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TITLE

Quality control of dosimetry in total body irradiation.

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QUALITY CONTROL OF DOSIMETRY IN TOTAL BODY IRRADIATION

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Vienna
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S U M M A R Y:

38 consentive cases have undergone TBI (total body irradiation) in hospital Lainz within the last 2 years. No pneumonitis causing death of the patient has been seen in these patients anymore after introducing Quality Control. In contrary to the first 8 patients before this time the incidence of pneumonitis was 37,5 percent.
Thus it is stressed that Quality Control is a strong aid for the medical doctors in struggling against leukemia.

Contents :

1. I N T R O D U C T I O N

Experience in the field of TBI / BMT (Total Body Irradiation / Bone Marrow Transplantation) shows that dosimetric considerations play an important role if succesful therapy is desired (Glasgow 1982). These ideas include exact treatment planning. The most important points that influence the radiation field are:

- .) irradiation geometry
- .) geometry of the patient
- .) dose rate
- .) absolute dose inside the patient
- .) total absorbed dose
- .) dose inhomogenity inside the patient
- .) lung dose
- .) density of the various organs

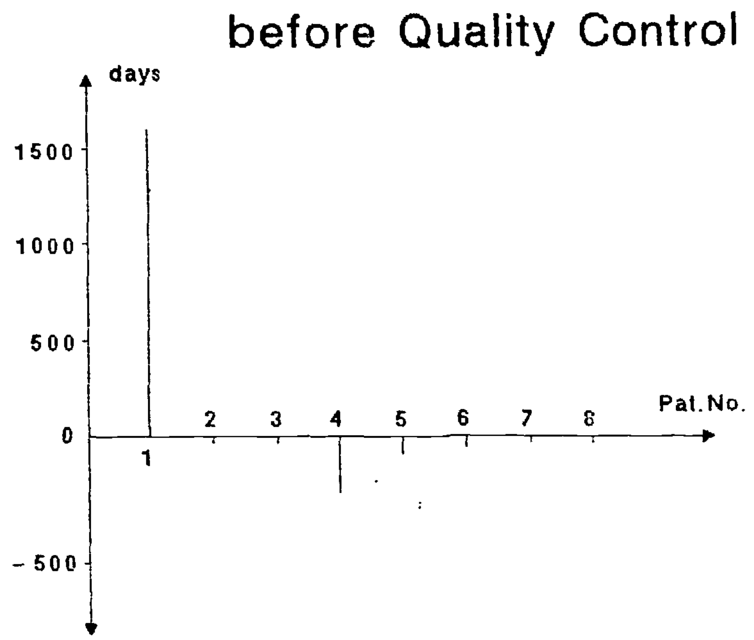
The planning procedure and the dose measurements inside a phantom as well as on the patient during irradiation do have to include all these parameters (Aget 1982 , Kallinger 1984). It was shown that doserate and dose - especially inside the lungs - do influence the percentage of early mortality very strongly. Thus the aim of the irradiation is to get a homogenous dose distribution all over the body and not to exceed dose limits at the critical organs. It should also be stated that these limits are not quite clear until now.

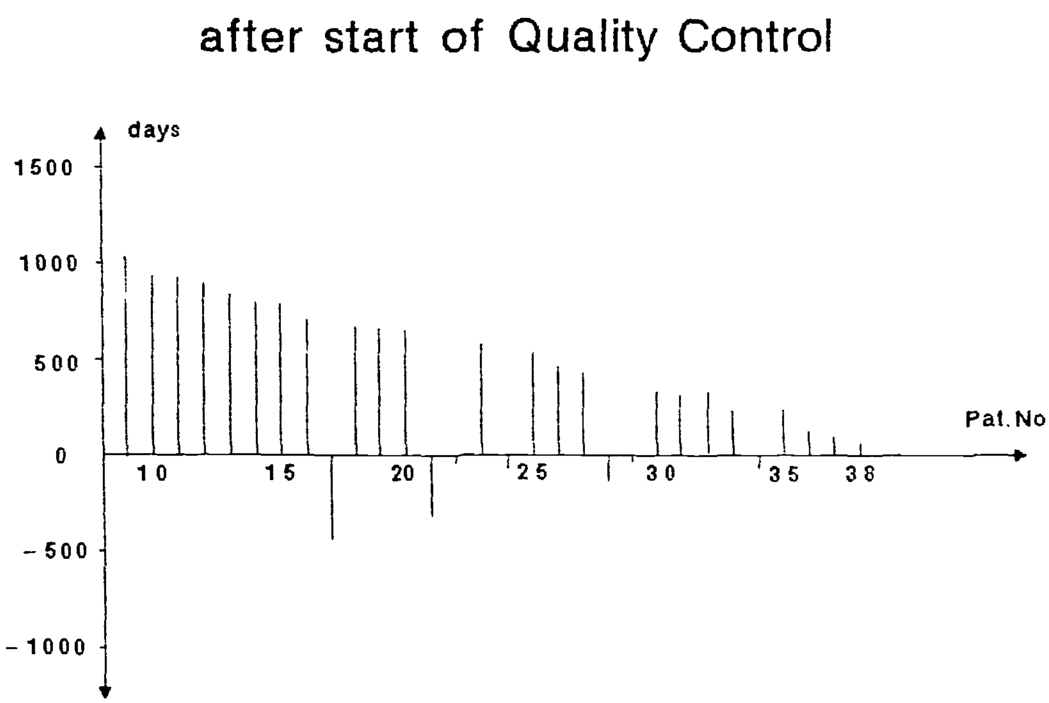
S H O U L D E R S

It can be shown that different planning procedures may lead to 10% difference in lung dosage (V. Dyk 1980). The warming up of ionisationchambers during irradiation from room temperature to body temperature may lead to a systematic error of 4%. Bearing in mind the risk for lung damage as it depends on the applied dose these figures show that a strong quality control should be included in the irradiation procedure. Since we have included all these parameters into the irradiation schedule the results have changed drastically and are shown in fig. 1.

In 30 consecutive cases of Quality Control we do not see Pneumonitis as cause of death any more. This is due to our Quality Control System.

Fig.1 : death and alive days per 30.06.1986





pos. days.....Days on which patient is alive

neg. days.....Days on which patient died

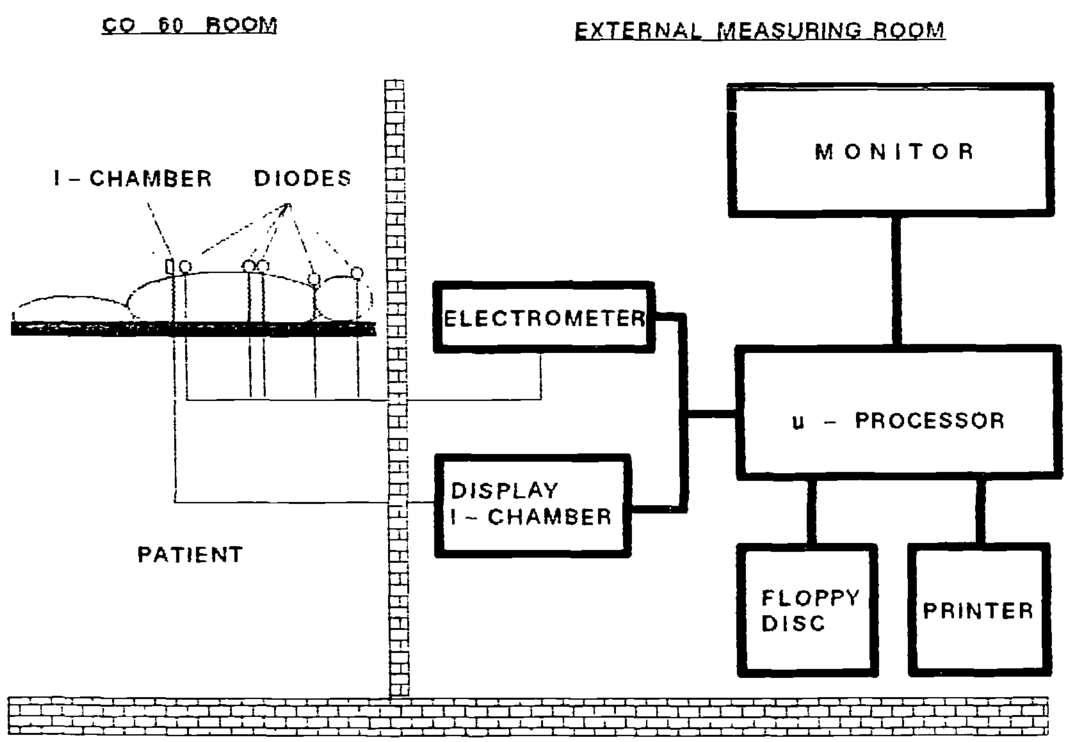
2. O N L I N E M E A S U R I N G D E V I C E

Experimental setup:

The complete measuring device is designed to compare the calculated skin doses with the actual delivered ones during irradiation, and to stop irradiation if a certain limit is reached.

The diagram below shows the arrangement of sensors on the patients surface and the connection to the microprocessor that is giving the actual dose value at any time of irradiation.

Block diagram



Construction of shielding :

Calibration on treatment day :

The diodes and the I-Chamber are positioned on the ground floor in a fixed distance and irradiated for 2 minutes. This procedure is repeated 5 times the stability of the reading is shown in the following table.

Calibration of diodes

	Diode					I-Chamber
No	1	2	3	4	5	
reading	32	33	32	34	31	29.4
"	32	34	32	34	31	29.4
"	31	33	32	34	31	29.3
"	32	33	32	35	31	29.4
"	32	33	32	34	31	29.4

The actual situation in our treatment room is shown with the help of a phantom in Fig. 2

The electrometers and the microprocessor system with the display and floppy disks are shown in Fig. 3

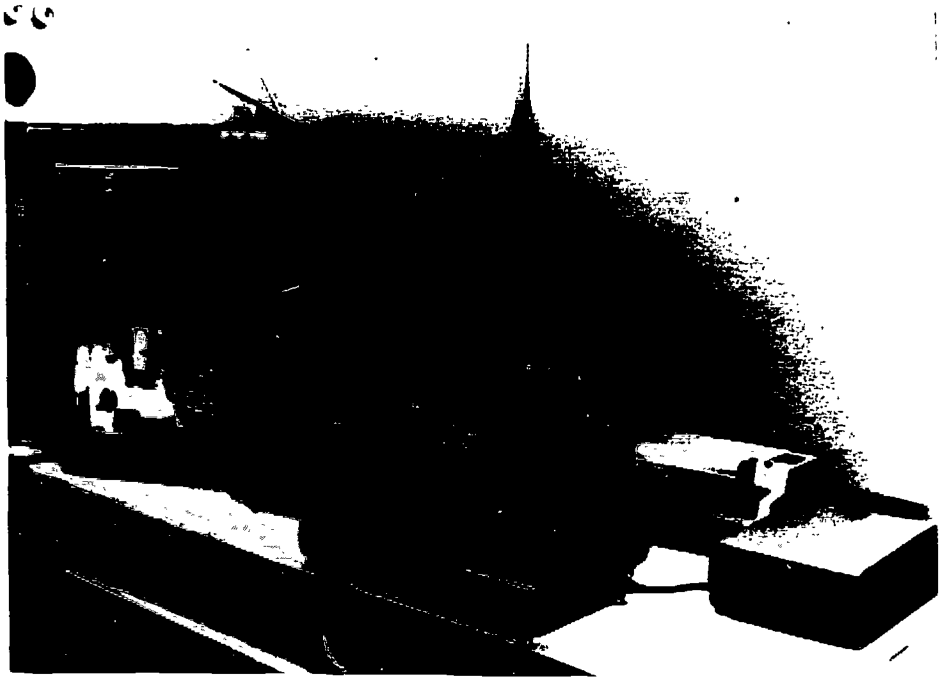
The dose displayed on the I-chamber - corrected for temperature and pressure - is used to evaluate the calibration factors for each diode individually as shown in the following table.

Calibration factors of diodes

diode no.	factor
1	.919
2	.891
3	.919
4	.865
5	.948

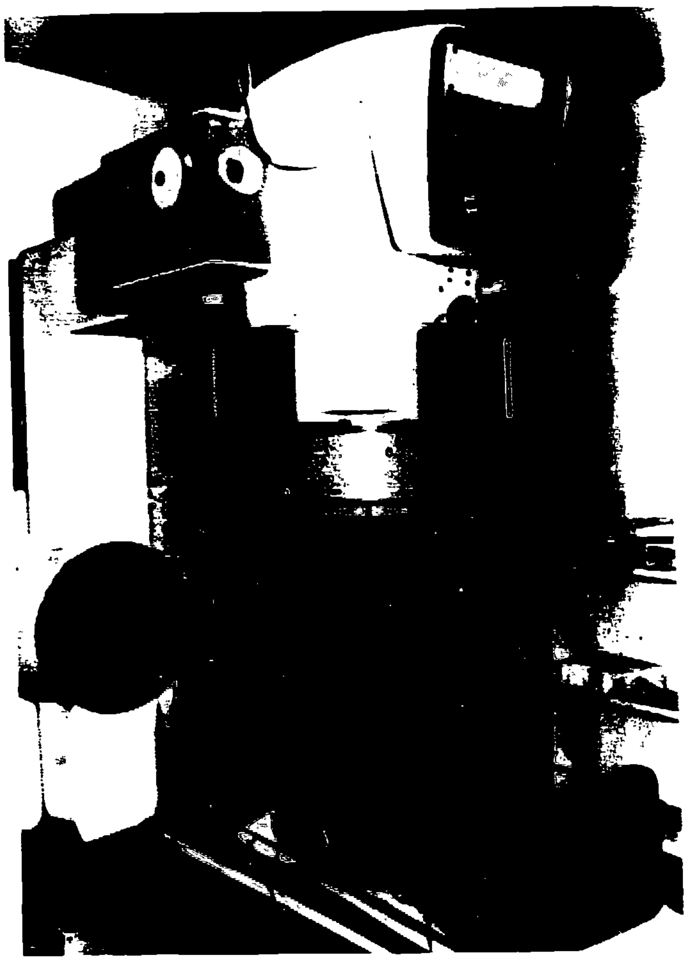
5. PROTOCOL OF TBI

Fig.2 : Electrometers and u-processor with disks, printer



6. Steps requiring Quality Control in TBI

Fig.3 : Electrometers and Aldersen phantom with sensors



3. S O F T W A R E

The software was designed such that it is now possible to have online connection of different sensors with a microprocessor and to display the corrected dose values at any time of TBI.

Thus the possibilities of the program are:

- .) storage of patient data on disk
- .) display of corrected and calibrated dosevalues
- .) control of dose rate
- .) measurement of the transmission of the shieldings
- .) statusprintout at any time of treatment
- .) stop the irradiation if a predefined doserate is exceeded
- .) stop the irradiation if a predefined dose is exceeded

The two last points are realised with the help of a relais in direct connection with the microprocessor.

7. R E S U L T S

4. DOSIMETRY AND PLANNING PROCEDURE

The field data in the right treatment distance are measured inside a water phantom. These data are then stored on a PDP 11/60 Computer and used for the calculation of isodoses and treatment times. An inhomogenity correction is done with the help of CT-data. So the individual density of each patient can be used in the calculation of the optimal treatment procedure.

The use of Hounsfield units for assessment of individual density is shown in the Fig. 4 below. In order to get accurate values, a gauge procedure has to be performend on the day the scan is done.

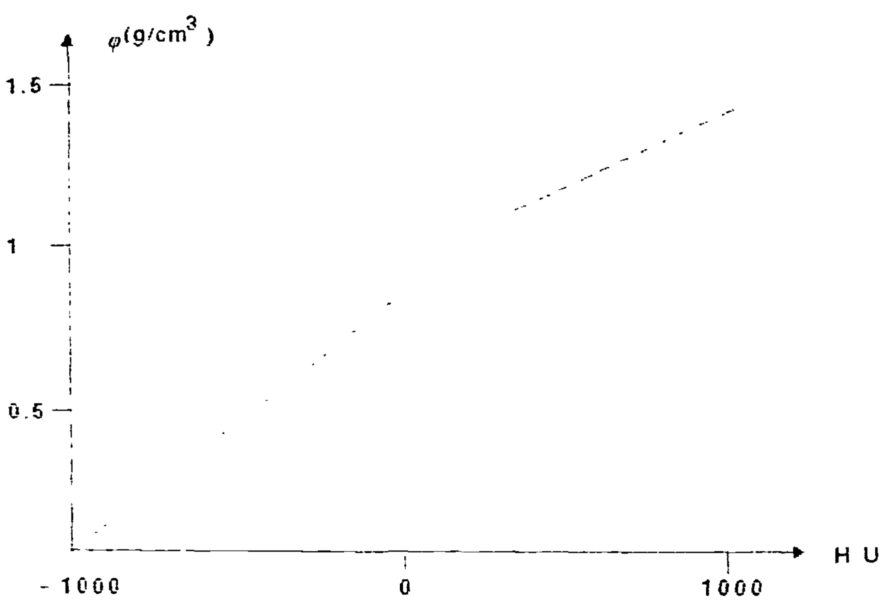


Fig. 4 : Relation between Hounsfield units and specific weight

The correction for the individual inhomogenities is simply given by the relation between the specific weight inside an organ and the specific weight of water.

$$f\ (i) = 1 - \varphi(i)\ /\ \rho(H_2O)$$

f (i) .... dose modifying factor for tissue type i

φ (i) .... specific weight of tissue type i

ρ (H_2O) ...... specific weight of water

Using this procedure it is possible, to calculate the isodose distribution inside the patient such, that the individual specific weight - as it influences the radiation field - of the lungs and other organs is included in the calculation. The results are shown in appendix 1.

9. References:

Dose Rate :

At the beginning of TBI in our institute , dose rate was considered as an average value for the complete period of treatment including breaks due to the positioning of the patient or other facts like vomiting. The actual doserate during the time when radiation was on , has been found to be between 11 and 22 cGy/min on the patient's surface. The distribution of doserate inside the patient is given in Fig.5

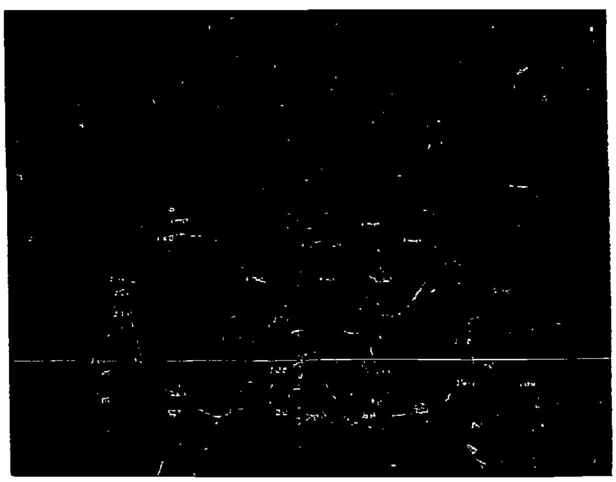


Fig. 5 : Dose rate inside the body during irradiation with frontal field

M. M. Bortin et al. (1983) have now given a clear hint , that the dose rate is an extremely important factor concerning early mortality. Therefore it was decided to consider dose rate only during the time when radiation was turned on, disregarding breaks.

Fig. 7 : TOTAL AREA AND LUNG AREA

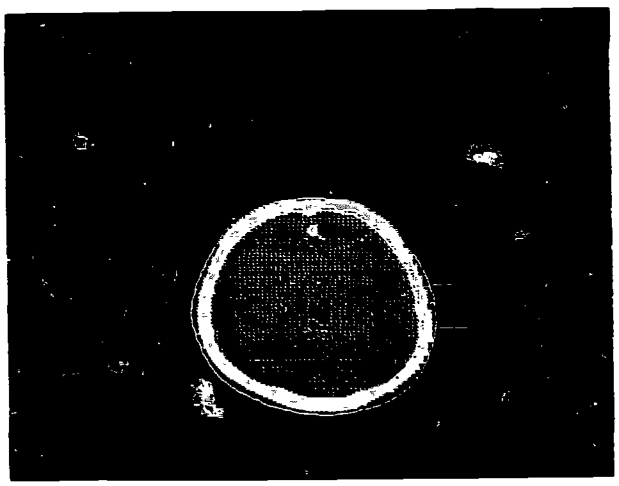
For this reason a lead filter was built. The resulting dose-rate is now lowered to 4 cGy/min on the surface of the patient.

In this connection it may be worthwile to note , that in the case of TBI with LINAC's the question of doserate is much more difficult to handle , as any LINAC will produce pulsed radiation. During the time of one pulse of the LINAC the doserate will be 50 times higher than the average value which is measured by the instruments. Maybe that this disadvantage of the LINAC is biologically significant.

Fig. 8 : RELATION BETWEEN LUNG AND TOTAL AREA

CT-SCANS, CONTOUR PLOTS AND RESULTING ISODOSE DISTRIBUTION

H E A D



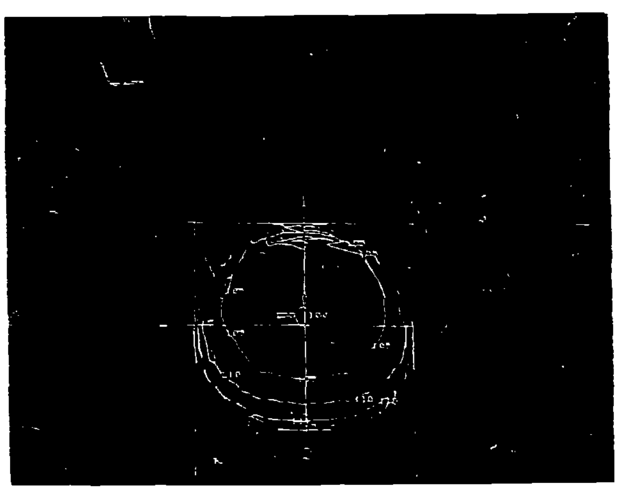
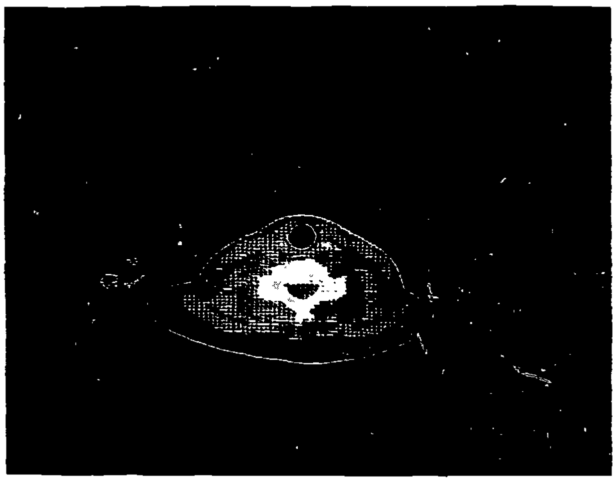


Fig. 9 : DOSE INSIDE LUNG LEFT WITHOUT SHIELDING

N E C K



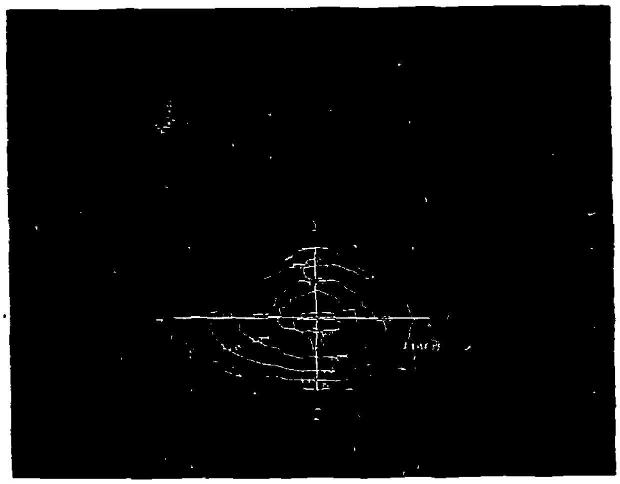
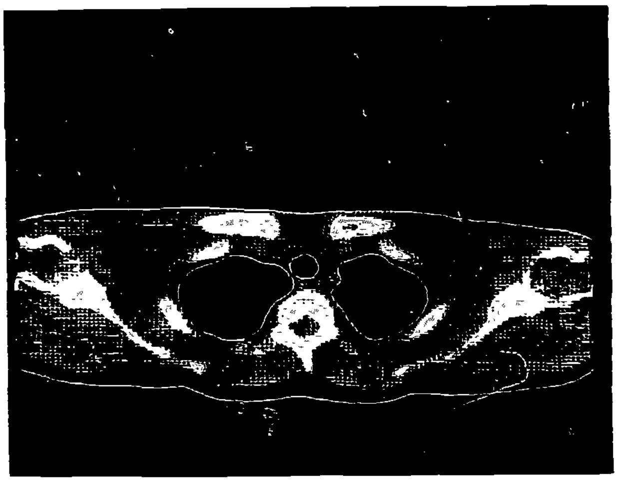


Fig. 10 : DOSE INSIDE LUNG RIGHT WITHOUT SHIELDING

S H O U L D E R S



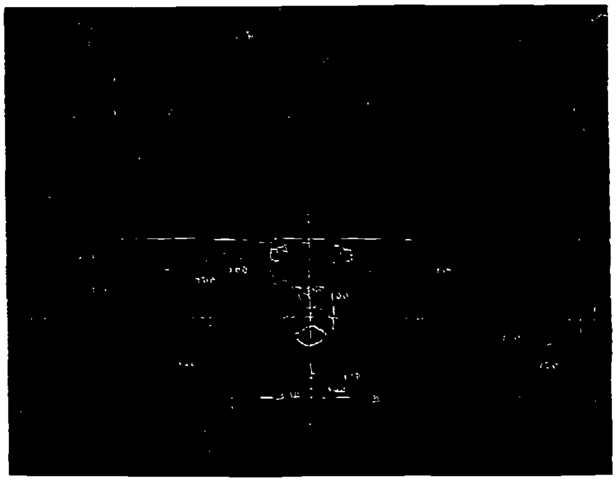


Fig. 11 : DOSE INSIDE LUNG WITH SHIELDING

L U N G S

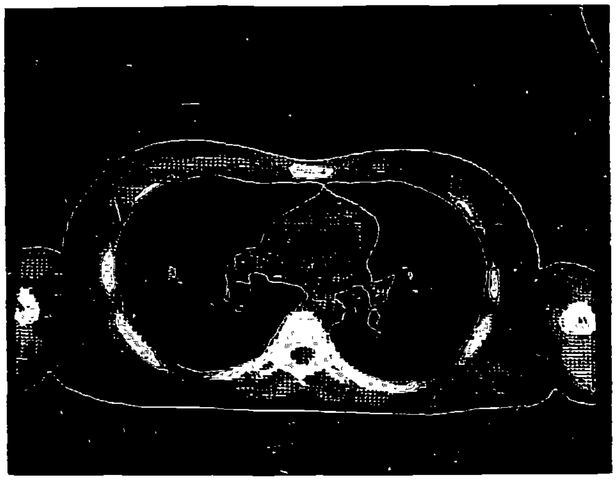
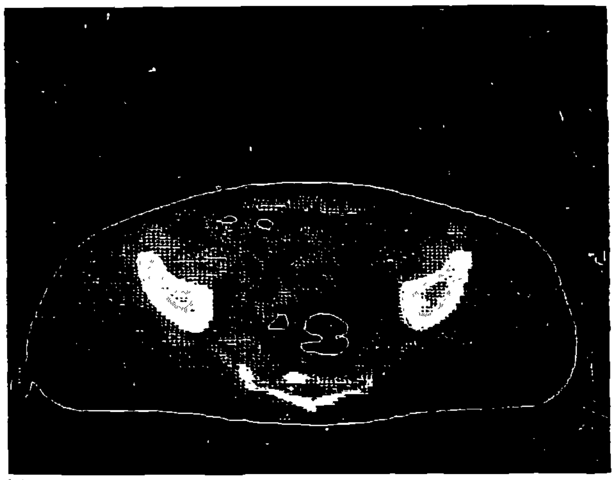


Fig. 12 : CENTRAL AXIS DOSE HEAD, NECK AND LUNG

ABDOMEN



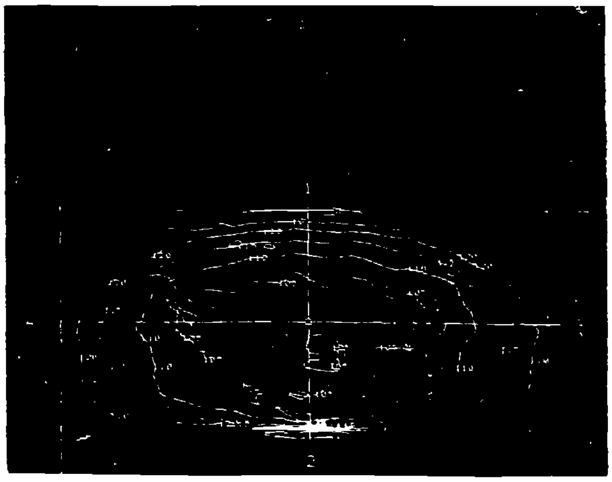


Fig. 13 : CENTRAL AXIS DOSE HEAD, NECK AND LUNG

Construction of shielding :

The dose inside the lungs is exceeding 8 Gy. Therefore lung - shields are constructed. Again we use CT - information to derive the original shape of the lungs as shown in Fig. 6

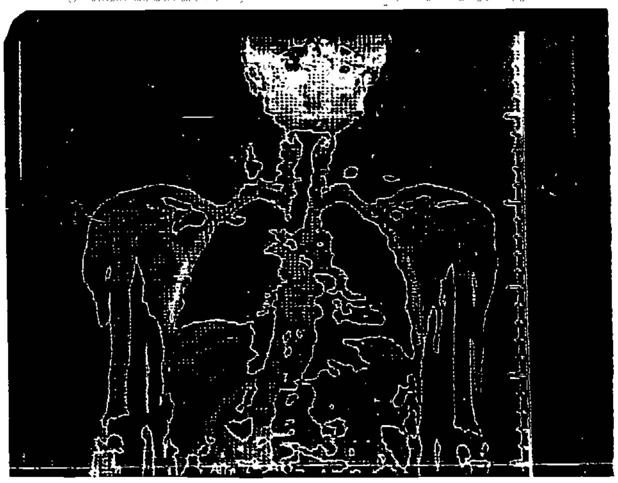


Fig. 6 : CT-Tomoscan of the lungs in maximum inspiration

Fig. 14 : MAXIMAL DOSE INSIDE HEAD, NECK AND LUNG

5. PROTOCOL OF TBI

As the protocols of the International Bone Marrow Registry (IBMR) are very rough , as far as TBI is concerned we would like to extend those data by the following:

- Dose rate at surface of body (during radiation is on)
  - frontal field
  - backside field
  - lateral field
- Total dose
- Number of fractions
- Midplane and maximum dose head
- Midplane and maximum dose neck
- Midplane , maximum and minimum dose lungs
- Mean dose lungs
- Midplane and maximum dose abdomen
- Dose to the ribs
- Treatmentplanning obligatuary
- Inclusion of CT data in planning procedures
- Individual construction of lung shieldings
- On line dose measurement during irradiation
- Accuracy of dose determination in air inside the patient

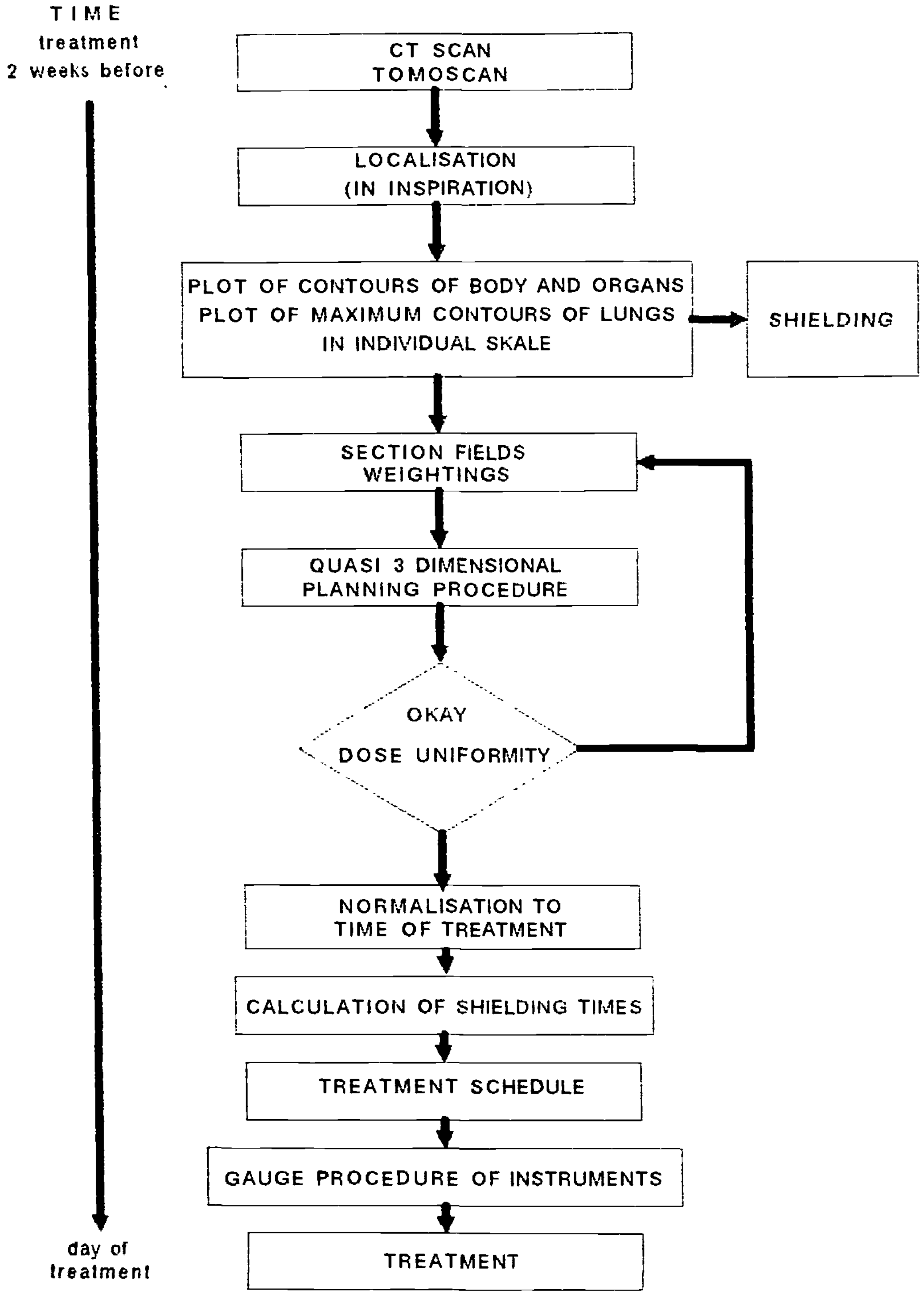
An example of the protocol governing the irradiation in Lainz is given in appendix 2.

6. Steps requiring Quality Control in TBI

In the following flow diagram the total procedure as it is done in our hospital is listed. The time schedule shows that it takes about 2 weeks to complete the protocols such that irradiation may be done safely. It is nearly selfevident that every step requires highest precision which can only be maintained by having Quality Control in this subject.

TOTAL AREA

Flow – Diagramm TBI



LUNG AREA

7. R E S U L T S

The reduction of dose rate was done in Aug. 1983. It resulted in a striking difference in the radiation effects as could be seen especially in mouth , skin and mucosa reactions. The problem of pneumonitis however was still left. Therefore the dose was reduced also to the values used by Barret. The values given by her in the literature (Barret 1983) are not the actual delivered ones , as we had to recognise when we tried to reproduce her data , using our qualitycriteria. However the statistics is not too big , we see dramatic differences in survival and cure (Fig. 1). It is emphasized that we should have an international intercomparison of the full dose distribution inside the patient. Individual dose planning and individual construction of shieldings show enormous differences.

This is mostly due to differences in lung size (Fig. 7,8). In Fig. 9 to Fig. 14 the variation of the dose values in different planes are also listed for all our patients. Fig. 1 shows the dramatic increase of our success after we started " Qualtiy Control " in TBI. We have not seen pneumonitis any more and our medical collegues confess that this is due to the changed physics methods.

It must be stressed that at least for Co 60 machines it is not correct to apply 10 Gy to the leukemia patient and that we should compare the full dosedistribution of the patient.

RELATION BETWEEN

8. Conclusion:

As shown above the authors claim, that dose planning for TBI including shielding must be done individually for every patient. As the protocolls of the International Bone Marrow Transplant Registry (IBMTR) are very rough, as far as the TBI is conserned we would like to extend those dates by the following.

Dose rate at body surface (during radiation on)
frontal field (mGy/min), backside field (mGy/min)
lateral field left (mGy/min), lateral field right (mGy/min)

total dose in...fractions within...days

1. Midplane dose (Gy), head, neck, lungs, abdomen
2. Maximum dose (Gy), head, neck lungs, abdomen
3. Minimum dose (Gy), lungs
4. Mean dose (Gy), lungs
5. Dose to the ribs ...Gy
6. Treatment planning done
   yes no
7. Treatment planning done on CT-basis
   yes no
8. Lung shielding constructed individually
   yes no
9. Dose checked during irradiation
   yes no
10. Accuracy of dose determination
    in free air ....%
    inside the patient ....%
11. Method of calculation of lung dose
    linear attenuation method, effective attenuation method, generalized Batho method, simplified aquivalent TAR, detailed equivalent TAR.

If we reevaluate the dose of as many existing cases as possible with these data we will certainly be able to find the right dose values, which are certainly not given by the steps of 2.00Gy.

9. References:

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W.Kallinger, G.Alth, R.Freund, H.Kolbabek, W.Hinterberger, G.Müller, W.Schmidmeier, J.Klumair, H.Koren
A suggestion to change the TBI protocol of the IBMTR
Phys.-techn.Prüfanstalt für Radiologie und Elektromed.,KH Lainz A-1130 Wien, Sonderabteilung für Strahlentherapie,KH Lainz A-1130 Wien, I.Med. Universitätsklinik,AKH A-1090 Wien ST.Anna Kinderspital,A1090 Wien, und Zentralröntgeninstitut, KH-Lainz A-1130 Wien, Austria

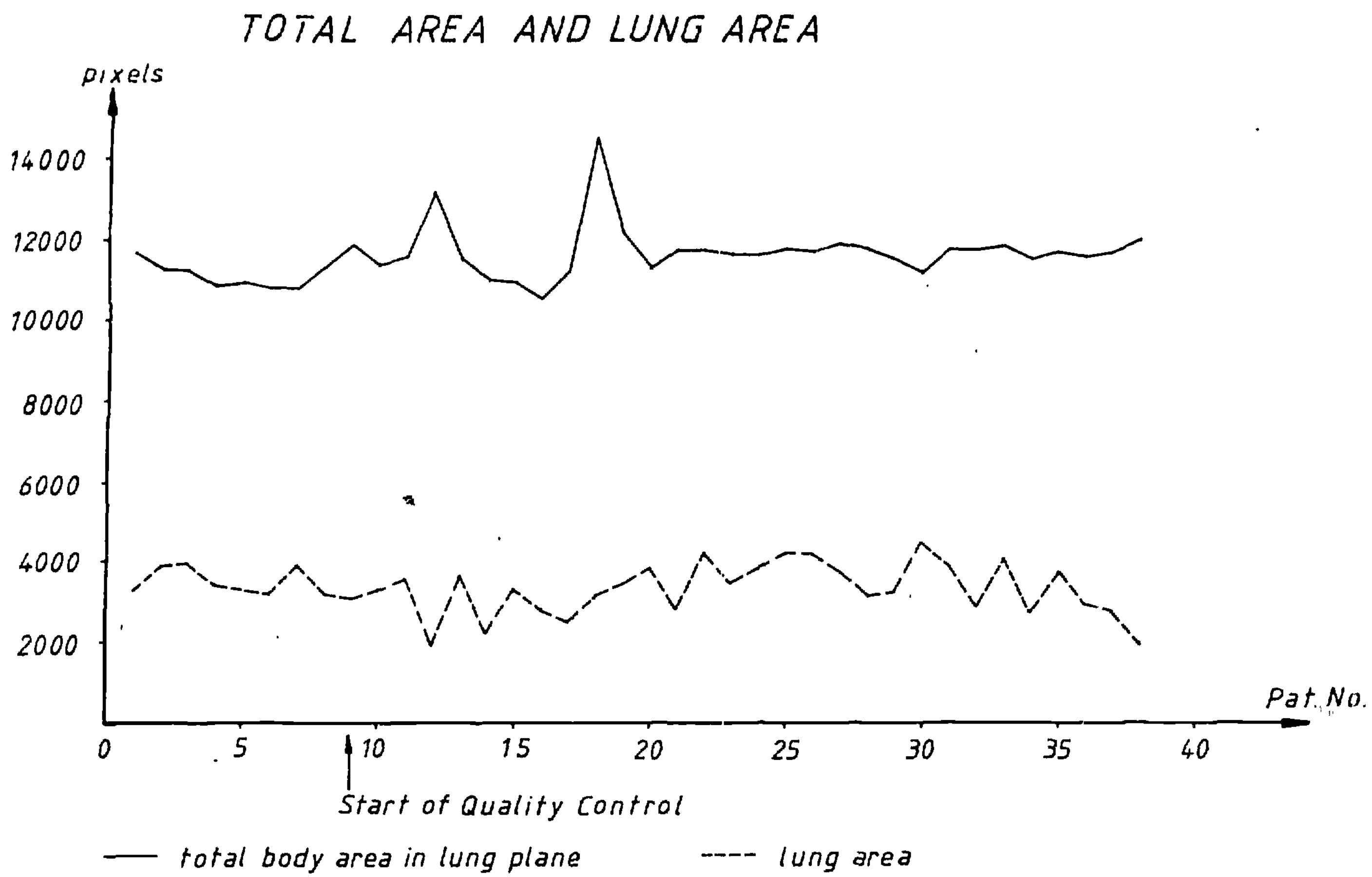


Fig. 7 : TOTAL AREA AND LUNG AREA

RELATION BETWEEN LUNG AND TOTAL AREA

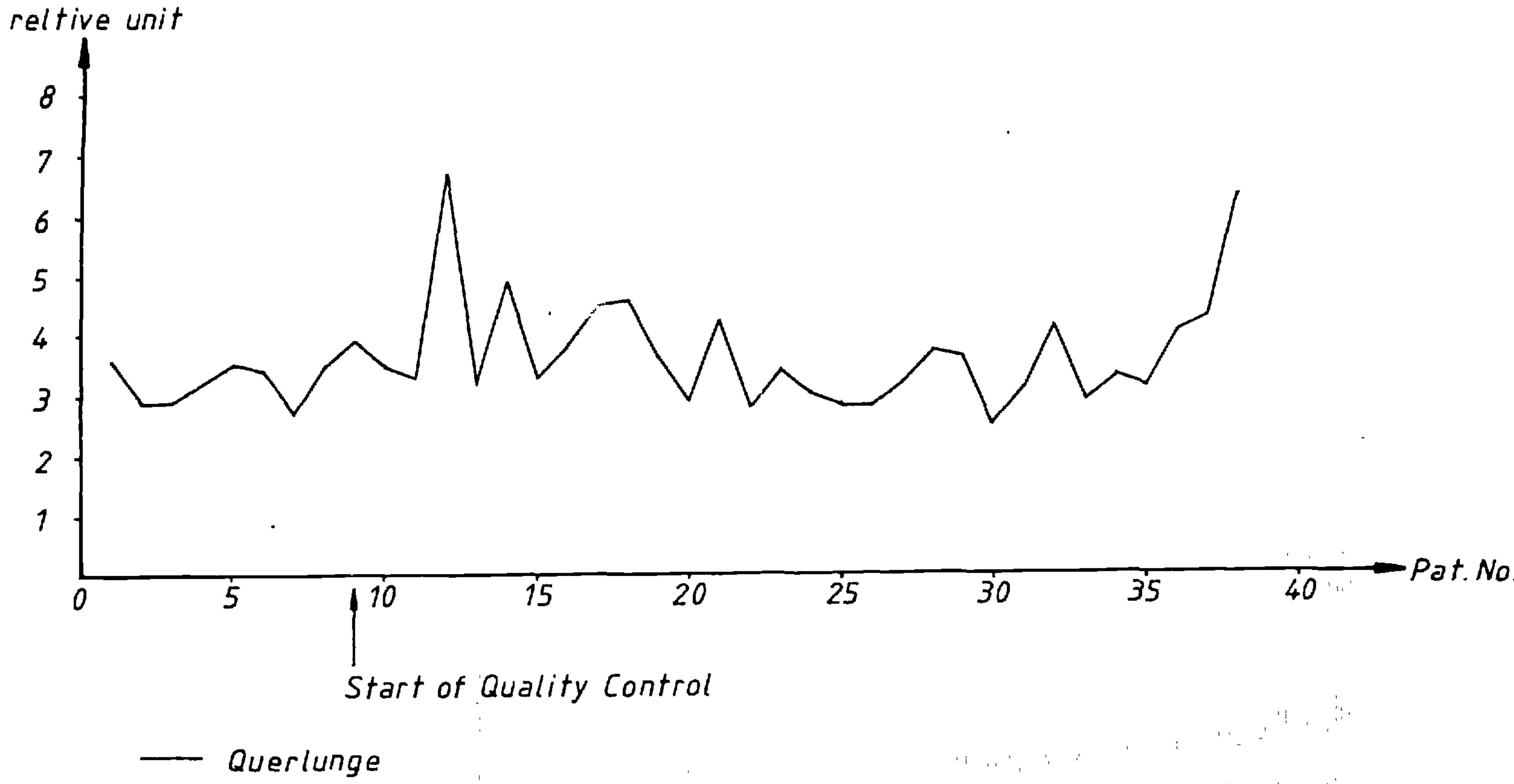


Fig. 8 : RELATION BETWEEN LUNG AND TOTAL AREA

DOSE INSIDE LUNG LEFT WITHOUT SHIELDING

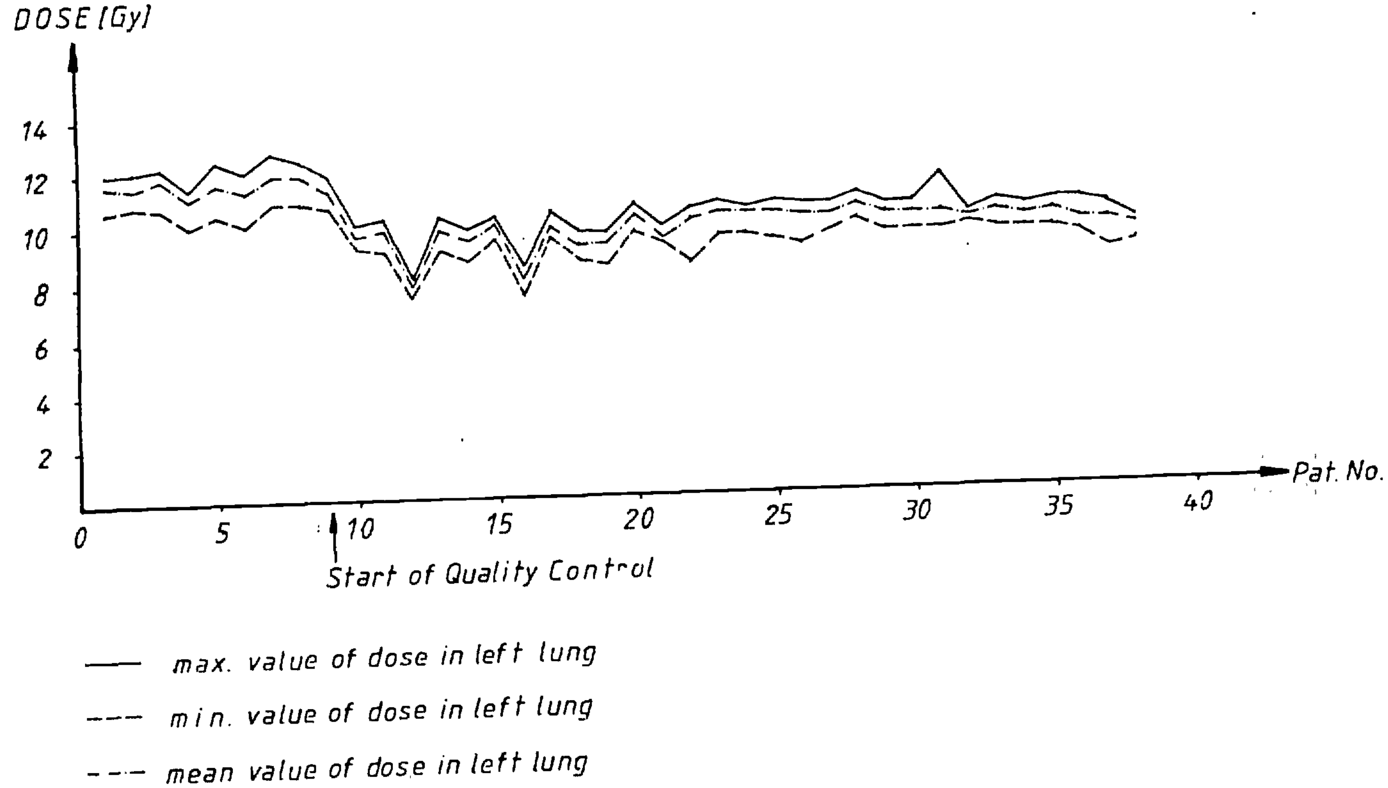


Fig. 9 : DOSE INSIDE LUNG LEFT WITHOUT SHIELDING

DOSE INSIDE LUNG RIGHT WITHOUT SHIELDING

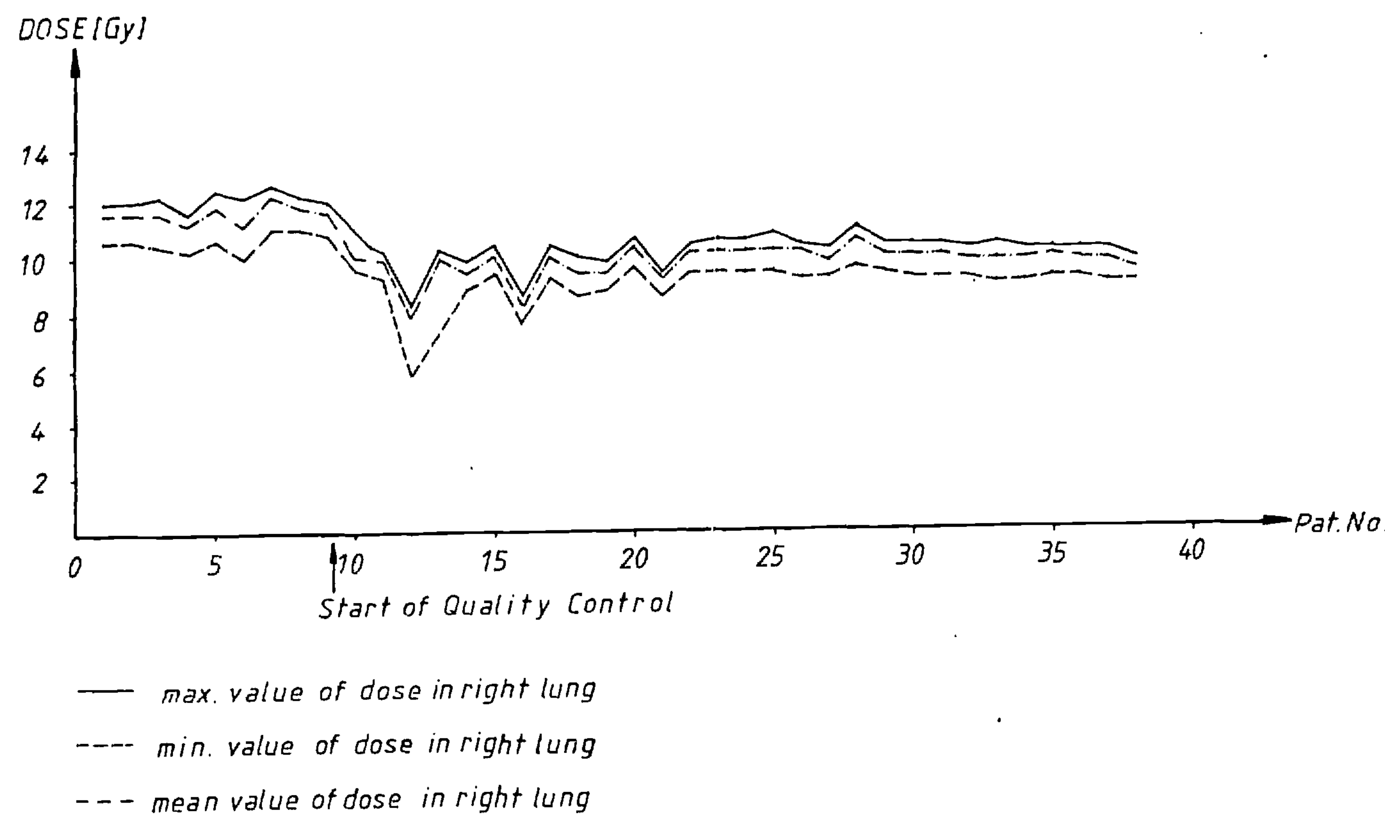


Fig. 10 : DOSE INSIDE LUNG RIGHT WITHOUT SHIELDING

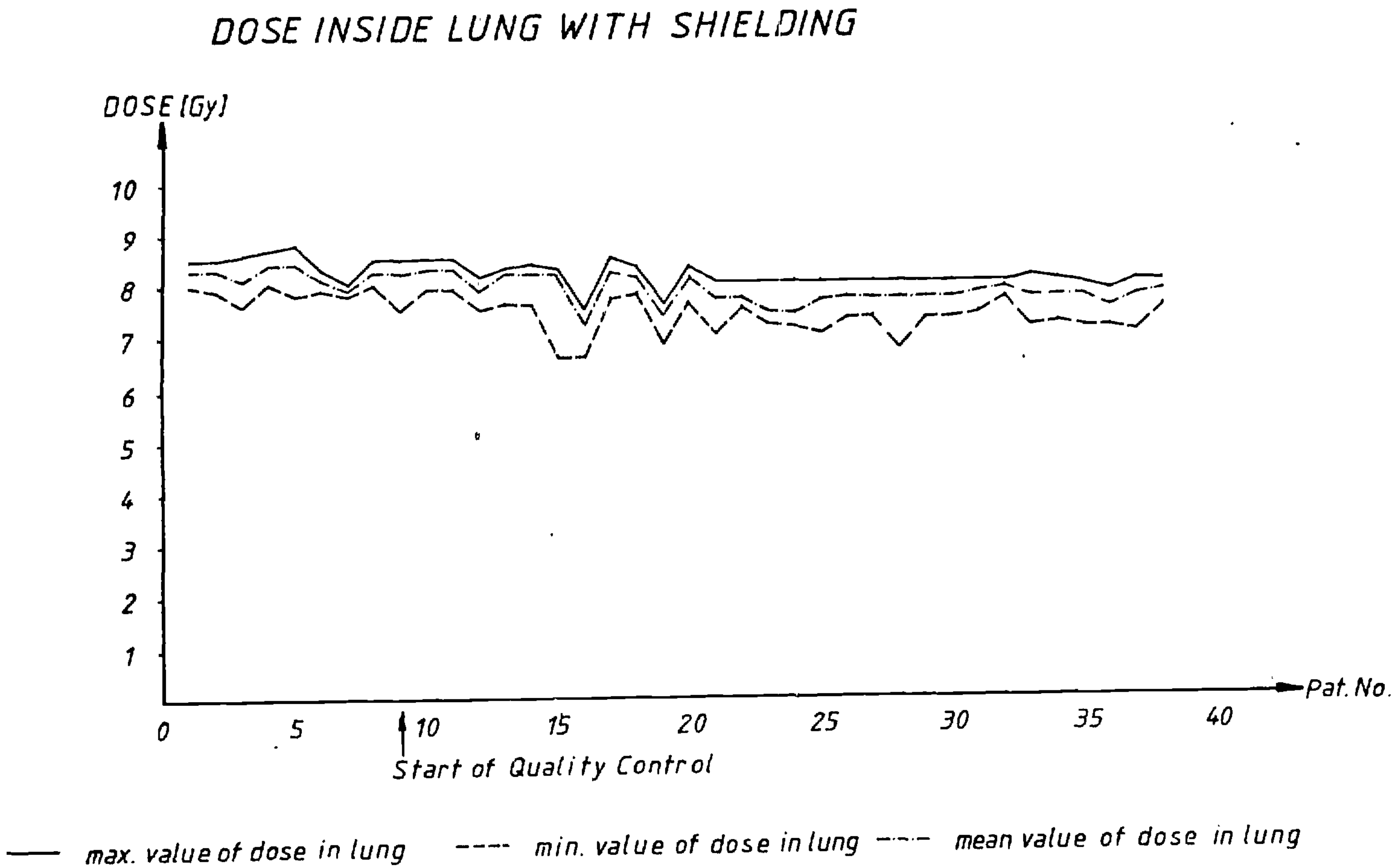


Fig. 11 : DOSE INSIDE LUNG WITH SHIELDING

CENTRAL AXIS DOSE HEAD, NECK AND LUNG

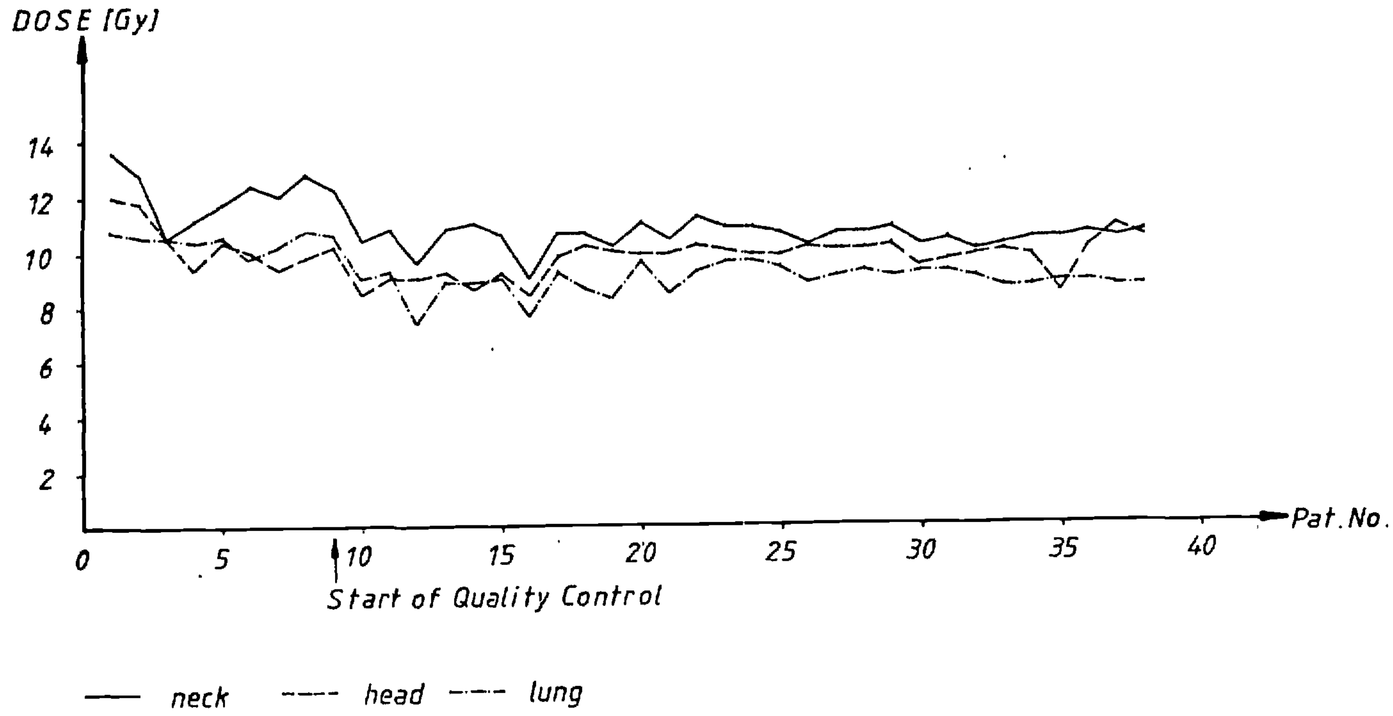
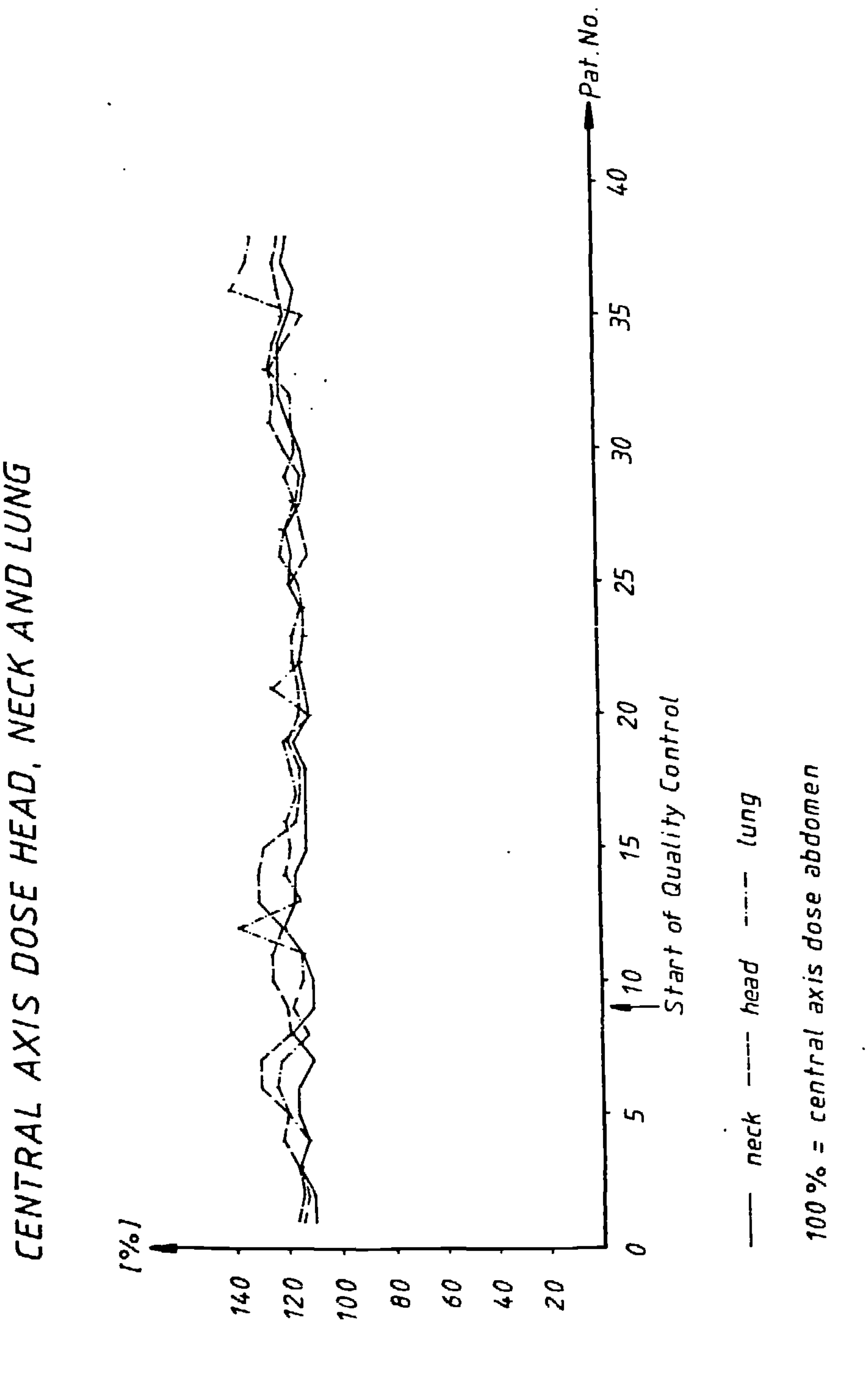


Fig. 12 : CENTRAL AXIS DOSE HEAD, NECK AND LUNG

Fig. 13 : CENTRAL AXIS DOSE HEAD, NECK AND LUNG



MAXIMAL DOSE INSIDE LUNG

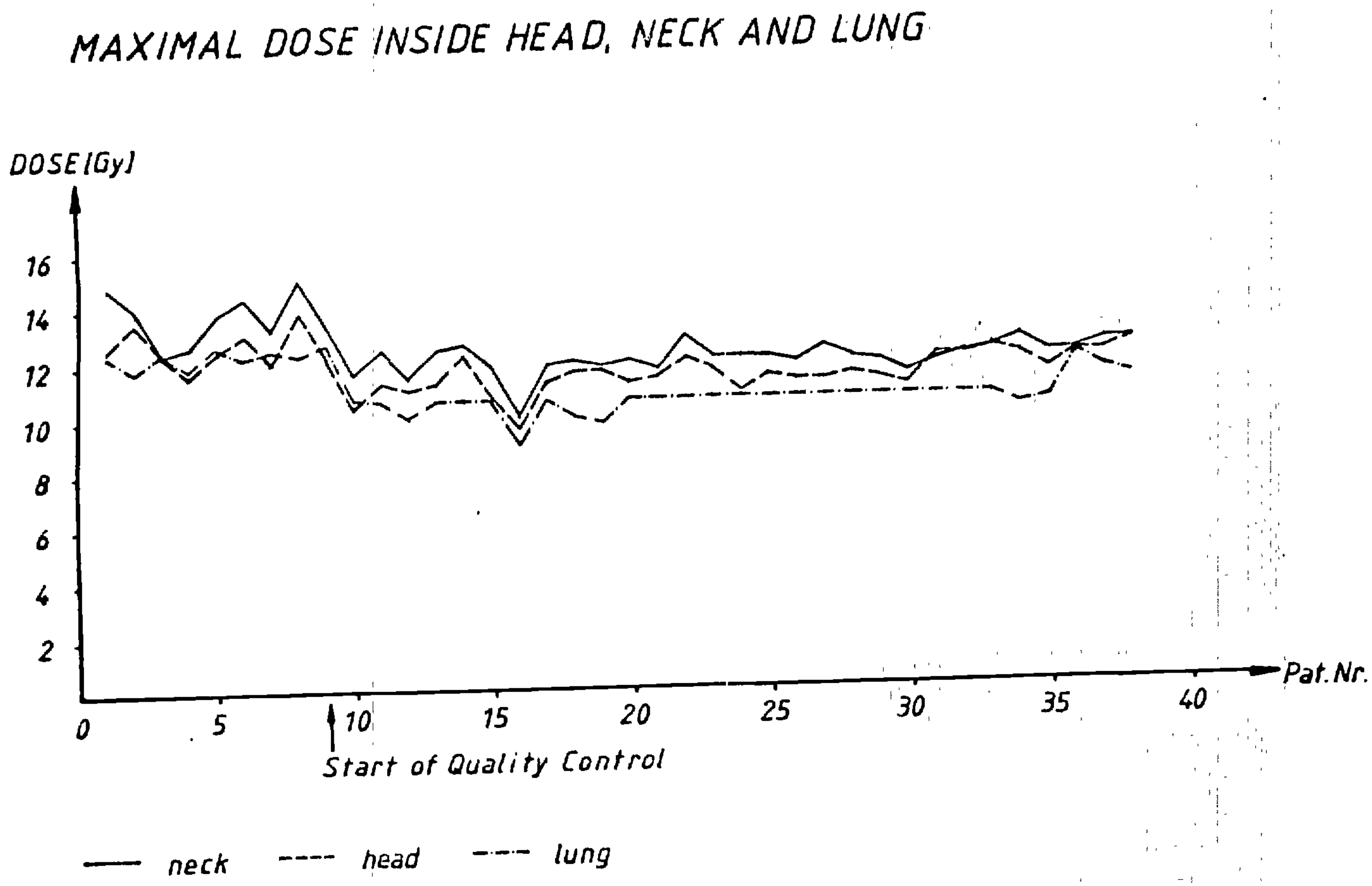
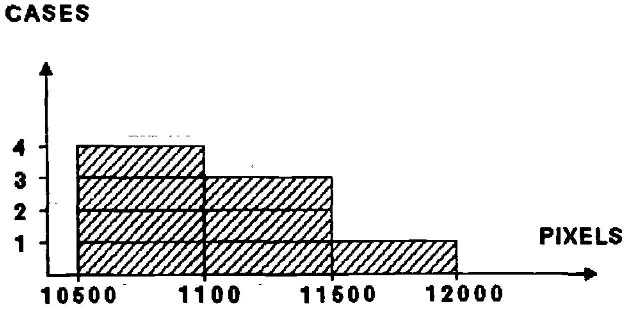


Fig. 14 : MAXIMAL DOSE INSIDE HEAD, NECK AND LUNG

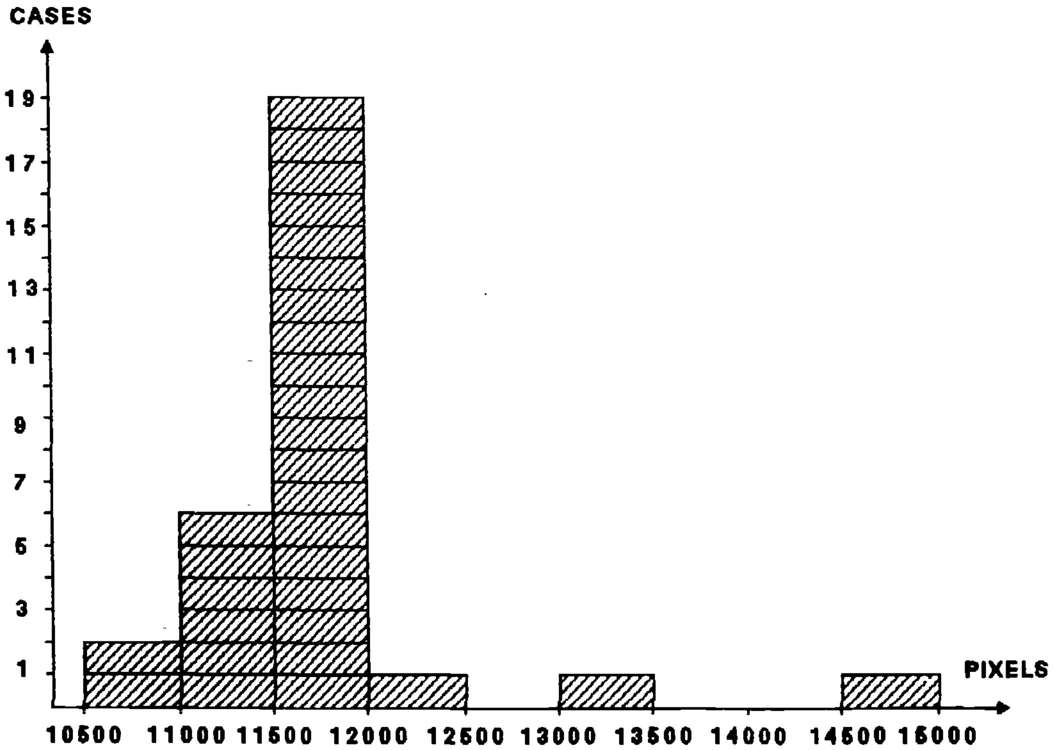
APPENDIX 1

TOTAL AREA

PATIENT 1 TO 8

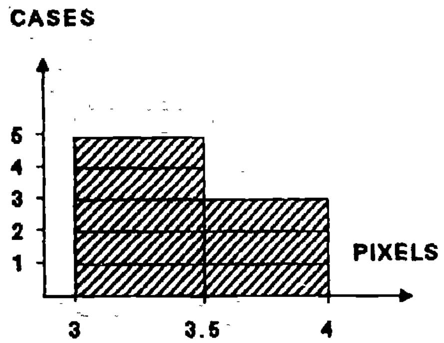


PATIENT 9 TO 38

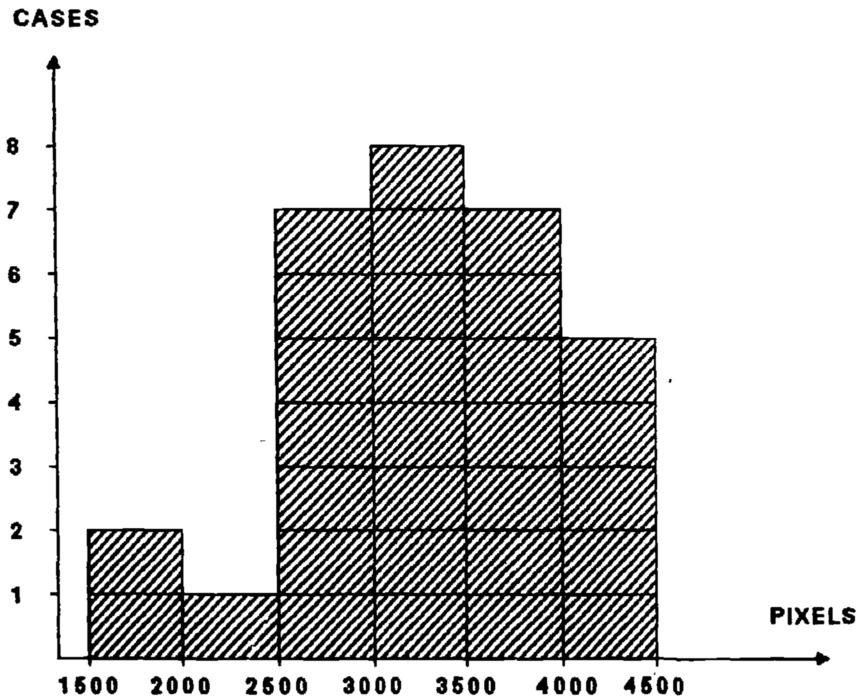


LUNG AREA

PATIENT 1 TO8

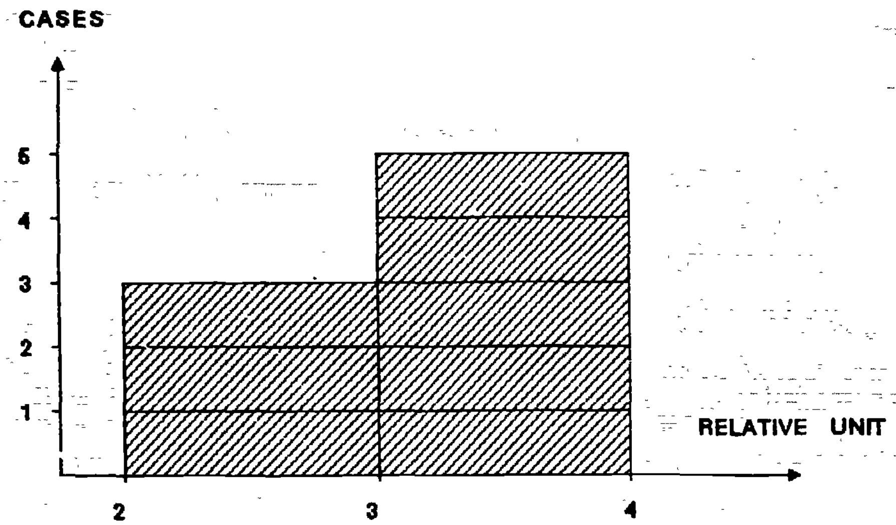


PATIENT 9 TO 38



RELATION BETWEEN LUNG AND TOTAL AREA

PATIENT 1 TO 8



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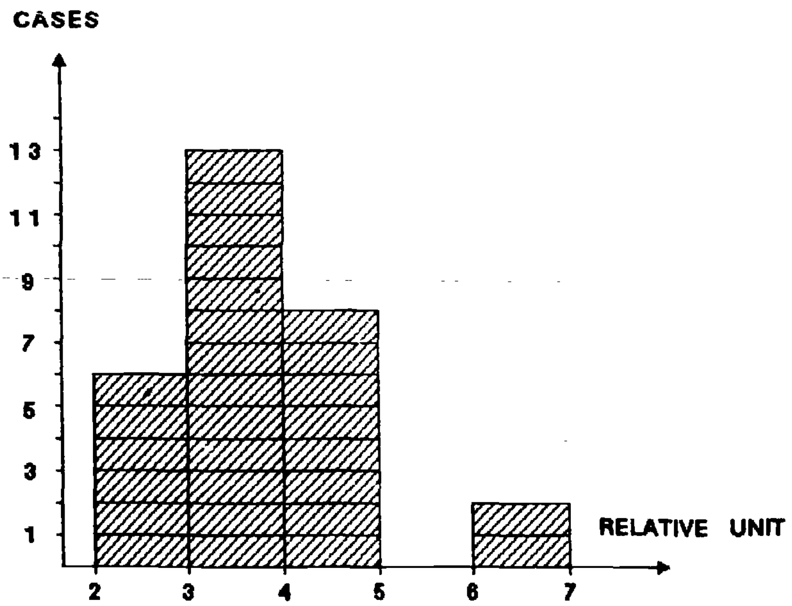
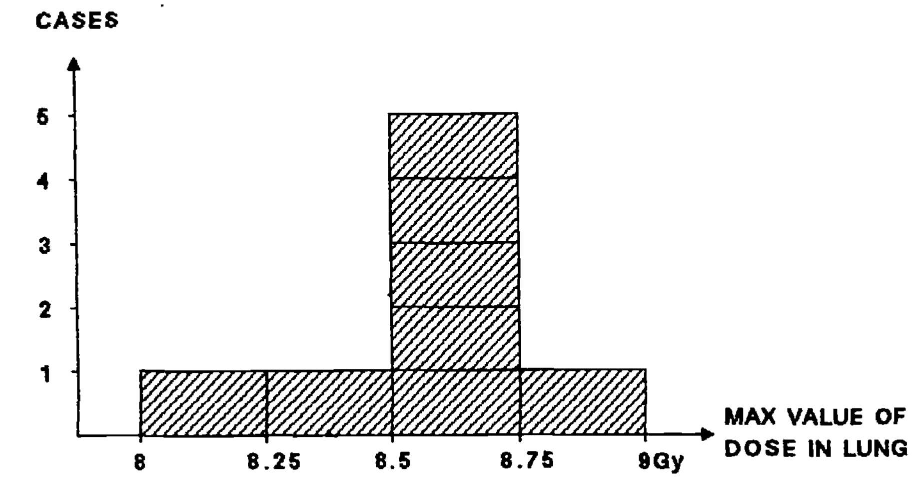


DOSE INSIDE LUNG WITH SHIELDING

PATIENT 1 TO 8



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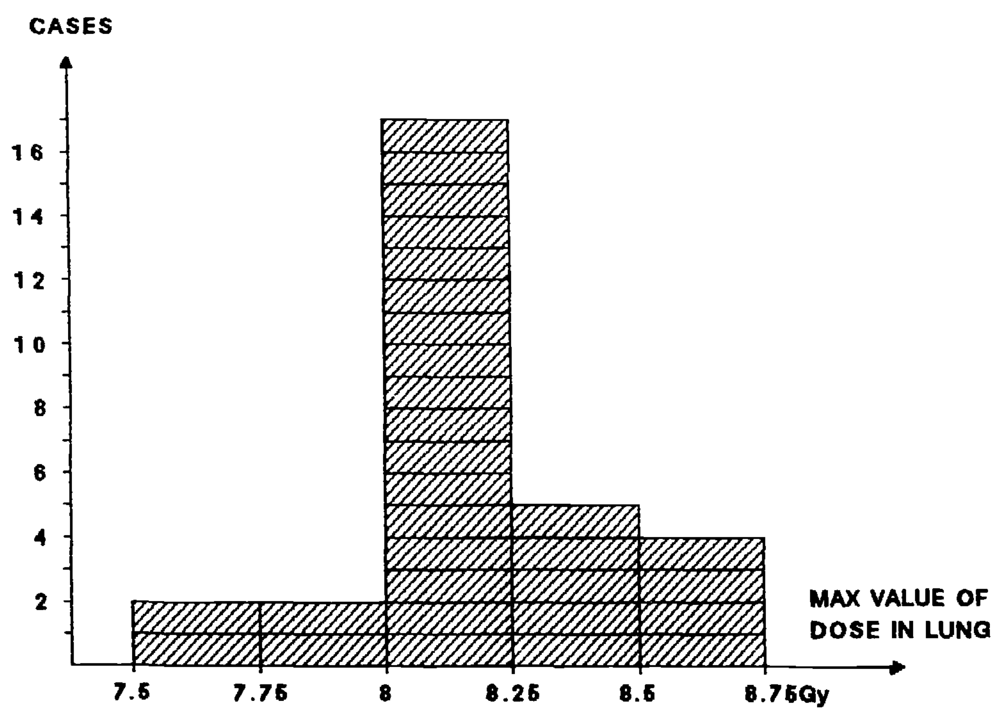
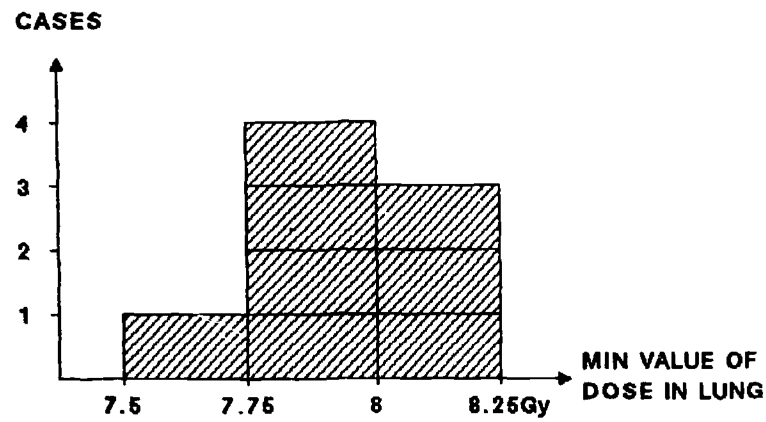
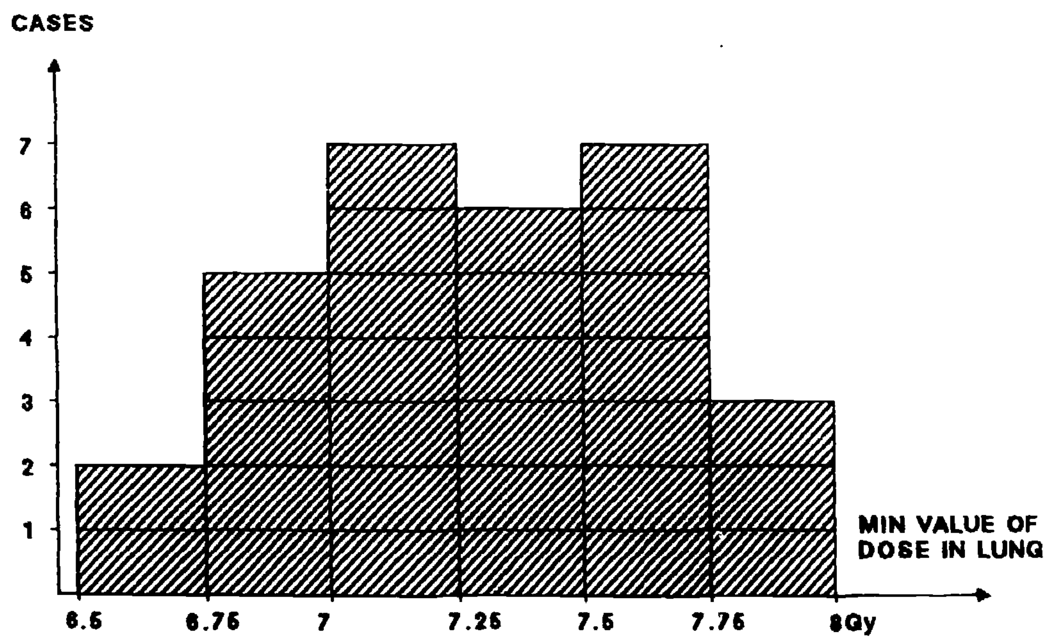


DOSE INSIDE LUNG WITH SHIELDING

PATIENT 1 TO 8

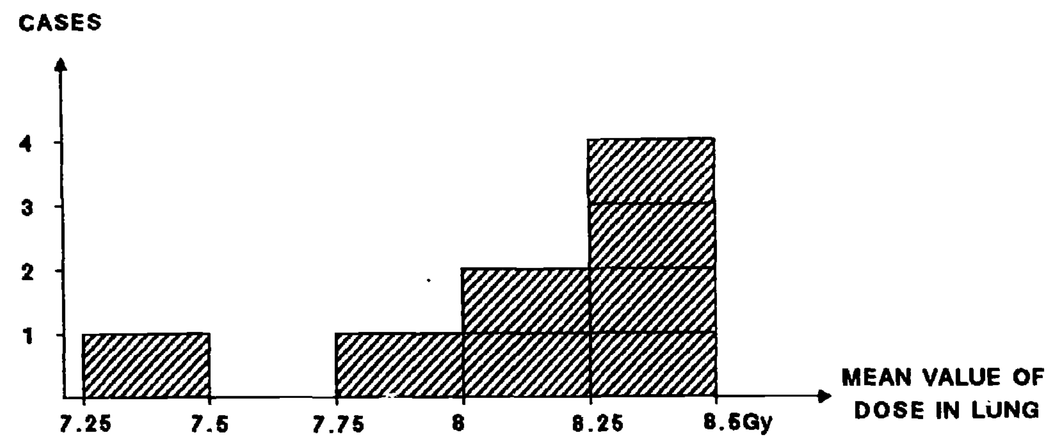


PATIENT 9 TO 38



DOSE INSIDE LUNG WITH SHIELDING

PATIENT 1 TO 8



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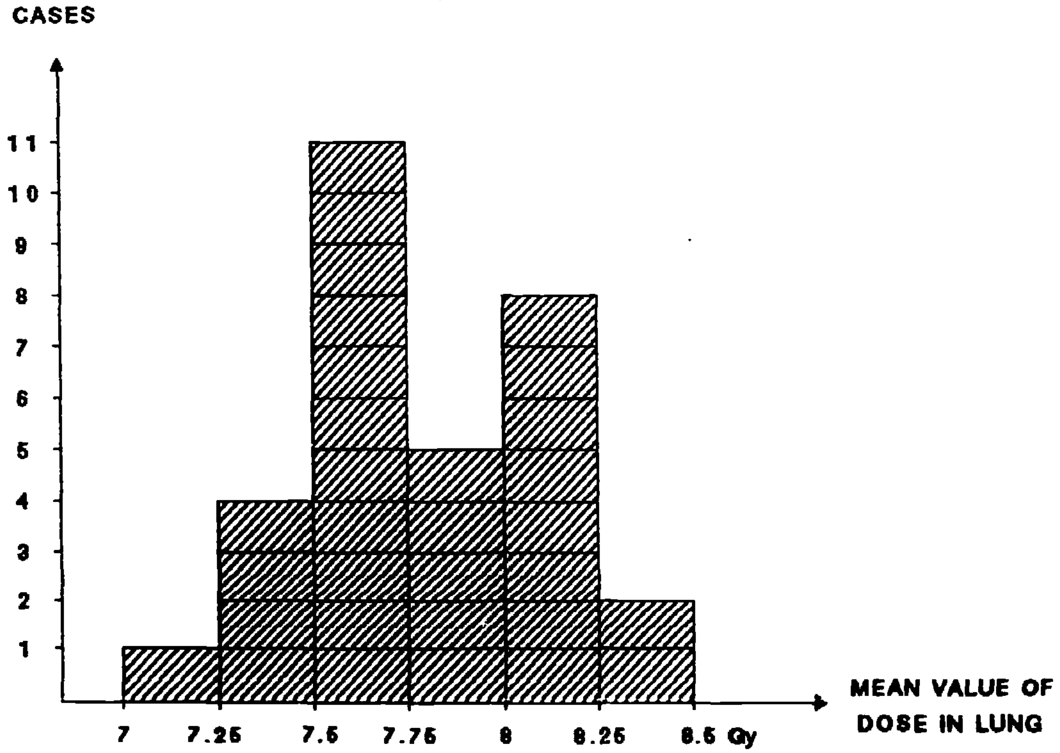
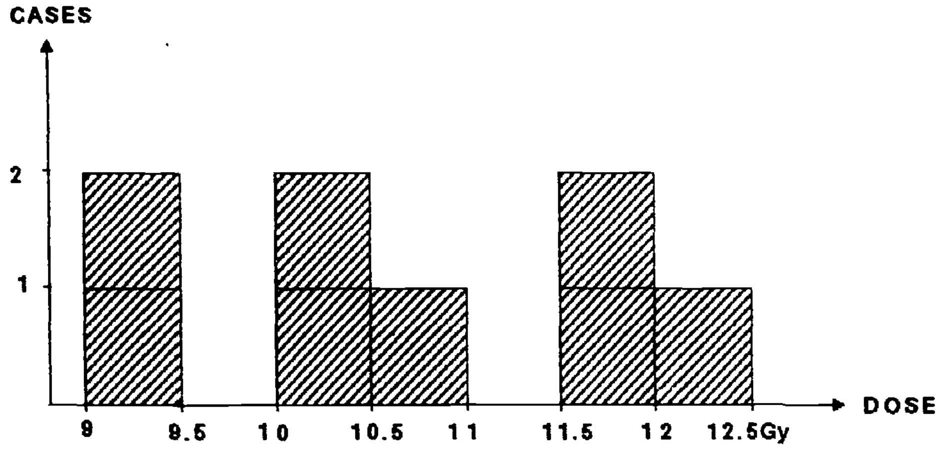
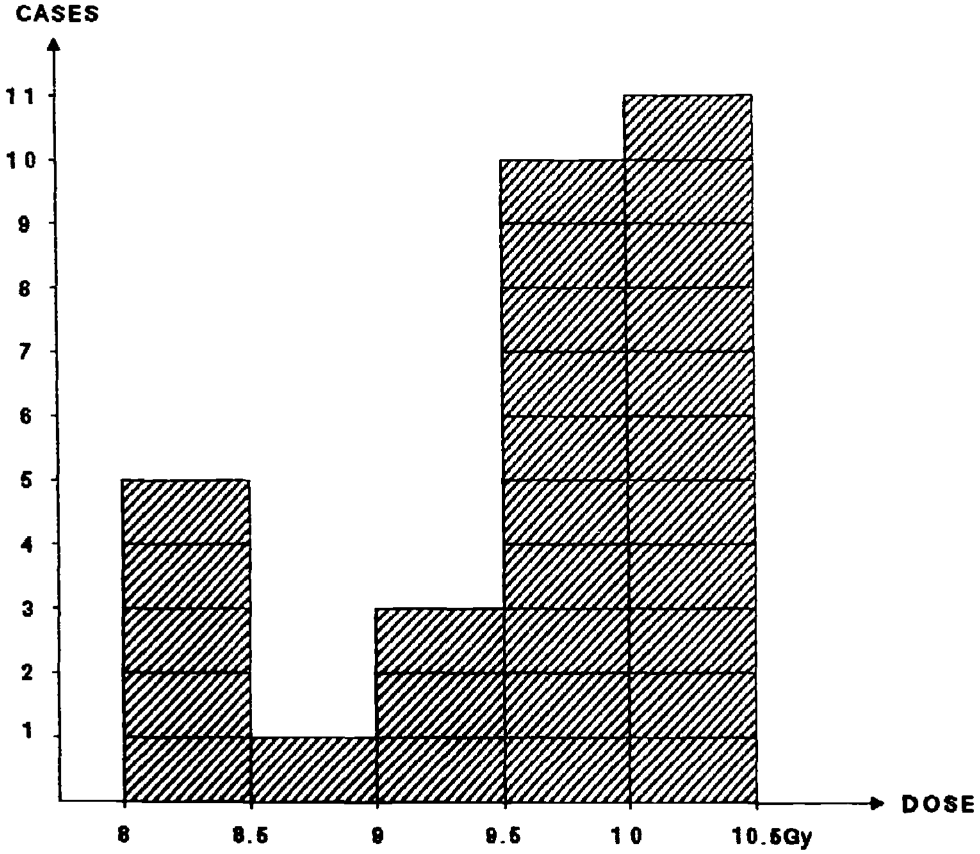


CENTRAL AXIS DOSE HEAD WITHOUT SHIELDING

PATIENT 1 TO 8

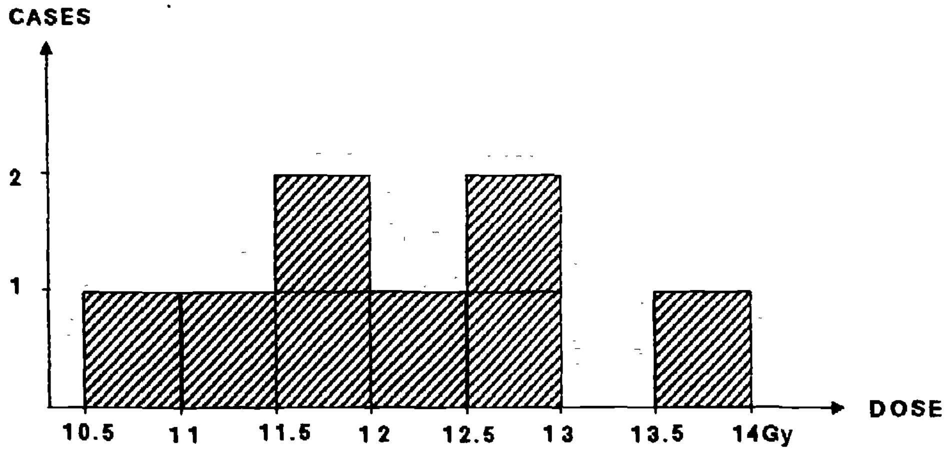


PATIENT 9 TO 38

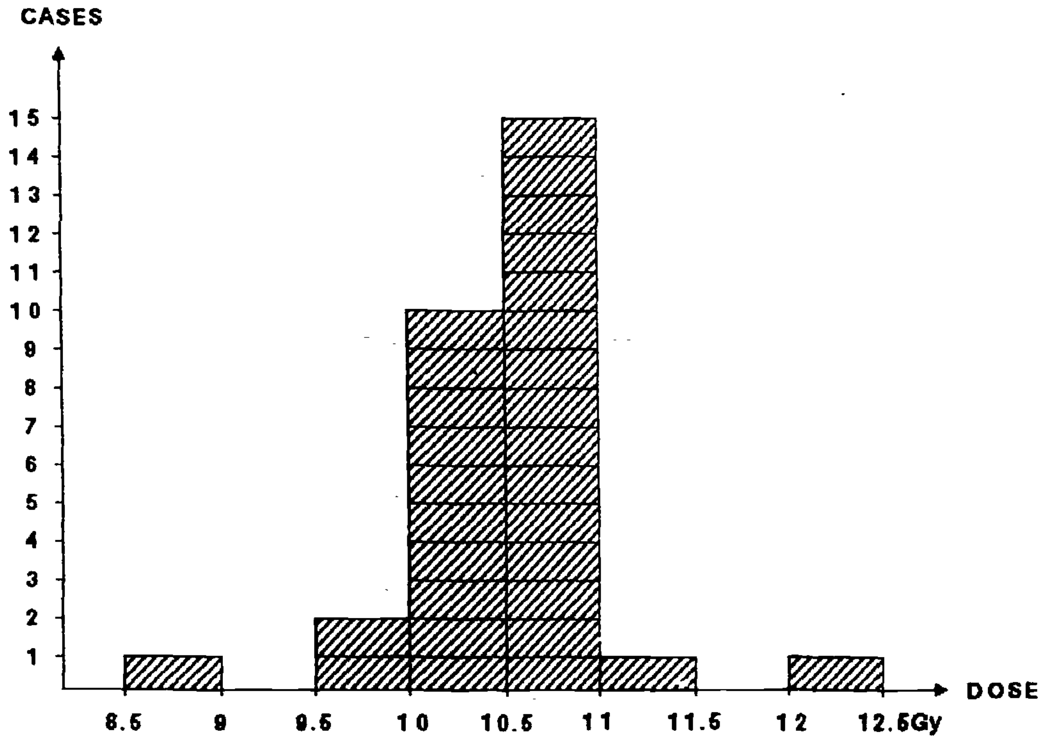


CENTRAL AXIS DOSE NECK WITHOUT SHIELDING

PATIENT 1 TO 8

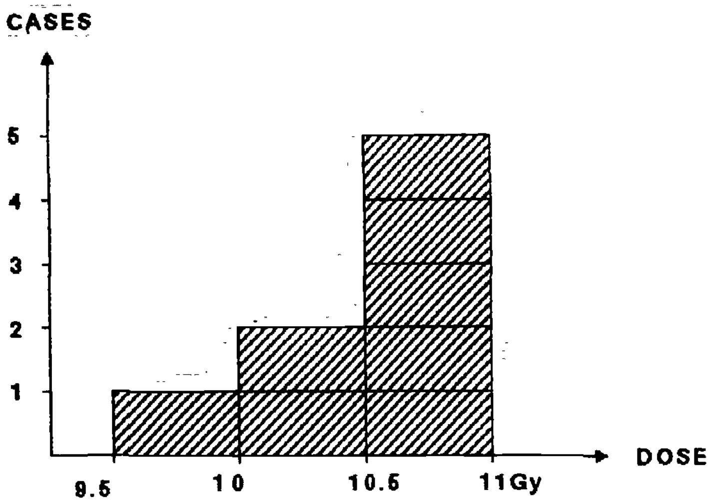


PATIENT 9 TO 38

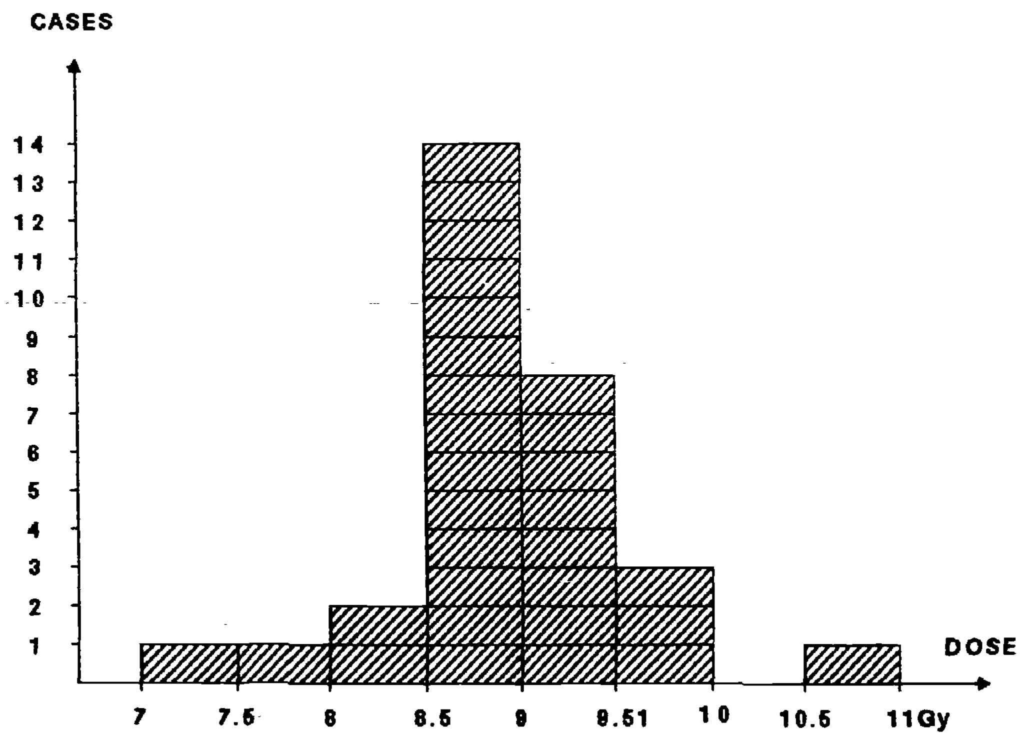


CENTRAL AXIS DOSE LUNG WITHOUT SHIELDING

PATIENT 1 TO 8

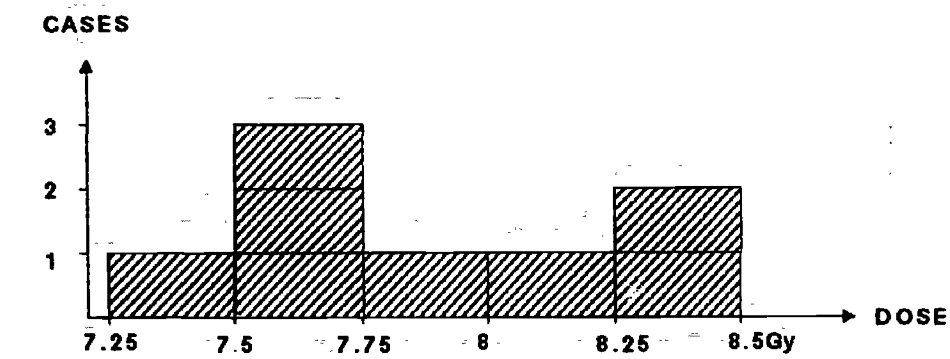


PATIENT 9 TO 38

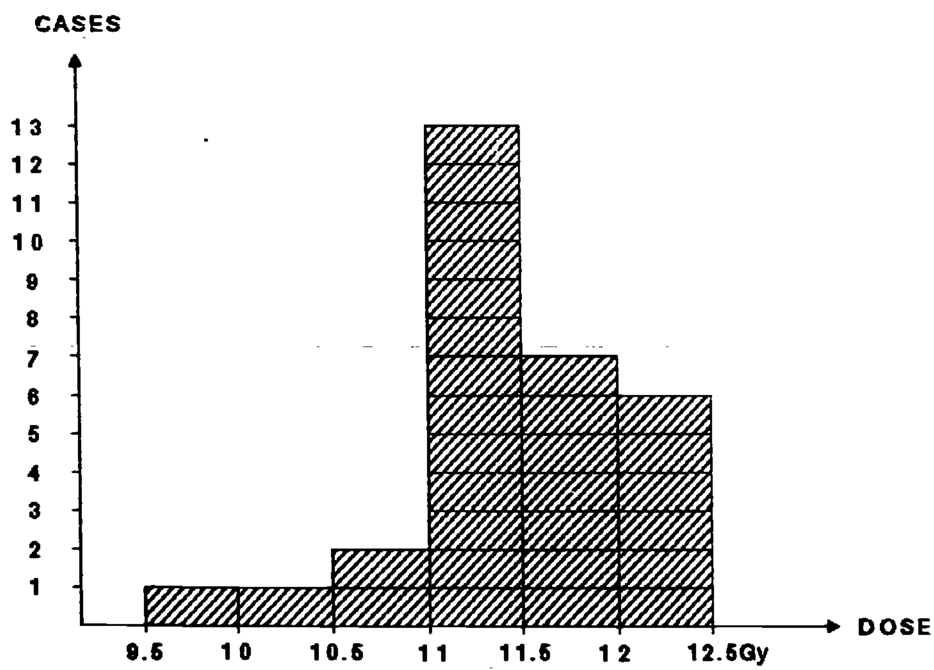


MAXIMAL DOSE INSIDE HEAD WITHOUT SHIELDING

PATIENT 1 TO 8

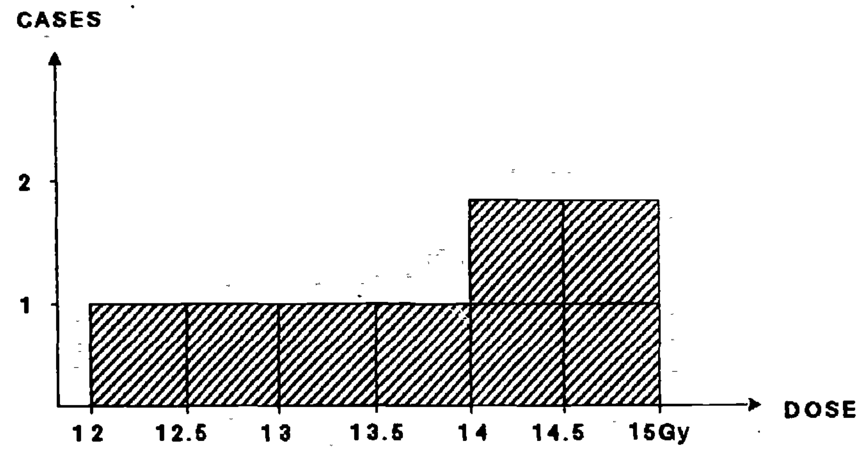


PATIENT 9 TO 38

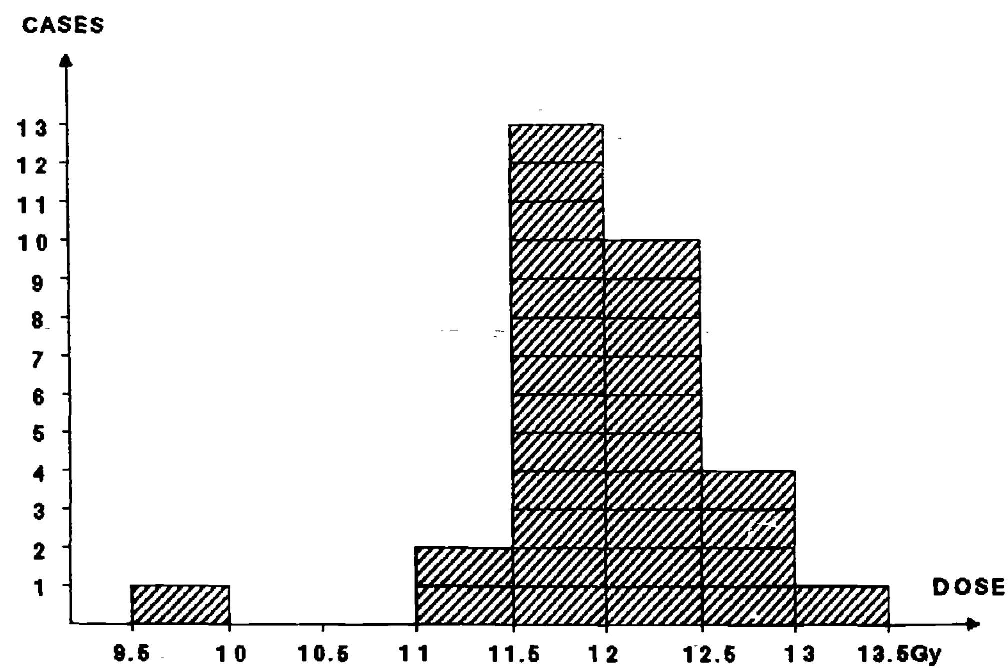


MAXIMAL DOSE INSIDE NECK WITHOUT SHIELDING

PATIENT 1 TO 8

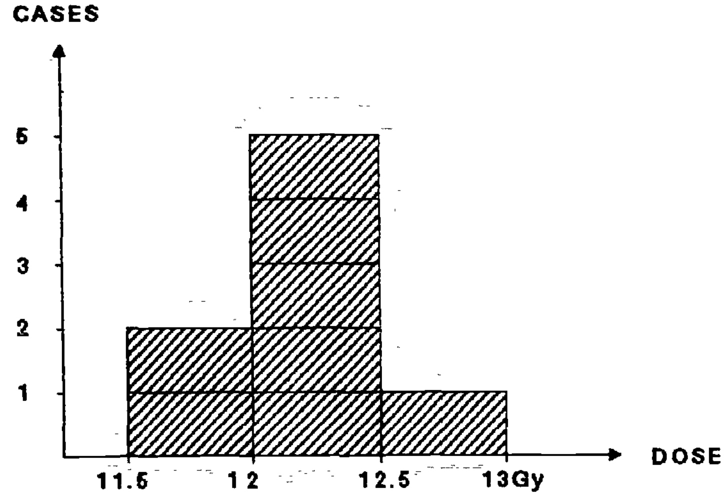


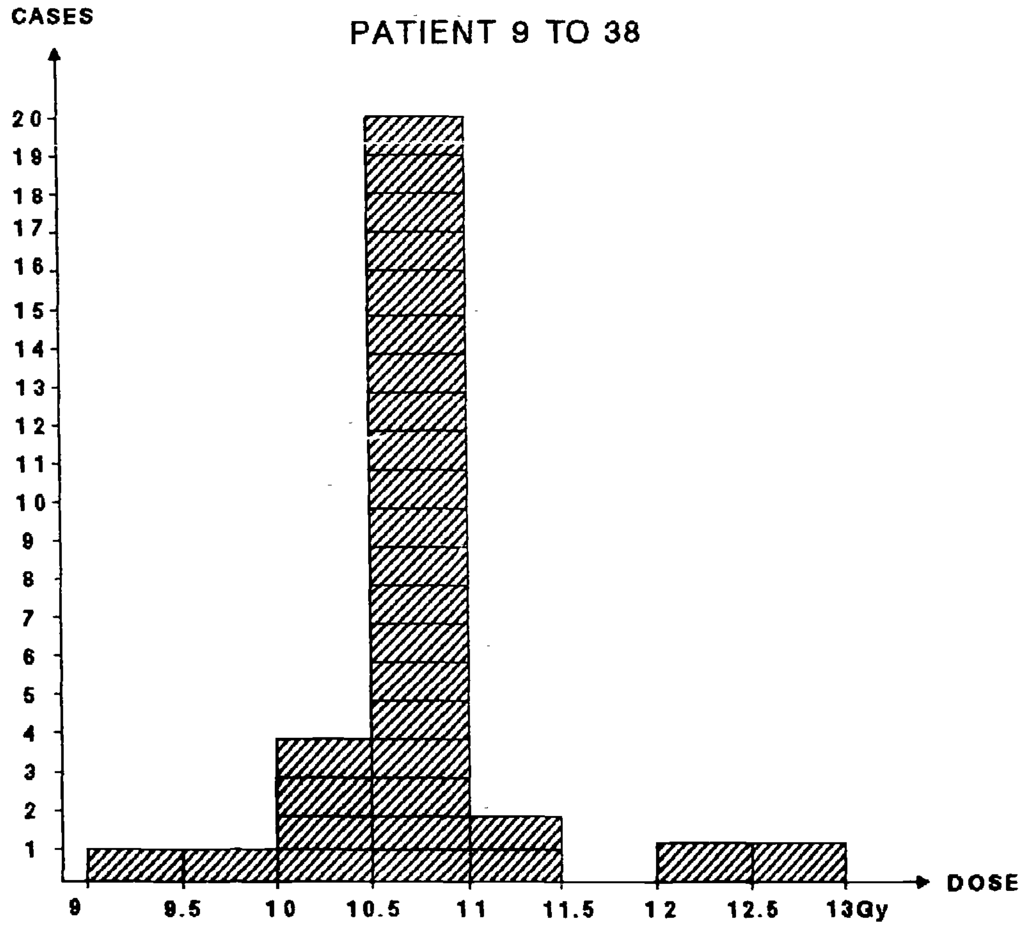
PATIENT 9 TO 38



MAXIMAL DOSE INSIDE LUNG WITHOUT SHIELDING

PATIENT 1 TO 8





APPENDIX 2

name of patient :
date :

t = 20 C
p = 743
f_{IONEX} = 1.029

$$D = Skt \times \frac{273+t}{293} \times \frac{760}{p} \times 0.95 \times f_{chamber} = Skt \times F$$

F_{IONEX} = .999916
F_1 = .8617
f_2 = .8878
F_3 = .9156
F_4 = .8878
F_5 = .8617

total dose vertical : 2.7

total dose lateral : 3.85

time factor vertical :5.26
latèral : 1.89

Field 1 . a p - position vertical
- patient marked
- floormarking
- dosemeter positioned
- head - neck - lung - shielding
- localisation
- Pb - filter

	Transm.	time	refdose	$read_{IONEX}$	time
head	20%	33.98	1.06	106	31.03
lung	30%	69.85	2.18	218	63.96
neck	30%	56.28	1.76	176	51.68
	end	86.42	2.70	270	79.28

Field 2 back position diagonal

- 1 1/2 cm distance
- dosemeter positioned
- Pb-filter

time	refdose	$read_{IONEX}$	time
86.42	2.70	270	100.87

Field 3 p a - position vertical

- patient + floor marked
- head - neck - lung - shielding
- dosemeter positioned
- localisation
- Pb - filter

	Transm.	time	refdose	$read_{IONEX}$	time
head	20%	33.98	1.06	111	33.33
lung	30%	69.85	2.18	218	66.33
neck	30%	56.28	1.76	176	53.48
	end	160.48	5.01	501	149.65

Field 4 abdomen position diagonal

- 1 1/2 cm distance
- dosemeter positioned
- Pb - filter

time	refdose	$read_{IONEX}$	time
160.48	5.01	501	178.07

Field 5 lateral right

- Pb - filter !

time	refdose	$read_{IONEX}$	time
101.57	3.85	385	81.80

Field 6 lateral left

- Pb - filter !

time	refdose	$read_{IONEX}$	time
101.57	3.85	385	79.72