Radiation protection in diagnostic radiology

RADIATION PROTECTION IN DIAGNOSTIC RADIOLOGY

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Medical uses of radiation became by far the greatest man-made source of doses to the population at large. As technology and health care improved there has been an increase in the usage of radiation, measured by the frequency of procedures per caput and by the levels of individual and collective dose. From the early 1920's there has been the gradually developing pressure to eliminate unnecessary exposures and to reduce individual doses. Justification of practices and optimization of protection became the leading principles for keeping individual doses and the number of patients exposed As low As Reasonably Achievable. However, less attention has been given to optimization in medical applications than in most other radiological fields. The range of doses associated with the same procedure is often extremely large, which implies that there is considerable scope for dose reduction. The first important factor for improvement is to increase awareness of the relative ease with which doses can be reduced. This requires familiarity with the levels of dose connected with the various procedures and with techniques of quality control. A new and potentially very strong tool is provided by dose constraints, which should be selected by appropriate professional bodies and which should be used in practice as a quantitative guide to good practice.

Justification of medical exposure

The justification of a practice leading to medical exposures should be dealt with in the same way as the justification of any other radiological practice, which implies that no practice should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment that it may cause.
The 1990 ICRP recommendations in Publication 60 [1] elaborate on this justification principle at two levels. First is justification at the level where the practices are defined in broad terms and the second is with respect to the case by case justification of individual procedures.
In earlier recommendations ICRP identified different categories of medical practices [2][3][4] and it is important to remind the distinctly different nature of the benefits associated with these various practices and the influence they should have on the justification process:

- examinations and treatments directly associated with individual illness or injury
- periodic health checks or mass screening of asymptomatic patients and employees
- examinations for medico-, legal or insurance purposes
- examinations and treatments forming part of a medical research programme.

Justification at a broad level of all four types of practices is a primary responsibility for the medical profession. For the last three categories also authorities outside the medical profession play a role in decision making on justification.

For radiological examinations and treatments of symptomatic patients, both the benefit and detriment accrue to the individual patient. The choice for a type of diagnostic examination should be based on a correct assessment of the clinical indications, the expected yield from the examination and its contribution to the further diagnosis and subsequent medical care of the patient. The same criteria should be used in considering alternative diagnostic procedures. The preferential option should be that procedure that yields the highest clinical benefit within the prevailing restraints of availability and costs. For therapeutic exposures, where radiation doses are generally much higher, the justification of a radiological procedure should be based on evaluative

analysis demonstrating a positive nett benefit in excess of that obtainable from any alternative therapeutic procedure not involving ionizing radiation.

Periodic health checks and mass screening are still regarded as medical rather than public exposures. In the case of health checks on individuals, the justification depends on the probability of obtaining useful information and the importance of this information to the individual's health. For X-ray examinations used in mass screening, the justification principle requires an assessment of the benefits both to the individuals examined and to the population as a whole. ICRP continues to emphasize that these factors may be too small to offset the radiation detriment, especially where it regards periodic health checks of employees. There only is clinical justification for X-ray screening of employees in some particularly hazardous occupations.
In the light of all the costs, including the health detriment of the screening programme it is important that the benefits of a screening programme are not always the same for different groups, and therefore the screening will often only be justified if it is limited to certain specified groups.
The benefit from radiological examinations for medico-legal purposes or to subscribers or beneficiaries of insurance, is primarily accrued to the third parties or the insurer. The benefit is of financial rather than of medical nature. Because of this general lack of direct health benefit to the exposed individual, the need and the usefulness of such examinations should be critically examined and reviewed with a particular role for independent radiological experts.

When patients themselves are likely to benefit from experimental methods of diagnosis or treatment the justification of their exposure in the course of a medical research programme is similar as for routine procedures. When there is no direct benefit to the exposed individual, for example in trials or research programmes including volunteers, justification should be examined by independent experts. Relevant guidance on radiological protection in biomedical research was recently reviewed by ICRP in the light of its 1990 recommendations, which call for special consideration of dose constraints for scientific and clinical studies involving the exposure of volunteers [5].

The second level of justification regards the individual patient. The decision to perform a diagnostic examination is the joint responsibility of the referring physician and the radiologist who is clinically directing the examination. For both it is imperative that they build their decision upon a correct assessment of the indications for the X-ray examination, the expected diagnostic yield from the X-ray examination, and the way in which the results are likely to influence the diagnosis and the subsequent medical care of the patient. It is equally important that this assessment be made against a background of adequate knowledge of the physical properties and the biologic effects of ionizing radiation.
In the specializing and rapidly changing field of modern X-ray diagnostics, all these factors and the concepts of benefits and risks in radiological protection cannot be expected to be completely understood by the referring physicians. Their proper concern is with the efficacy of the examination, that is, whether it will contribute to the management of the patient's health problem. To achieve the necessary overall clinical judgement the referring physician may need to consult with the radiologist. The referring doctor should at least provide a clear request, describing the patient's problem and indicating the clinical objectives, so that the radiologist can carry out the correct examination. Referring physicians should refrain from making routine requests, not based on clinical indications.
Special attention should be given to the avoidance of unjustified examinations in case the necessary information is already available, either from radiological examinations already done, or from any other medical tests.

A particular responsibility for the radiologist, who will not always see the patient prior to the examination, is to exercise clinical direction by establishing clear criteria for accepting or rejecting referrals which should be followed by the department staff who physically conducts the examinations. Any patient who does not meet these criteria should be referred to the radiologist, who should be seen as the guardian of the justification of individual procedures, before commencing the X-ray exposure.

Optimization of patient protection

Medical exposures of patients are intended to provide a direct benefit to the exposed individual. Assuming that each examination or treatment is justified all further attention must be given to the optimization of protection, which basically implies that the dose to the patient shall be as low as compatible with the medical purpose. Any further application of individual dose limits for the patient might be to the patients detriment. Generalized individual dose limits could well jeopardize the efficacy of an examination or enervate the power of a treatment. The ICRP therefore continues to recommend that individual dose limits do not apply to medical exposures.
In the light of the absence of any dose limits for patient exposure, the radiological protection of patients in justified practices, therefore entirely rests on the concept of optimization of protection. This concept aims at keeping the probability of detrimental side effects of exposure to ionizing radiation, as low as reasonably achievable, compatible with the standards of good medical practice, and duly accounting for social and economic considerations.
The ICRP principle of optimization of protection is stated as: "In relation to any particular source within a practice the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received, should all be kept as low as reasonably achievable, economic and social factors being taken into account.
The principle of optimization should be the main driving force for radiological protection in medical exposures, at both the design and operational stages and it should be an essential element in regulatory control over the use of ionizing radiation. The key to its successful implementation is commitment at all organizational and professional levels.

The ICRP principle of optimization evolved over a number of decades as a more quantitative approach of the ALARA principle. The judgements however, involved in optimizing protection are not purely quantitative, they involve preferences between detriments of different kinds and between deployments of resources and health effects. Guidance on available techniques has already been published by the ICRP in its publications 37 and 55 [6][7]. ICRP Publication 55 covers the various techniques for quantitative optimization, including cost-benefit analysis and it clearly demonstrates that the principle can be applied appropriately to various kinds of problems at different levels of complexity. Various available techniques were described, putting optimization in place as part of a quantitative decision aiding technique.
Where in nuclear technology the optimization of radiological protection evolved to take its place as a part of quantitative decision-aiding techniques, the situation in protection of the patient in medicine is very different. Traditionally the medical practitioners have concentrated on the quality of the diagnostic information which is often perceived as being the only determining factor in reaching a diagnosis. Much less attention has been given to the optimization of protection in medical diagnostic exposures. As repeatedly stated by ICRP, there is considerable scope for dose reduction in diagnostic radiology. Simple, low cost measures are available for reducing doses without loss of diagnostic information.
Attempts to introduce even the simple techniques of cost-benefit analysis have not so far met with great acceptance or application. This might be explainable by the fact that professionals in medical

practice are confronting immediate and obvious health risks and therefore value the delayed health risks from radiation doses as remote. However, there may also be less good reasons, such as lack of necessary attention or awareness about levels of dose and risk associated with particular procedures and particular techniques.
During the last decade more widely concern became apparent with regard to the unwarranted dose variations, associated with common procedures. The probably most important factor is an increasing awareness, both of the reality of the harm from unnecessary radiation exposure and of the relative ease with which it can be reduced. Series of studies and seminars that were held to review the progress of optimization of protection in the medical field, clearly have indicated that the need in practice is not primarily for elaborated quantitative analysis techniques for optimization, but a major impact could be achieved by the introduction of reference values to identify the upper bound of patient exposure associated with particular procedures under good medical practice conditions.

Dose constraints for diagnostic procedures

With the sound objective to meet the practical need for guidance on what is to be regarded as the acceptable level of patient exposure under good medical practice, the 1990 ICRP recommendations advocate the concept of dose constraints, selected by the appropriate professional bodies and health authorities, for application in common diagnostic procedures. Constraints, or otherwise called reference levels for investigation, serve principally as a criterion against which the responsible practitioners can compare the exposure levels that result from their techniques. Further they should be used by others, including professional bodies and supervising authorities to assist in assessing where the respective medical radiological practices are performed with levels of exposure, that can be regarded as low as reasonably achievable. They are not to be seen as regulatory dose limits and have no formal function for the regulatory authorities. They shall not be regarded as inflexible limits for individual exposure but should serve as reference levels above which the cause and the implications of the uncommonly higher exposure levels should be investigated. An internal investigation should be carried out by the department if the average dose for a specific type of examination is found to exceed the agreed dose upper bounds. Where appropriate, steps should be taken by the practitioner or by the department to improve practice. This might involve changes in working technique or equipment to reduce exposure levels, without compromising diagnostic quality. As is explicitly stressed by the ICRP, for medical exposures dose constraints should be applied with flexibility to allow for higher doses where indicated by sound clinical judgement.
Dose constraints for diagnostic examinations, can best be set by professional and advisory bodies on a national scale, after due consideration of the ranges of actual doses delivered by the different radiology departments around the country for the same examination. Since dose levels may vary significantly with the size of the patient and with the complexity of the individual patient's status, numerical values must relate to typical practice for an examination, as measured under representative samples of patients under standard conditions.

The process of setting and use of dose constraints for medical examinations is envisaged as a continuing process that is schematically represented by the following principles.

Principles for use of dose constraints in diagnostic radiology

Step 1: Nation wide collection and registration of dosimetric data per type of examination

Step 2: Review of dose distribution and professional judgement to define upper bounds of standard good practice per type of examination

Step 3: Periodic surveys in local radiology departments
Measurements of exposure levels in actual practice.

Step 4: Comparison of actual distributions with reference levels for good practice

Step 5: Investigation of methodology and procedures when systematically exceeding dose constraints

At an international level, joint efforts have been undertaken within the United Nations' framework and the European Union to complete the first two steps. Consensus has been reached for the most common types of diagnostic procedures on reference levels that may trigger investigation in situations that are probably well away from the generally achievable level of quality. For the most frequent diagnostic procedures in radiology and nuclear medicine, internationally adopted reference levels were recently published in the Basic Safety Standards for Protection Against Ionizing Radiation [8]. The recommended levels for diagnostic radiology are summarized in table 1. Values for routine radiographs are in terms of entrance surface kerma in air. For fluoroscopy the appropriate quantity is the kerma rate in air at body entrance surface. For computed tomography they refer to the multiple scan average kerma, with further specification of measurement conditions. For diagnostic procedures in nuclear medicine reference levels are specified in terms of administered activity per nuclide for particular examinations.
The recommended values for diagnostic radiology were derived from the rounded third quartile values of the observed dose distribution from the national patient dose surveys, carried out world wide and collected in the international framework of the UNSCEAR [9]. Extremely valuable basic information was adopted from reports on joint work of the Royal College of Radiologists and the National Radiological Protection Board in the UK, carried out since the mid 1980's [10].
Responsible professionals in diagnostic radiology departments should be aware of the actual dose levels which they apply for their patients during examinations in their facility. This requires that the local radiology departments organize periodic surveys and measure the exposure data in their local situation. A logic next step is that the results of these surveys should be compared with agreed standards for good practice. If the patient exposure levels for a particular technique or examination consistently fall outside the normal range, the facility staff should take actions to bring the exposures down below the respective constraints, if this can be done without reducing the diagnostic value of the examination. Investigation by responsible professionals is certainly indicated when the results of local surveys show that the appropriate reference levels are systematically exceeded without explicit medical indications. Further investigation must address the performance of the X-ray equipment as well as the applied methodology and protocols in the department.

In various countries protocols have been developed for systematic evaluation of radiation exposure from diagnostic radiology [11][12]. Those nation wide guides are intended to foster an awareness of acceptable exposure levels associated with specific examinations or projections and to assist facilities in assessing their own exposure levels. The prerequisite for this determination, obviously is the ability to make measurements. Larger diagnostic radiology facilities will have a quality assurance programme in place, managed by their radiological physicist. With attention to certain basic principles and the use of consultation services of a qualified physicist, however, facilities without staff physicists can also competently measure exposure levels. The recommended protocols give facilities that are not yet making such measurements the essential information to institute a systematic measurement policy. The use of nationally agreed methodologies for measurements will provide a means of relating a facility's exposure values to nation wide collected data from all institutions. Implementation of such nation wide intercomparison will provide a useful mechanism for periodic review of existing reference levels and for expansion to setting such guidance for a wider range of examinations.

Scope for dose reduction

As mentioned above the ICRP 60 recommendations re-emphasize that there is considerable scope for dose reduction in diagnostic procedures without impairment of their value. This opinion is founded on the fact that world wide research programs have repeatedly shown that levels of patient exposure associated with the same procedure vary enormously. Doses for a given examination vary between departments by a factor up to 20 and between patients far more.
A particular example of unwarranted dose variations that therefore needs special attention for dose reduction are examinations of children. In the course of a study in European countries a 50-fold variation in entrance surface dose to infants was observed [13]. Much of this variation resulted from inadequate equipment or techniques that were pourly suited for pediatric radiology. A promising finding in the study was that significant dose reduction was achieved after implementation of protocols including appropriate dose constraints. The study clearly demonstrated the importance of systematic local dosimetric surveys. Only through the systematic approach to quality control of performance these apparently serious problems can be identified.

Various studies during the last decade especially, have indicated that lessons can be learned from the general pattern of individual dose distribution in X-ray examinations. As a general approximation a 80-20 distribution rule seems to apply. Roughly speaking about 80% of all examinations show individual patient exposure levels within a range of a factor 2, but the remainder 20% of the same type of procedures show variations in patient exposure levels of far more than a factor 10. Characteristic of this 80-20 distribution is that the mean dose value for the lower 80% subgroup is roughly equal to the median value of the overall distribution. However, individual doses in diagnostic examinations which belong to the upper 20% of the distribution, are considerably higher. They range from triple to more then tenfold the median value. From further analysis of this type of distribution it can be easily deduced that the lower 80%-group roughly corresponds with about half the collective dose per type of examination. The other half of the collective dose is caused by the upper 20% of all procedures. With some simple mathematics it can be shown that an appreciable reduction of about 25% in collective dose could be achieved if a substantial part of the high dose examinations could be avoided and replaced by performance at dose levels below the 80th percentile value.
This short explanation on the characteristics of the 80-20 rule of distribution may illustrate why the rounded third quartile values from national patient dose surveys are chosen as reference levels for investigation of technique and protocols.

Techniques of radiology continue to evolve and usage changes, so there is some uncertainty in combining data from different periods of times. However, the available data, as regularly updated by the UNSCEAR, indicate that the annual collective dose for medical radiology substantially and rapidly increased because of computed tomography. The CT imaging technique provides excellent radiographic contrast between soft tissues and delivers high quality clinical information for localized planes within the body. CT has allowed significant improvement in good patient care. Considerable advances in scanner design have subsequently allowed the routine performance of more extensive and elaborate examinations. Notwithstanding the undoubted benefits of CT in health care, the rapid growth of the technique has taken place with unsufficient appreciation of the relatively high patient doses involved. Table 2 demonstrates that the typical levels of patient dose from CT are relatively large compared with the doses in conventional X-ray examinations (with exception for the doses to the foetus from CT pelvimetry, which is broadly similar to the doses achievable with rare earth screens in cassettes and good technique). It certainly should be recognized that a superficial comparison of imaging modalities solely with respect to patient dose, ignores the superior clinical information from CT techniques. However, the comparison at least illustrates that doses from modern digital techniques of radiography are not inherently low.

Variations in dose for specific radiology procedure are widely described in literature. An excellent with summary with discussion and analysis is given in the UNSCEAR 1993 report [9]. The following highlights of the conclusions in the UNSCEAR report demonstrate that there is considerable scope for reduction in patient dose.

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TABLE 1: Reference levels for investigation for diagnostic radiological procedures for a typical adult patient

Adopted from International Basic Safety Standards for Protection Against Ionizing Radiation (IAEA Safety Series No. 115, 1994)

Radiography		Per radiograph * (mGy)
Lumbar spine	AP	4 - 10
	LAT	10 - 30
	LSJ	25 - 40
Abdomen, intravenous urography & cholecystography	AP	4 - 10
Pelvis	AP	4 - 10
Hip Joint	AP	4 - 10
Chest	PA	0.2 - 2.4
	LAT	1 - 1.5
Thoracic spine	AP	4 - 7
	LAT	8 - 20
Skull	AP	3 - 5
	PA	3 - 5
	LAT	2 - 3
* Entrance surface kerma in air with backscatter. Higher values are for conventional film-screen combination in the relative speed of 200. Lower values for high speed film-screen combinations (400-600).		

Computed Tomography	Average * (mGy)
Head	50
Lumbar spine	35
Abdomen	25
* Multiple scan average kerma derived from measurements on the axis of rotation in water equivalent phantoms, 15 cm in length and 16 cm (head) and 30 cm (lumbar spine and abdomen) in diameter	

Fluoroscopy	Rate * (mGy/min)
Normal	25
High level **	100
* Entrance surface kerma rate in air with backscatter. ** For fluoroscopes that have an optional "high level" operational mode, such as those frequently used in interventional radiology.	

TABLE 2: Typical levels of patient dose from scan projection radiography (SPR), rotational CT and conventional X-ray (CONV) procedures

Adopted from NRPB Report R249 [14]

	Typical effective dose (mSv)		
Examination	SPR	CT	CONV
Head	0.02	2	0.2
Cervical spine	0.03	2	-
Thoracic spine	0.2	7	1
Chest	0.2	9	0.05
Abdomen	0.2	9	2
Lumbar spine	0.1	6	2
Pelvis	0.2	10	1