

COMMONWEALTH OF AUSTRALIA



DEPARTMENT OF
HEALTH AND FAMILY SERVICES

RADIATION DOSES FROM COMPUTED TOMOGRAPHY IN AUSTRALIA

by

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ABSTRACT

Recent surveys in various countries have shown that CT is a significant and growing contributor to the radiation dose from diagnostic radiology. Australia, with 334 CT scanners (18 per million people), is well endowed with CT equipment compared to European countries (6 to 13 per million people). Only Japan, with 8500 units (78 per million people), has a significantly higher proportion of CT scanners. In view of this, a survey of CT facilities, frequency of examinations, techniques and patient doses has been performed in Australia.

A questionnaire was sent out to each of the CT facilities in Australia requesting information on patient numbers and technique factors (kVp, mA, number of slices etc). Central axis free-in-air doses were determined from these factors using known or measured CT Dose Indexes (CTDI in mGy/mAs.) for the particular CT equipment used. Organ doses and effective doses were determined from these using Monte Carlo modelling techniques. Summation of the results from all centres yielded population collective effective doses from which the overall risk from CT to the Australian population has been estimated. Individual reports were sent to each participant advising them of the doses from their particular techniques and indicating possible reasons for any higher than average doses.

There were 182 (55%) fully completed and 11 (3%) partially completed questionnaires returned. Computation of effective doses indicated that although head scans (mean 2.6 mSv) made up 30 % of all examinations they contributed only 11% of the overall dose from CT. On the other hand, abdomen examinations (mean 16.7 mSv) made up 11% of all examinations but contributed 36% to the overall dose. There was a wide range in doses for most examinations and this could generally be attributed to the variations in technique, particularly in the number of slices used. For example, the effective dose for an abdomen examination ranged from about 3 mSv. to 75 mSv. while the number of slices ranged from 9 to 60. The overall average effective dose for a CT examination was 6.6 mSv.

It is estimated that there are 1 million CT examinations in Australia each year, resulting in a collective effective dose of 7000 Sv and a per caput dose of 0.39 mSv. This per caput dose is much larger than found in earlier studies in the UK and New Zealand but is less than 0.48 mSv in Japan. Using the ICRP risk factors, radiation doses from CT could be inducing about 280 fatal cancers per year in Australia. CT is therefore a significant, if not the major, single contributor to radiation doses and possible risk from diagnostic radiology.

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RADIATION DOSES FROM CT IN AUSTRALIA

1. INTRODUCTION

Recent surveys in various countries have shown that CT has become a significant contributor to the radiation doses from diagnostic radiology⁽¹⁻¹³⁾. Australia is well endowed with CT equipment and there is ample evidence of the growth in the number of CT units in recent years.

In order to assess the current situation, the Australian Radiation Laboratory has conducted a survey of all CT facilities in Australia. The survey data was collected from 1994 to late 1995. The primary aim of the survey was to determine the average dose to the population from CT examinations. In addition, statistical information was collected on the types of equipment and techniques used. It was also our intention to provide feedback to radiologists on doses from their particular examinations, highlighting where unusually high doses have occurred and possible reasons for them.

2. METHODS.

2.1 Overview of Survey.

The method used to achieve the above aims was to survey, by mail, every CT facility in Australia to determine examination frequencies, equipment type and technique factors used. Initial lists of the whereabouts of CT facilities and the makes and models of equipment were obtained from State Health authorities and equipment manufacturers. A questionnaire (Appendix A), together with a letter of support from the Royal Australasian College of Radiologists, was sent to each of these CT facilities. Non-responders were sent up to two reminders over a period of about one year.

The questionnaire requested information on the kVp, mAs, number of slices, slice width and couch increment for each type of examination performed at the centre. Organ and effective doses were calculated from these using known data on the radiation output and beam qualities for the type of CT equipment used.

2.2 Computation of Organ and Effective Dose.

The method used to evaluate the doses from a given CT examination was the same as that developed by Shrimpton et al. at the National Radiation Protection Board ⁽¹⁻³⁾

In the NRPB study, Monte Carlo Techniques were used to calculate the dose to an organ of a mathematical phantom per unit free-in-air dose at any point 'x' on the central axis. The parameter '**qual**' refers to beam geometry and quality factors for different classes of machines surveyed. For a given examination, the organ dose is given by:

$$\text{Organ Dose} = \text{Average free-in-air dose on axis} \cdot \sum_{x=\text{Start}}^{x=\text{Finish}} \mathbf{D(x,qual,organ)}$$

The NRPB work provided look up tables for **D(x,qual,organ)** quantity for 24 different types of machine giving doses to 21 organs for slice positions in 5mm increments from the top of the head to the bottom of the torso.

The average 'free-in-air' dose on the central axis can be determined from technique factors by using the 'free-in-air' Computed Tomography Dose Index or CTDI. In simple terms, the 'free-in-air' CTDI is a measure of the radiation output, on the central axis, per unit tube loading. It is equivalent to the 'free-in-air' dose on the central axis resulting from a infinite series of abutting slices with one mAs per slice. The CTDI may be expressed in units of mGy per mAs. In general, the CTDI depends on tube efficiency, slice width, beam geometry and beam quality factors.

The average free-in-air dose for a scan of length **L** containing **n** slices of thickness **T** is given by:

$$\text{Average free-in-air dose on axis} = \frac{\mathbf{n \cdot T}}{\mathbf{L}} \cdot \mathbf{CTDI} \cdot \mathbf{mAs}$$

Where:

'**CTDI**' is the Free-in-Air Computed Tomography Dose Index in units of mGy per mAs.,

mAs	is the exposure factor used per slice and
$\frac{\mathbf{n.T}}{\mathbf{L}}$	is the packing factor which takes into account the averaging of the dose along the axis. (<1 for space between slices,=1 for abutting slices and >1 for overlapping slices.).

Combining the above equations we have the dose to an organ from an examination given by:

$$\text{Organ Dose} = \frac{\mathbf{n.T}}{\mathbf{L}} \cdot \text{CTDI} \cdot \text{mAs} \cdot \sum_{x=\text{Start}}^{x=\text{Finish}} \mathbf{D(x,qual,organ)}$$

It should be noted that all the parameters except the CTDI and $D(x, \text{qual}, \text{organ})$ were determined from the responses to the survey questionnaire.

2.3 Determination of Effective Doses.

The organ doses resulting from each examination at a centre were computed by summing the contributions from the fraction of exams done without contrast only, the fraction done with contrast only and the fraction done both with and without contrast. Effective doses were computed from these using the organ weighting factors given in ICRP 60⁽¹⁴⁾.

2.4 Values of the CTDI Used.

An important finding of the NRPB study was that the variation in CTDI for different examples of the same make and model of CT was small. This enabled us to use known CTDI's, for a given type of equipment, in the evaluation of doses from the survey responses.

In the present work we have, where possible used values of the CTDI found in the literature⁽¹⁵⁻²⁰⁾. There were, however, many makes and models of CT's in Australia for which there was no published CTDI data. For most of these we have made our own measurements of the CTDI's using a pencil ionization chamber or by a method we have developed⁽²¹⁾ using TLD powder. At the completion of the survey we had CTDI data for approximately 90% of the equipment surveyed.

In general the CTDI depends upon the slice thickness. There were some machines for which the CTDI was known for some but not for all slice thicknesses. If an assumption is made that there is a constant amount of beam outside the nominal slice thickness, T , the CTDI will have the functional form:

$$\text{CTDI}(T) = a_0 + a_1 / T$$

In the vast majority of cases an accurate fit to the data could be obtained using this form. In computations we have used fits to CTDI data of the form above to determine the CTDI for any required slice thickness.

Figure 1 shows a histogram of all CTDI data for which we had measured data. We note that the CTDIs range from 0.1 to 0.4 mGy per mAs with an average value of 0.21 and a standard deviation of about 0.1 mGy per mAs. For the CT equipment for which we had no data, (approx 10%) we have used a value for the CTDI of 0.2 mGy per mAs. For individual cases this assumption may lead to uncertainties in organ doses of up to 50%. However, because it affected only 10% of equipment surveyed and that within this group the true CTDI's would be expected to be distributed throughout the range, there will be little error introduced into the aggregate determined by the survey.

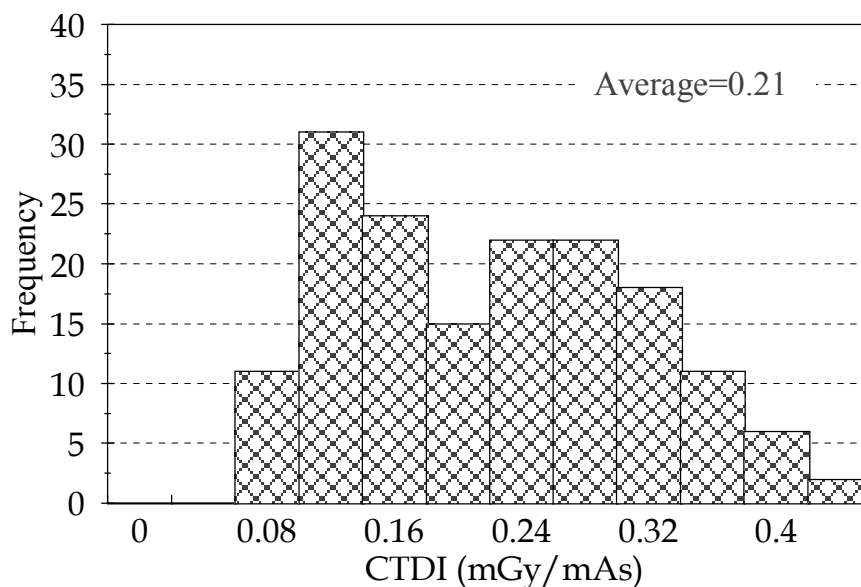


Figure 1 Histogram of known Computed Tomography Dose Indices (CTDI).

2.5 The Datasets for $D(x, \text{qual}, \text{organ})$.

The Monte Carlo results give organ doses normalised to a unit free-in-air dose at a point on the central axis. There is a dependence therefore on beam quality and to a lesser extent on focus axis distance. This latter dependency is only of importance for off axis organs such as the breast. One would expect that for the fairly hard beam used in CT, the variation of organ doses, per unit central axis dose, for a wide range of beam qualities would be quite small. This was definitely the finding of the Monte Carlo Studies at the GSF laboratories in Germany ^(22 - 24), where the data indicated less than a 25% variation for a wide range of beam qualities from an 80 kV soft beam to a 137 kV hard beam.

This is not the case with the NRPB data. Figure 2 shows the effective dose (weighted sum of organ doses) for a whole body scan for a unit dose on the axis. The solid data points are for the different NRPB datasets and are plotted as a function of Half Value Layer. Excluding the two very soft beams, it is noted that there is an approximately linear relationship between effective dose and HVL. However the range in values is large, from 0.3 mSv to 0.7 mSv.

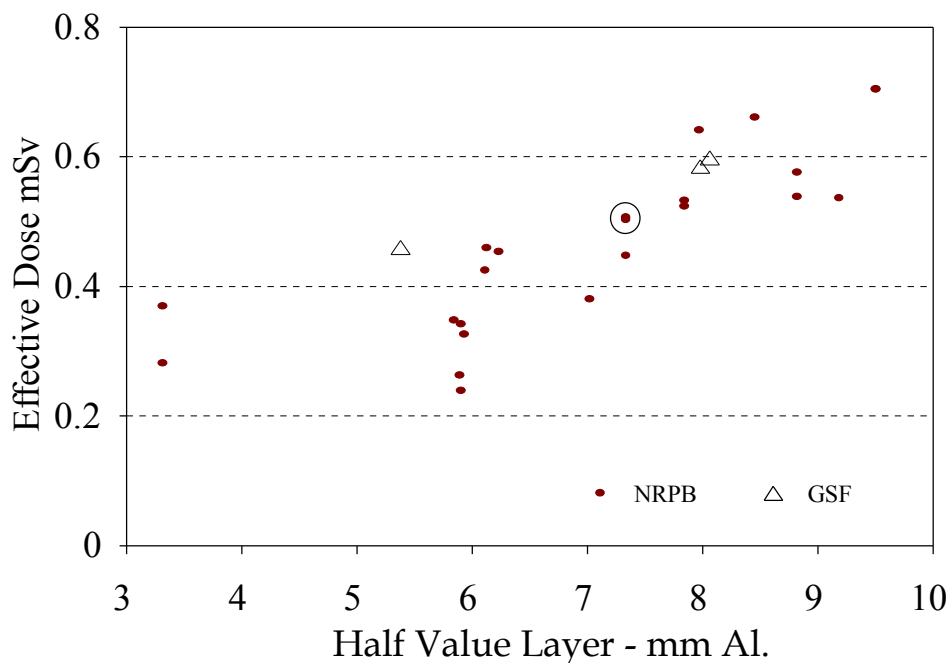


Figure 2 Effective dose from whole body scan of abutting slices with a unit free-in-air dose on central axis derived from the NRPB (ref. 3) and GSF (ref. 22) Monte Carlo Results.

We have corresponded with NRPB ⁽²⁸⁾ and they also find this large range difficult to explain but suggests it may in part be due to the differences in shaping filters used. The effective doses evaluated from the GSF study are also shown on Figure 2 (open triangles). For the harder beams there is good agreement with the NRPB results. As pointed out above there is little change in the GSF doses between hard and soft beams whereas the NRPB doses are considerably less for the softer beams.

About 50 % of the CT units in Australia were makes and models not covered by the NRPB Monte Carlo data sets and we do not have the data from manufacturers to extend those data. In view of this, we have attempted to match machines for which we have no data to a NRPB dataset for a CT of a similar geometry and beam HVL. A similar procedure to this has been used in the Norwegian survey ⁽⁹⁾. Where it has not been possible to choose a dataset for an equivalent machine, the dataset which results in the effective dose indicated with the circle in Figure 2 has been used. Again this choice may lead to large uncertainties in some of the individual dose calculations but should result in an uncertainty of less than about 15% for the organ doses and effective doses averaged over all centres.

2.6 Computational Facilities.

The entire survey was managed using a properly normalized relational database system 'RADBASE' written in Borland dBase IV. For the CT study, three major relational tables were used. The CENTRES table contained information related to the location and contact person for each radiological practice. The CT_MACHINE__INFORMATION table contained information on the type of equipment at each centre and the gross number of procedures performed. The TECHNIQUES_&_DOSES table contained details of the numbers and techniques used as well as the computed organ doses and effective doses for each type of examination performed. These tables were linked using a Centre-ID key in the CENTRES table and a composite (Centre-ID,Machine-No) key for the other two tables. All computation of doses were derived from the stored technique factors using dBase IV code which accessed where necessary the additional tables, CT_DATA containing known CT physical data (eg. CTDI's), CT_EQUIV which contained equivalence relations for CT machines of different makes and models and CT_MONTE which contained the NRPB Monte Carlo data.

A stand alone interactive program 'CTXDOSE' has also been developed which computes patient doses from machine type and technique factors input from the keyboard. This code is similar that developed at NRL ⁽²⁵⁾ but has the advantage that a new machine may be easily catered for by addition a new equivalence and/or new CTDI data etc. to the relevant tables.

3 RESULTS AND DISCUSSION.

3.1 Survey Responses.

Initial lists of the whereabouts of CT facilities and the makes and models of equipment were obtained from State Health authorities and equipment manufacturers. After checking these for duplication and evidence of decommissioning, there were 332 CT units left in our data base.

Negative responses, indicating unwillingness to participate, were obtained from 35(10%) of facilities and 106(32%) failed to reply. Positive responses, with either complete or partially complete questionnaires, were obtained from 193(58%) facilities. Fully completed questionnaires were obtained for 182 (54.8%) CT facilities.

Where necessary in this report we have made the assumption that the results for the non-responders would be statistically the same as for those who responded.

3.2 Types of Equipment.

The number of CT units of different makes and the most common models are shown in Table 1. General Electric is the market leader with 104(32%) units followed by Toshiba 81(24%) and Siemens 53(16%).

Table 1 Makes and Models of CT Equipment in Australia.

MAKE	NUMBER OF MODELS	NUMBER OF UNITS	MAIN MODELS
GENERAL ELECTRIC	20	104	PACE, 9800, SYTEC, PROSPEED
TOSHIBA	23	81	X-SPEED, X-PRESS, 80, 600, 400
SIEMENS	16	53	HIQ, PLUS, DRH, DR3, DR2, DR1
HITACHI	7	34	CTW 1000, 600, 400, 800, 450
SHIMADZU	9	18	SCT 3000, 5000, 4500
PICKER	7	16	PQ 2000, 1200SX
ELSCINT	3	13	EXCEL 1800, 2000, 2002
PHILIPS	3	9	LX
TECHNICARE	1	1	DELTA 2060
UNKNOWN		3	
TOTAL CT UNITS		332	

3.3 Number of CT Units.

The number of CT units, and the number per million people, in the different States of Australia are shown in Table 2. There is a very uniform distribution of CT units between states with the exception of the ACT which has nearly twice as many CT units compared with the national average of 18.5 per million.

Table 2 Number of CT Units in Australian States.

STATE	NUMBER OF UNITS	NUMBER PER MILLION PEOPLE
NEW SOUTH WALES	113	18.3
VICTORIA	88	19.6
QUEENSLAND	55	17.7
SOUTH AUSTRALIA	30	19.6
WESTERN AUSTRALIA	24	14.5
A.C.T	10	34.2
TASMANIA	9	18.3
NORTHERN TERRITORY	3	17.5
TOTAL	332	18.5

Table 3. shows the number of CT units and the number of units per million people in various countries. As noted earlier, with 332 units, Australia is well endowed with CT equipment. This is about the same number of CT units as the UK ⁽¹⁾. Note that Australia, with 18.7 CT units per million has nearly triple the number of CT units per caput than UK or NZ ⁽⁶⁾ but has a comparable number to the US ⁽¹³⁾. As can be seen, Japan ⁽²⁶⁾ is in a league of its own with a staggering 8500 CT units and 68 CT units per million people.

Table 3 Number of CT Units in Various Countries.

COUNTRY	NUMBER OF UNITS	CT UNITS PER MILLION PEOPLE
JAPAN (1995)	8500	68.5
AUSTRALIA (1994)	332	18.7
USA (1990)	>4600	>18
NORWAY(1993)	70	16.1
ITALY (1991)	741	13.0
NEW ZEALAND (1992)	21	7.0
UK (1993)	340	6.0

3.4 Annual Number of Examinations and Equipment Utilization.

The annual number of CT examinations was computed assuming that the centres who did not respond performed on average the same number of examinations as those who did. On this basis in 1995 there were 1.06 million examinations per year. As a check on this result, an independent estimate based on national Medicare records was made. The Medicare data had to be adjusted for those examinations done in public hospital and not billed through Medicare as well as for the fact that many Medicare examinations are multiple examinations in the context of their report.(e.g. one billing for a chest and abdomen exam). Our questionnaire asked for the percentage of non-Medicare examinations and the responses indicated that on average 24% of exams were non-Medicare funded. Making these adjustments to the medicare data resulted in an estimate of between 900,000 and one million examinations, which is in good agreement with our survey findings.

The annual number of CT examinations together with the number of CT examinations per 1000 people are given in Table 4. Note that in Australia there are just over 1 million exams per year or about 60 examinations per 1000 people. This is about triple the examination rate of the UK⁽¹⁾ or New Zealand⁽⁶⁾ but again is comparable to the USA⁽¹³⁾. Japan⁽¹²⁾ has the largest examination rate, with about 100 exams per 1000 people.

Table 4 Number of CT Examinations in Various Countries.

COUNTRY	NUMBER 1000's	CT EXAMS PER 1000 PEOPLE
JAPAN (1989)	12,000	97
AUSTRALIA (1994)	1,060	60
NEW ZEALAND (1992)	62	21
UK (1993)	1,270	22
USA(1990)	> 13,000	52

The histogram in Figure 3 shows the average annual number of examinations per CT unit or utilisation at different centres. The distribution is log normal in shape with a wide range of utilisation from 500 to over 8000 examinations per year with an average of 3200 examinations per year. The average number of examinations done on each CT unit per year in Australia compared with other countries is shown in Table 5. Although there is a large variation in the number of CT's on a per capita basis, the utilisations are remarkably similar. The UK works each machine a little harder and Japan does slightly less examinations on each machine.

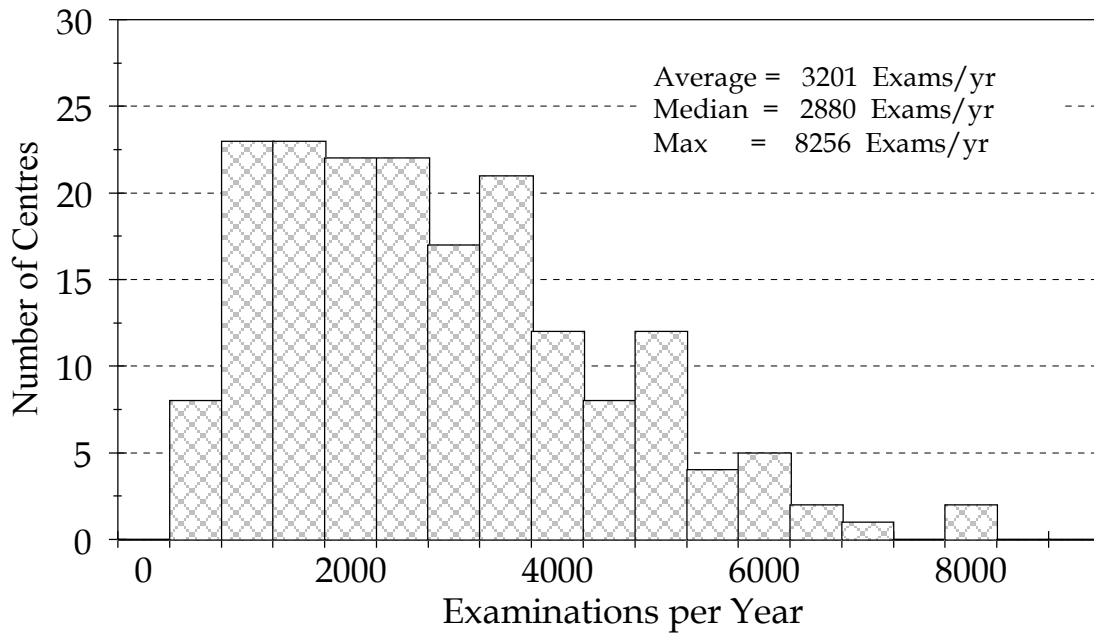


Figure 3 Histogram of the number of examinations performed per year.

Table 5 Average Number of Examinations per CT Unit (Utilization).

AUSTRALIA (1994)	3201	Exams/yr
UK (1988)	4228	Exams/yr
NEW ZEALAND (1992)	2952	Exams/yr
JAPAN (1989)	2150	Exams/yr
USA (1990)	2900	Exams/yr

3.5 Variations in Techniques.

The questionnaire requested information on the use of contrast so that the average dose for examinations could be calculated. Table 6. gives the percentages of each type of exam that has a scan without contrast only, with contrast only and both with and without contrast.

Table 6 Use of Contrast Medium in CT Examinations.

TYPE OF EXAM	% OF ALL ALL EXAMS	% EXAMS ONLY WITH CONTRAST	% EXAMS ONLY W/O CONTRAST	%EXAMS BOTH WITH AND W/O CONTRAST
HEAD	30.4	2.8	34.8	62.5
ABDOMEN	14.6	12.5	14.2	73.3
LUM SPINE	12.4	6.2	91.8	2.0
CHEST	8.1	20.5	39.8	39.7
PELVIS	5.9	23.4	25.7	50.9
FACE BONES	4.4	3.8	93.1	3.1
POST FOSSA	4.3	6.2	21.2	72.6
CERV SPINE	3.6	8.7	89.1	2.2
LIVER	3.1	8.5	9.5	82.0
IAM	2.6	31.1	21.0	48.0
MEDIASTM	2.0	27.4	16.2	56.4
PANCREAS	1.3	11.7	6.6	81.7
SINUS	1.2	0.4	99.0	0.6
ORBITS	1.2	18.1	39.1	42.7
KIDNEYS	1.1	6.8	8.5	84.6
PELVIMETRY	1	0.0	97.5	2.5
THOR_SPINE	0.8	3.7	95.5	0.8
PITUITARY	0.7	51.1	4.0	44.9
ADRENALS	0.5	10.0	10.3	79.7
NECK	0.4	23.6	16.6	59.8

Tables 7 and 8 list statistical information relating to the number of slices and slice widths for scans done with and without contrast medium. What is clear from this data is that there is a very large range in the number of slices used for most examination types which will lead to a correspondingly large range in patient doses. An example of this variation is shown in the histogram in Figure 4 of the number of slices for a routine abdomen exam with contrast. There is a wide variation in the number of slices range from 10 to 48 with a median of 30.

Although, for most examinations there was a wide range in the number of slices used, there were a few examinations for which the spread in the number of slices was quite small. An example of this is illustrated in Figure 5 showing a histogram of the number of slices used for a lumbar spine examination. In this case the distribution is quite narrow with most centres using between 26 and 34 slices.

Table 7. Techniques Used for Examinations WITH Contrast.

TYPE OF EXAM	AVG.. No. of SLICES	MAX. No. of SLICES	MIN. No. of SLICES	St. Dev. No. of SLICES	AVG. SLICE WIDTH	St. Dev. SLICE WIDTH
HEAD	16.0	40	7	5.8	9.0	1.9
ABDOMEN	31.3	60	9	9.7	9.9	1.2
LUM SPINE	26.2	45	6	8.2	4.7	1.6
CHEST	27.8	50	3	7.4	9.5	1.5
PELVIS	19.9	50	8	6.4	9.7	1.5
FACE BONES	23.1	45	3	8.6	3.9	1.7
POST FOSSA	13.8	44	5	6.9	6.0	2.8
CERV SPINE	26.4	40	6	6.7	4.0	3.8
LIVER	21.8	60	10	8.8	9.5	1.4
IAM	17.4	74	4	9.7	3.0	2.8
MEDIASTM	24.4	50	8	8.6	9.1	1.8
PANCREAS	18.8	50	5	9.3	6.4	4.2
SINUS	24.7	46	8	10.5	3.8	1.1
ORBITS	19.0	50	7	7.8	3.9	2.1
KIDNEYS	22.1	50	8	9.6	8.3	4.2
PELVIMETRY	3.6	30	1	7.1	9.5	1.4
THOR_SPINE	25.2	45	8	7.0	5.3	2.1
PITUITARY	18.4	48	1	9.1	2.5	2.2
ADRENALS	16.9	50	4	9.8	5.0	2.3
NECK	24.5	35	15	6.1	5.6	1.5

Table8 Techniques Used for Examinations WITHOUT Contrast.

TYPE OF EXAM	AVG.. No. of SLICES	MAX. No. of SLICES	MIN. No. of SLICES	St. Dev. No. of SLICES	AVG. SLICE WIDTH	St. Dev. SLICE WIDTH
HEAD	14.6	40	4	5.6	7.6	2.8
ABDOMEN	23.4	92	7	13.9	9.8	1.1
LUM SPINE	27.9	54	7	5.7	4.6	1.1
CHEST	23.5	50	3	9.9	9.0	2.5
PELVIS	18.8	50	7	6.7	9.5	1.5
POST FOSSA	23.5	46	3	8.1	3.9	1.3
FACE BONES	12.3	35	4	6.2	5.5	7.1
CERV SPINE	27.6	45	2	6.6	3.2	1.6
LIVER	18.5	60	7	9.5	9.5	1.5
IAM	16.4	65	2	9.9	2.4	1.7
MEDIASTM	22.0	45	8	9.6	8.9	2.0
PANCREAS	15.9	50	5	9.3	6.4	4.3
SINUS	26.0	50	12	9.3	3.7	1.2
ORBITS	16.7	45	1	7.7	3.5	1.4
KIDNEYS	18.4	50	6	9.4	7.8	2.5
PELVIMETRY	1.9	20	1	2.3	9.0	2.1
THOR_SPINE	25.7	50	8	6.1	5.2	1.7
PITUITARY	16.5	45	1	9.1	2.3	1.6
ADRENALS	14.2	50	3	8.9	5.4	2.4
NECK	21.9	35	5	7.8	6.0	1.9



Figure 4 Histogram of the number of slices used for a routine abdomen examination with contrast medium.

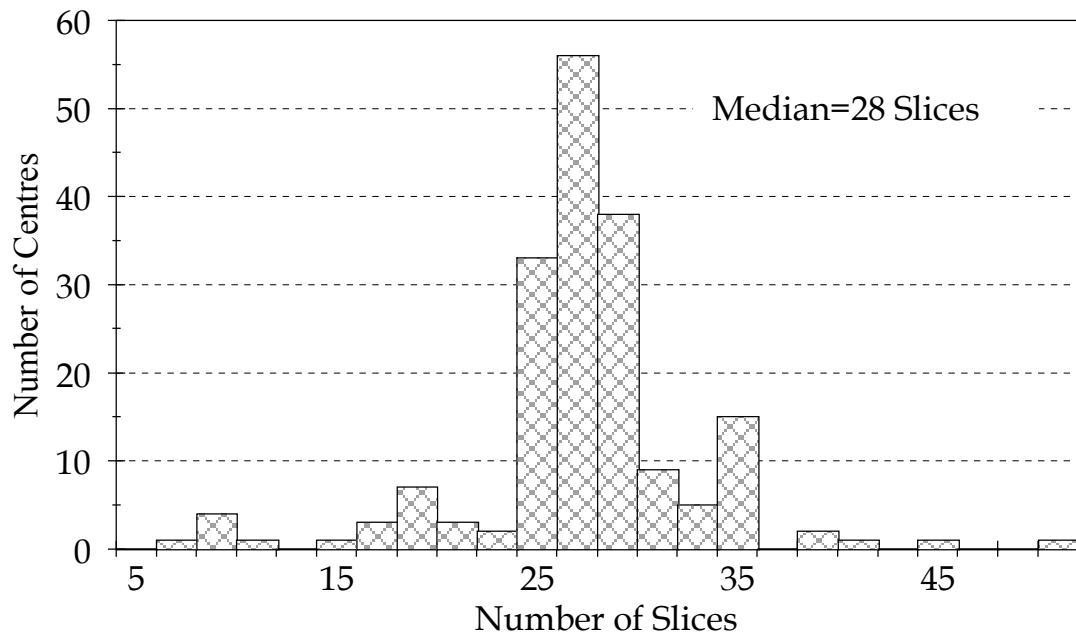


Figure 5 Histogram of the number of slices used for a lumbar spine examination without contrast medium.

3.6 Distribution of Organ Doses.

In general there was a wide spread in organ doses from the different centres. As an example the histogram given in Figure 6 shows the distribution of doses to the eye from a routine head examination at different centres. The distribution shows a wide spread in doses with a median value of 61 mGy. This large median dose was more or less as expected. The wide spread in doses results from variation in techniques used rather than equipment type.

The evaluation of the uterine dose is important when a pregnant patient is about to be or has been examined. The histogram in Figure 7 shows the distribution of the uterine doses from a routine abdomen examination. The spread in the doses is extremely large. A large component of this spread has probably come about because, depending on technique, the uterus may be fully, partially or not covered at all by the scan. This case illustrates the difficulty that may arise in making an estimate of an organ dose for a particular exam unless full details of the procedure are available.

3.7 Effective Doses for Common Examinations.

Effective whole body doses were computed from the organ doses for each examination using the ICRP 60⁽¹⁴⁾ weighting factors. Table 9 gives a statistical breakdown of the effective doses from the most common examinations ranked in order of their frequency. The columns to the right show the maximum and minimum effective doses found in the survey. Note that in general, the range of effective doses is extremely large.

Head examinations, which make up 30% of all exams, were the most common examination and had an average effective dose of 2.6 mSv. Although they were the most common examination they contribute only 11% to the overall effective dose from CT. The distribution of effective doses from head examinations is given in Figure 8 and shows a wide spread in doses ranging from about 0.5 to 8 mSv.

The next most common examination was that of the abdomen which makes up 14% of all examinations. This examination had the largest average effective dose of 16.7 mSv and contributed nearly 40% of the overall effective dose from CT. The distribution of effective doses from abdomen examinations is shown in Figure 9 again exhibits a wide range in doses from 3 to 50 mSv.

The predominant factor contributing to the wide spread in the effective doses, noted above, for the same examination is again the large variation in the number of slices used.

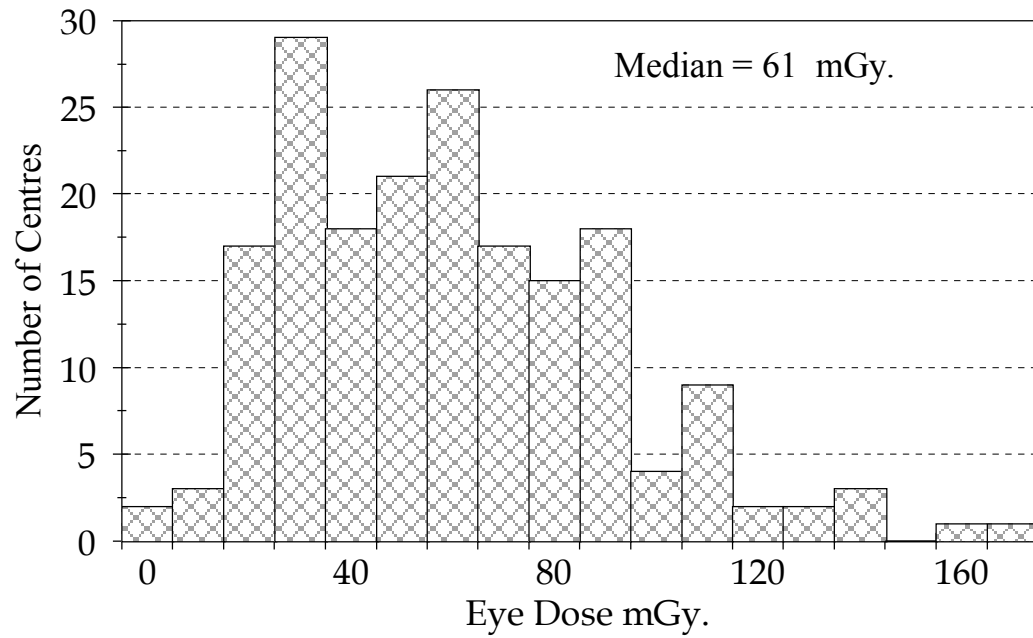


Figure 6 Histogram of the dose to the eye from routine head examination

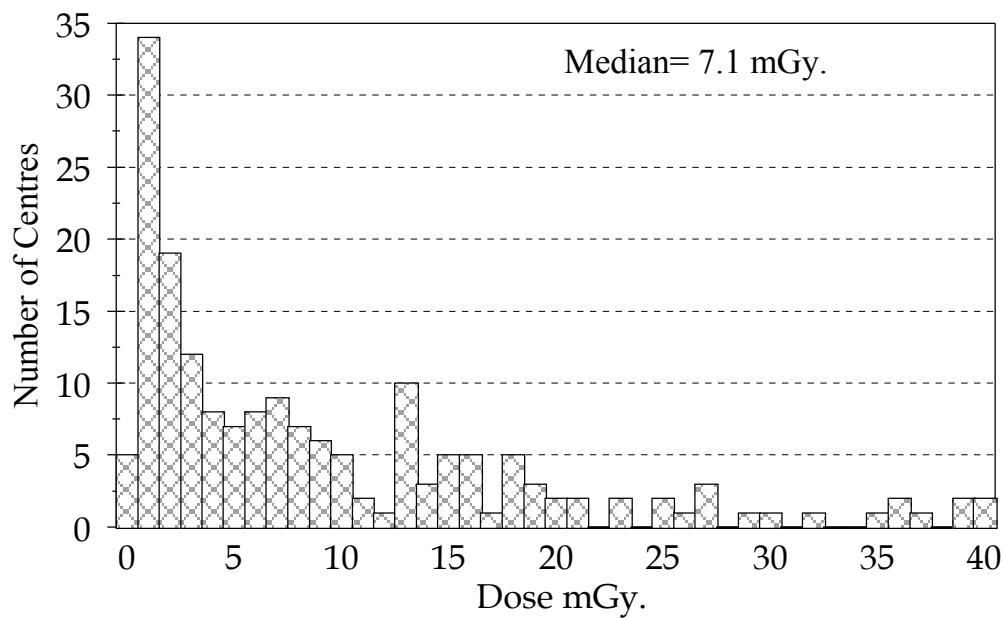


Figure 7 Histogram of the dose to the uterus from routine abdomen examinations.

Table 9. Effective Whole Body Doses from CT Examinations in Australia.

TYPE OF EXAM	% OF AL EXAMS	Wtd. % OF OVERALL CT DOSE	MEDIAN DOSE mSv.	MEAN DOSE mSv.	ST'DEV DOSE mSv.	MAX DOSE mSv.	MIN DOSE mSv.
HEAD	30.4	11	2.0	2.6	2.0	11.5	0.4
ABDOMEN	14.6	35.9	12.9	16.7	11.8	75.5	3.0
LUM SPINE	12.4	9.6	4.7	5.2	3.3	16.9	0.7
CHEST	8.1	12	9.0	10.4	7.1	44.7	0.7
PELVIS	5.9	8.6	9.4	11.0	8.1	49.3	2.8
FACE BONES	4.4	0.8	0.7	1.2	1.5	6.9	0.1
POST FOSSA	4.3	1.2	1.1	1.9	2.3	13.2	0.1
CERV SPINE	3.6	2.9	4.3	5.2	3.9	17.6	1.0
LIVER	3.1	7.4	10.7	12.7	8.9	43.4	2.7
IAM	2.6	0.4	0.4	1.1	2.1	10.9	0.1
MEDIASTM	2.0	3.2	8.8	10.5	6.2	29.5	1.8
PANCREAS	1.3	1.7	6.3	8.1	5.9	31.2	1.6
SINUS	1.2	0.1	0.6	0.7	0.5	2.1	0.2
ORBITS	1.2	0.3	0.7	1.4	2.2	15.4	0.1
KIDNEYS	1.1	1.7	9.1	10.6	7.4	33.2	1.8
THOR_SPINE	0.8	0.8	6.5	7.2	3.7	17.9	1.3
PITUITARY	0.7	0.1	0.5	1.2	2.4	14.1	0.1
ADRENALS	0.5	0.4	5.5	6.6	5.2	24.6	0.7
NECK	0.4	0.4	5.8	6.9	3.8	12.9	2.4
TOTALS	98.6 %	98.6 %					

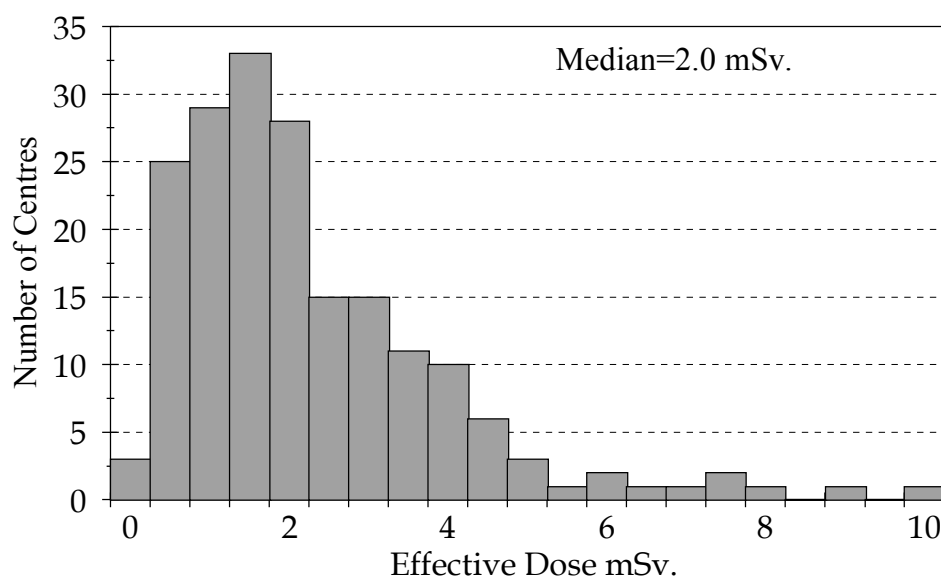


Figure 8 Histogram of the effective doses from routine head examinations.

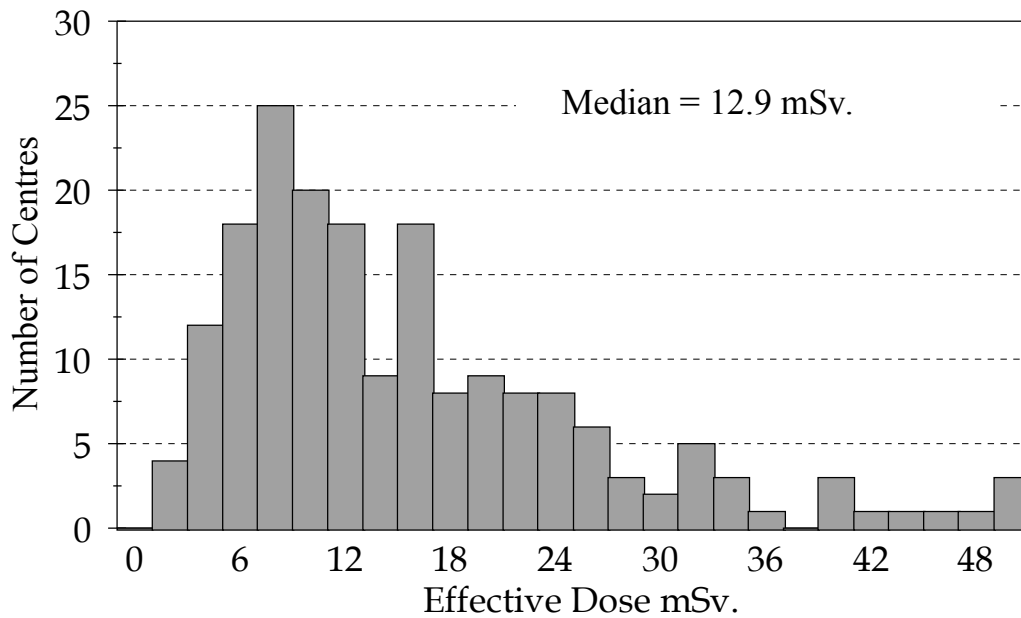


Figure 9 Histogram of the effective doses from routine abdomen examinations.

3.8 Comparison of Effective Doses with Other Works.

Table 10. shows the average effective doses from this survey compared to those from surveys in Norway ⁽⁹⁾, UK (NRPB) ⁽²⁾ and New Zealand (NRL) ⁽⁶⁾.

There is generally good agreement between the doses from the present work and those from Norway and New Zealand. The doses from the UK study are consistently lower than the other studies. A more detailed comparison of the present results with those from New Zealand indicates good agreement except for routine abdomen, pelvis and post fossa examinations. In these particular cases dose values from the present work are considerably higher. It is suspected that the main reason for this lies in the difference in the average number of scans per exam recorded by the two surveys. An examination may consist of only one scan, either without or with contrast. Alternatively, an examination may consist of two scans, one with and one without contrast. If other factors remain unchanged, the exams with two scans will result in twice the dose. The average number of scans per examination are displayed in the right hand columns of Table 10. For the exceptions noted above, the differences in the doses is consistent with the greater number of scans per exam used in Australia.

Table 10 Comparison of average effective dose with those from surveys in Norway, UK and NZ.

EXAM	MEAN DOSE mSv (This Work)	MEAN DOSE mSv (NORWAY)	MEAN DOSE mSv (UK)	MEAN DOSE mSv (NZ)	AVG NO OF SCANS Per Exam (This Work) (NZ)	
HEAD	2.6	2.0	1.8	2.2	1.63	1.28
ABDOMEN	16.7	12.8	7.2	11.6	1.72	1.11
LUM SPINE	5.2	4.5	3.6	5.0	1.02	0.97
CHEST	10.4	11.5	8.3	9.9	1.40	1.14
PELVIS	11.0	9.8	7.2	7.2	1.50	1.02
POST FOSSA	1.9	-	0.7	1.0	1.72	1.40
FACE BONES	1.2	-	0.7	0.6	1.03	1.00
CERV SPINE	5.2	-	2.9	3.2	1.03	1.01
LIVER	12.7	11.9	7.2	6.6	1.81	1.12

It is not clear why the doses from the UK study are generally lower than the other studies. It may be attributed in part to a lesser number of scans per exam in the other studies. It is not clear in the NRPB report how the data on examinations both pre and post contrast were treated in relation to examinations only requiring a single scan. The NRPB questionnaire appears flawed in that the answer to the question '% of patients having contrast medium?' does not allow the data to be separate into the three possibilities; only without contrast, only with contrast and both with and without contrast. It may be that this inability to separate the three alternatives has led to an underestimate of the doses for examinations in the NRPB results.

3.9 Mean and Collective Population Doses.

The mean effective dose per CT examination in Australia was determined by summing the product of the effective dose and the number of examinations for each type of examination at each centre, and dividing this by the total number of examinations recorded in the survey. The collective effective dose was determined by multiplying the mean dose per examination by our estimate of the total annual dose from CT examinations in Australia. The per caput effective doses were determined by dividing the collective dose by the size of the Australian population. The mean effective dose per examination, collective dose, and dose per caput are shown in Table 11 compared to those in other Countries.

Table 11 Mean and Collective Population Doses.

	AUSTRALIA This Work (1994)	U.K. NRPB (1989)	N.Z. NRL (1992)	JAPAN (1989)	
NUMBER OF EXAMS in 1000's	1060	850	62	12000	
MEAN DOSE PER EXAM	6.6	3.9	4.4	4.7	mSv.
COLLECTIVE DOSE	7000	3300	273	56000	Person.Sv
MEAN DOSE per CAPUT	0.39	0.059	0.08	0.45	mSv

The mean effective dose of 6.6 mSv for Australia is higher than that found by studies in other countries. A probable explanation for this, as indicated earlier, is that on the average a larger number of scans per examination is used in Australia.

The mean effective dose per caput of 0.39 mSv in Australia is approximately 5 times greater than in New Zealand and 7 times greater than in the UK. This larger per caput effective dose in Australia is predominantly due to the larger number of CT examinations per head of population. It should be noted that the UK data was for 1989 and we would anticipate a significantly larger value today because of the steady growth in the use of CT. The per caput dose is, however, comparable with the value of 0.45 mSv found for the Japanese population which has about a 50% greater examination rate than Australia.

In the UK, the NRPB estimated a per caput effective dose from diagnostic procedures excluding CT, of about 0.4 mSv. There have been no recent estimations of the effective dose per caput from general diagnostic radiology in Australia. If assumed that the overall dose from non - CT procedures in Australia is of a similar size to that found in the UK, then the per caput dose of 0.39 mSv from CT examinations, determined by the present study, is about half of the total population dose from all diagnostic examinations.

4. RISK FROM CT IN AUSTRALIA.

The ICRP 60⁽¹⁴⁾ gives a risk coefficient of 4×10^{-2} for radiation induced fatal cancers per Sv. (4 per 100 Sv.) for a population of working age. Using this coefficient, and the doses from the present survey, the total number fatal cancers and the number fatal cancers per examination have been determined and are given in Table 12. It is estimated that CT procedures in Australia could be inducing about 280 fatal cancers per year and that is about one fatal cancer induced for every 4000 examination.

Table 12. Risk from CT Examinations in Australia.

ICRP RISK OF FATAL CANCERS (Working Age Population)	4 X 10	per Sv
COLLECTIVE DOSE	7000	Sv/yr
INDUCED FATAL CANCERS	280	Cancers/yr
RISK per EXAM.	0.0003	Cancers/Exam.

To put these into perspective the total number of induced cancers is of the order of 15% of the breast cancer deaths or 20% of the motor vehicle deaths in Australia. The risk per examination is about the same as driving 30,000 km.

There is, however, considerable uncertainty in this risk coefficient. The only direct evidence for radiation induced cancers in humans comes from studies of population exposed to high doses of radiation. Estimates of risk at low doses are made by extrapolation from these high dose studies using a linear-quadratic dose response function. Apart from the validity of this type of extrapolation, there are many other sources of uncertainties. An extensive survey of these sources of uncertainty and their effect on the risk coefficient has been carried out by the National Council on Radiological Protection⁽²⁷⁾. This study puts the 95% confidence limits on the overall risk coefficient at between 1.5 to 8.2 x 10⁻² fatal cancers per Sv. In the present study, this uncertainty alone will give the 95% confidence range for the number of fatal cancers induced per year from CT examinations at between 100 and 570.

There are also some mitigating factors that may reduce the estimate of the number of induced cancers made here. One such factor is that CT patients may have a shorter life expectancy than the general population because of their poorer state of health. Unfortunately we have no data on this but judging from the very large number of CT examinations the majority must be performed on patients with life expectancies not too different from the overall population.

The assessment of risk from radiation exposure depends on the age distribution of the exposed population. This comes about partly because young people are more radiologically sensitive and partly because younger people will carry the ongoing risk for a longer period because of their greater life expectancy. Figure 10 shows Medicare data on the ages of patients undergoing all types of CT examinations. The distribution is weighted towards the ages from 30 to 70 yrs and has a median age of about 45 years of age. This distribution is not very different to the adult worker population of between 25 and 64 yrs used by the ICRP which also has a median age of about 45 yrs. The patient age distribution is, however, different for

different types of examination. For examinations of the spine, the age distribution is weighted toward middle age. For examination of the brain with and without contrast the distribution is weighted towards older ages but for examinations only without contrast the distribution is fairly flat with age. The age distribution for extremity examinations is unusual in that it is significantly weighted towards young people.

In view of the age distribution found for CT examinations the assumption of a risk factor based on an adult working population would seem to be reasonable and would not be expected to lead to large errors in the risk assessment.

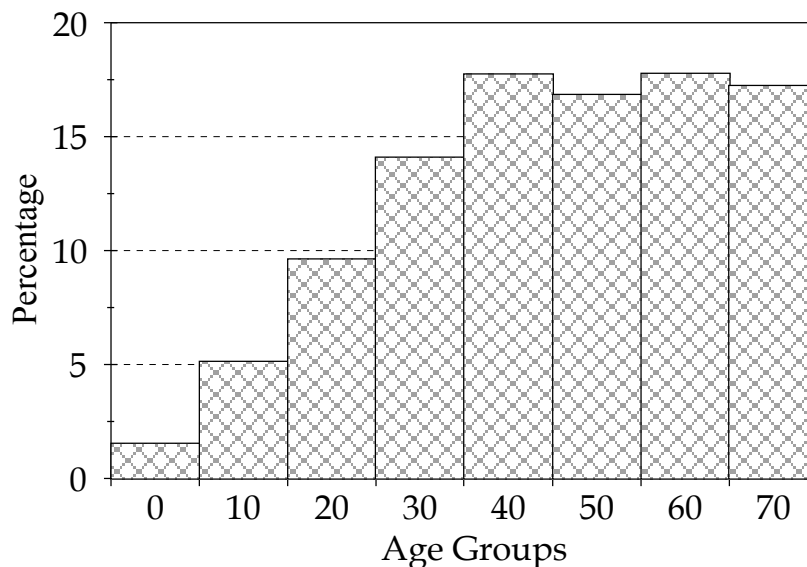


Figure 10 Age distribution of all patients having CT examinations (Medicare data).

5. CONCLUSIONS

The main conclusion to be drawn from the survey results is that CT has become a major if not the main contributor to the doses from diagnostic radiology. There is a potential risk of inducing between 100 and 570 fatal cancer per years from CT examinations in Australia. In view of this potential risk, effort needs to be put into dose reduction techniques and strategies. Some of the more important factors are the reduction in the number of slices used to the minimum needed to obtain the required clinical information and the tailoring of technique factors for different sized patients. Referring physicians should be aware of the potential risks from CT and choose this modality only if the likely benefit to the patient is greater.

References

1. Shrimpton, P. C., Hart, D., Hillier, M. C., Wall, B. F. and Faulkner, K. *Survey of CT Practice in the UK. Part 1: Aspects of Examination Frequency and Quality Assurance.* Report No NRPB-R248 (National Radiological Protection Board, Chilton, UK) (1991).
2. Shrimpton, P. C., Jones, D. G., Hillier, M. C., Wall, B. F., Le Heron, J. C. and Faulkner, K. *Survey of CT Practice in the UK. Part 2: Dosimetric Aspects.* NRPB Report No NRPB-R249 (National Radiological Protection Board, Chilton, UK) (1991).
3. Jones, D. G. and Shrimpton, P. C. *A National Survey of CT Practice in the UK, Part 3: Normalised Organ Doses Calculated using Monte Carlo Techniques.* Report No NRPB-R250 (National Radiological Protection Board, Chilton, UK) (1991).
4. Shrimpton, P. C. and Wall, B. F. *Assessment of Patient Doses from Computed Tomography.* Radiat. Prot, Dosim. 43,(1/4), 205-208 (1992).
5. Shrimpton, P. C. and Wall, B. F.,. *The Increased Importance of X-ray Computed Tomography as a Source of Medical Exposure.* Radiat. Prot, Dosim. 57,(1/4), 413-415 (1995).
6. Poletti, J. L. *Doses to Patient from CT Scanning in New Zealand.* Report NRL 1992/5 (Christchurch: National Radiation Laboratory) (1992).
7. Poletti, J. L. *Patient Doses from CT in New Zealand and a Simple method for Estimating Effective Dose.* Br. J. Radiology 69, 432-436, (1996).
8. Van Unnik, J. G., Broerse, J. J., Geleijns, J., Jansen J. Th. M., Zoetelef, J. and Zweers, D. *Survey of CT Techniques and Absorbed Dose in Various Dutch Hospitals.* Br J Radiology 70, 367-371, (1997).
9. Olerud, H. M. *Analysis of Factors influencing Patient Doses from CT in Norway.* Radiat. Prot. Dosim. 71,(2), 123-133 (1997).
10. Szendro, G., Axelsson, B. and Leitz, W. *Computed Tomography Practice in Sweden. Quality, Control, Techniques and Patient Dose.* Radiat. Prot. Dosim. 57(1/4), 469-473 (1995).
11. Jessen, K. A., Christensen, J. J., Jorgensen, J., Petersen, J. and Sorensen, E. W. *Determination of Collective Effective Dose Equivalent due to Computed Tomography in Denmark in 1989.* Radiat. Prot. Dosim. 43(1/4), 37-40 (1992).

12. Maruyama, T., Kumamoto, Y., Noda, Y., Iwai K., Mase, N., Nishizawa K. and Furuya, Y. *Determination of Organ or Tissue Doses and Collective Effective Dose from Diagnostic X Ray Examinations in Japan*. Radiat. Prot, Dosim. 43,(1/4), 213-216 (1992).
13. Metler, F. A., Briggs, J. E., Carchman, R., Altobelli, K. K., Hart B. L. and Kelsey, C. A. *Use of Radiology in U.S. General Short Term Hospitals: 1980 - 1990* Radiology 189, 377-380 , 1993.
14. International Commission on Radiological Protection. 1990 *Recommendations of the International Commission on Radiation Protection*. ICRP Publication 60 (Oxford: Pergamon Press) (1991).
15. Nishizawa, K., Maruyama, T., Takayama, M., Okada, M., Hachiya, J. and Furuya, Y. *Determinations of Organ Doses and Effective Dose Equivalents from Computed Tomographic Examinations*. Br. J. Radiol. 64, 20-28 (1991).
16. Jessen, K. A., Franklin, P., Jensen, L. C and Christensen, J. J. *Phantom Measurements for Quality Control In Computed Tomography*. Radiat. Prot. Dosim. 49,(1/3), 237-240 (1993).
17. Janeczek, J. and Pernicka, F., *The Measurement of CT Scanner Radiation Dose Profile Using TL Dosimeters*. Radiat. Prot. Dosim. 60,(3), 231-235 (1995).
18. Calzado, A., Ruiz Sanz. S. and Melchor, M. *Dosimetric Study of-the Diagnostic Examinations with Computer Tomography in the Autonomous Community of Madrid during 1991*. Internal Report (Catedra de Fisica Medica, Madrid) (in Spanish) (1992).
19. Christensen, J. J., Jensen, L. C., Jessen, K. A., Jorgensen, J., Petersen, J. and Sorensen, E. W. *Dosimetric Investigations in Computed Tomography*. Radiat. Prot. Dosim. **43(1-4)** 233-236 (1992)
20. Jansen J. Th. M., Geleijns, J., Zweers, D., Schultz, F. W. and Zoetelef, J. *Calculation of Computed Tomography Dose Index to Effective Dose Conversion Factors Based on Measurement of the Beam Profile Along the Fan Shaped Beam*. Br J Radiology 69, 33-41, (1996).
21. Thomson, J. E. M. and Tingey, D. R. C. *Measurement of Computed Tomography Dose Indices with a Mailed Out Thermoluminescence Dosimetry Monitor*. to be published as an Australian Radiation Laboratory Technical Report.
22. Zankl, M., Panzer, W. and Drexler, G. *Tomographic Anthropomorphic Models. Part II: Organ Doses from Computed Tomographic Examinations in Paediatric Radiology*. GSF-Bericht 30/93 (GSF-Forschungszentrum fir Umwelt und Gesundheit, Neuherberg, Germany) (1993).

23. Zankl, M., Panzer, W. and Drexler, G. *Calculation of Organ Doses from Computed Tomographic Examinations*. Radiat. Prot. Dosim. 43(1/4), 237-239 (1992).
24. Panzer, W., Scheurer, C. and Zankl, M. *Dose to Patients in CT Examinations. Results and Consequences from a Field Study in the Federal Republic of Germany*. In: *Optimization of Image Quality and Patient Exposure in Diagnostic Radiology*, BIR Report 20. Eds. B. M. Moores, B. F. Wall, H. Eriskat and H. Schibilla, pp. 185-188 (London: British Institute of Radiology) (1989).
25. Le Heron, J. C. et al '*A Computer Program to Calculate Organ and Effective Doses using NRPB Data.*' National Radiation Laboratory Christchurch New Zealand.
26. Nishizawa, K., Personal Communication. (1995)
27. '*Uncertainties in Fatal Cancer Risk Estimates in Radiation Protection.*' National Council for Radiation Protection Report NCRP No 126 (1997)
28. Shrimpton. P. C., Personal Communication.(1995)

Appendix A

QUESTIONNAIRE PAGE 1.

Ref. no:

1. DO YOU WISH TO PARTICIPATE IN THIS SURVEY ?

YES / NO

If you answer NO you will not be contacted again concerning C.T. However, you may care to indicate your reason for not participating (e.g. No longer perform C.T. , Data requested is not available, have already participated in too many surveys). This will enable us to close off your entry in our data base the most appropriate manner.

2. RADIOLOGICAL CENTRE (Update where necessary in space provided)

Practice Name:

Address:

Contact Person:

Phone No:

Practice Type (private or public) ?

3. SCANNER DETAILS (Update where necessary in space provided)

Location:

Room/Dept:

Address:

Contact Person:

Phone No:

Make of Scanner:

Model:

4. TOTAL NUMBER OF EXAMINATIONS PER MONTH ?

5. WHAT PERCENTAGE OF ALL EXAMS ARE FUNDED BY THE HOSPITAL OR INSTITUTION AND WILL NOT RESULT ANY MEDICARE CLAIM ? †

† This question is optional but answers would greatly assist us in making statistical estimates, from our Medicare records, of the contribution to population doses from centres who do not reply to this survey.

QUESTIONNAIRE PAGE 2.

Ref. no:

5. TECHNIQUE FACTORS:

	ROUTINE HEAD	POST FOSSA	PITUITARY	IAM's	ORBITS	FACIAL BONES	CERVICAL SPINE	THORACIC SPINE	ROUTINE CHEST	MEDIA - STINUM
Number of Examinations per Month (see note 1)										
Applied Potential (kVp)										
Radiographic mAs. per Slice.										
% of Exams. done only without contrast.										
% of Examinations done only with contrast.										
% of Exams done both with & without contrast.										
Slice Thickness (mm)										
Number of Slices per scan (see note 2)										
Couch Increment (mm) (see note 2)										
% having non-tomo Survey Scans (see note 3)										

- Notes:**
1. Consider each category separately although individual patients may undergo combinations of examinations. Fractions may be necessary for infrequent examinations.
 2. If different techniques used with and without contrast write, answers as ' num. slices without/ num. slices with ' etc. for example 20/10.
 3. Scans, Scoutview, Scanogram, Topogram etc.

QUESTIONNAIRE PAGE 3.

Ref. no:

5. TECHNIQUE FACTORS:(Continued)

	ROUTINE ABDOMEN	LIVER	PANCREAS	KIDNEYS	ADRENALS	LUMBER SPINE	ROUTINE PELVIS	PELVI- METRY	OTHER	OTHER
Number of Examinations per Month (see note 1)										
Applied Potential (kVp)										
Radiographic mAs. per Slice.										
% of Exams. done only without contrast.										
% of Examinations done only with contrast.										
% of Exams done both with & without contrast.										
Slice Thickness (mm)										
Number of Slices per scan (see note 2)										
Couch Increment (mm) (see note 2)										
% having non-tomo Survey Scans (see note 3)										

- Notes:**
1. Consider each category separately although individual patients may undergo combinations of examinations. Fractions may be necessary for infrequent examinations.
 2. If different techniques used with and without contrast write, answers as ' num. slices without/ num. slices with ' etc. for example 20/10.
 3. Scoutview, Scanogram, Topogram etc.