Contents lists available at

Journal of Association of Radiographers of Nigeria

Journal homepage: www.jarn-xray.org

Estimates of Paediatric Doses for Common Radiographic Procedures in some Nigerian Hospitals

Nneoyi O. Egbe[1*], Samuel O. Inyang[2], Olisemeke Bernard[3], William E. Azogor[4]

1. *Department of Biomedical Physics & Bioengineering, University of Aberdeen, UK*
2. *Department of Physics, University of Calabar ,Calabar, Nigeria*
3. *Queen Elizabeth Hospital, Heart of England NHS Trust, Birmingham, UK*
4. *Department of Radiography, University of Calabar, Calabar,Nigeria.*

Correspondence

Permanent Address:

Department of Radiography, College of Medical Sciences, University of Calabar, Nigeria.

E-mail*: nneoyiegbe@yahoo.com*

ARTICLE INFO

Article history

Received March 5, 2008;
Revised November 15, 2008;
Accepted December 12, 2008
Available online, 2008

Keywords:

Effective dose, organ dose, Radiology, Technique, paediatric radiography

Abstract

Purpose: To determine and establish doses in paediatric radiography for hospitals which have no previous data.

Materials and Methods: X-ray examination data were collected and used as input in a dose calculation software (DOSECAL, from St. Georges' Hospital, London) to obtain absorbed doses to the skin (entrance surface dose, ESD) as well as organ and effective doses. The study covered five common radiological examinations.

Results: Entrance surface and effective doses were found to be generally higher in agreement with an earlier study using thermoluminescent dosimetry, while organ doses were lower than the values for similar age groups in the literature. Causes of these high doses are attributed to the type, age and conditions of radiographic equipment, radiographic exposure factors (low kVp - which also accounts for low organ doses, and high mAs in some cases), film processing conditions and lack of quality assurance programmes. Suggestions and recommendations are outlined for dose reduction to within recommended international limits.

Conclusion: Doses obtained in this study will serve as a basis for comparison of future studies in the area.

Introduction

Doses from medical sources remain, to date, the highest source of ionizing radiation to mankind. Radiographic examination of the patient is carried out when the accruing benefits outweigh the

disadvantages, because every radiological procedure involving x-ray has some risk associated with it [1–3]. The quantity of radiation received by a patient depends on the radiographic technique, quality of equipment used, the operator's skills and local standards [4]. To regulate radiation dose, the International Commission for Radiological Protection (ICRP) recommends adherence to the 'as low as reasonably achievable' (ALARA) principle [5]. Similar guidelines have been developed in Europe[6], while in Nigeria, the Nigerian Nuclear Regulatory Authority (NNRA) has been set up to regulate the use of ionising radiations and nuclear radiation sources[7].

The establishment of the NNRA notwithstanding, actual quantification of the risk involved in radiological practice involving x-rays, generally and children in particularly, in Nigeria has been lacking and as such there is for now, and to the best of our knowledge, no data on radiographic dose quantities for paediatric patients, and no national dose reference levels for the country. The work carried out by Ogundare et al [8] reports ESDs in children in three Nigerian hospitals, but did not include effective doses.

Paediatric patients' examinations require special care and attention, special equipment and rooms, adequate time, special techniques, adequate radiation protection measures essential for good practice. Besides, these patients are more sensitive to radiation injury [9 – 10] and have a higher life expectancy than adults. Technical conditions are less optimized in paediatric radiology than in investigations of the adult patient [9].

This work follows from UNSCEAR's recommendation of the review of practice [11] and attempts to assess the quantities of entrance surface dose (ESD) and radiation risk (detriment), from the effective doses E, to paediatric patients in three Nigerian hospitals, for some common radiological examinations. This is important because stochastic radiation risks of carcinogenesis and genetic effects are generally greater for children than for adults [1] and the problems encountered in undertaking radiological procedures in developing countries, like aging and in many cases inadequate equipment, poor radiation protection practice and insufficiently developed quality assurance and control programmes suggest a high profile need for acquisition of data on radiological services.

The present study highlights the radiographic technique for paediatric patients in the listed centres, and the ESD and effective doses for the most frequently performed radiological procedures. It was observed that paediatric patients form about 60% of total attendance at the three x-ray centres over the period of monitoring (1 month) for each centre. The results will add to the available dose information for this category of patients. It is expected that it will not only provide information on the radiation risk to paediatric patients

undergoing common radiological procedures, but serve as reference material against which future measurements will be compared.

Materials and Method

The study was carried out in three public tertiary hospitals with x-ray facilities for general purpose radiography. The hospitals were assigned identification codes for the study PAM, NAM and SAM. The codes had no particular meanings, but were used purely for identification in the current study.

None of these has dedicated facilities for paediatric radiology examinations or quality control programme of the x ray facilities. Summary of the departmental positions on equipment, patient distribution for the examinations as well as average and range of exposure factors recorded in the study are presented in Tables 1, 2 and 3, respectively. Only routine examinations, which excluded the use of contrast media, were included in the study. The distribution of the examinations studied reflects, the frequency of their occurrence in the centres

Over a period of three months, 168 children between the ages of 1 month and 10 years who presented in the hospitals for radiological examination were monitored in the study. Exposure data from respective patient radiographic examination in chest, abdomen, skull, pelvis and lumbar spine studies were recorded. The tube potentials (kVp), tube current and exposure time (mAs), focus to film distance (FFD), tube filtration, as well as patient weight and age were used as input data into the Dosecal. The Dosecal software was developed by St. Georges Hospital, London, and has been used in patient dose studies elsewhere [3, 12]. ESD (mGy), E (mSv) and organ equivalent doses were obtained as output. Doses obtained were compared across the hospitals and with values in the literature.

Results

The results are given in age limits of 0 - 1 year, 1 - 5 years and 5 – 10. Sample sizes in some examinations were very small (< 10) as shown in Table 2. However, doses for such examinations are reported because it was very difficult to obtain sufficient numbers of patients in every category. Though these small sample sizes would normally introduce increased error, they are reported because this work is the first attempt at estimating effective doses in the area of study, and as such, the data is essential for comparison with future measurements.

Mean entrance surface dose per age range are presented for the three hospitals and compared with published data [13-14] in Figure 1. The mean values of ESD and effective doses (E) with their first and third quartile values, as well as the standard error (SE) of mean are shown in Table 4, presented by age range.

Table 5 shows mean effective doses for the three hospitals in this study

compared with data published for two hospitals in Brazil and a large Italian hospital [12, 15–16]. No data was found for countries in the same healthcare level with Nigeria for direct comparison. Typical organ doses for ICRP organs are presented in Table 6 for three projections, chest, abdomen and pelvis for the age range 0-1 years. Organ doses were generally lower than the values given for children aged 0 years in NRPB-R279 [17]. The results generally show high ESD and E values across the hospitals monitored with SAM recording the lowest values for both ESD and E, respectively.

Discussion

Radiographic parameters observed in this study (Table 1) show that apart from tube filtration in the three hospitals, all other parameters were found to be below the CEC guidelines for good radiographic practice [6, 18]. The use of different equipment types, radiographic technique for the wide range of patient parameters, naturally introduces variation in doses from examination to examination and from centre to centre for the same examination. This is visible in the wide range of doses recorded in respective centres.

Mean values of entrance surface doses were found to agree with those obtained in the same area in an earlier study [18] using thermoluminescent dosemeters (TLD). Doses were generally higher than recommended dose levels [6] and values found in the literature [12, 15-16].

The absence of quality assurance (QA) programmes in all centres, use of old equipment or mobile units for routine and special cases, a seeming indifference to radiation protection requirements and the use of manual processing which gives room for manipulation, can be cited as reasons for the high doses recorded in this study. Values of ESD and E vary from projection to projection for the same examination, in the same centre and for patients of the same age grouping. Differences in technique, low kVp in NAM as well as high mA in PAM and SAM, were common in centres with more than one radiographer. This could be a direct consequence of the lack of any form of standardization and quality control in any of the hospitals. The type, age and quality of the equipment used might also have contributed to this. Of the three hospitals, only the SAM had equipment aged below ten years. In PAM, a mobile unit (> 20 years) was being used for all cases despite the risk accruing from such use as a result of the increased lower energy photons resulting from the pulsating potential in mobile units [20]. Film processing technique is also a major contributor to the high doses. There is no regular and standardized replenishment of processing chemicals often leading to use of very flat chemicals, necessitating an increase in exposure factors in order to maintain quality of the image. No reference is made in such situations to the increase in dose to the patient. However, the Nigerian Nuclear Regulatory Authority has laid out guidelines towards ensuring

dose control by recommending the presence of radiation quality control personnel in radiological centres.

The organ doses determined by the Dosecal software in this study are lower than those reported in the NRPB-R279 report (Table 6). This may largely be due to the low tube filtration, the predominant use of low kVp in all the centres, and lower average focus to film distance (FFD) than the value (100 cm) used in the NRPB computation. The results in this study are averaged over a spectrum of patient thickness (which couldn't be determined under the clinical conditions) between ages 0 and 1, while the NRPB report was based on a patient thickness of 9.80 cm. An adjustment in radiographic technique, generally, and an increase in beam quality could close this gap.

The probability of radiation risk increases with exposure factors. The presence of radiosensitive organs in the region which received the highest doses for the projection used determines the magnitude of the risk involved. AP projections of the chest have a higher effective dose than PA projection for the same tube potential [21] . This is due to the presence of the relatively radiosensitive breast tissue at the patient entrance where the absorbed dose is highest. Most procedures involving children at the ages studied were done in the AP view, and as may be seen from the result presented, the effective doses (E) obtained in this study are generally higher than recommended values. The danger this portends to children undergoing radiology procedures cannot be overemphasized. The stochastic radiation risks of carcinogenesis and genetic effects are generally greater for children than for adults [1, 4, 10].

Considering the high degree of risk the subjects of this study represent, as a result of higher life expectance and high rate of cell proliferation, these results portend grave consequences for the future of the country. Corrective measures including those listed below are suggested to redress the situation.

1. Withdrawal of mobile units from routine (general) pratice and subsequent restriction of such units to ward and theatre radiography only.
2. introduction of QA in technique and equipment monitoring as well as radiation protection
3. replacement of old equipment with new, preferably dedicated equipment for paediatric radiography
4. Adherence to the justification for examination recommendation.
5. Introduction of radiation protection training and retraining for all radiology personnel [22].
6. Increased surveys to provide data that will lead to the development of national reference doses for the country.
7. Setting up of medical physics units in all tertiary medical facilities with radiation therapy and diagnostic equipment for routine quality control assessment.

Conclusion

Radiation doses (ESD and E) to paediatric patients undergoing radiography have been found to be above those reported in the literature for similar patient elsewhere. The high risk of this category of patients necessitates immediate adoption of dose reduction procedures. The wide range of doses in respective hospitals and across hospitals is indicative of the need for regular surveys geared towards standardization in technique across the country. This report can serve as a basis for comparison, both at the local and national levels. The country's radiation regulatory authority should facilitate urgent surveys towards applying some control on radiological doses to children. There should also be an established dose reference levels. This and the suggestions listed above will provide the needed basis for dose reduction in paediatric radiology in the country.

Acknowledgement

The authors appreciate the staff of the three x-ray departments for their co-operation in carrying out this study. We are thankful to St. Georges Hospital, London, for the use of 'Dosecal' in this work.

References

1. Huda W, Gkanatsios N. (1997). Effective dose and Energy Imparted in diagnostic Radiology. American Association of physicist in medicine, 24(8): 1311-1316.
2. Huda W. (2004). Assessment of the Problem: paediatric doses in screen-film radiography. Pediatr Radiol. 34 (Suppl 3): S173 – S182.
3. Mohammadain KEM, da Rossa LAR, Azevedo ACP, Guebel MRN, Boechat MCB, Habani F (2004). Dose evaluation for paediatric chest x-ray examinations in Brazil and Sudan: low doses and reliable examinations can be achieved in developing countries. Phys Med Biol. 49: 1017 – 1031.
4. Axelsson B, Khalil C, Lidegram M, Schuwert P, Mortensson W (1999). Estimating the effective doses to children undergoing heart investigations – a phantom study. Br J Radiol. 72: 378 – 383.
5. International Commission of Radiological protection, publication 26: Recommendations of the international commission on Radiological protection. Annals of the ICRP. 1(3) Pergamum, Oxford 1977.
6. EUR 16261: European Guidelines on quality Criteria for diagnostic Radiographic Images in paediatrics. 1996.
7. Nigerian Nuclear Regulatory Authority. Radiation safety regulations 2006: Radiotherapy, Nuclear medicine and Diagnostic radiology. Lagos: Federal Government of Nigeria; 2006.
8. Ogundare FO, Ajibola CL, Balogun FA (2004). Survey of radiological techniques and doses in children undergoing some common x-ray examinations in 3 Nigerian hospitals. Med Phys. 31 (3): 521 – 524.

9. Almen A, Mattsson S (1995). The radiation dose to Children from x-ray examinations of the pelvis and the urinary tract. British jour of Radiology, 68: 604 - 613.
10. Roebuck DJ (1999). Risk and benefit in paediatric radiology. Pediatr Radiol, 29: 637 – 640.
11. UNSCEAR. 'Sources and Effects of ionizing radiation'. UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000. Report to the General Assembly, with Scientific annexes. Vol 1.
12. Azevedo ACP, Osibote OA, Boechat MC B (2006) Paediatric x-ray examinations in Rio de Janeiro. Physics in Medicine and Biology, 51: 3723 – 3732
13. Hart D, Hillier MC, Wall BF (2002). Doses to Patients from Medical X-ray examinations in the UK – 2000 Review. NRPB W14, National Radiological Protection Board, Chilton, Didcot, England.
14. Hart D, Wall BF, Shrimpton PC (2000) Reference doses and patient size in paediatric radiology. National Radiological Protection Board Report R318, NRPB, Oxon
15. Geleijns T, Broerse JJ, van Vliet M, Lopez N, Zonderland HM (2000). Assessment of Effective dose in paediatric radiology: A survey at 14 Dutch hospitals. Rad Prot Dosim. 90 (1/2): 135 – 140.
16. Compagnone G, Pagan L, Bergamini C (2005). Effective Dose calculation in conventional diagnostic examinations for adult and paediatric patients in a large Italian hospital. Rad Prot Dosim 114 (1 – 3): 164 – 167.
17. Hart D, Jones DG, Wall BF (1996). Coefficients for estimating effective doses for paediatric x-ray examinations. NRPB-R279.
18. Perlmutter N, Arthur RJ, Beluffi G, Cook V, Horwitz EA, Kramer P et al. (1998). The quality criteria for diagnostic radiology images in paediatrics. Radiat Prot Dosim, 80 (1-3): 45 – 48.
19. Egbe NO, Inyang SO, Ibeagwa OB, Chiaghanam NO (2008). Paediatric radiography entrance doses for some routine procedures within eastern Nigeria. Journal of Medical Physics, 33 (1):19 – 35.
20. Simpson PD, Martin CJ, Darragh CL, Abel R (1998). A study of chest radiography with mobile X-ray units. The British Journal of Radiology, 71: 640 – 645.
21. Padovani R (2004). The importance of education and training in reducing patient doses. Eur Radiol Syllabus, 14: 2 – 8.
22. Lee SC, Wang JN, Liu SC, Jiang SH (2005). Effective dose evaluation for chest and abdomen x-ray tests. Radiat. Prot. Dosim., 116 (1-4): 613 - 619

Table 1: Departmental equipment parameters in the centres studied

Parameter	**Details for the centres**		
	PAM	**SAM**	**NAM**
Generator type	GEC MX-4 Mobile , 1phase	Digital Visitor AR30 3 phase, 300 mHz	Easymatic Super 325 1 phase (Universal UX)
Age	> 20 years	3 years	10 years
Focal spot size	1.0/0.5	0.6/1.2	1.0/2.0
Filtration	0.6 mm Al eq.	0.5 mm Al eq.	0.7 mm Al eq.
Film Speed	200	200	200
Film processing	Manual	Manual	Automatic
QA programme	None	None	None

Table 2: Distribution and total number of patients monitored in the study

	No. of patients		
Examination	PAM	SAM	NAM
Chest	44	18	21
Abdomen	6	3	3
Pelvis	10	7	8
Skull	19	8	10
Lumbar spine	-	4	7
Total no. of patients	**79**	**40**	**49**

Table 3: Average and range of patient ages for respective examinations and the mean and range of radiographic exposure parameters recorded in the study.

		Hospital/centres		
Projection	Criterion	PAM	SAM	NAM
Chest	Age (years)	2.13 (0-9)	2.57 (0-9)	2.25 (0-6)
	kV	50.8 (50-55)	70.04 (60-84)	49.89 (48-50)
	mAs	28.91 (10-80)	1.39 (0.3-6.4)	25.66 (15-45)
	FFD	104.17 (100-150)	105.6 (100-150)	107.9 (100-150)
Abdomen	Age (years)	3.56 (0-10)	2.84 (0-10)	0.45 (0-1)
	kV	71.67 (70-75)	52.5 (50-65)	50
	mAs	40.8 (30-62.4)	3.72 (2-8)	50 (30-75)
	FFD	96.7 (90-100)	92.5 (90-100)	96.7 (90-100)
Skull	Age (years)	3.43 (1-9)	1.41 (0-2)	1.56 (0-2)
	kV	78.4 (75-88)	50	50
	mAs	58.6 (50-62.5)	2.13 (2 -3.2)	43.5 (30 – 45)
	FFD	95 (90- 100)	94.4 (90 -100)	91 (90 – 100)
L. Spine	Age (years)	-	0.75 (0 -2)	0.15 (0 – 1)
	kV		50	50
	mAs		4 (2- 10)	22.5
	FFD		95 (95- 100)	92.5 (90 – 100)
Pelvis	Age (years)	0.53 (0 – 1)	0.5 (0-1)	0.56 (0 – 1)
	kV	67.3 (60 – 84)	50	47.5 (40 – 50)
	mAs	23.5 (12 -45)	4.14 (2 – 8)	23.4 (15 -45.5)
	FFD	95 (90-100)	94.3 (90-100)	91.3 (90-100)

Figures in parenthesis indicate range of variables.

Table 4: ESD (mGy), E (mSV), Q_1, Q_3 values with SEM for all projections in the respective hospitals.

Projection	Age range (years)	ESD (mGy)				E (mSv)			
		Mean	Q_1	Q_3	SEM	Mean	Q_1	Q_3	SEM
NAM									
Abdomen	0 – 1	1.24	1.10	1.41	0.09	0.10	0.08	0.12	0.01
Chest (AP)	0 – 1	1.08	0.96	1.20	0.05	0.11	0.09	0.12	0.01
Chest (AP)	1 – 5	1.09	0.99	1.20	0.07	0.10	0.10	0.12	0.01
Chest (PA)	5 – 10	1.13	1.00	1.30	0.09	0.11	0.10	0.14	0.01
Pelvis	0 – 1	0.72	0.34	0.99	0.12	0.07	0.05	0.99	0.01
Skull (AP)	0 – 1	1.36	1.18	1.49	0.09	0.01	0.01	0.01	0.001
Skull (lat)	0 – 1	1.12	1.01	1.31	0.08	0.11	0.09	0.13	0.01
Skull (AP)	1 – 5	1.35	1.18	1.45	0.06	0.01	0.01	0.01	0.0002
Skull (lat)	1 – 5	1.13	1.10	1.33	0.08	0.11	0.09	0.13	0.01
L. spine	0 – 1	1.15	0.96	1.10	0.15	0.10	0.08	0.13	0.02
SAM									
Abdomen	0 – 1	0.13	0.10	0.16	0.02	0.04	0.01	0.11	0.03
Chest (AP)	0 – 1	0.07	0.06	0.08	0.01	0.01	0.01	0.08	0.001
Chest (AP)	1 – 5	0.13	0.04	0.18	0.05	0.02	0.01	0.02	0.004
Chest (PA)	5 – 10	0.15	0.03	0.33	0.08	0.01	0.003	0.02	0.005
Pelvis	0 – 1	0.17	0.09	0.24	0.03	0.02	0.02	0.04	0.002
Skull (AP)	1 – 5	0.10	0.07	0.11	0.01	0.001	0.0004	0.0006	0.00004
Skull (lat)[a]	1 – 5	0.09	0.07	0.11	0.01	0.001	0.0004	0.0006	0.00004
L. spine	0 - 1	0.20	0.12	0.34	0.07	0.01	0.01	0.02	0.004
L. spine lat	0 – 1	0.32	0.33	0.40	0.02	0.07	0.06	0.94	0.002
PAM									
Abdomen	0 – 1	1.80	1.70	1.90	0.05	0.18	0.17	0.19	0.01
Chest (AP)	0 – 1	0.65	0.52	0.82	0.05	0.30	0.21	0.49	0.05
Chest (AP)	1 – 5	2.02	0.90	2.30	0.28	0.33	0.19	0.50	0.04
Chest (PA)	5 – 10	1.70	0.80	2.60	0.34	0.18	0.08	0.28	0.04
Pelvis	0 – 1	1.58	0.68	2.20	0.27	0.22	0.08	0.31	0.04
Skull (AP)	1 – 5	6.16	5.95	6.72	0.31	0.08	0.06	0.12	0.01
Skull (lat)	1 – 5	5.20	5.24	5.29	0.26	0.07	0.05	0.14	0.02
Skull (AP)	5 – 10	4.67	3.00	6.60	0.52	0.03	0.03	0.05	0.003
Skull (lat)	5 – 10	4.03	3.00	5.60	0.32	0.02	0.02	0.03	0.003

[a] largely same exposure as AP

SEM is the standard error of the mean.

Table 5: Comparison of Effective doses E (mSv) from this study with published values (µSv).

Projection	Age range	This study	*Azevedo et al[12]	#Geleijns et al[15]	++Compagnone et al[16]
Chest (AP)	0 – 1	0.148	9/12		10
	1 – 5	0.149	9/12		
	5 – 10	0.101	9/11	7	
Pelvis (AP)	0 – 1	0.103	88		21
	1 – 5	-	104	26	76
	5 – 10	-	138		
Skull (AP)	0 – 1	1.353+	46/30		
Lateral		-	-		
Skull (AP)	1 – 5	-	28/12		
Lateral		-	11/22		
Skull(AP)	5 – 10	0.029	24/8		15
Lateral		-	11/12		
L. spine (AP)	0 – 1	0.038	-		
	1 – 5	-	-/28		
	5 – 10	-	-/65		
Abdomen	0 – 1	0.108**	-/53		
	1 – 5	-	125/50		
	5 – 10	-	212/51	43	102

+ Data from only one hospital
* Data from two Brazilian hospitals (IFF/HMJ) in Azevedo et al, 2006
** Mean from two hospitals.
# Doses for five year old patient
++ Data for newborn taken as age range 0 – 1 and five year olds as 5 - 10

Table 6: Mean organ doses for ICRP and remainder organs for neonates (0 – 1 year patients) in respective hospitals.

	Organ Dose (mGy)			
Organ	**NAM**	**PAM**	**SAM**	**NRPB**
		Abdomen		
Ovaries	0.105	0.27	0.011	0.574
Testes	0.019	0.05	0.002	1.151
Lungs	0.002	0.008	0.0002	0.280
Stomach	0.24	0.48	0.025	0.822
Lower Large Intestine	0.12	0.29	0.013	
*Upper Large intestine	0.20	0.45	0.021	
Urinary bladder	0.32	0.64	0.034	0.850
Red bone marrow	0.014	0.042	0.0015	0.115
*Small intestine	0.154	0.362	0.016	0.642
*Uterus	0.149	0.365	0.016	0.654
Breasts	0.0014	0.0039	0.0001	
Skin	0.078	0.118	0.008	0.291
Average Remainder	0.071	0.138	0.0075	
		Pelvis		
Ovaries	0.059	0.238	0.014	0.480
Testis	0.419	1.05	0.099	1.396
Lungs	0.00	0.0005	0.00	0.002
Stomach	0.008	0.033	0.0019	0.014
Lower Large Intestine	0.076	0.279	0.018	
*Upper Large intestine	0.107	0.354	0.025	
Urinary bladder	0.202	0.614	0.048	0.921
Red bone marrow	0.007	0.032	0.0016	0.063
*Small intestine	0.084	0.297	0.019	0.088
*Uterus	0.089	0.328	0.021	0.598
Breasts	0.0003	0.0009	0.0001	
Skin	0.054	0.126	0.013	0.212
Average Remainder	0.045	0.131	0.011	
		Chest		
Ovaries	0.0003	0.0003	0.00	0.004
Testis	0.00	0.00	0.00	0.001
Lungs	0.189	0.144	0.012	0.709
Stomach	0.196	0.145	0.012	0.136
Lower Large Intestine	0.0004	0.0004	0.00	
*Upper Large intestine	0.0035	0.0037	0.0002	
Urinary bladder	0.00	0.0001	0.00	0.002

Red bone marrow	0.043	0.031	0.0027	0.104
*Small intestine	0.0020	0.0023	0.0001	0.015
*Uterus	0.0002	0.0003	0.00	0.007
Breasts	0.563	0.361	0.035	
Skin	0.096	0.059	0.006	0.219
Average remainder	0.054	0.039	0.0034	

**Remainder organs*

Average remainder includes the remainder organs not listed above.

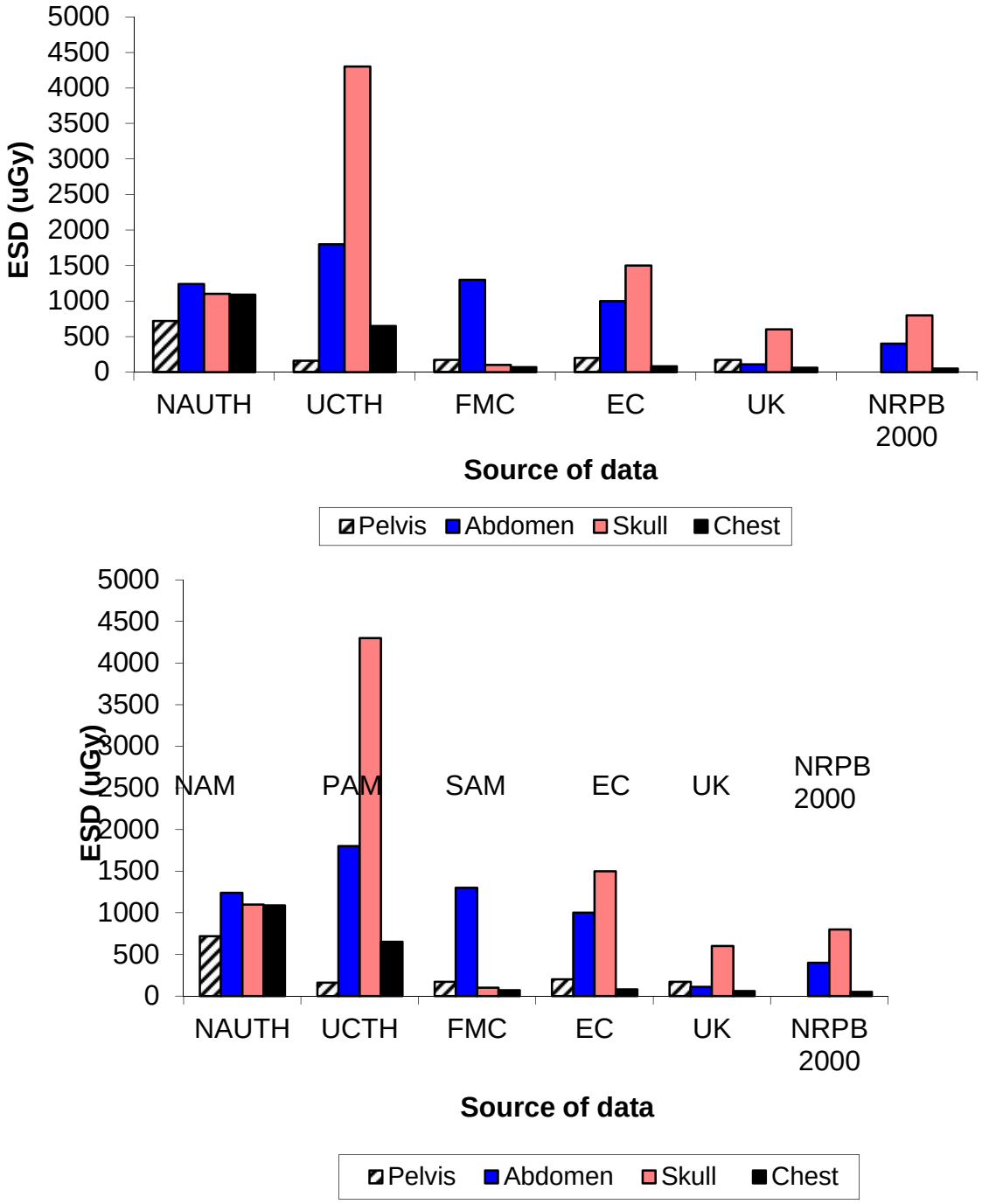

Figure 1: A comparison of ESD from this study (NAM, PAM, SAM) with data from the CEC guidelines (EC) [6] NRPB-W14 report (UK) [13] and NRPB 2000 [14].