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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/773-26

College on Medical Physics:
Radiation Protection and Imaging Techniques

5 - 23 September 1994

Patient Dose Reduction in Diagnostic Radiology

A. Benini

International Atomic Energy Agency
Vienna, Austria

CONTENTS

On sale through HMSO
Price £5.00

ISSN 0958-5648

ISBN 0-85951-327-0

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Documents of the NRPB, Vol 1, No 3, 1990

NRPB

DOCUMENTS OF THE NRPB

Patient Dose Reduction in Diagnostic Radiology

VOLUME 1 NO 3 1990

National Radiological Protection Board
Chilton, Didcot, Oxon OX11 0RQ

The National Radiological Protection Board was created by the Radiological Protection Act, 1970. The functions of the Board are to give advice, to conduct research, and to provide technical services in the field of protection against both ionising and non-ionising radiations.

In 1977 the Board received Directions under the Radiological Protection Act which require it to give advice on the acceptability to and the application in the UK, of standards recommended by international or intergovernmental bodies, and to specify Emergency Reference Levels (ERLs) of dose for limiting radiation doses in accident situations.

Documents of the NRPB contain both the formal advice of the Board on standards of protection as well as guidance on their application in practice.

NRPB

DOCUMENTS OF THE NRPB

Patient Dose Reduction in Diagnostic Radiology

Report by the Royal College of Radiologists and the National Radiological Protection Board

VOLUME 1 NO 3 1990

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Patient Dose Reduction in Diagnostic Radiology

SYNOPSIS

A joint working party on patient dose reduction was established between the Royal College of Radiologists and the National Radiological Protection Board towards the end of 1988. It was set up to investigate the potential for reducing the radiation dose to patients without adversely affecting patient care and to make recommendations on effective methods of patient dose reduction during medical X-ray examinations. This report contains the results of the working party's investigations and makes recommendations for dose reduction, with particular emphasis on the correct justification for X-ray examinations and for the optimisation of radiological procedures and X-ray imaging equipment.

The potential for patient dose reduction on a national scale was found to be high. Earlier studies by RCR on the effective use of diagnostic X-rays, and data from recent surveys of radiology practice by NRPB, enabled a rough estimate to be made of the extent of clinically unhelpful, repeated and unoptimised X-ray examinations in the UK. This indicated that a reduction of nearly one-half in the current collective dose to the population from medical X-rays might be possible without detriment to patient care. This potential reduction in unnecessary medical radiation outweighs the combined contribution of all other manmade sources of population radiation exposure by a factor of three.

An assessment was made of the possible health effects that might occur in patients as a result of medical X-ray exposures, to provide an indication of the need for achieving this potential for dose reduction. In most cases the benefits of diagnostic radiology to the health care of the patient far outweigh the risks from the radiation. However, recently revised radiation health effects models were used to predict that for individual patients undergoing extensive radiological examination in, for example, the course of a long-standing illness or following severe injury, the risk of inducing a fatal cancer could accumulate to a level of one in only a few hundred or so, particularly if the patient is young. This level of risk is justified only when patients receive a commensurate health benefit and everything reasonable has been done to reduce the dose and hence the risk.

A wide range of methods for reducing doses to patients is reviewed, concerned with both the *justification* and the *optimisation* of medical exposures.

It is considered essential that there should be a valid clinical indication for all X-ray examinations and the guidelines on referrel criteria in the new RCR booklet, *Making the Best Use of a Department of Radiology*, are endorsed, with the recommendation that the booklet should be distributed as rapidly as possible to

referring clinicians. The correct justification of X-ray examinations in health screening programmes is particularly emphasised in the report, with specific recommendations for breast cancer screening and for employment-related chest screening programmes.

Optimisation of medical exposures can be achieved by improvements both in radiological *procedures* and in the X-ray *equipment*.

It is recommended that some simplification in the procedures that are adopted for many types of X-ray examination is possible without loss of useful diagnostic information. To help reduce the number of radiographs per examination a list is given of frequently taken projections that are no longer considered necessary following *routine* requests to X-ray particular areas of the body. Procedures are also recommended for minimising the dose during fluoroscopy by encouraging the use of shorter exposure times, smaller X-ray beams and lower dose rates.

A valuable procedure that should be carried out in all radiology departments is the adoption of a quality assurance (QA) programme. As well as regularly checking the operating characteristics of the X-ray imaging equipment, fully effective QA programmes should also assess the performance of the operators of the equipment and must be managed in a way that enables rapid and effective remedial action to be taken when required. A first essential step in optimising patient dose is to make radiologists and radiographers aware of their own performance in this regard and how it relates to generally accepted practice. It is consequently recommended that, as part of a routine QA programme, periodic measurements should be made of the patient entrance surface dose for a few common X-ray projections. Guideline reference values based on the results of national surveys by NRPB are provided as a practical aid to identify those radiology departments in most urgent need of better quality control.

Many recent, and some not so recent, developments in X-ray imaging equipment that offer considerable potential for reducing doses to patients are discussed in the report. It is recommended that priorities for introducing such dose saving equipment into radiology departments should be based on the expected collective dose savings and the financial costs involved. Equipment changes involving lower costs per man Sv averted should take priority, provided that the diagnostic value is not seriously compromised. The working party was particularly concerned that full advantage has not yet been taken of the well-established potential for rare-earth intensifying screens to reduce substantially patient dose while retaining adequate image quality at very moderate financial cost. Long-term cost savings can sometimes result from the reduced power demands of more sensitive imaging equipment and, if so, plans for the progressive installation of such equipment are essential. Health Authorities should be made aware of the regulatory requirements in the UK for a planned programme for replacing equipment that does not incorporate certain dose saving components, such as low attenuation carbon fibre materials in table tops, cassettes and antiscatter grids. It is recommended that the Department of Health should provide Health Authorities with central guidance on the need for, and means of, achieving patient dose reductions when purchasing X-ray equipment.

INTRODUCTION

1 A joint working party (JWP) between the Royal College of Radiologists and the National Radiological Protection Board was set up on the initiative of the Chairman of the Board of NRPB. Members of the Board had been concerned for some time that patients may be receiving unnecessary doses of radiation during X-ray examination. They were also aware of the paradoxically high levels of expenditure in reducing radiation exposure by the nuclear industry compared with the economic stringency faced by many radiologists when seeking improved dose saving equipment in NHS hospitals.

2 The following terms of reference for JWP were agreed at a meeting on 26 August 1988, by the President of the Royal College of Radiologists and the Chairman, Director and appropriate members of the Board of NRPB.

> 'To review the available information on doses incurred during various radiological examinations.
>
> 'To investigate the reasons for variations in patient doses and the potential for dose reduction without adversely affecting patient management.
>
> 'To report to the College and the Board, making recommendations on the means for dose reduction with particular reference to equipment, procedures (including training) and indications for examination.'

3 JWP decided to concentrate on the problems of dose reduction in X-ray examinations which, of all medical diagnostic procedures, make the major contribution to the collective population dose. Consequently, this report deals solely with medical exposures involving X-rays. It summarises the potential and need for patient dose reduction, assesses priorities from amongst the multitude of methods available for reducing medical X-ray exposures and makes specific recommendations to enhance awareness of the most effective methods of dose reduction and to encourage their more widespread application.

4 The membership of JWP is shown in Appendix A.

POTENTIAL AND NEED FOR PATIENT DOSE REDUCTION

Potential dose savings

5 The doses received by patients from diagnostic medical X-rays comprise about 87% of the total collective dose to the population of the UK from all manmade sources of radiation. This in one sense testifies to the enormous benefit to the health of the nation that is attributed to this use of radiation, by both the medical profession and the public. The overall effect of medical X-rays is undoubtedly seen as an improvement in health care and efforts to reduce or control patient doses should in no way jeopardise their potential clinical benefit.

6 Medical X-rays are used far less frequently in the UK than in many other developed countries, with about half the number of X-ray examinations per head of population than in the USA or France, for example. While a net benefit to health may well be achieved by an increase in the provision of radiology services in the UK and a concomitant increase in the collective dose from this source, it can also

be argued that British radiology practice is justifiably more selective than in other developed countries.

7 It is clear that to be of benefit, patient dose reduction measures must be aimed only at *unnecessary* medical exposures. They may be unnecessary because they make no positive contribution to the clinical management of the patient or because they can be reduced by employing alternative procedures or equipment without impairing the diagnostic value. The potential for beneficial dose reduction depends ultimately on the extent to which *unnecessary* medical exposures currently occur.

8 It is difficult to make an overall estimate of the extent to which clinically unhelpful X-ray examinations are requested in the UK. A few studies have been made for specific types of examination, such as routine preoperative chest X-rays[1] and skull radiography following head injury[2], where considerable over utilisation of these procedures had been suspected and was confirmed. JWP feels that it would not be unreasonable to suggest that at least 20% of X-ray examinations currently carried out in the UK are clinically unhelpful in the sense that the probability of obtaining information useful for patient management is extremely low. There are situations where complete X-ray examinations, or individual radiographs that form part of an examination, are repeated on the same patient for reasons that with better management or with better quality control would be avoidable. These also represent unnecessary medical exposures. The problem of the unnecessary repetition of X-ray examinations due to the unavailability of previously-taken films has been studied recently at an orthopaedic clinic in Scotland[3]. One-third of all patients had repeat examinations because the original X-ray films were not sent on by general practitioners, despite being requested. One-third of these repeats were relatively high dose examinations of the lumbar spine. Radiographs are also repeated when the image quality appears unsatisfactory at the first attempt. Studies of repeated radiographs at a number of hospitals throughout the UK[4–6] indicate wide variations in repeat rates (3%–15%), with evidence that the instigation of suitable quality control procedures should enable X-ray departments to reduce their overall repeat rates from the region of 10% to about 5%.

9 It is perhaps useful at this stage to indicate the relative contributions made by different types of X-ray examination to the total collective dose to the population of the UK from all medical and dental X-ray examinations. They will help to identify those areas of radiology where dose reduction measures could be most effectively carried out. These are shown in Table 1, together with the relative frequency of each type of examination. The quantity 'effective dose equivalent' has been used to express the risk-related dose for each type of examination. It can be seen that while examinations of the chest, limbs and teeth are high in frequency they are low in collective dose, because of their low values of effective dose equivalent per examination.

10 An impression of the extent to which the dose from X-ray examinations may be reduced by improvements in techniques or equipment can be gained from studies of the variability in the doses delivered to patients for the same diagnostic procedures.

TABLE 1 *Contributions to the UK collective effective dose equivalent from all medical and dental X-ray examinations*

Examination	% frequency	% collective dose
Computed tomography	2.0	17
Lumbar spine	3.3	15
Barium enema	0.9	14
Barium meal	1.6	12
Intravenous urography	1.3	11
Abdomen	2.9	8
Pelvis	2.9	6
Chest	24	2
Limbs and joints	25	1.5
Skull	5.6	1.5
Thoracic spine	0.9	1
Dental	25	1

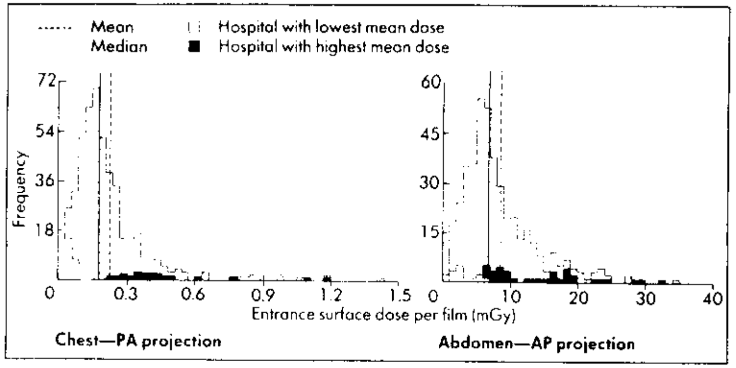
11 In a survey of adult patient doses at 20 randomly-selected hospitals in England in 1983[7], entrance skin doses per film for nominally the same type of radiograph typically ranged over factors of between 20 and 100 for individual patients and between 5 and 20 in the mean value averaged over about 20 patients for different X-ray rooms. A sample of these maximum-to-minimum ratios is shown in Table 2. While higher doses are necessary for individual adult patients of large physique, this fact alone cannot account for maximum-to-minimum ratios of more than about 10 in entrance skin dose. Moreover, this effect should be substantially nullified in the mean dose values for each X-ray room, and yet range factors of between 4 and 24 still persist. Some hospitals would appear to be applying substantially lower dose techniques than others and, as illustrated in Figure 1, are capable of exerting

TABLE 2 *Maximum-to-minimum ratios of entrance skin dose observed at 20 hospitals in England*

Examination	Projection*	Entrance skin dose per film (maximum/minimum)	
		Individual patients	X-ray room mean values
Skull	AP	19	5
	Lat	25	15
Chest	PA	48	11
	Lat	76	24
Thoracic spine	AP	43	4
	Lat	94	4
Lumbar spine	AP	71	11
	Lat	29	5
Abdomen	AP	88	8
Pelvis	AP	37	5

*Projections: AP—anteroposterior; PA—posteroanterior; Lat—lateral.

FIGURE 1 *Entrance surface dose per film during two common X-ray projections at 20 hospitals in England*



much tighter control over the range of doses delivered for each examination. Since it is the entrance skin dose for a presumably adequate image that is being measured, the bulk of this variation will be due to differences in the sensitivity and reliability of the imaging equipment and the way in which it is operated. These operational and technical factors are discussed in more detail later (paragraphs 47–79) and important methods for reducing entrance skin doses per film, which Table 2 suggests are not being universally applied around the country, are included in Appendix B.

12 It could be argued that hospitals with mean dose values lying, for example, in the upper quartile of those observed in the survey are using X-rays inefficiently and are exposing their patients to unnecessarily high doses. On this criterion some 1300 man Sv of unnecessary collective dose could be saved by persuading the 25% of hospitals with the higher doses for each of the six types of examination in Table 2 to change their techniques to fall in line with the remaining 75%. It could also be argued that the median or modal values for the number of films used or for the fluoroscopy time for particular examinations in the survey represent a consensus view on a reasonable maximum value for these parameters. It is believed that a working party of the Royal College of Radiologists will be making recommendations on the desirable number of radiographs to be taken in routine X-ray examinations, and that these recommended numbers will be equal to or less than the median or modal values used in this analysis. This method for selecting a reasonable maximum would consequently not appear to be over-restrictive.

13 Rough, quantitative estimates of the potential annual collective dose savings that could be achieved if these and other sources of unnecessary patient exposure were eliminated are indicated in Table 3, with annual collective doses from other artificial sources given for comparison ('dose' is used here as an abbreviation for 'effective dose equivalent'). They are based on a detailed analysis, currently being carried out by NRPB for the Department of Health, of the English patient dose survey. It is assumed that each method of dose reduction is applied independently

TABLE 3 *Potential patient dose reduct*

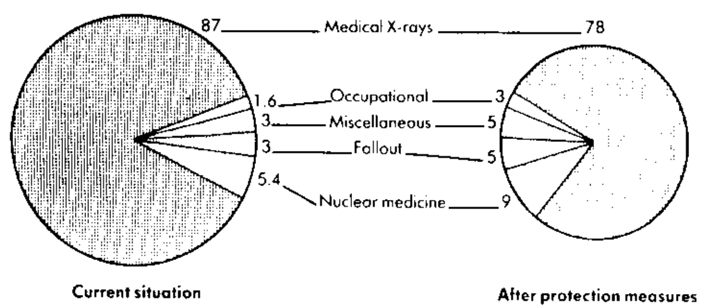
Method of dose reduction	Potential annual collective dose savings (man Sv)
Eliminate clinically unhelpful examinations	3200
Reduce repeat rate from 10% to 5%	600
Reduce number of films per examination to ≤ survey median value	2500
Reduce fluoroscopy time to ≤ survey median value	1500
Reduce hospital mean doses to ≤ survey third quartile value	1300
Other artificial sources	**UK annual collective dose (man Sv)**
Nuclear medicine (patients)	1000
Weapons test fallout	550
Miscellaneous sources (mostly air travel)	550
All occupational doses	300
Nuclear power discharges	30
Chernobyl (first year)	2100

to the current total annual collective effective dose equivalent of about 16 000 man Sv from medical X-ray examinations in the UK[8]. (It is also assumed that about 70% of this total is due to film radiography, the bulk of the remainder being due to fluoroscopy and computed tomography.) The combined effect of the different methods would naturally be smaller than the sum of their individual collective dose savings, since methods applied later would be operating on a progressively smaller collective dose. The potential dose savings from two of the methods of X-ray patient dose reduction would each outweigh the total collective dose from all other recurring artificial sources, even when these other sources include a major component from nuclear medicine. Each method of patient dose reduction considerably outweighs the contributions from the nuclear power industry and all types of occupational exposure.

14 If the above methods of patient dose reduction were to be applied successively throughout the UK the total collective dose reduction could amount to about 7500 man Sv per year, ie, a reduction of nearly one-half in the current annual collective population dose from medical X-rays. The significance of this potential reduction in manmade radiation is illustrated in Figure 2. (Some specific methods of dose reduction involving X-ray equipment, that are discussed in paragraphs 63–68 and Appendix B, could result in even greater dose savings.)

15 In summary, the *potential* for beneficial patient dose reduction is high in the light of evidence for substantial numbers of clinically unhelpful, repeated and unoptimised X-ray examinations, and outweighs the combined contributions from all other recurring manmade sources of population exposure, by a factor of three.

IGURE 2 *Manmade collective dose— potential effects of ical X-ray protection measures*



Note Nuclear power discharges are too small to indicate on piecharts.

Need for patient dose reduction

16 The *need* to reduce patient doses depends on the level of risk to both populations and individuals associated with X-ray examinations. Ultimately, in a resource-limited health service, the need will be met only if the methods and benefits of dose reduction can compete cost effectively with other forms of health care.

17 The paucity of direct evidence for detrimental effects from low doses of radiation has led some radiologists to question the need for any concern. The following quotation from a recent paper on radiology for back pain[9] highlights this opinion.

> 'A restriction or alteration of radiological investigation is often suggested to avoid possible radiation hazard; however, the world literature does not contain a single report of a patient injured by modern diagnostic radiography of the lumbar spine no matter how complex or repeated and it borders on the absurd to argue that this should restrict the patient's investigation.'

JWP does not agree with this opinion.

18 The health effects to be expected from the low levels of exposure prevalent in diagnostic radiology will not, of course, be observable in the short term. They will be delayed by many years and will usually be indistinguishable from those arising from other causes, rendering it difficult to pin-point their origin. It is consequently not surprising that no reports of particular patients being 'injured' by diagnostic X-rays appear in the literature. There is, however, sufficient evidence of the harmful effects of radiation to suggest that a small fraction of cancer deaths may have been caused by prior exposure to medical X-rays. In particular, increases in cancer rates have been identified where defined cohorts of those exposed to diagnostic radiation have been studied, as in those exposed to *diagnostic* radiography whilst *in utero* or those exposed to fluoroscopy that includes the breast.

19 On the basis of recently revised risk estimates for low levels of ionising radiation[10], the estimated annual collective population dose in the UK from unnecessary diagnostic radiology of about 7500 man Sv could be responsible for

between 100 and 250 of the 160 000 cancer fatalities that occur each year. A monetary valuation of the harm associated with an exposure of 1 man Sv in general radiology was estimated at between £5000 and £10 000 by Russell and Webb in 1987[11]. (A value five times higher was suggested for paediatric and obstetric radiology because of the higher risk per unit dose for young patients and parental anxiety.) Since this estimate was made the perception of the cancer risk has increased and so has the Retail Price Index on which the valuation of the human capital losses from radiation-induced fatalities and genetic effects was based. These considerations have led to a 67% increase in the baseline value of the man Sv[12]. Consequently, it would be more appropriate to take about £12 500 as the current value of a man Sv in adult diagnostic radiology. This puts the cost of the harm from the unnecessary exposures in diagnostic radiology at an estimated annual value of about £100 million. The importance of the effort to reduce unnecessary patient exposures is evident.

Somatic risks

20 The probability of a fatal cancer being induced in an individual patient from a single X-ray examination is, of course, very small and is dependent on the age of the patient as well as the type of examination. Approximate estimates for the risk of fatal cancers arising within the lifetime of patients exposed to typical doses from a number of common types of X ray examination are shown in Table 4. The doses and risks apply to complete examinations with average numbers of films and fluoroscopy times. The radiation health effects model used for estimating these lifetime risks is described in Appendix C. It leads to an estimate of the upper and lower bounds of the probability of fatal radiation-induced cancers per unit dose. These two extreme values have been multiplied by a suitably weighted combination of typical organ doses for each type of examination to give the values quoted in Table 4. It should be appreciated that the risk factors used have been averaged over all ages and both sexes in the UK population.

TABLE 4 *Typical lifetime risks of fatal cancer from X ray examinations*

	Lifetime risk of fatal cancer* (per million)	
Examination	Lower bound	Upper bound
Skull	2	7
Chest	0.7	2
Thoracic spine	15	40
Lumbar spine	30	100
Abdomen	20	60
Pelvis	15	55
Intravenous urography	60	200
Barium meal	50	170
Barium enema	100	350

*Average for all ages and both sexes.

21 For those exposed over the age of 70 years the risks will typically be less than one-third of the lower bound values in Table 4, because their shorter life expectancy reduces the opportunity for expression of delayed radiation effects. For those exposed in the first 10 years of life the situation is not so clear, for reasons explained in Appendix C. On the most pessimistic assumption the risks for those exposed in childhood could be twice the upper bound values shown in Table 4. In addition to these fatal cancers, radiation will induce cancers that can be successfully treated, and it is estimated[10] that the probability of non-fatal cancers arising from radiation exposure will be about 50% of the risk of fatal cancers.

Genetic and fetal risks

22 If patients are of or below reproductive age and their gonads are exposed to X-rays, there is a further risk of inducing severe hereditary disease, which is estimated at 2% per gray to the gonads of either parent, if effects in all subsequent generations are considered[10]. For this reason the use of gonad shields on patients of reproductive capacity has long been advocated for those radiological investigations where the gonads lie close to the primary beam and a shield is unlikely to obscure essential diagnostic information. There is evidence from a previous NRPB survey[11] that such shields are not used as often as they might be, especially on young adult patients.

23 The risk of childhood cancer induction following fetal irradiation *in utero* is now estimated to be 6% per gray to the fetus, with half of these cases expected to be fatal. There are also some indications that fetal exposure can result in adult cancers[10]. While there are large uncertainties in the estimated risk factor it would appear to be similar to that for exposure in the first 10 years of life. The developing brain has been shown to be particularly sensitive to radiation damage between 8 and 15 weeks of gestation and estimates of the risk of severe mental retardation currently stand at 45% per gray for exposures during this period only and on the assumption of a linear dose–response relationship with no threshold[10]. There is some evidence for a threshold dose of between 200 and 400 mGy, below which this effect will not occur, but the data are insufficient to rule out completely a linear dose–response down to zero dose.

24 The probabilities of these effects of gonadal and fetal exposure occurring as a result of typical doses from common types of X-ray examination are shown in Table 5. It must be remembered that the effects of radiation are cumulative and that many patients undergo intensive periods of radiological examination during the course of their medical treatment. The risk of inducing fatal cancer from a series of X-ray examinations required in the course of a long-standing illness or severe trauma may well accumulate to a level of one in only a few hundred or so, particularly if the patient is young. This level of risk is unjustified unless the patient receives a commensurate benefit and everything reasonable has been done to reduce the risk.

25 In general, the exposure of staff in radiology departments to radiation is small, and on a population basis is 10 000 times smaller than the exposure of patients. Techniques of radiation protection of staff are of a high standard in the UK and reductions in staff dose by further refinement of the protection methods can be

TABLE 5 *Typical r of hereditary and f effects from X-ray examinations*

	Probability of radiation effect occurring (per million)			
	Hereditary effect		Effect on fetus	
Examination	Paternal irradiation	Maternal irradiation	Childhood cancer*	Mental retardation†
Lumbar spine	0.2	16	200	1560
Abdomen	2.0	11	170	1300
Pelvis	24	6.3	100	740
Intravenous urography	23	19	220	1610
Barium meal	0.8	9.4	220	1620
Barium enema	5.4	26	960	7200

*Fatal and non-fatal.
†For exposures between 8 and 15 weeks of gestation only and assuming a linear dose-response with no threshold.

expected to have only a marginal effect. However, it should be remembered that reducing the radiation dose to the patient will almost invariably reduce the dose to the staff. This reduction in staff dose is a further incentive to achieve reductions in patient ionising radiation exposure.

26 In summary, the *need* to reduce unnecessary patient doses is evident from the significant levels of risk involved both to certain individual patients and to the population as a whole.

PRIORITIES IN PATIENT DOSE REDUCTION

27 There exists a wide range of methods for reducing doses to patients and the more important ones are listed in Appendix B. They are divided into two types: those that involve changes in radiology procedures, and those that involve changes in the equipment used.

28 In an attempt to assess the relative importance of these methods, two estimates of their potential for dose reduction are indicated wherever possible. The first is an estimate of the percentage by which patient dose can be reduced per examination for which the technique is appropriate, assuming that the method was not being employed previously. The second is an estimate of the potential saving in the annual collective effective dose equivalent from diagnostic radiology if the method were to be applied throughout the UK. This is far more difficult to predict since it requires knowledge of the fraction of the collective dose that will be affected by the particular dose reduction method and the degree to which the method is already being employed in the country. Only a few approximate values are available for this measure of potential dose reduction and some of them have

been taken from Table 3. It should be appreciated that each method is assumed to act independently on the current collective dose of 16 000 man Sv, so that the combined effect will be less than the sum.

29 Perhaps the best method for allocating priorities amongst patient protection options is to rank them in order of cost effectiveness. The financial resources required by each option to effect unit collective dose reduction, measured in cost per man Sv, provide a useful guide to its cost effectiveness. A few illustrative estimates of the cost per man Sv averted are indicated in the last column of Appendix B for those methods of dose reduction where such figures have been published or where the costs may be safely assumed to be zero.

30 The majority of the methods involving a change in *procedure* can be seen to have the great advantage of minimal resource implications and hence zero cost per man Sv averted. Such options should receive priority. Options involving improvements in *equipment* usually cost money and dose reductions will accrue over only the remaining working life of the equipment. Valuations of the cost per man Sv averted will consequently vary considerably for the same equipment modification carried out in different rooms, even in the same radiology department, depending on the patient workload and the remaining useful working life of the equipment in each room.

31 It should be noted that in Appendix B the replacement of calcium tungstate intensifying screens with more sensitive ones, such as those containing rare earths, is indicated to involve zero costs, on the basis of concomitant savings in the cost of films and extended X-ray tube life offsetting the initial replacement cost within a few years. The many methods of patient dose reduction for which no reliable estimates are available of their potential dose savings, or their costs, indicate useful areas for further study. These, and other methods for assessing priorities for spending on dose saving equipment in diagnostic radiology, are discussed further in paragraphs 69–74.

32 It is undoubtedly true that in all cases where the cost effectiveness of patient protection measures has been assessed the measures represent value for money orders of magnitude greater than the corresponding figures of between £5000 and £500 000 per man Sv apparently expended on radiation protection in the nuclear power industry in this country and abroad[14].

33 In the following paragraphs recommendations are made regarding the application of some of the more effective of the dose reduction methods given in Appendix B. The areas mentioned in the terms of reference for JWP are considered under the following headings: referral criteria (indications for examination), radiological procedures, equipment, and training. Specific recommendations are displayed as they occur in the text and are summarised on pp 30–32.

34 It should be appreciated that many of the techniques of patient dose reduction discussed here have been documented previously, particularly in the *Guidance Notes for the Protection of Persons Against Ionising Radiations Arising from Medical and Dental Use*, prepared by NRPB, the Health and Safety Executive and the UK Health Departments and published by NRPB in 1988.

REFERRAL CRITERIA Indications for examination

> JWP considers that it is essential that there should be a valid clinical indication for all examinations of patients where ionising radiation is used. This is particularly important in health screening where there is often considerable controversy regarding the possible benefit.

RCR Study Group booklet

Making the Best Use of a Department of Radiology

35 A committee of the Royal College of Radiologists has, for some years, been investigating the reasons for the increasing demand on radiological facilities. Member of the RCR Committee considered that there was little justification for many radiological examinations and that a reduction in the workload would not only produce considerable cost savings but would also reduce the radiation dose to the patient without adversely affecting patient management.

36 A series of multi centre studies has provided conclusive evidence that certain examinations, such as routine preoperative chest radiographs, should not be carried out. Guidelines have been formulated listing the exceptions, including patients proceeding to cardio/pulmonary surgery, where clinical examination suggests that malignancy or pulmonary tuberculosis is a strong possibility, or when the incidence of pulmonary tuberculosis in the patient's ethnic group may be more than 1:1000[1]. An important study involving patients with head injury has also shown that routine examination in such cases should not be recommended[15]. Guidelines for clinicians where selective radiographic examinations are advised have been shown to be effective in reducing radiological examinations in such cases without detriment to the patient[2].

37 The RCR Committee has now produced a booklet which presents a set of advisory guidelines to help hospital doctors and general practitioners make the most efficient use of their local X ray departments. The guidelines are not intended to replace clinical judgement but to enhance it in times of doubt or difficulty.

38 In the booklet, requests for radiological examinations have been divided into three categories: 'selective', 'routine' and 'screening'. When a patient has signs and symptoms of a particular disease and radiology is used to confirm the diagnosis, such an examination is used *selectively*. In many diagnostic situations circumstantial, as opposed to symptomatic, evidence of a particular disease has become accepted as significant to generate strong suspicion. If an X-ray examination is used to confirm or refute such suspicion, then it is said to be used *routinely*. When the disease occurs only very infrequently, ie, the association between the circumstantial evidence and the disease is weak, then routine radiological examination cannot be justified. When a patient is well and has no signs or symptoms suggesting the presence of a disorder which radiography might reveal, then the examination is used as a *screening* test. Examples include screening for lung cancer or pre-employment examinations in persons without signs or symptoms of respiratory disease. Apart from certain exceptional circumstances such requests should be actively discouraged.

39 The booklet contains guidelines for 12 categories of radiological examinations covering over 70 important clinical circumstances. At present, as part of a research project, the booklet has been introduced into five NHS hospitals and has been accepted by them as hospital policy. National acceptance is being achieved but only slowly. Introducing the booklet and evaluating its impact is a formidable task.

> JWP commends the initiative of the Royal College of Radiologists and endorses its recommendations on referral guidelines. It wishes to encourage rapid dissemination of the booklet.

Mammography screening

40 The Forrest Report on Breast Cancer Screening[15] recommends that breast screening should be reserved for women aged 50–64 years and for those of age 65 years and over on demand. Until strong evidence is available to support the screening of younger women mammographic screening should be limited to women of 50 years or older, with the possible exception of those with a history of premenopausal breast cancer in a first degree relative (sister or mother)[17,18]. Other groups of women who may be considered to be at a higher risk of developing breast cancer, eg, younger women on the contraceptive pill, should not be routinely screened. Cyclical breast pain is not in itself an indication for mammography. Patients with breast symptoms should be referred to a specialist breast clinic where mammography may be requested.

> In the absence of a close family history of breast cancer, JWP recommends that mammography should not be carried out in asymptomatic women under the age of 50 years. In the light of present evidence, there is no justification for the increasing tendency in some sectors actively to encourage women younger than 50 years to take part in mammography screening.

Employment-related chest screening

41 No recent information is available on the frequency of employment-related radiological examinations. The NRPB 1983 review of the frequency of X-ray examinations[19] assumed a total of 140 000 examinations per year, mostly of the chest. This is a small percentage of all examinations carried out, but would still give rise to an annual collective dose of about 5 man Sv. There is no clinical justification for such screening except for those at special risk, eg, some laboratory technicians, those in particularly hazardous occupations, such as beryllium workers or workers from countries in which tuberculosis is endemic (unless they have had a normal chest X-ray in the preceding 6 months). In these groups regular chest examination is justifiable. There is no clinical justification for regular chest screening in other groups, although this has become increasingly popular in some circles.

42 Experience from the NRPB Radiation Protection Adviser work suggests that the justification for many employment-related X-ray screening programmes rests solely on established practice and that some programmes have developed without proper justification for X-ray screening ever having been made.

> JWP therefore recommends that all employment-related radiological screening programmes should be clinically justified and the reasons for screening explained in writing to the employees. The term 'employment-related' should be widely interpreted and encompass programmes aimed at students, the armed forces and those working abroad, as well as general health care programmes for employees.

Computed tomography

43 The number of computed tomography (CT) scanners in the UK has doubled in the past 5 years to the current level of about 200. The complexity of CT examinations has also steadily increased and, in particular, the number of slices imaged on each patient has risen as modern technology has dramatically reduced the time required to perform the scans and reconstruct the images. Little impact has been made, however, on the dose required per slice for images of acceptable quality. Recent developments in CT imaging are consequently likely to have led to substantial increases in both the number of CT examinations undertaken per year and the dose to the patient per examination.

44 NRPB is currently conducting a national survey of CT practice and patient doses and it may well emerge that this method of imaging has become one of the major contributors to an increased collective population dose from medical radiology.

> JWP feels that there may be some radiologists who are not fully aware of the high patient dose implications of CT examinations and recommends that the results of the NRPB CT survey be published and promulgated as soon as possible to remedy this situation.
>
> As far as referral criteria are concerned, all patients subjected to CT examination should be individually referred to an experienced radiologist who will be able to advise whether CT is the most appropriate procedure to be adopted.

45 While this pattern may be the norm in most NHS hospitals, JWP considers that, in the private sector, the criteria for referral should also be under strict control.

Obstetric radiography

46 Ultrasound has now reached such a state of development that almost all imaging of the pregnant uterus to assess fetal development can be satisfactorily carried out using ultrasound. Pelvimetry, in the few cases when it is required, remains the one diagnostic task in obstetrics where an X-ray examination is justified. Low fetal doses can be assured either by using very strict collimation, an air gap instead of an antiscatter grid and fast films and screens[20], or by using a CT scanner to take a linear scanned projection view and a low dose axial scan[21]. Table 6 indicates the potential dose savings of these two techniques compared with conventional pelvimetry[22].

> JWP recommends that no woman should be referred for X-ray examination to assess fetal development when ultrasound facilities are available and that, in the few cases where X-ray pelvimetry is indicated, low dose techniques should be used.

TABLE 6 *Fetal doses from pelvimetry*

Method	Reference	Projection*	% of fetus exposed	Mean dose of fetus (mGy)
Conventional views:	22	AP	50	4
Antiscatter grid		Lat	50	4
Highly collimated:	20			
No grid		AP	5	0.01
Fast film and screen		Lat	5	0.006
CT:	21			
Linear scanned projection		Lat	50	0.02
Low dose axial scan		CT	5	0.005

*Projections: AP—anteroposterior; Lat—lateral.

RADIOLOGICAL PROCEDURES

Availability of previous films

47 There are many occasions, as briefly mentioned in paragraph 8, where radiographs are taken which could have been avoided, if the referring clinician or radiologist had been aware of the existence of previously-taken films and if administrative arrangements existed for their rapid identification, retrieval and transfer. If records of all previously-taken films and their whereabouts were available to referring clinicians, considerable expense as well as patient dose could possibly be averted.

48 The utilisation and effectiveness of film storage, retrieval and transfer systems is known to vary widely around the country and between X-ray departments operating within different areas of health care. JWP is generally not in favour of patients being given responsibility for storing and making available their own films, as is often the case in the private sector. Experience has shown, for example, that only about one-half of films stored in this way in a private sector mammography screening situation were available when required. A lower rate of success could be expected for general radiology patients in NHS hospitals.

JWP can only recommend that a more uniform system is adopted throughout the Health Service regarding who keeps films and where they are stored (eg, general practitioner, clinician or X-ray department), for how long they are stored, and to whom they are transferred on request (eg, radiologist, physician or surgeon).

Limitation of routine projections in radiography

49 An important method for the reduction of radiation dose to patients from diagnostic radiology is the limitation of *routine* projections used in radiological examinations. By routine is meant those projections that would be automatically taken by the radiographer when just a particular type of examination is requested and no additional information is supplied on the request form. The specification of these routine projections is ultimately the responsibility of the radiologist in charge of the department and considerable variation in what is regarded as routine is known to exist from department to department.

50 To obtain up-to-date information on current practice, a survey of 62 hospitals in the UK was undertaken by JWP in March 1989. Radiologists at these hospitals were asked a series of questions to ascertain which projections were used routinely, that is where the radiographer has no specific instructions from a radiologist or clinician, other than to X-ray a particular area. The questions asked and a summary of the answers obtained are listed in Appendix D, together with comments on the results of each examination surveyed. This limited study into some aspects of routine radiographic projections indicates variations from department to department, but it is clear that many departments in the survey have considered the problem and have reduced the number of projections to as few as is reasonably practicable without detracting from the clinical value of the examination. Nevertheless, it is a subject which is under review by a working party of the Royal College of Radiologists and should be audited by every radiology department, for it has both radiation dose and cost implications.

As a result of this survey, JWP recommends that the projections listed in Table 7 should *not* be 'routine'.

TABLE 7 *Radiographic projections which should not be routine*

Examination	Projections* to exclude from routine
Skull	Axial (submento-vertical)
Pituitary fossa	Coned view (PA and Lat skull only should be routine)
Sinuses	PA and Lat (occipitomental only should be routine)
Cervical spine	Lat in flexion Lat in extension Both obliques AP odontoid (if not trauma)
Chest	Lateral
Abdomen (acute)	Erect abdomen (supine abdomen and erect chest only should be routine)
Lumbar spine	Coned view of L5/S1 AP of sacroiliac joints Both obliques
Intravenous urography	One minute film Post micturition films More than six films
Cholecystogram	More than four films (ultrasound is now first method of investigation)
Barium enema	Post evacuation film
Knee	Skyline and tunnel (AP and Lat only should be routine)

Note Further explanation for this selection of undesirable routine projections can be found in the 'Comments' of Appendix D.

*Projections: AP—anteroposterior, PA—posteroanterior, Lat—lateral

Minimisation of dose in fluoroscopy

51 Patient radiation dose can be significant during procedures that involve fluoroscopy. Although a decreasing number of barium examinations of the upper gastrointestinal tract is being performed, the number of barium enemas and small bowel examinations requiring fluoroscopy is mostly unchanged. Overall, fluoroscopy is on the increase and this is mainly because of the increasing number and complexity of interventional diagnostic and therapeutic procedures that are being performed under fluoroscopic control. Many of these procedures are carried out in areas remote from the X-ray department, including intensive care units, endoscopy suites and orthopaedic operating theatres.

52 There are a number of ways that the radiation dose to the patient can be reduced during fluoroscopy.

(1) With improvement in the performance of image intensifiers and the use of image processors with noise reduction facilities, newer fluoroscopy units are capable of a sizeable reduction in dose without loss of image quality.

(2) Significant reductions in radiation dose to the patient can be made by the conscious efforts of radiologists and other clinicians who perform fluoroscopy. During barium studies it may be necessary to follow the column of barium intermittently as it flows through part of the gastrointestinal tract being examined, but this should only be for short periods. Otherwise, fluoroscopy should only be used for positioning and obtaining spot views of a particular segment of intestine or suspected abnormality. The radiologist will frequently identify abnormalities during these short periods of fluoroscopy and may then obtain spot views of the lesion for confirmation. It is important to rely upon the radiographs obtained to identify any abnormal features and the segments that require further evaluation. Extensive fluoroscopy should not be routinely performed in an effort to identify any abnormal features. Short periods of fluoroscopy are permissible when compressing the lumen of the stomach, duodenal cap, segments of small intestine (particularly the ileum), and for compression of the colon.

(3) Intermittent fluoroscopy for short periods with as long intervals as possible in between can significantly reduce patient dose. The memory facility, whereby the last image is stored on the television screen for viewing until the next period of fluoroscopy, is now being used more widely and helps further to reduce fluoroscopy time.

(4) During fluoroscopy the beam should be collimated to the smallest field that is necessary to show the features required. The mA and kV should always be kept as low as is necessary to give an adequate image for the procedure that is performed. On many occasions when catheters, probes, needles, pacemakers, endoscopes and metal parts are being manipulated under fluoroscopic control, the factors are set to give an optimum picture on the image intensifier when much lower factors would produce an adequate picture.

(5) There are still some fluoroscopic X-ray machines being used where collimation to the size of the spot films is not automatic. Thus, when the film is larger than the image intensifier field, the operator has to open the collimator to an unknown distance so that the whole of the film is exposed, often causing irradiation of parts of the patient outside the useful field. After exposure the operator has to remember to 'cone' down again to the size of the intensifier field. Automatic collimation should be added to existing equipment, but if this is not possible the machine should be replaced at an early date.

(6) The antiscatter grid may be dispensed with during fluoroscopy when detail is not required, eg, during the filling phase of a barium enema or during placement of a small bowel tube. Similarly, the grid may be dispensed with if the field size is small, as during some stages of cardioangiography[23,24]. A grid is not necessary during contrast examinations of small neonates.

(7) Fluoroscopy units should incorporate an audible warning system which sounds after a pre-set fluoroscopy time has elapsed, prior to automatic termination of the exposure. Radiologists should be aware of the serious patient dose implications of repeatedly resetting this device during a single examination.

(8) Dose–area product meters, such as the Diamentor (PTW, Freiberg), can be conveniently fitted to the diaphragm housing of X-ray sets to monitor the radiation dose to the patient during fluoroscopic examinations. These can provide a useful guide to the performance of both the equipment and the radiologist in keeping patient dose to a minimum. Diamentor measurements observed during the NRPB national survey are shown in Table 8. They indicate a wide variation in performance at a sample of 20 hospitals. If radiologists were to make their own measurement they would be able to compare their performance with the national norms.

TABLE 8 *Diamen measurements fo fluoroscopic examinations fron NRPB national su*

	Diamentor reading (cGy cm^2) (R cm^2)				
Examination	Minimum	First quartile	Median	Third quartile	Maximum
Barium meal	49	933	1 645	2 766	16 259
Barium enema	618	2 573	4 050	6 093	27 176

JWP recommends that the patient dose during fluoroscopic examinations should be reduced and kept to a minimum by using as low mA and kV factors as possible, by attention to good collimation and short periods of intermittent fluoroscopy and by dispensing with antiscatter grids whenever possible.

Automatic collimation at least down to the cassette size or to the field of view of the image intensifier should be provided at all times.

Regular measurements with a dose–area product meter would establish the effectiveness of these dose reduction techniques.

Quality assurance programmes

53 Quality assurance (QA) is primarily concerned with the maintenance of X-ray imaging equipment at the optimal operational condition for providing the required diagnostic information. It is generally accepted that this condition should be achieved at minimum cost both financially and in relation to the radiation hazard to the patient. The World Health Organisation[25] has defined quality assurance programmes in X-ray medical diagnosis as '. . . an organised effort by the staff operating a facility to ensure that the diagnostic images produced by the facility are of sufficiently high quality so that they consistently provide adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient to radiation'. Establishing acceptable criteria for the benefits, costs and risks associated with medical X-rays should form an essential part of quality assurance activities and hence provide a valuable opportunity for bringing together the prime interest of radiologists (and hence of RCR) in image quality and the interests of health physicists (and hence of NRPB) in patient and staff protection.

54 While the main elements of a QA programme deal with the tests and criteria required to check the operating characteristics of X-ray imaging equipment, the link between the equipment and the patient is the operator (radiologist and radiographer) whose performance should also be of concern in fully effective QA programmes. The factors which indicate the effectiveness of the checks on equipment and personnel performance are the patient dose and the image quality. An indirect method of assessing image quality which is often included in QA programmes is film retake analysis.

55 X-ray equipment performance checks are generally carried out under one of three circumstances:

(1) during acceptance testing of newly installed equipment;
(2) following major repair of faulty equipment;
(3) as routine checks at regular intervals to ensure reliable and optimum performance at all times.

The detailed baseline measurements required in circumstances (1) and (2) will be more exhaustive and require a higher level of accuracy and reproducibility than the routine checks in (3) that need to be simple and quick to perform.

56 The Institute of Physical Sciences in Medicine (IPSM) considers acceptance testing to be an important role of the medical physicist in the scientific and technical support of diagnostic X-ray services and has published a substantial report[26] describing the measurements required for these more exhaustive types of X-ray equipment performance tests. These are given in Table 1 of Appendix E.

57 Routine performance tests are aimed primarily at monitoring constancy of performance. Their results should be comparable with the levels of performance established during acceptance testing on installation but they need to be less time consuming and hence must be less comprehensive. It is a requisite of these checks that they provide early warning of gradual deteriorations in equipment performance that might otherwise go unnoticed, leading to unwitting use of inferior images and/or excessive patient doses. Table 2 of Appendix E gives those tests which are specifically recommended by IPSM for use as routine checks. They are arranged in order of their recommended frequency. Practical guidance on routine performance tests can also be found in references 27 and 28. Routine tests are worthless unless their results are evaluated promptly and accurately and any necessary corrective measures are undertaken. A complete quality assurance programme must include the assignment of responsibility for remedial action as well as the setting-up of routine test procedures and criteria.

> JWP recommends that an appropriate QA programme along the lines indicated above should be instituted in all radiology departments. Where the departments are sizeable it would be appropriate to set up an officially recognised QA group.

Patient dose measurement

58 Patient dose measurements rarely form an integral part of QA programmes. Some dosimetry is undertaken during acceptance testing and routine checks in the form of X-ray tube output measurements under specified operating conditions, but there is generally little quantitative information available to those clinically and physically directing medical X-ray exposures on the specific radiation doses to patients from the procedures that they practice in their departments. X-ray imaging equipment rarely provides direct indication of the dose being delivered to the patient. Practitioners are forced to rely upon general information from the manufacturers or the published literature, that is unlikely to apply to their specific procedures, or on infrequent measurements by their local medical physicists.

59 A first essential step in attempting to optimise patient dose is to make practitioners aware of their own performance and how it relates to generally accepted practice. The data from the NRPB national patient dose survey[7] can provide practical reference doses for assessing performance at the local level. It is recommended that, as part of a routine quality assurance programme in a department, hospitals should regularly monitor their levels of entrance surface dose in each X-ray room for a few common X-ray projections. Initially, a baseline can be established by calculating the mean value of measurements on a sample of adult patients selected at random for each category of radiograph, but excluding extremely large and small patients so that the mean weight of the group is close to 70 kg. Subsequent measurements in the department will allow the impact of any changes in equipment or technique to be monitored.

60 As an initial guideline, it is recommended that all X-ray departments should aim to achieve mean dose levels that are less than the reference doses given in Table 9[29]. These figures are based on the third quartile values for the distributions of mean dose at individual hospitals participating in the national survey. Departments observing levels of mean dose above the reference values should undertake a thorough review of radiographic practice to justify or improve techniques. The proposed reference doses should be seen as a practical aid to increasing general awareness of levels of patient dose and hence to promoting optimisation in medical radiology. The adoption of the third quartile values for these doses is a purely pragmatic approach to help identify the 25% of hospitals, for each type of examination, which would seem to be most urgently in need of better quality control. Attainment of doses below the reference values should not

TABLE 9 *Guideline values of entrance surface dose per film (including backscatter) for a standard 70 kg patient*

Examination	Projection*	Reference dose (mGy)
Skull	AP/PA	5.0
	Lat	3.0
Chest	PA	0.3
	Lat	1.5
Thoracic spine	AP	7.0
	Lat	20
Lumbar spine	AP	10
	Lat	30
	LSJ	40
Abdomen	AP	10
Pelvis	AP	10

*Projections: AP—anteroposterior; PA—posteroanterior; Lat—lateral; LSJ—lumbosacral junction.

be construed as achievement of optimum performance: further dose reductions may still be reasonably practicable. It will be necessary to review regularly the levels of reference dose quoted here in the light of developments in the practice of diagnostic radiology.

61 Reference doses similar to those in Table 9 have been included in a recent European initiative proposing 'quality criteria for diagnostic radiographic images' for selected examinations[50]. These criteria take the form of a specification of the important anatomical structures and details that should be visible in a radiograph of good diagnostic quality of a normal patient, together with examples of good radiographic technique and guidelines on patient dose.

62 Measurement of the entrance surface doses required for checking against the recommended reference levels can be conveniently made by thermoluminescent dosemeters (TLDs) attached to the patient's skin. X-ray departments are encouraged to measure doses to their own patients, either with the help of their local medical physicists or by using a postal TLD patient dosimetry service that NRPB has under consideration. In the long term, manufacturers should be encouraged to build patient exposure monitoring devices (eg, dose–area product meters) into diagnostic X-ray equipment, to provide automatic and instantaneous indication of patient doses for quality control purposes.

> JWP recommends that quality assurance programmes should include periodic measurements of patient entrance skin dose which should be compared with guideline doses based on previous results from each department and on national norms, and this information should be fed back to those clinically and physically directing the medical exposure so that any necessary corrective action can be taken.
>
> Manufacturers should be encouraged to build patient exposure monitoring devices (eg, dose–area product meters) into diagnostic X-ray equipment to provide automatic and instantaneous indication of patient doses for quality control purposes.

EQUIPMENT

Recent developments

63 There have been many developments in medical X-ray imaging equipment in the last decade or so that offer considerable potential for reducing doses to patients. Notable ones are included in Appendix B. It should be remembered, however, that developments in equipment have been primarily aimed at improving the diagnostic value of medical images and that improvements in image quality frequently run counter to reductions in patient dose. Computed tomography is a good example of a modern imaging technique that has considerable advantages in terms of diagnostic value, but at the expense of relatively high patient doses that cannot be reduced without degrading the image. Sensitive imaging systems are invariably 'quantum limited' in the sense that reducing the dose to the image receptor below a certain value will introduce sufficient random variation in the photon fluence rate to give a disturbing mottled appearance to the image. Notwithstanding the above limitations, there are many situations where perfectly adequate image quality can be obtained using more sensitive imaging equipment or where improved design of equipment reduces the dose to the patient but not to the image receptor (eg, carbon fibre components).

64 It should be appreciated that reductions in patient dose resulting from changes in radiological procedures (eg, referral patterns or examination techniques) need constant effort to maintain the benefits. Reducing the radiation dose delivered by the equipment for a given examination, however, will often result in a constant reduction without further effort throughout the life of the equipment. Moreover, it should be appreciated that the cost of some of the modifications to X-ray equipment, that will lead to significant savings in patient dose, is a very small fraction of the capital cost of the complete imaging system.

65 JWP is particularly concerned that the radiology profession appears to be taking an inordinately long time to take advantage of the well-established potential for rare-earth intensifying screens to reduce substantially patient dose while retaining adequate image quality at very moderate financial cost. Rare-earth screens have been available since the early 1970s. However, in a survey at 25 randomly selected English hospitals in 1983[7] only 23% of radiographic X-ray examinations were carried out using rare-earth screens and by 1986 replies from 172 UK hospitals[51] indicated that the figure was still below 50%. Both of the above studies indicate that approximately a further 3000 man Sv could be avoided each year if the most sensitive rare-earth screens, compatible with retaining adequate image quality, were used for all radiographic examinations.

66 Radiologists should also be aware of a number of new imaging systems, that are just becoming available in this country, that all promise considerable reductions in patient dose as well as improvements in image quality. Although many of them involve substantial capital outlay, they may well prove to be more cost effective in comparison with conventional equipment when the time comes to replace existing systems. In particular, recent developments in digital imaging, such as computed radiography (Fuji, Toshiba, Philips, Siemens) and digital spot imaging (Philips), offer digitally-enhanced images at a fraction of the patient dose

required by conventional film-screen or film-intensifier systems. Chest imaging systems are now available that utilise slot or scanned beam radiography to reduce scattered radiation, and use either a linear image intensifier (Philips Pulmo Diagnost 100) or beam equalisation techniques (AMBER—Advanced Multiple Beam Equalisation Radiography) to produce high quality images at low doses.

67 The other methods of patient dose reduction relating to X-ray equipment, given in Appendix B, should not be overlooked. The Supplies Technology Division of the NHS Procurement Directorate carries out evaluations of many different types and components of X-ray imaging equipment which can have a direct effect on the dose levels required to make a diagnosis. Results of these objective measurements are published in the 'Blue Cover' report series and provide useful guidance to Health Authorities contemplating the purchase of specific items of imaging equipment. These reports are available free of charge to anyone employed in the NHS. However, it is not seen by the Department of Health to be the responsibility either of the Supplies Technology Division or of the National Centre for Responsibility for Diagnostic X-ray Equipment, that is operated by the Southeast Thames Regional Health Authority, to provide technical criteria that will ensure that X-ray equipment purchased in the NHS incorporates appropriate patient dose saving features. Decisions as to what equipment to buy and why are made by individual Health Authorities, usually at regional or district level.

68 JWP would like to see more central guidance from the Department of Health down to District Health Authority level of the necessity for, and appropriate means of, achieving patient dose reduction when purchasing diagnostic X-ray equipment.

> JWP recommends that all radiographic examinations should be carried out with the most sensitive rare-earth intensifying screens compatible with retaining adequate image quality.
>
> Radiologists should be aware of the dose saving potential of some of the new digital imaging systems.
>
> The Department of Health should provide central guidance to Health Authorities on the need for, and means of, achieving patient dose reduction when purchasing diagnostic X-ray equipment.

Priorities for spending on improved equipment

69 The assessment of priorities for introducing dose saving equipment into X-ray departments should be based on the expected collective dose savings and the financial costs involved[52]. Equipment changes involving lower costs per man Sv averted take priority, with the overriding stipulation that the diagnostic value of the X-ray examinations should not fall below what is judged to be a critical level. X-ray departments should be encouraged to carry out these priority assessments for their own particular situations, in order to advise Health Authorities of the most cost-effective equipment modifications available to them.

70 Illustrative ranges for values of the cost per man Sv averted for a number of dose saving modifications to X-ray equipment applied in a hypothetical radiology department are shown in Table 10. The ranges quoted in the table for the same equipment modification cover the values found for different rooms in the

TABLE 10 *Illustrative costs per unit dose saving in a hypothetical X-ray department*

Protection option	Cost effectiveness (£ per man Sv)
Rare-earth screens	2–20
Carbon fibre grids	50–1500
Carbon fibre cassettes	200–1000
Carbon fibre table tops	250–4100

department. The cost effectiveness can vary considerably because of differences in patient workload and in the remaining working life of the equipment and indicates the need to base these estimates on local conditions. Overall, the values range from £2–£4000 per man Sv saved. Rare earth screens are usually the best buy.

71 In this example, adventitious cost savings that might result from the proposed equipment modification, such as the ability to install a cheaper, lower power X-ray generator or the delayed replacement cost for the X-ray tube, when changing over to faster rare-earth screens, have not been taken into account. In some cases these can result in an overall negative cost, ie, a long-term cost saving, for the protection measure[53], in which case the need for its implementation is irrefutable. Even health service managers might find this a convincing argument. The cost per man Sv, even for relatively expensive items, such as carbon fibre table tops, is seen to be considerably lower than the monetary valuation of the harm from 1 man Sv in general radiology of £12 500 that was mentioned in paragraph 19, and even lower still than the figures of up to £500 000 per man Sv often quoted for expenditure on protection in the nuclear power industry[14].

72 However, there will always be competing demands for resources in the Health Service, many of which may represent more cost-effective ways of improving the nation's health than radiation protection. Moreover, health service managers are frequently unsympathetic to the idea of spending now in order to save later, especially when 'later' could be decades later and the saving, in terms of a few potential delayed deaths, is by no means readily apparent. It would be extremely useful to be able to make a comparison between the cost effectiveness of radiation protection options and other medical procedures which are competing for the same resources. Measuring cost effectiveness in terms of the cost per quality adjusted life-year saved (£/QALY) is perhaps one way of doing this, and might present a more persuasive argument to health service managers. Cost-Utility Analysis (CUA) is a special case of cost-effectiveness analysis where the outcome is expressed in terms of the number of life-years gained, ideally adjusted for quality. It has been applied to a variety of health care programmes where the use of an adjustment for the quality of life allows the method to be applied to medical procedures that enhance life as well as to those that extend it.

73 An illustrative exercise carried out by Wall and Russell[54] estimated the number of QALYs gained by adopting different patient protection measures in a typical radiology department. The QALY estimates included the years of life gained by

reducing the risk of fatal radiation-induced cancers and the improved quality of life gained by avoiding the pain and distress experienced prior to dying from such a fatal cancer or during the treatment of a curable radiation-induced cancer. Typical costs and collective dose savings were estimated for three patient protection options involving carbon fibre components to reduce the attenuation between the patient and the image receptor.

74 Illustrative examples of the costs per QALY for these options in comparison with published values for established medical procedures are shown in Table 11.

TABLE 11 *Examples of costs per QALY for medical procedures and patient protection options*

	Cost per QALY (£)
Medical procedure	
Neonatal intensive care	100
Pacemaker implant	700
Hip replacement	750
Heart valve replacement	900
Coronary artery bypass grafting (three vessel disease)	2 400
Kidney transplant	3 000
Mammographic breast screening	3 500
Percutaneous transluminal coronary angioplasty (one vessel disease)	3 400
Cervical screening	3 750
Heart transplant	5 000
Kidney dialysis	11 000
Patient protection option	
Carbon fibre grids	540
Carbon fibre cassettes	1 800
Carbon fibre table tops	2 400

Although these estimates are very approximate and will depend critically on local circumstances (and will probably need revising in view of recent increases in radiation risk estimates), they at least indicate that even relatively expensive patient protection measures, such as carbon fibre table tops, appear to compete favourably with a number of medical procedures that already consume large amounts of health service resources. Rare-earth screens, which can provide larger dose reductions at considerably lower costs than carbon fibre components, will of course be even more cost effective in terms of costs per QALY.

> JWP recommends that radiology departments should assess their priorities for introducing dose saving equipment on the basis of the cost per man Sv averted.
>
> The need to install dose saving equipment that results in long-term cost savings is irrefutable.

Regulatory controls

75 It is perhaps not appreciated by all those clinically directing medical exposures that there are European and UK regulations that oblige them to have a planned programme for the replacement of all X-ray equipment that does not restrict patient exposure as far as is reasonably practicable. CEC Directive 84/466 (of 3 September 1984) requires the establishment of criteria of acceptability for radiological installations, strict surveillance of equipment with regard to radiological protection and quality control, and that all installations which no longer meet the criteria should be taken out of service or replaced.

76 A major component of the quality assurance programmes discussed in paragraphs 53–57 should be the measurement of equipment performance both on installation and at regular intervals throughout its working life. Frequent quality control checks are particularly important for equipment that is prone to a gradual and hence otherwise undetectable degradation in performance, such as film processors and image intensifiers. The results of these regular performance checks, and in particular any difficulties experienced in maintaining adequate performance, should play a large part in decisions as to the appropriate time for equipment replacement.

77 The UK Ionising Radiation (Protection of Persons Undergoing Medical Examination or Treatment) Regulations 1988, that were drawn up to ensure UK compliance with the CEC Directive, require medical exposures to be conducted in accordance with accepted diagnostic practice and that only those procedures are selected that ensure the dose to the patient is as low as reasonably practicable. The Health Circular issued by the Department of Health at the same time as the Regulations made it clear that Health Authorities, together with clinicians, should encourage the formulation of a strategy for dose reduction.

78 Regulation 33 of the UK Ionising Radiations Regulations 1985 also states that medical exposures must be carried out on equipment that restricts the exposure of the patient as far as is reasonably practicable. Inspectors from the Health and Safety Executive will be enforcing this regulation and JWP has been assured that, in the course of inspections of X-ray departments HSE will discuss and agree with 'employers' a programme for the progressive replacement of all equipment that in particular does not conform to that recommended in paragraph 3.36 of the *Guidance for the Protection of Persons Against Ionising Radiations Arising from Medical and Dental Use*, published by NRPB in 1988. Paragraph 3.35 states:

> 'The imaging system should be chosen to ensure minimum dose to the patient consistent with obtaining adequate diagnostic information. Doses to patients and staff should be reduced by using low attenuation materials in ancillary equipment, such as carbon fibre in tables and cassettes, and rare-earth intensifying screens should be used wherever clinically possible.'

HSE Inspectors would expect employers responsible for radiology departments to have a current purchasing policy for rare-earth screens and low attenuation ancillary equipment.

79 JWP would wish the Department of Health to urge strongly Health Authorities to ensure that proven dose saving components are incorporated into X-ray equipment at the time of purchase so that the need for expensive modification or withdrawal from service at a later date is avoided.

> JWP recommends that all X-ray imaging equipment should be subject to regular performance checks which, if necessary, should lead to appropriate corrective action or replacement.
>
> Prime consideration should probably be given to rare-earth screens, to optimal operation of film processors and image intensifiers and to carbon fibre components.
>
> Health Authorities should be made aware of the expectations of HSE Inspectors regarding evidence of a planned programme for the replacement of equipment that does not include low attenuation components and for the purchase of rare-earth (or similarly sensitive) screens wherever clinically possible.

Alternative imaging equipment avoiding X-rays

80 Reference has already been made in paragraph 46 to the major role of ultrasound in obstetrics and in Table 7 and Appendix D to the replacement of cholecystography by ultrasound. It has a particularly important role to play in the investigation of renal tract disorders in children and in investigation of congenital heart disease. Every effort should be made to employ ultrasound where appropriate, particularly in children where the risks from X-ray exposure are probably higher than for adults, as explained in paragraph 21 and Appendix C.

81 There is evidence that magnetic resonance imaging (MRI) can replace radiculography in the investigation of disorders affecting the intervertebral discs and is superior to computed tomography, particularly in the posterior cranial fossa and the cranio-cervical junction. It is probable that MRI could reduce the number of invasive investigations in congenital heart disease and in the diagnosis of vascular disorders. There is little doubt that the UK is lagging behind other developed countries in the provision of MRI.

> JWP recommends increasing the availability of both ultrasound and MRI, which will reduce reliance upon techniques involving X-rays, particularly for young patients at higher risk.

TRAINING

82 The Ionising Radiation (Protection of Persons Undergoing Medical Examination or Treatment) Regulations 1988 require that those directing medical radiation exposure for diagnostic or therapeutic purposes should be adequately trained. A schedule in the Regulations lays down a core of knowledge requisite for persons directing medical exposures. Persons physically directing a medical exposure are required to select procedures such as to ensure a dose of ionising radiation to the patient as low as reasonably practicable in order to achieve the required diagnostic or therapeutic purpose. It is part of the training of every radiographer and radiologist to understand the importance of this principle, and to have covered the core of knowledge in the Regulations. However, other persons who direct medical exposures, such as cardiologists, orthopaedic surgeons and persons making injections of radioactive substances, will need to attend a course of instruction on the core of knowledge. Employing authorities are responsible for:

(1) identifying personnel requiring training,
(2) keeping records of those persons having attended an appropriate course,
(3) ensuring compliance with the Regulations,
(4) ensuring the availability of expert physics advice,
(5) dissemination of information on available courses,
(6) maintaining an inventory of equipment that produces ionising radiation.

83 The syllabuses of the first FRCR examination include the core of knowledge, and the Royal College of Radiologists believes that everyone holding the FRCR and the DMRD of the Conjoint Board is adequately trained for both clinically and physically directing a medical exposure. Similarly, all persons holding the Diploma in Radiography of the College of Radiographers are considered to be adequately trained for physically directing a medical exposure. Dental surgeons are apparently considered by the General Dental Council to have undergone sufficient training in their undergraduate syllabus. However, the advice given by the Council to dental surgeons on the need for additional training is equivocal, and a number of training courses set up to provide the core of knowledge are directed specifically at dentists. All others who clinically or physically direct medical exposures will need training. Some medical schools have already included the core of knowledge in the curriculum of undergraduate training. This provision will avoid, for example, the necessity for junior doctors to attend a special course before performing procedures such as insertion of pacemaker electrodes under fluoroscopic control.

> JWP recommends that consideration should be given by medical schools to incorporate the 'core of knowledge' defined in the Ionising Radiation (POPUMET) Regulations 1988 into the curriculum of all undergraduate medical students.

84 An essential part of the required core of knowledge is an appreciation of the ranges of doses that are given to patients with a particular procedure and the principal factors which affect the dose. Methods of measuring patient doses and of assessing the somatic and genetic risks are also to be understood. While NRPB has produced many detailed technical reports covering these areas of radiation protection, there is a clear need for a concise booklet indicating the likely risks associated with a range of doses arising from medical X-ray procedures, in a manner that can be readily appreciated by those clinically and physically directing X-ray examinations. Such a booklet would provide valuable source material for medical physicists lecturing on training courses and could be used as an *aide memoire* for radiology practitioners.

> JWP supports the proposal that NRPB should produce such a booklet indicating the likely risks associated with a range of doses arising from medical X-ray procedures.

CONCLUSIONS

85 This review has clearly identified that the *potential* for patient dose reductions is high. The importance of this potential is emphasised by the fact that it considerably outweighs the combined contributions from all other recurring manmade sources of population exposure. Also from assessments of the risks involved both to certain individual patients and to the population as a whole it is evident that there is a positive *need* to reduce patient dose.

86 The review has been able to use data from recent studies to bring the problem more sharply into focus than previously. However, it must be stated that the potential and need for dose reductions has been recognised for a number of years and it is of some concern that there appears to have been slow progress in addressing the problem. It is therefore concluded that there is need for an increased priority to be given to patient dose reductions. The onus for this rests not only with those clinically and physically directing radiological examinations, but with referring clinicians and with the various levels of administration within the Health Service that have direct influence over the allocation of resources. To help in this process the report has addressed mechanisms that can help rank the priorities for dose reduction both between competing patient protection techniques and in the wider context of allocation of resources in total health care spending.

87 The recommendations contained in the body of the report are listed in the following summary by headings under which they appear. The recommendations have been numbered sequentially and, since they are directed at different professional groups within the Health Service, the recommendations that are particularly appropriate for each group are identified below.

Group	*Recommendations*
Referring clinicians*	1–6
Radiologists	5,6,8–12,14–16,19
Radiographers	11,12,15,16
Medical physicists	11,12,14–16
DH and Health Authorities	7,13,17–19
X ray equipment manufacturers	9,18
RCR (General Medical Council)	20
NRPB	5,12,21

*These include general practitioners, physicians, obstetricians, gynaecologists and surgeons.

Summary of recommendations

Referral criteria Indications for examination

1 It is essential that there should be a valid clinical indication for all examinations of patients where ionising radiation is used. This is particularly important in health screening where there is often considerable controversy regarding the possible benefit.

2 The guidelines on referral criteria in the RCR Study Group booklet, *Making the Best Use of a Department of Radiology*, are endorsed. The booklet should be disseminated as rapidly as possible.

3 In the absence of a close family history of breast cancer, mammography should not be carried out in asymptomatic women under the age of 50 years. In the light of present evidence, there is no justification for the increasing tendency in some sectors actively to encourage women younger than 50 years to take part in mammography screening.

4 All employment-related radiological screening programmes should be clinically justified and the reasons for screening explained in writing to the employees. The term 'employment-related' should be widely interpreted and encompass programmes aimed at students, the armed forces and those working abroad, as well as general health care programmes for employees.

5 The results of the current NRPB survey of computed tomography (CT) practice and patient doses should be published and promulgated as soon as possible so that all radiologists are aware of the high patient dose implications of CT examinations.

Prior to CT examination, all patients should be individually referred to an experienced radiologist who will be able to advise whether CT is the most appropriate procedure to be adopted.

6 No woman should be referred for X-ray examination to assess fetal development when ultrasound facilities are available. In the few cases where X-ray pelvimetry is indicated, low dose techniques should be used.

Radiological procedures

7 A more uniform system should be adopted throughout the Health Service regarding the storage, retrieval and transfer of radiographic films, that will improve their availability.

8 The projections given in Table 7 (p 17) should not be used as 'routine'.

9 Patient dose during fluoroscopy should be kept to a minimum by using as low mA and kV factors as possible, by attention to good collimation and short periods of intermittent fluoroscopy and by dispensing with antiscatter grids whenever possible.

Automatic collimation at least down to the cassette size or to the field of view of the image intensifier should be provided at all times.

10 Radiologists should be encouraged to make regular measurements with a dose–area product meter to establish the effectiveness of the above fluoroscopy dose reduction techniques.

11 All radiology departments should institute an appropriate quality assurance programme. Where departments are sizeable it would be appropriate to set up an officially recognised quality assurance group to manage and direct such programmes.

12 Quality assurance programmes should include periodic measurements of patient entrance skin dose which should be compared with guideline doses based on previous results from each department and on national norms. This information should be fed back to those clinically and physically directing the medical exposures so that any necessary corrective action can be taken.

Equipment

13 The Department of Health should provide central guidance to Health Authorities on the need for, and means of, achieving patient dose reduction when purchasing diagnostic X-ray equipment.

14 Radiology departments should assess their priorities for introducing dose saving equipment on the basis of the cost per man Sv averted.

The need to install dose saving equipment that results in long-term cost savings, without diminishing the diagnostic value of examinations below a critical level, is irrefutable.

15 Prime consideration should probably be given to rare-earth screens, to optimal operation of film processors and image intensifiers and to carbon fibre components.

16 All X-ray imaging equipment should be subject to regular performance checks which, if necessary, should lead to appropriate corrective action or replacement.

Radiologists should be aware of the dose saving potential of many of the new digital imaging systems.

17 Health Authorities should be made aware of the expectations of HSE Inspectors regarding evidence of a planned programme for the replacement of equipment that does not include low attenuation components and for the purchase of rare-earth (or similarly sensitive) intensifying screens wherever clinically possible.

18 Manufacturers should be encouraged to build patient exposure monitoring devices (eg, dose–area product meters) into diagnostic X-ray equipment, to provide automatic and instantaneous indication of patient doses for quality control purposes.

19 Increasing the availability of both ultrasound and MRI will reduce reliance upon techniques involving X-rays, particularly for young patients at higher risk.

Training

20 Consideration should be given by medical schools to incorporate the 'core of knowledge' defined in the Ionising Radiation (POPUMET) Regulations 1988 into the curriculum of all undergraduate medical students.

21 Support is given to the proposal that NRPB prepare a booklet indicating the likely risks associated with a range of doses arising from medical X-ray procedures, in a manner that can be readily appreciated by those clinically and physically directing X-ray examinations.

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Appendix A

MEMBERSHIP OF RCR/NRPB JOINT WORKING PARTY ON PATIENT DOSE REDUCTION

CHAIRMAN

Professor K T Evans, Emeritus Professor of Radiology, University of Wales College of Medicine, Cardiff

ROYAL COLLEGE OF RADIOLOGISTS REPRESENTATIVES

Dr I F Kerr, Vice-President, the Royal College of Radiologists, London

Dr D J Nolan, Consultant Radiologist, John Radcliffe Hospital, Oxford

Dr J C B Russell, Consultant Radiologist, St Mary's Hospital, Manchester

NATIONAL RADIOLOGICAL PROTECTION BOARD REPRESENTATIVES

Dr B H MacGibbon, Assistant Director (Medical), NRPB, Chilton

Mr J F Croft, Principal Scientific Officer, NRPB Northern Centre, Leeds

SECRETARY

Mr B F Wall, Principal Scientific Officer, Medical Dosimetry Group, NRPB, Chilton

Appendix B

METHODS FOR REDUCING DOSES TO PATIENTS FROM X-RAY EXAMINATIONS

Method	Potential dose reduction		
	Per examination (%)	Annual collective (man Sv)	Cost per man Sv (£)
Radiological procedures			
1 Define strict referral criteria to exclude clinically unhelpful examinations	100	3200	0
2 Improve availability of previously-taken films and their transfer between hospitals	100	?	?
3 Minimise number of radiographs per examination	20	2500[a]	0
4 Minimise fluoroscopy time and current	30	1500*	0
5 Introduce QA programme to make regular checks on and to optimise staff and equipment performance	?	?	?
6 Regularly assess repeat rates and reasons for rejected and repeated films	5	600	?
7 Periodically measure patient doses and take action if they exceed 'guideline' doses	20	1300[a]	?
8 Collimate X-ray beam to minimise size	20	?	0
9 Shield sensitive organs when possible	75	?	0
10 Choose projections which minimise dose to sensitive organs	50	?	0
11 Radiologists to specify a low mean optical density for radiographs	20	?	0
12 Use patient compression when appropriate	50	?	0
13 If radiographic exposure factors are selected manually, develop and employ reliable and accurate methods for matching them to patient stature	50	?	?
Radiology equipment			
14 Select the most sensitive film/screen combination available consistent with good diagnostic quality (eg, rare-earth screens)	50	3000[b]	0
15 Operate film processor optimally (especially temperature)	15	2000[c]	?
16 Reduce attenuation between patient and image receptor to a minimum, eg, use carbon fibre components in:			
couch tops	10	1000	280[d]
antiscatter grids	20	2000	110[d]
cassette fronts	10	1000	250[d]
Radiology equipment (continued)			
17 Improve the reliability and ease of use of AEC devices and use more widely	?	?	?
18 Use 'Diamentor' dose-area product meter to make regular checks on patient exposure and to monitor performance of those physically directing fluoroscopic examinations	?	?	?
19 Install antiscatter grids with lowest grid factors compatible with adequate scatter rejection	20	?	?
20 Remove antiscatter grid during fluoroscopy or photofluorography when field size is small or detail not critical	50	?	?
21 Use equipment with automatic beam collimation to image receptor	?	?	?
22 Develop X-ray generators that reliably deliver the low dose rates demanded by rare-earth screens and paediatric examinations	?	?	?
23 Install modern image intensifiers with sensitive (eg, CsI) photocathodes and digital image processing	?	?	?
24 Use video recorder instead of cine camera during fluoroscopy wherever possible	90	?	?
25 Use spot film photofluorography with a modern image intensifier and 100 mm camera instead of radiography whenever appropriate	75	?	?
26 Use pulsed systems with image storage devices in fluoroscopy	75*	?	?
27 Use slot or scanned beam radiography	50	?	?
28 Replace conventional radiography by computed radiography	50	?	?

*Fluoroscopy component only.

Notes

Figures derived from

(a) Shrimpton, P C, Wall, B F, Jones, D G, Fisher, E S, Hillier, M C, Kendall, G M, and Harrison, R M. A national survey of doses to patients undergoing a selection of routine X-ray examinations in English hospitals. Chilton, NRPB-R200 (1986) (London, HMSO).

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Appendix C

RADIATION HEALTH EFFECTS MODEL USED IN PREDICTING LIFETIME RISK OF FATAL CANCER

The estimates of the lifetime risk of fatal cancers following exposure to typical X-ray examinations that appear in Table 4 (p 9) are based on a health effects model developed in NRPB-R226[1], which in turn is based mainly on the 1988 UNSCEAR report[2].

Estimates of the risk of radiation-induced fatal cancer based on Japanese atomic bomb survivors have increased since the 1977 UNSCEAR report[3] because of revisions in dosimetry, the longer period of follow-up and a change in the projection model used for calculating lifetime risks. In particular, a relative risk model is now used for most solid cancers where, after a latent period of 10 years, the temporal pattern of radiation-induced cancers follows a constant multiple of the age-related natural cancer rate occurring in an unexposed population.

Japanese bomb survivors have now been followed-up for 40 years since exposure, and for the last 30 years of this period the relative risk for solid cancers has remained substantially constant. Two extreme cases have been adopted to predict the upper and lower bounds of the probability of excess cancers appearing in the remaining lifespan (beyond 40 years post-exposure) for those irradiated at a young age. The upper bound assumes that the constant relative risk continues until the end of life and the lower bound assumes that it terminates at 40 years post-exposure.

The difference between lifetime risk estimates based on these two extremes depends critically on the age distribution of the exposed population. The higher the proportion of young people the bigger the difference, so that for a population of workers with no one below 18 years of age it is less than a factor of two, while for the whole population it is a little over a factor of three. The risks quoted in Table 4 are averaged over the whole population and the upper and lower bounds demonstrate this latter degree of difference.

If the exposed population is comprised of children below 10 years of age only, the difference between the upper and lower bound is greater still, with the upper bound about a factor of two above that of the whole population and the lower bound about a factor of two below that for the whole population.

While there is some indication that the relative risk is beginning to fall after 40 years for those exposed early in life, data are currently too sparse to predict where, between the two extremes, the complete lifetime risk will eventually be found to lie. A few more years observation of exposed populations will help to resolve this problem. In the meantime, it may be prudent to assume a projection model close to the upper bound, in which case the lifetime risk for those exposed below the age of 10 years would be about twice the upper bound values averaged over the whole population shown in Table 4.

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3 United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. 1977 report to the General Assembly, with annexes. New York, United Nations (1977)

Appendix D

SURVEY OF RADIOGRAPHIC PROJECTIONS USED AS A ROUTINE IN 62 HOSPITALS

Hospitals in survey

Teaching	**30**	
District General	**30**	
Other	**2**	(1 military, 1 MRC)

Sinuses

Do you routinely take more than an OM film for suspected sinus infection?

Yes **43**
No **19**

Comment As one-third of radiologists only require one projection, this seems to be another area for audit.

Cervical spine

Do you routinely take: (a) AP?

Yes **59**
No **3**

(b) AP odontoid?

Yes **20**
No **42**

(c) Lateral?

Yes **60**
No **2**

(d) Lateral in flexion?

Yes **3**
No **59**

(e) Lateral in extension?

Yes **4**
No **58**

(f) Both obliques?

Yes **3**
No **59**

Number of views taken

1 view	**3**
2 views	**31**
3 views	**23**
4 views	**5**

If you do not routinely take an AP view of the odontoid is it part of your routine to take it in cases of trauma?

Yes	**34**
No	**5**
Not applicable	**20**
No answer	**5**

Comment The number of projections taken in many departments varied with the referral criteria. Thus, many departments have set up different protocols for different groups of patients depending on the symptoms, the suspected diseases and the referring clinician. The usual routine is an AP view and a lateral with about one-third adding an AP view of the odontoid, although three quarters performed the AP of the odontoid in cases of trauma. In the absence of trauma, AP and lateral views only are recommended

Chest

Do you agree that only a PA view is required routinely?

Yes **57**
No **5**

Are your routine chest X-rays taken below or above 100 kV?

Above **18** (teaching hospitals, 15; non teaching hospitals, 3)
Below **44** (teaching hospitals, 16; non-teaching hospitals, 28)

Comment There is little or no saving of radiation dose using high kV technique when a grid is used to eliminate scattered radiation. There is, however, a useful reduction in radiation dose if an 'air gap' technique is used. High kV technique has wider latitude and reduces the possibility of repeats.

Abdomen

Do you routinely take an erect abdomen in patients with an acute abdomen?

Yes **30**
No **32**

Do you routinely take a chest X ray in patients with an acute abdomen?

Yes **53**
No **9**

Comment Some radiologists stated that the erect abdomen film was only obtained to satisfy the requests of surgeons and other clinicians. The present radiological opinion is that the routine examination of such patients should be an erect chest radiograph to include the diaphragm area and a supine abdomen film'.

Lumbar spine

Do you routinely take: (a) AP?

Yes **62**
No **0**

(b) Lateral?

Yes **62**
No **0**

(c) Coned view of L5/S1?

Yes **52**
No **10**

(d) AP view of SI joints?

Yes **2**
No **60**

(e) Both obliques?

Yes **0**
No **62**

Number of films	2 films	**9**
	3 films	**51**
	4 films	**2**

Comment Although the majority of departments include in their routine a coned view of L5/S1, this should be questioned as a 25% reduction in radiation dose can be achieved by omission of this, and inclusion of the area in the routine lateral projection.

JWP agrees with the suggestion that, in the investigation of backache where there are no suspicious features and the symptom has been present for less than 3 weeks, radiography is not required. Furthermore, patients aged between 20 and 55 years of age with persisting backache but without several well-defined clinical criteria require only a single, well-centred, long lateral radiograph[2,3].

Intravenous urography

Please list your routine

Control	1 film	**45**
	2 films	**42**
Renal areas	1 film	**5**
	2 films	**28**
	3 films	**23**
	4 films	**1**
Full length	0 film	**1**
	1 film	**46**
	2 films	**7**
Pre-micturition bladder		**18**
Post-micturition bladder		**42**
Post-micturition full length		**9**
Total number of films	3 films	**1**
	4 films	**3**
	5 films	**15**
	6 films	**21**
	7 films	**15**
	8 films	**2**
Number with no standard routine		**5**

Comment The information gained from a routine post-micturition radiograph has been shown to be small, and some consider unreliable[4]. Morewood and Scally[5] consider that significant residual urine in the bladder can be estimated on the plain radiograph (control film). Those departments in which more than five or six routine films are taken should perhaps review the necessity of this practice.

Cholecystogram

Please list your routine

Control		**35**
Post-contrast	2 films	**5**
	3 films	**9**
	4 films	**19**
	5 films	**6**
	6 films	**2**

Fluoroscopy with variable number of films **8**

After fatty meal (included in number of post-contrast films) **40**

Examination not now performed **13**

Comment Nearly all departments now perform very few cholecystograms, ultrasound having taken over as the first method of investigation. Those departments using more than four films could perhaps review the reasons for doing so.

Barium enema

Do you routinely use a double contrast technique?

Yes **58**
No **4** (2 paediatric hospitals)

Do you routinely take a post-evacuation film?

Yes **12** (1 paediatric hospital)
No **50** (1 paediatric hospital)

Comment The need for a post-evacuation film is doubtful.

Knees

Do you routinely take: (a) Skyline view of the patella?

Yes **1**
No **61**

(b) Tunnel view?

Yes **0**
No **62**

Comment Routine views are AP and lateral.

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Appendix E

ACCEPTANCE TESTS AND ROUTINE QUALITY ASSURANCE TESTS FOR DIAGNOSTIC X-RAY SYSTEMS

TABLE 1 *Acceptance tests for medical X-ray imaging systems recommended in IPSM Report TGR-32*

Physical parameters to be measured	Equipment required
X-ray tubes and generators	
Tube output and consistency	Dosemeter
Filtration and half-value layer	Dosemeter, Al filters
Exposure time	Spinning top or electronic timer
Applied potential calibration	Penetrameter or digital kVp meter
Falling load operation	As above plus oscilloscope
Capacitor discharge units	As above
Focal spot size	Pinhole or star resolution grid
Light beam diaphragm alignment	Film/screen cassette and wire markers
Films and intensifying screens	
Film-screen characteristic curve (hence speed, contrast and base plus fog indices)	Dosemeter, step wedge or sensitometer, densitometer
Threshold contrast	Leeds test object TOR (RAD)
Spatial resolution	Leeds test object TOR (RAD)
Film-screen contact	BS4304 test grid
Relative screen sensitivity	Densitometer
Automatic film processors	
Speed, contrast and base plus fog indices as function of developer temperature	Thermometer, sensitometer, densitometer
Relative density and pH of developer and fixer	pH papers or meter, hydrometer
Residual hypo	Residual hypo test kit
Silver recovery	Silver estimating papers
Transport speed	Stop watch
Replenishment rates	Calendar
Automatic exposure control (AEC) systems	
Consistency in producing optimal density for repeated standard exposure	Densitometer
Consistency between detectors	Densitometer
Consistency with change in tube voltage	Densitometer
Consistency with change in tube current	Densitometer
Consistency with change in phantom thickness	Densitometer and variable phantom
Image intensifiers	
Field size and distortion	Metal grid, filter, camera, projector, screen
Conversion factor*	Dosemeter, filters, photometer, wire grid
Contrast ratio*	Dosemeter, filters, photometer, wire grid
Video voltage output	Dosemeter, oscilloscope
Grey scale	Leeds test object GS1
Threshold contrast	Leeds test object TOR (TVF)
Spatial resolution	Leeds test object TOR (TVF)
Minimum visible detail	Leeds test object TCDD
Automatic brightness control (ABC)	Dosemeter, filters, phantoms

Table 1 *(continued)*

Physical parameters to be measured	Equipment required
Conventional tomographic equipment	
Cut height	Test object
Cut plane orientation	Test object
Cut plane thickness	Test object
Tomo movement and swing angle	1 mm pin hole
Spatial resolution	Resolution test grid, angled jig
Masking and coning	Test object
Computed tomography scanners	
Noise	Suitable water phantoms
Pixel size	Circular water phantoms
Spatial resolution	Phantom containing edge
Slice width	Phantom with two crossed Al strips
Axial dose profiles	Head and body phantoms, film and TLDs
Uniformity of CT values	Water phantoms with suitable inserts
Linearity of CT values	Water phantoms with suitable inserts

*Involves dismantling parts of imaging equipment and should be undertaken by, or in close collaboration with, manufacturer's representative.

TABLE 2 *Routine quality assurance checks recommended in IPSM Report TGR 32*

Frequency	Nature of routine check	
Daily	Speed, contrast and base plus fog indices	film processors
	Silver recovery	film processors
	Noise	CT scanners
	Low contrast detectability	CT scanners
Monthly	Residual hypo—film processors	
	Mechanical function	CT scanners
	Spatial uniformity	CT scanners
	Structured noise	CT scanners
	Reproducibility of CT values	CT scanners
Quarterly	Physical condition of cassettes and screens	
	Physical condition of illuminators	
Six-monthly	Linearity of CT values	CT scanners
	Accuracy of patient positioning device	CT scanners
	Tube output	CT scanners
Yearly	Film-screen contact	
	Darkroom safelights	
	Film storage conditions	
	AEC (all acceptance tests)	
	Spatial resolution—CT scanners	
Regular* (unspecified) intervals	X-ray tube output at various kV and mA	
	Image-intensifier input dose rate with 1 mm Cu phantom	
	Image-intensifier minimum visible detail	
	ABC control	
	Selection of tests on conventional tomographical equipment	

*Reference to Quality Assurance in Diagnostic Radiology, published by the World Health Organisation (1982), would indicate that the first four checks should be carried out at weekly intervals and the last one at six-monthly intervals.