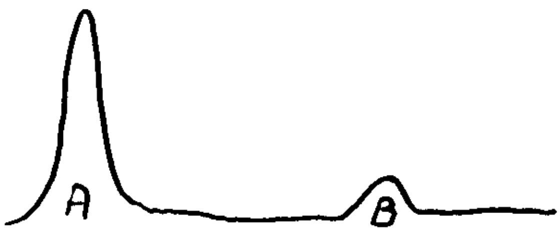
Note: nmt = not more than; nlt = not less than.

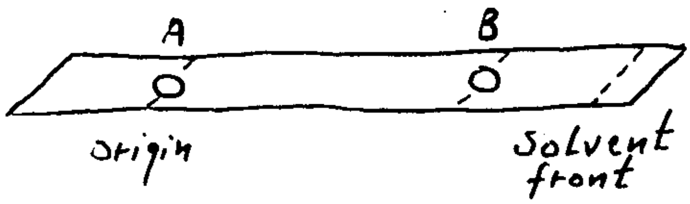
$^{99}Tc^{m}$ pharmaceuticals — pertechnetate, colloidal Tc

^{131}I —"— iodide

Thin-layer and paper chromatography

silica gel on glass





acetone
H_2O
0,9% NaCl

A Rf = 0

B Rf = 0,7

Column Chromatography

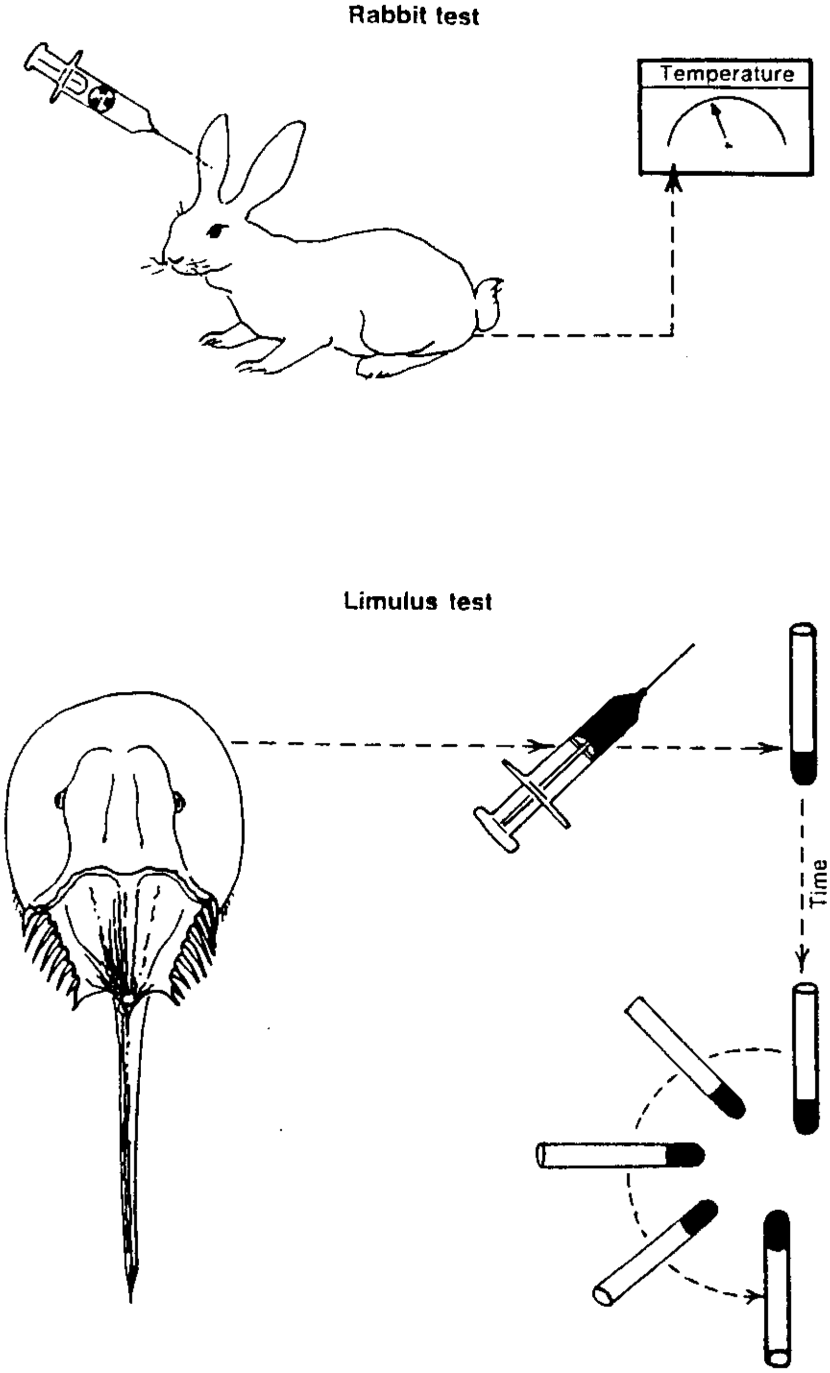


Fig. 5-7. Pyrogen testing employs either rabbits or amoebocytes obtained from blood of horseshoe crab. In first test, end point is rise in body temperature. In second test, end point is gelation of lysate of amoebocytes.