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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/773-4

College on Medical Physics:
Radiation Protection and Imaging Techniques

5 - 23 September 1994

Principles of Radiation Protection in Medicine

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"... more than three quarters of the world's population have no chance of receiving any radiological examination, regardless of what disease they have"

UNSCEAR, 1988

Effective dose equivalent rate

mSv per year

World average

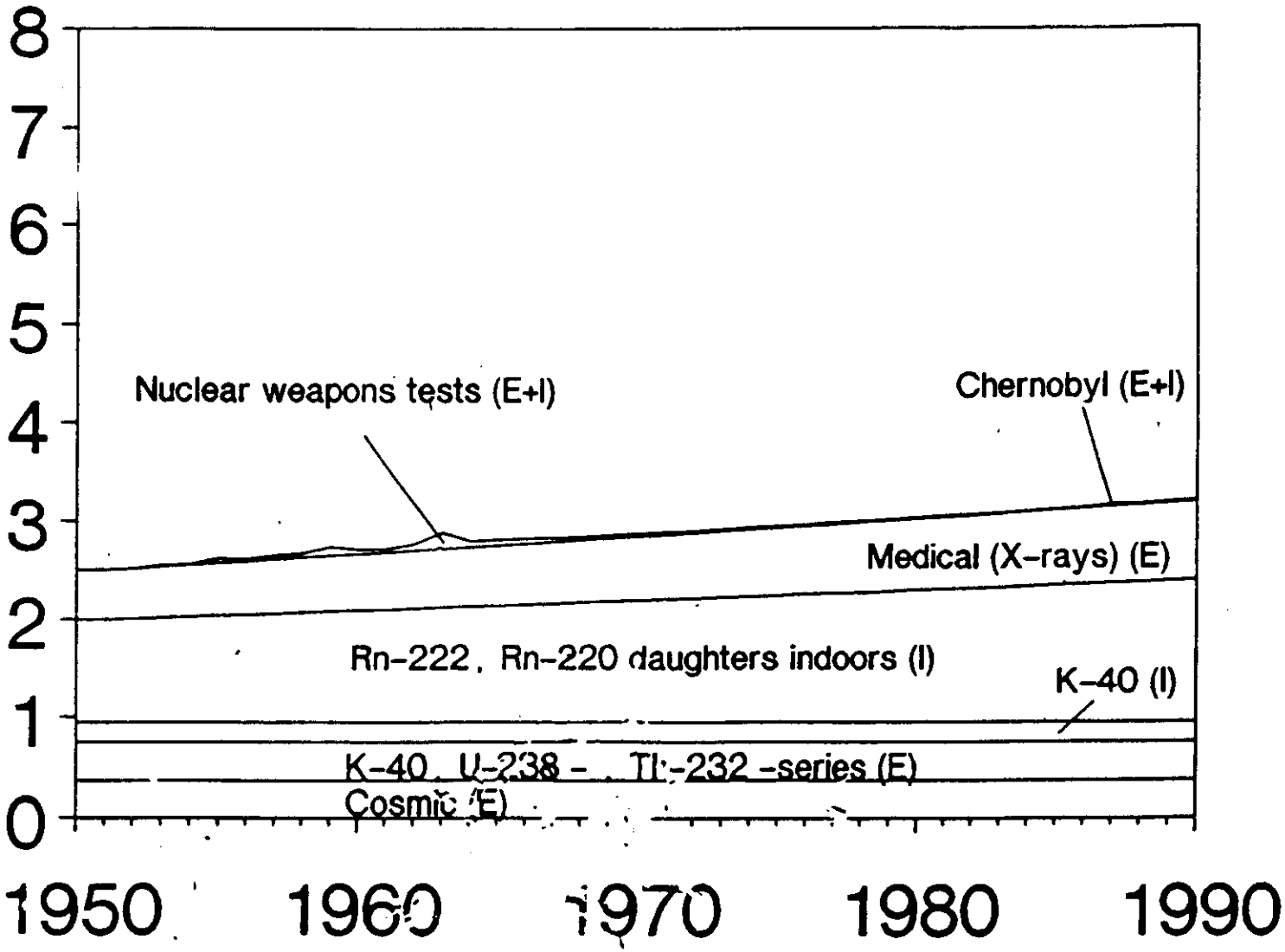
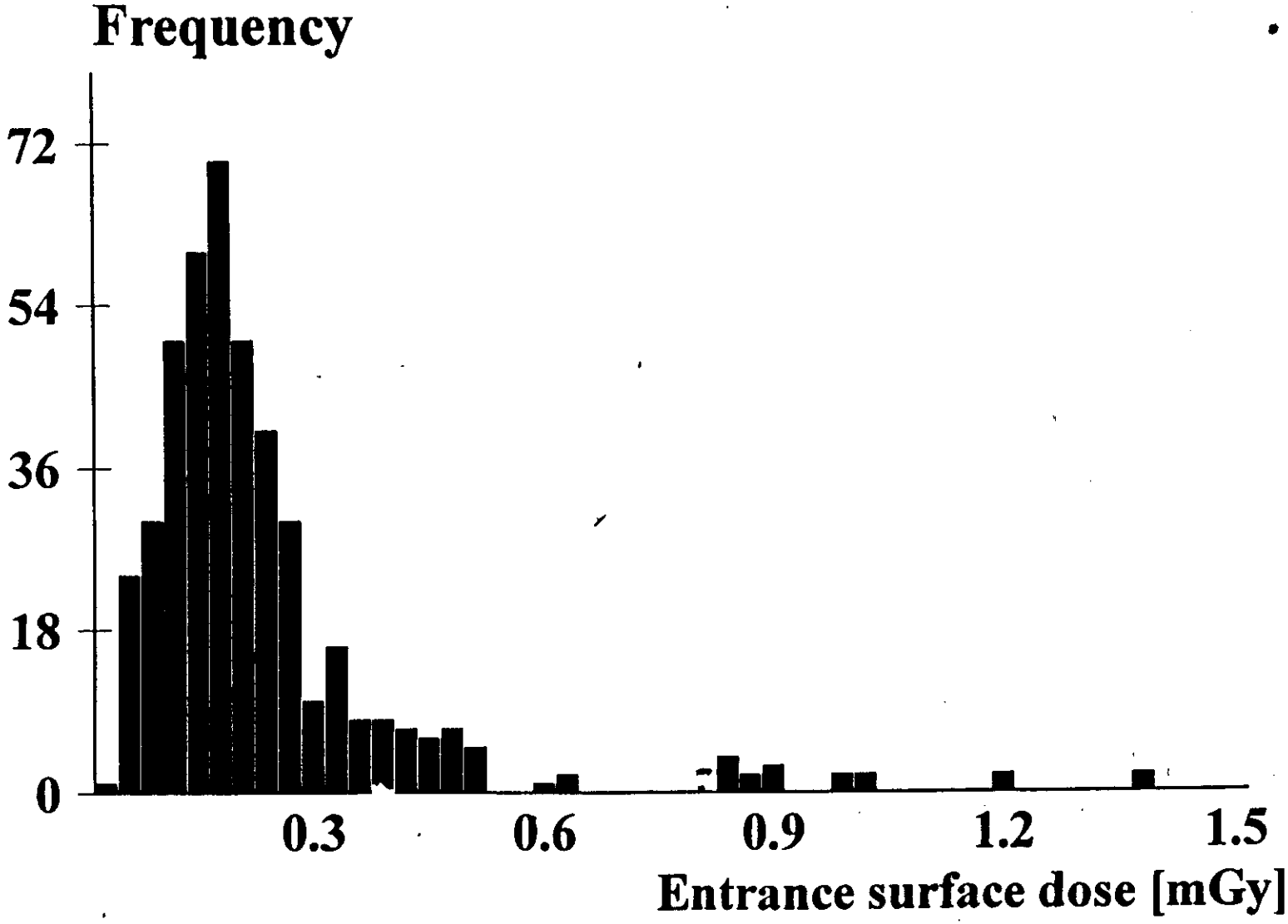


Table 52
Estimated doses to the world population from medical uses of radiation

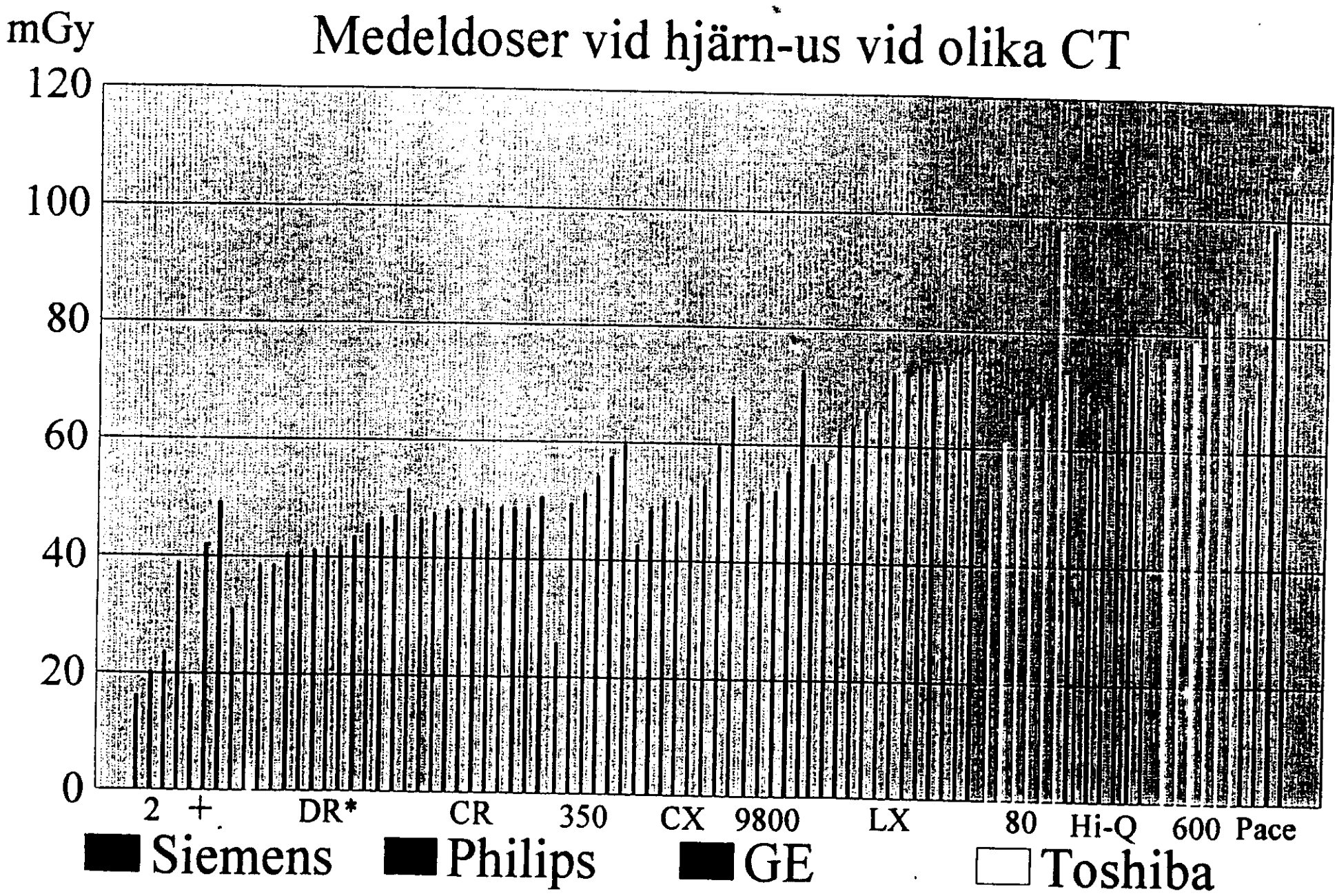
Medical radiation use	*Effective dose equivalent per caput (mSv)*					*Collective effective dose equivalent (10^3 man Sv)*				
	Level I	*Level II*	*Level III*	*Level IV*	*World*	*Level I*	*Level II*	*Level III*	*Level IV*	*World*
Diagnosis										
Medical x-ray examinations	1.0	0.1	0.04	0.04	0.3	1300	290	40	20	1600
Dental x-ray examinations	0.01	0.001	0.0003	0.0003	0.003	14	3	0.3	0.1	17
Nuclear medicine	0.09	0.008	0.008	0.008	0.03	130	20	6	4	160
Total	1.1	0.1	0.05	0.05	0.3	1400	310	46	24	1800
Therapy [a]										
Radiotherapy	0.7	0.2	0.03	0.02	0.3	980	480	26	7	1500
Nuclear medicine	0.004	0.0009	0.0009	0.0004	0.002	6	2	0.8	0.2	9
Total	0.7	0.2	0.03	0.02	0.3	990	480	27	7	1500

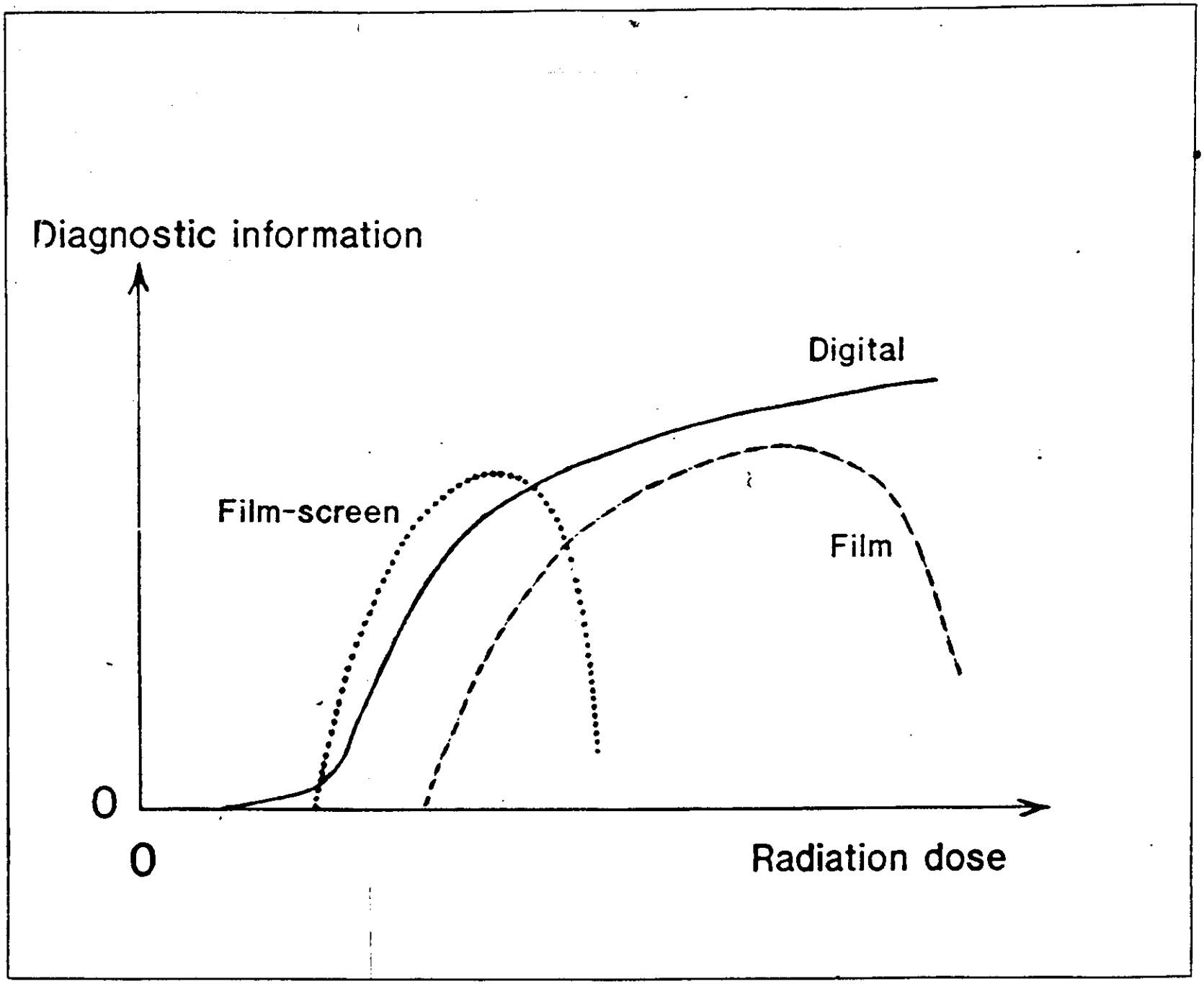
[a] Evaluated for effective doses.

Chest-PA projection

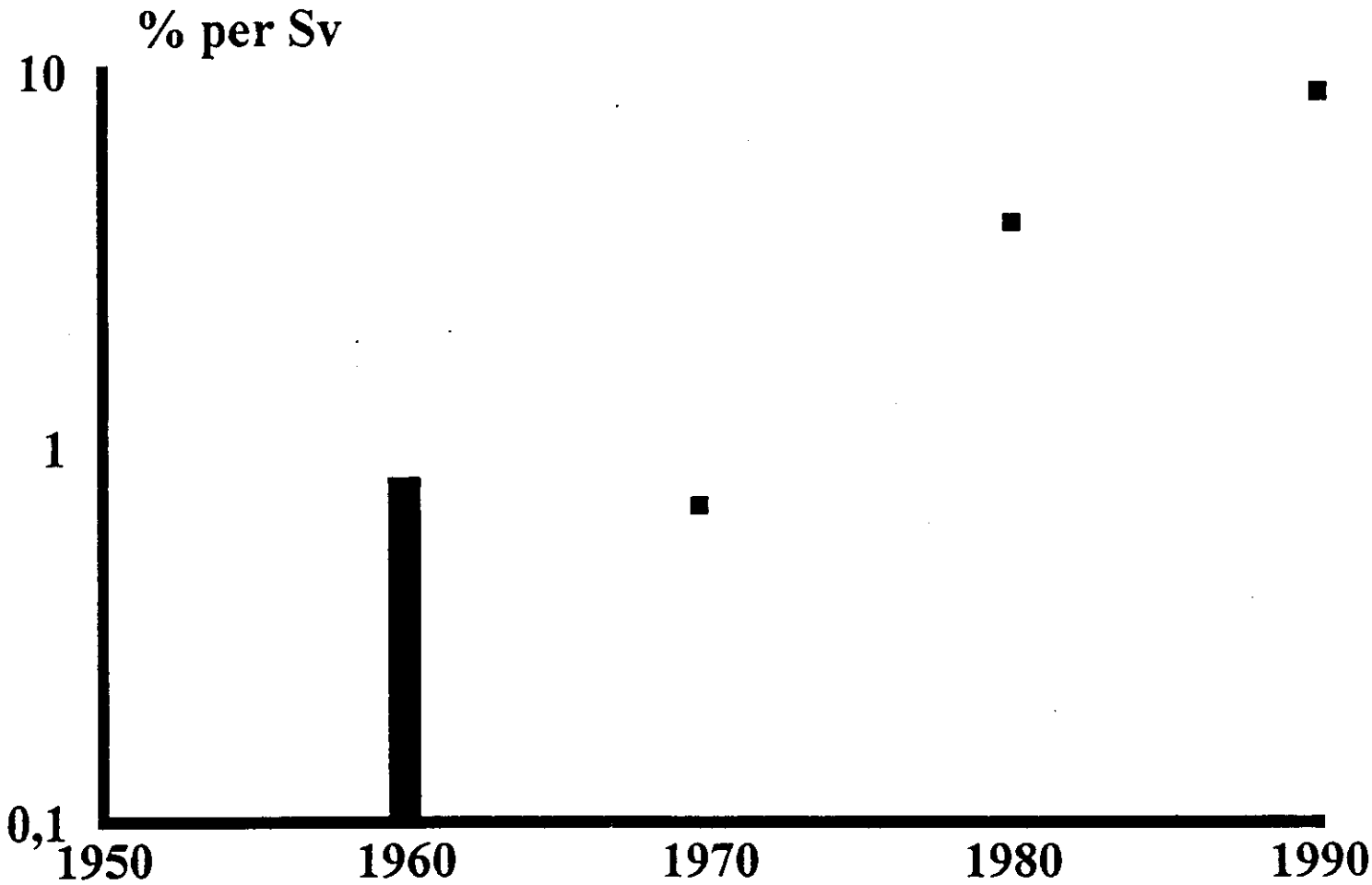


(NRPB, Vol 1, No 3, 1990)


mGy
Medeldoser vid hjärn-us vid olika CT
120
100
80
60
40
20
0
2 +
DR*
CR
350
CX
9800
LX
80
Hi-Q
600
Pace
Siemens
Philips
GE
Toshiba


Diagnostic information
Digital
Film-screen
Film
0
0
Radiation dose

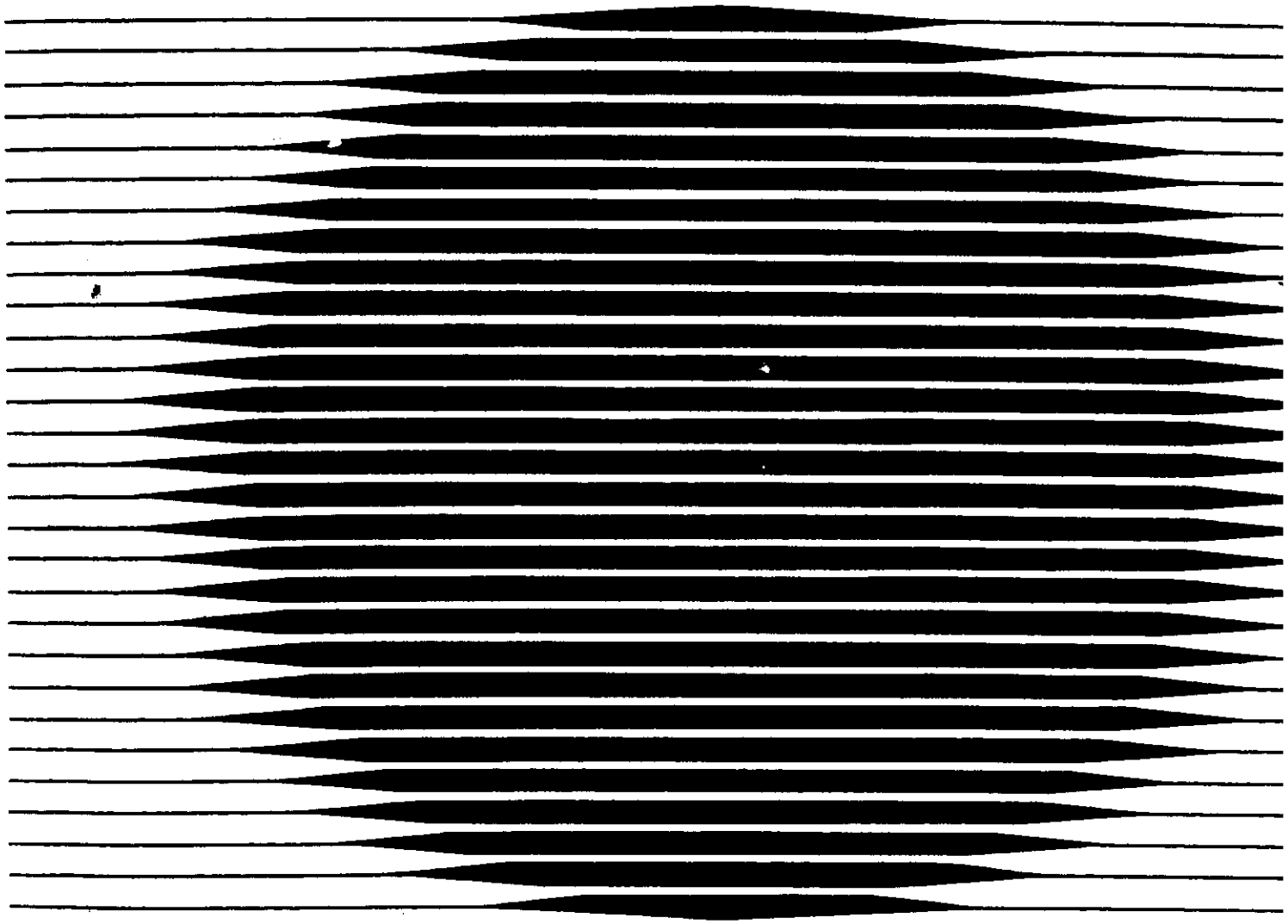
Cancer incidence



(Bengtsson G, Swedish Inst. of Rad. Prot.)

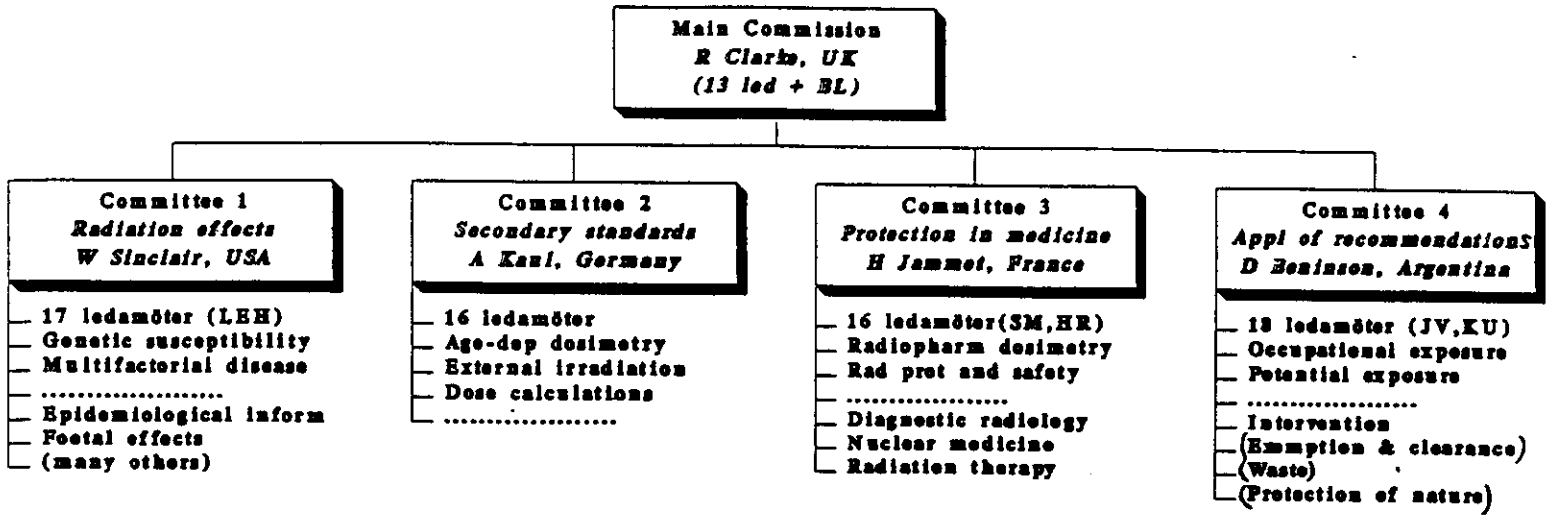
SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation
UNSCEAR 1993 Report to the General Assembly,
with Scientific Annexes



UNITED NATIONS

International Commission on Radiological Protection, ICRP



HEALTH EFFECTS OF EXPOSURE TO LOW LEVELS OF IONIZING RADIATION

BEIR V

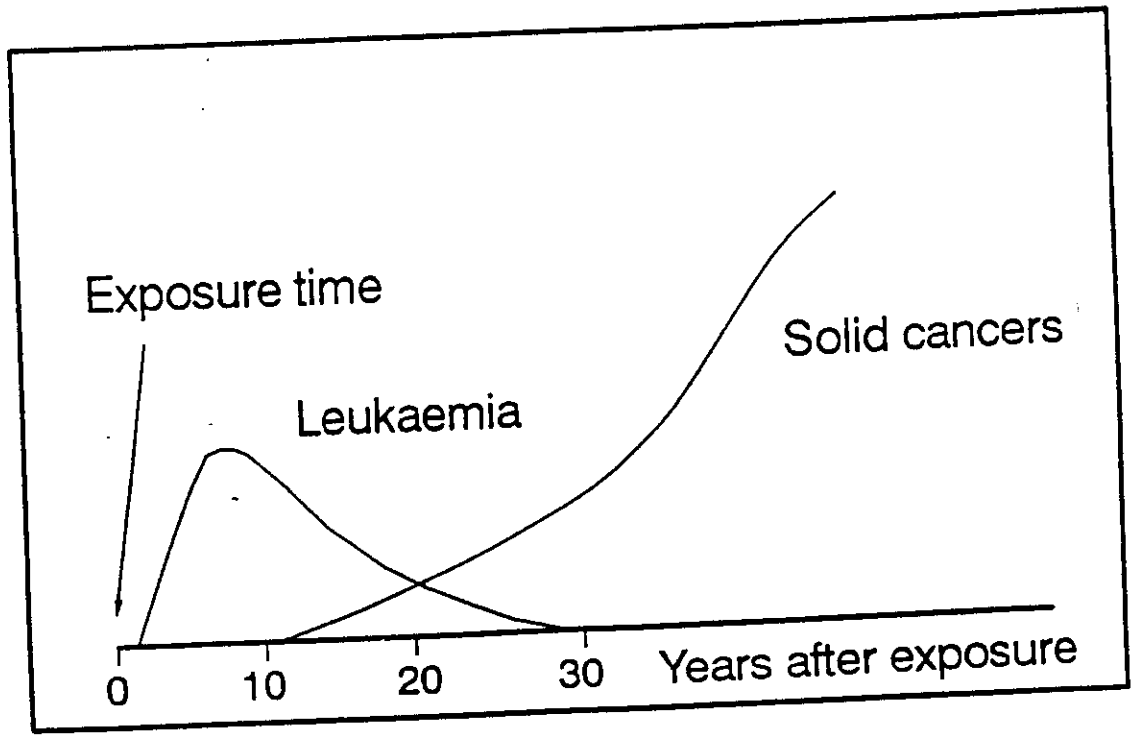
Committee on the Biological Effects
of Ionizing Radiations
Board on Radiation Effects Research
Commission on Life Sciences
National Research Council

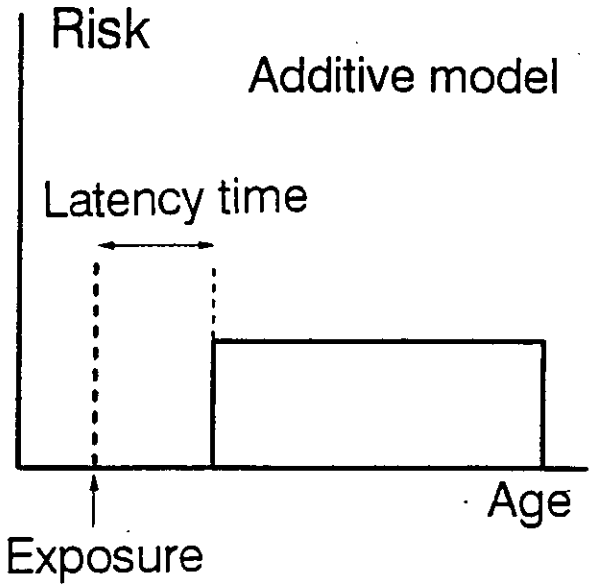
NATIONAL ACADEMY PRESS
Washington, D.C. 1990

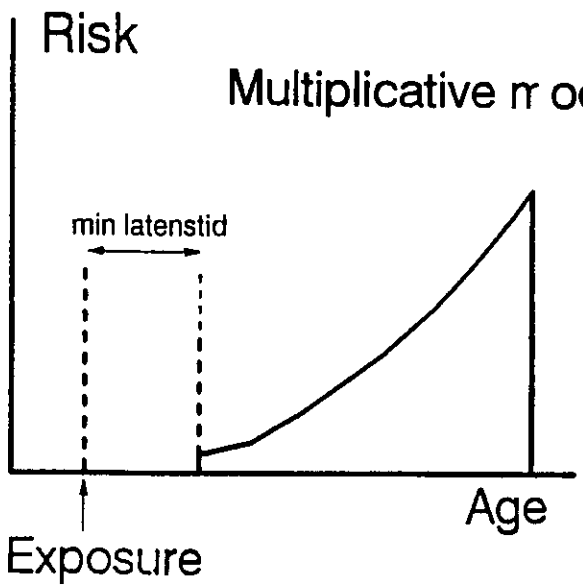
Table 1.

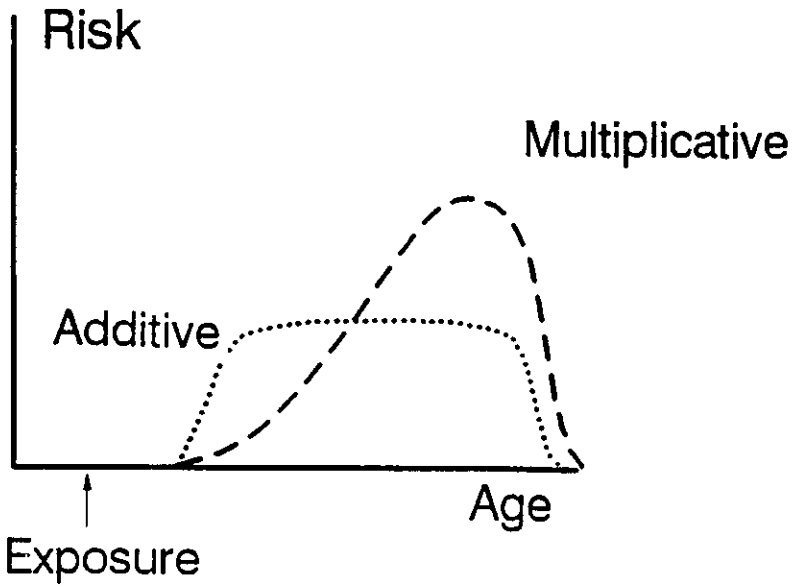
Exposed human populations for Risk Estimation (Sinclair) [7]

- Atomic bombs
  - Japanese survivors
  - Marshall Islanders
- Medical therapy
  - Pelvic radiotheraphy
  - Spinal radiotherapy (ankylosing spondylitis)
  - Neck and chest radiotherapy (thyroid)
  - Scalp irradiation (tinea capitis)
  - Breast radiotherapy
  - Radium-224 treatment
- Medical diagnosis
  - Multiple fluoroscopies (breast)
  - Prenatal irradiation
- Occupational
  - Uranium miners
  - Radium-226 ingestion (dial painters)


Exposure time
Leukaemia
Solid cancers
0
10
20
30
Years after exposure



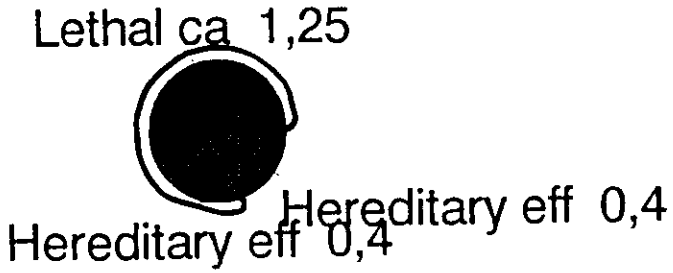




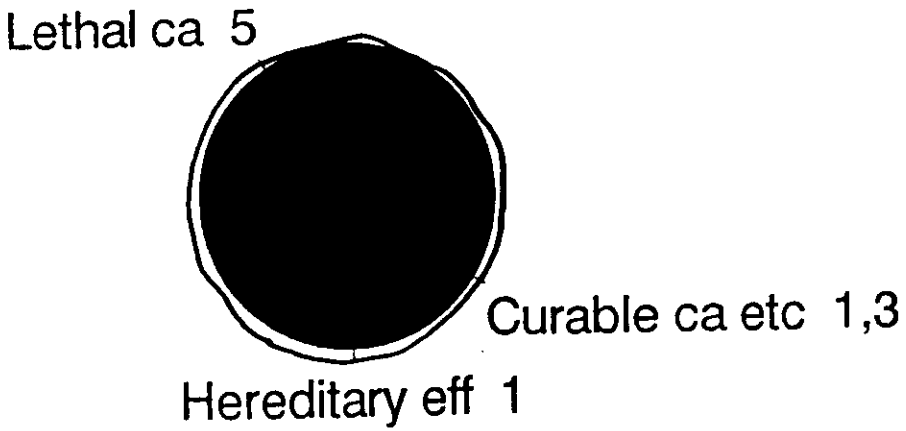
c:\LEO\LECTURE\ADDMULTP.DRW

Risks from ionizing radiation, % per Sv

1977



1990



Why changes?

1. New dosimetry, DS86
2. More cancers than expected

.....

The neutron contribution is no longer significant

Persons exposed at younger ages have higher risk than expected

Data fits a multiplicative projection model

Lifetime cancer risk estimates based on UNSCEAR (1988) and NAS/BEIR (1990) reports, in comparison with those assumed in ICRP 26 (1977).

	Cancer deaths/10^4/Sv	
Organ at risk	**ICRP 26**	**UNSCEAR/BEIR[1]**
Bone marrow	20	85
Bone	5	5
Lung	20	100
Thyroid	5	10
Breast	25	20
Subtotal	75	220
Remainder		
G-I tract		150
Ovary		15
Bladder		30
Multiple myeloma		15
Skin		2
Other		65
Subtotal	50	282
Total	125	500

1 Rounded values, based on averages of the UNSCEAR and BEIR multiplikative projections derived with age-specific risk coefficients, divided by DREF of 2.0 for compatibility with the estimates in ICRP 26, which were applicable to irradiation at low dose rates.

Estimated relative contribution of organs to the total detriment and
selected values of organ weighting factors (W_T)
(ICRP Publ.60, Annex B [1]).

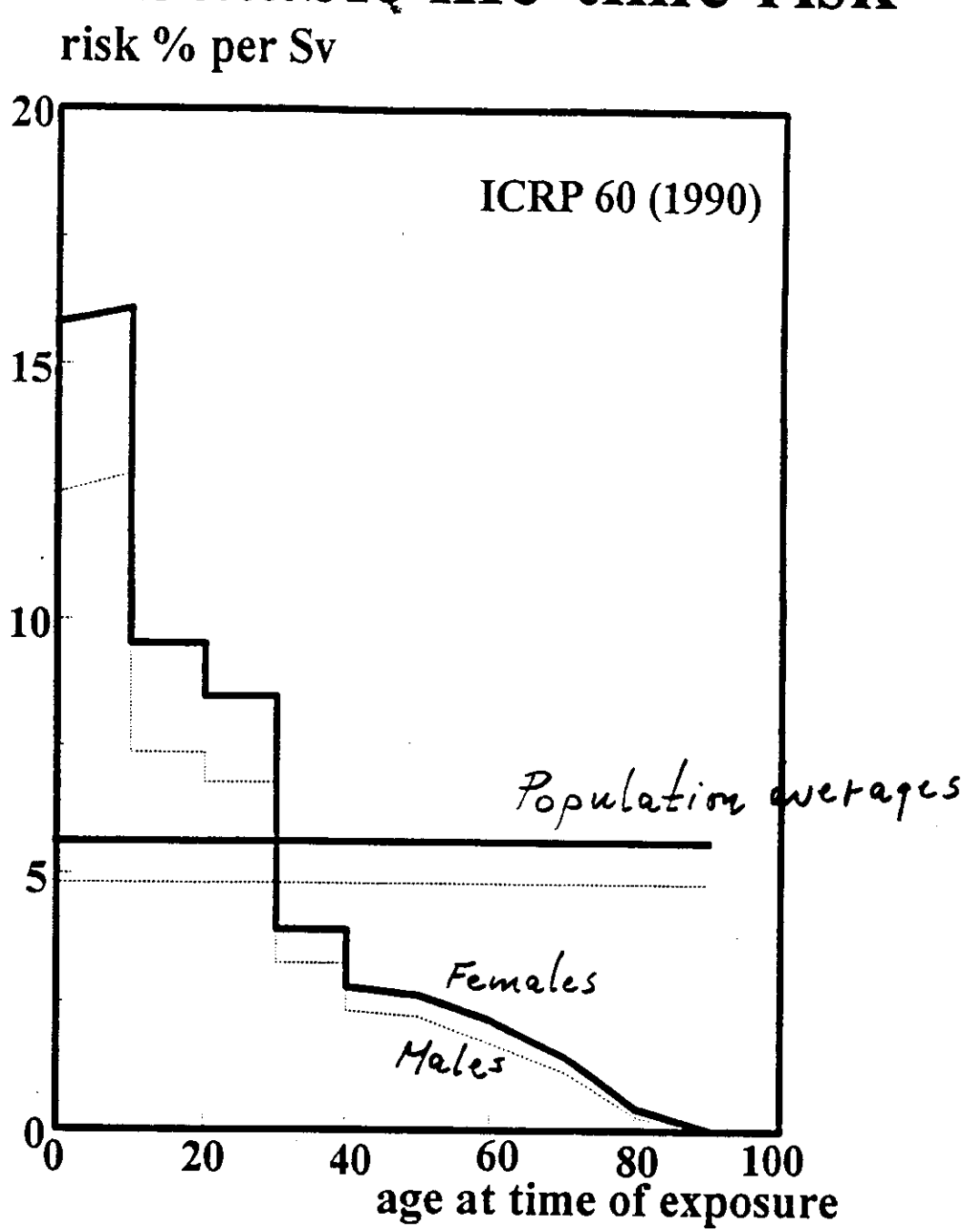
Organ	Relative contribution	Values of W_T
Bladder	0.040	0.05
Bone marrow (red)	0.143	0.12
Bone surface	0.009	0.01
Breast	0.050	0.05
Colon	0.141	0.12
Liver	0.022	0.05
Lung	0.111	0.12
Desophagus	0.034	0.05
Ovary	0.020	-
Skin	0.006	0.01
Stomach	0.139	0.12
Thyroid	0.021	0.05
Remainder **	0.081	0.05
Gonads	0.183*	0.20

* - including hereditary changes
** - includes: adrenals, brain small intestine
kindney, muscle, pancreas spleen, thymus
uterus and upper large intestine (?)

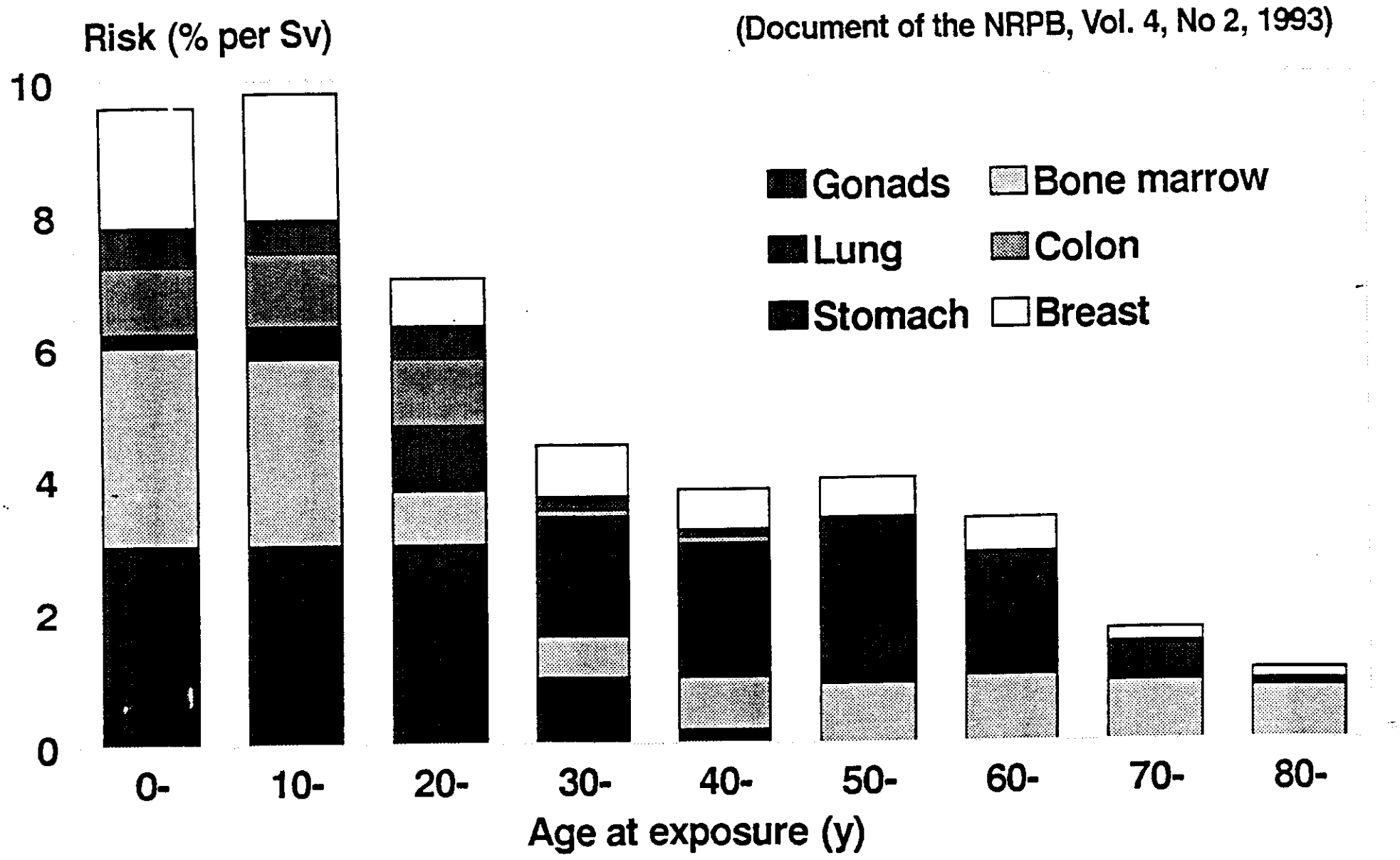
Factors affecting the risk to get cancer

1. Age at exposure
2. Sex
3. Genetic factors
4. Other carcinogens
5. Sociogeographic factors

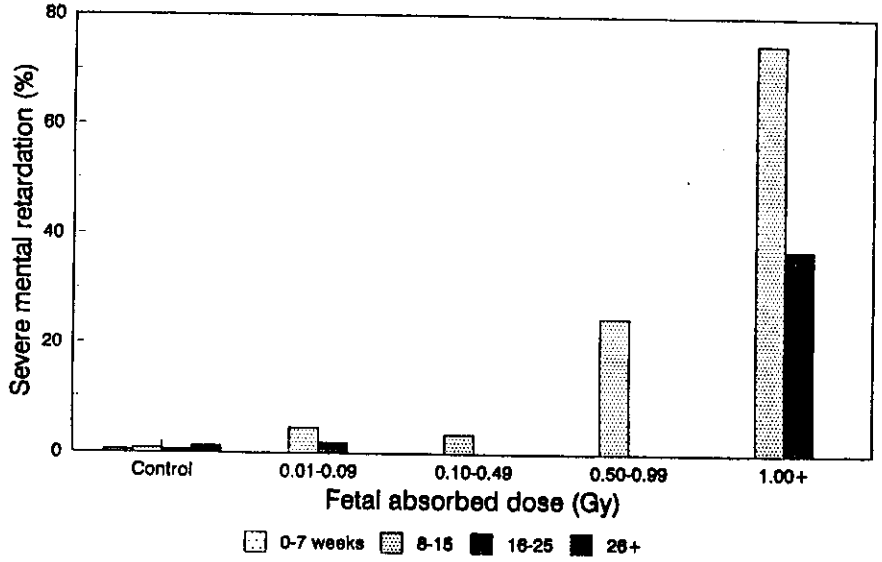
Attributablę life-time risk



Contributions from six specified organs to total aggregated detriment



Severe mental retardation



1) week 8-16 = high risk threshold?

40% per Gy

2) week 16-26 = medium risk threshold?

3) week 0-7 and 26- = low risk

Effect	Population	Exposure period	Probability
Mental effects Reduction in IQ	Fetus	8-15 weeks of gestation	30 IQ points/Sv
Severe mental retardation	Fetus	"	40% per Sv
Hereditary effects	Whole population	All generations	1% per Sv
Fatal cancer	"	Lifetime	5% per Sv
Fatal cancer	Working population	Lifetime	4% per Sv
Health detriment	Whole population	Lifetime	7.2% per Sv
Health detriment	Working	Lifetime	5.5% per Sv

Table 3.7: Summary of ICRP's estimates of probabilities of effects of exposure to ioni-ing radiation.

Protection of the patient

PUBLICATION 34

Protection of the Patient in Diagnostic Radiology

1982

PUBLICATION 44

Protection of the Patient in Radiation Therapy

1984

PUBLICATION 52

Protection of the Patient in Nuclear Medicine

1987

Protection of the patient

ICRP PUBLICATION 53

Radiation Dose to Patients from Radiopharmaceuticals

1987

ADDENDUM to ICRP PUBLICATION 53

Radiation Dose to Patients from Radiopharmaceuticals

1992

Protection of the worker

PUBLICATION 57

Radiological Protection of the Worker in Medicine and Dentistry

1989

Recommendations of the ICRP

ICRP PUBLICATION 26

Recommendations of the International Commission on Radiological Protection

Jan. 1977

ICRP PUBLICATION 60

1990 Recommendations of the International Commission on Radiological Protection

Nov. 1990

ICRP PUBLICATION 60

1990 Recommendations of the International Commission on Radiological Protection

ADOPTED BY THE COMMISSION IN NOVEMBER 1990

Risks Associated with Ionising Radiations

Five papers prepared by a Task Group of Committee 1 of the International Commission on Radiological Protection

Protection of the patient

Summary of the Current ICRP Principles for Protection of the Patient in Diagnostic Radiology

1993

Radiological Protection of the Patient
News in ICRP Publication 60

- Justification *for each procedure*
- Optimisation - *Application of constraints or reference levels*
- Limitation (not for patients)
- *Applicable also for potential exposure (accidents) (Safety)*
- *Check if the system for protection is good or not (Assessment of effectiveness)*

5 4.2. *The optimisation of protection in medical exposure*

(180) Because most procedures causing medical exposures are clearly justified and because the procedures are usually for the direct benefit of the exposed individual, less attention has been given to the optimisation of protection in medical exposure than in most other applications of radiation sources. As a result, there is considerable scope for dose reductions in diagnostic radiology. Simple, low cost, measures are available for reducing doses without loss of diagnostic information, but the extent to which these measures are used varies widely. Doses from similar investigations cover ranges of as much as two orders of magnitude. Consideration should be given to the use of dose constraints, or investigation levels, selected by the appropriate professional or regulatory agency, for application in some common diagnostic procedures. They should be applied with flexibility to allow higher doses where indicated by sound clinical judgement.

(181) Constraints should also be considered in the optimisation of protection when the procedures are not intended to be of direct value to the exposed individual, as in scientific and clinical studies involving the exposure of volunteers.

5.4.3. *Dose limits in medical exposure*

(182) Medical exposures are usually intended to provide a direct benefit to the exposed individual. If the practice is justified and the protection optimised, the dose in the patient will be as low as is compatible with the medical purposes. Any further application of limits might be to the patient's detriment. The Commission therefore recommends that dose limits should not be applied to medical exposures. The question of dose constraints is discussed in Section 5.4.2.

(183) For reasons similar to those given in the previous paragraph, it is not appropriate to include the doses incurred by patients in the course of diagnostic examinations or therapy when considering compliance with dose limits applied to occupational or public exposures. Furthermore, each increment of dose resulting from occupational or public exposure results in an increment of detriment that is, to a large extent, unaffected by the medical doses.

5.4.4. *Medical exposure of pregnant women*

(184) As discussed in Section 3.4.4, exposure of the embryo in the first three weeks following conception is not likely to result in deterministic or stochastic effects in the liveborn child. A pregnant patient is likely to know, or at least suspect, that she is pregnant after one missed menstruation, so the necessary information on possible pregnancy can, and should, be obtained from the patient herself. If the most recent expected menstruation has been missed, and there is no other relevant information, the woman should be assumed to be pregnant. Diagnostic and therapeutic procedures causing exposures of the abdomen of women likely to be pregnant should be avoided unless there are strong clinical indications.

PATIENT EXPOSURE TO RADIATION
IN MEDICAL X-RAY DIAGNOSIS

Possibilities for dose reduction

MUNICH APRIL 1981

Criteria and Methods for Quality Assurance in Medical X-ray Diagnosis

UDINE APRIL 1984

Technical and Physical Parameters for Quality Assurance in Medical Diagnostic Radiology

BRUSSELS FEB. 1988

Optimization of Image Quality and Patient Exposure in Diagnostic Radiology

OXFORD SEPT 1988

Commission of the European Communities

Radiation Protection Programme

CEC Quality Criteria for Diagnostic Radiographic Images and Patient Exposure Trial

C. Maccia[1], B.M. Moores[2], U. Nahrstedt[3], R. Padovani[4], B. Wall[5]

1) Centre d'Evaluation pour l'Assurance de Qualité des Applications Technologiques dans le Domaine de la Santé/ Institut National de la Santé et de la Recherche Médicale, Cachan (F)
2) Radiation Protection Service, Liverpool (GB)
3) Gesellschaft für Strahlen- und Umweltforschung, Neuherberg (D)
4) Unità Sanitaria Locale N° 7, Udine (I)
5) National Radiological Protection Board, Chilton (GB)

----- Preprint -----

EUR 12952

List of quality criteria for diagnostic radiographic images

Chest

PA projection

1. Diagnostic requirements

Image criteria

1. Performed at deep inspiration.
2. Symmetrical reproduction of the thorax.
3. Reproduction of the whole rib cage above the diaphragm.
4. Reproduction of the vascular pattern in the whole lung, particularly the peripheral vessels.
5. Visually sharp reproduction of:
   (a) the bronchial tree, the borders of the heart and aorta;
   (b) the diaphragm and costophrenic angles.
6. Visualization of the retrocardiac lung and the mediastinum.

2. Example of good radiographic technique

1. Radiographic device: vertical bucky or vertical chest stand with stationary grid.
2. Focal spot size: ≤1.3 mm.
3. Total filtration: ≥3.0 mm Al equivalent.
4. Anti-scatter grid: $r = 12$; 40/cm.
5. Film–screen combination: speed class 200–400.
6. FFD: 180 (140–200) cm.
7. Radiographic voltage: 100–150 kV.
8. Automatic exposure control: chamber selected, lateral.
9. Exposure time: <20 ms.

3. Guidelines for good imaging performance

1. *Important image details*
   Small, round details in the whole lung, including the retrocardiac areas: high contrast, ≥0.7 mm; low contrast, ≥2 mm diameter.
   Linear and reticular details out to the lung periphery: high contrast, ≥0.3 mm in width; low contrast, ≥2 mm in width.
2. Entrance surface dose for a standard-sized patient: 0.3 mGy.

Lateral projection

This projection may be indicated for anatomical localization of any abnormality seen on the PA projection.

1. Diagnostic requirements

Image criteria

1. Performed at deep inspiration.
2. Visually sharp reproduction of the posterior border of the heart, aorta, mediastinum, trachea, diaphragm, sternum and thoracic spine.

2. Example of good radiographic technique

1. Radiographic device: vertical bucky or vertical chest stand with stationary grid.
2. Focal spot size: ≤1.3 mm.
3. Total filtration: ≥3.0 mm Al equivalent.
4. Anti-scatter grid: $r = 12$; 40/cm.
5. Film–screen combination: speed class 200–400.
6. FFD: 180 (140–200) cm.
7. Radiographic voltage: 100–150 kV.
8. Automatic exposure control: chamber selected, lateral.
9. Exposure time: <40 ms.

3. Guidelines for good imaging performance

1. *Important image details*
   Small, round details in the whole lung, including the retrocardiac area: high contrast, ≥0.7 mm; low contrast, ≥2 mm diameter.
   Linear and reticular details out to the lung periphery: high contrast, ≥0.3 mm in width; low contrast, ≥2 mm in width.
2. Entrance surface dose for a standard-sized patient: 1.5 mGy.

Pelvis

AP projection

1. Diagnostic requirements

Image criteria

1. Symmetrical reproduction of the pelvis.
2. Visualization of the sacrum and its intervertebral foramena.
3. Visualization of the pubic and ischial rami.
4. Visualization of the sacroiliac joints.
5. Reproduction of the necks of the femora, which should not be distorted by foreshortening or rotation.
6. Reproduction of spongiosa and corticalis, and visualization of the trochanters.

2. Example of good radiographic technique

1. Radiographic device: bucky table.
2. Focal spot size: ≤1.3 mm.
3. Total filtration: ≥3.0 mm Al equivalent.
4. Anti-scatter grid: $r = 12$; 40/cm.
5. Film–screen combination: speed class 400.
6. FFD: 115 (100–150) cm.
7. Radiographic voltage: 70–90 kV.
8. Automatic exposure control: chamber selected, central or both lateral.
9. Exposure time: <400 ms.

3. Guidelines for good imaging performance

1. Important image details: 0.5 mm.
2. Entrance surface dose for a standard-sized patient: 10 mGy.

Remarks

Radiation protection: where appropriate, gonad shields should be employed for male patients, and for female patients if possible.

Breast

Fulfilment of image criteria might require more than one projection.

1. Diagnostic requirements

Image criteria

1. Visually sharp reproduction of the breast.
2. Reproduction of the adjacent chest wall.
3. Visually sharp reproduction of the cutis and subcutis.
4. Nipple should be parallel to the film.

2. Example of good radiographic technique

1. Radiographic device: specially dedicated equipment. Anode material: Mo.
2. Focal spot size: ≤0.6 mm.
3. Total filtration: ≥0.03 mm Mo or 0.5 mm Al equivalent.
4. Anti-scatter grid: specially designed moving grid (see "Remarks") might be necessary.
5. Film–screen combination: dedicated high-resolution film–screen combinations with special processing; speed class 20–40.
6. FFD: ≥60 cm.
7. Radiographic voltage: 25–35 kV.
8. Automatic exposure control: chamber selected, specially positioned.
9. Exposure time: ≤2 s.
10. Breast compression: should be applied to a level that the patient can tolerate.

3. Guidelines for good imaging performance

1. Important image details: round details (3 mm diameter), microcalcifications (0.2 mm).
2. Entrance surface dose for a standard-sized patient: 4.5 cm compressed breast and no grid, 10 mGy.

Remarks

The choice of anode material, total filtration, tube voltage and the use of an antiscatter grid required to obtain satisfactory image quality at an acceptable level of average entrance surface dose will be greatly affected by the density and thickness of the breast under investigation.

For more dense and/or thicker breasts (in excess of 6 cm compressed) a tungsten anode, aluminium or other special filtration, higher tube voltages and use of an antiscatter grid might be preferable.

For thinner breasts (≤4 cm) the use of an antiscatter grid will not be necessary.

Examination		Entrance surface absorbed dose per radiograph (mGy)
Lumbar spine	AP	10
	LAT	30
	LSJ	40
Abdomen, intravenous urography & cholecystography	AP	10
Pelvis	AP	10
Hip joint	AP	10
Chest	PA	0.4
	LAT	1.5
Thoracic spine	AP	7
	LAT	20
Dental	Periapical	7
Skull	AP	5
	PA	5
	LAT	3

PA= Posterior - anterior projection; LAT= Lateral projection; LSJ= Lumbo- sacral-joint projection; AP= Anterior - posterior projection

Computed tomography

Examination	Multiple scan average absorbed dose (mGy)
Head	50
Lumbar spine	35
Abdomen	25

Mammography

Average glandular dose per cranio-caudal projection
1 mGy (without grid) 3 mGy (with grid)

Fluoroscopy

Mode of operation	Entrance surface absorbed dose rate (mGy/min)
Normal	25
High level	100

FACTOR	EFFECT
Referral criteria	Reduced number of unhelpful examinations
Availability of previous films	Reduced number of repeated examinations
Number of radiographs	Lower dose
Fluoroscopy time and current	Lower dose
QA-programme	Reduced number of repeat films
X-ray beam collimation	Lower effective dose
Shielding of radiosensitive organs	Lower equivalent dose to organs
Choice of projection	Lower dose to certain radiosensitive organs
Compression	Lower dose
Tube potential / X-ray spectra	Reduces dose and contrast
Tube filtration	Reduces dose and contrast
Grid / air gap	Higher dose and better image quality
Minimize post-patient attenuation	Carbon fibre material reduces dose
Screen-film combination	Faster combination lower dose
Optimized film processing	Improved image quality and lower dose
Image intensifier	Lower dose
Video recording	Reduces patient dose
Pulse fluoroscopy	Shorter fluoroscopy time
Spot film radiography	Lower dose / image
Computed radiography	Dose and image quality related

RADIATION PROTECTION

ICRP PUBLICATION 62

Radiological Protection in Biomedical Research

A report of Committee 3 adopted by the
International Commission on Radiological Protection

ADOPTED BY THE COMMISSION IN NOVEMBER 1992

PUBLISHED FOR
The International Commission on Radiological Protection
by

PERGAMON PRESS
OXFORD · NEW YORK · SEOUL · TOKYO

Table 2. Categories of risk and corresponding levels of benefit

Level of risk	Risk category (total risk—see text)	Corresponding effective dose range (adults) (mSv)	Level of societal benefit
Trivial	Category I ($\sim 10^{-5}$ or less)	<0.1	Minor
Minor to intermediate	Category II		Intermediate to moderate
	IIa ($\sim 10^{-5}$)	0.1-1	
	IIb ($\sim 10^{-4}$)	1-10	
Moderate	Category III ($\sim 10^{-3}$ or more)	>10[a]	Substantial

[a]To be kept below deterministic thresholds except for therapeutic experiments.

Radiological Protection in Diagnostic Radiology

Areas of special concern:

- # Paediatric
- # Interventional
- # CT
- # Digital

Proposed ICRP work
Radiological Protection in Medicine

1. Radiological Protection and Safety in Medicine

2. Radiological Protection in Diagnostic Radiology
3. ... Nuclear Medicine
4. ... Radiation Therapy

5. Radiation Dose to Patients from Radiopharmaceuticals
   (updating of ICRP Publ 53; continued)

International organisations

National authorities

Manufacturers

Hospital administration

Practioneers

Nurses P A T I E N T Assistants

Radiologists Engineers

Medical physicists

Universities Research organisations

Ethical committees

Radiation Protection Dosimetry, XX, X-X (1994) in press

PRACTICAL IMPACT OF THE EVOLUTION AND CHANGES OF ICRP RECOMMENDATIONS ON RADIOLOGICAL PROTECTION IN MEDICINE

S. Mattsson and A. Almén, Department of Radiation Physics, Lund University, Malmö General Hospital, S-214 01 Malmö, Sweden.

Abstract

The International Commission on Radiological Protection (ICRP) has given recommendations concerning the radiological protection of the patient in diagnostic radiology, nuclear medicine and radiation therapy, as well as of the worker in medicine and dentistry. In spite of these earlier recommendations, the situation in medicine is far from optimal showing a very wide distribution of patient doses among various departments and hospitals without any similar variation in diagnostic information.

There is a special need to emphasise such areas which have the potential of high patient doses and/or high risk, e.g. interventional radiography, computed tomography, and paediatric radiology.

For medical exposures, ICRP (Publication 60) still indicates that if the practice is justified and the protection optimised, dose limits should not be applied. However, it does recommend the development of reference levels as a quantitative guide to optimisation.

Consideration should also be given to potential accidents and intervention in case they occur.

PRACTICAL IMPACT OF THE EVOLUTION AND CHANGES OF
ICRP RECOMMENDATIONS
ON RADIOLOGICAL PROTECTION IN MEDICINE

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Introduction

The medical use of ionising radiation, which has an enormous benefit to the patients, also contributes significantly to the radiation exposure of individuals and populations [1,2]. Diagnostic radiology is the largest man-made source of ionising radiation, although more than 3/4 of the world's population have no chance of receiving any radiological examination, regardless of what disease they might have [1].

In the field of diagnostic radiology, the potential for reducing the absorbed dose to patients is well established [3]. The unnecessary exposures may be the clinically unjustified as well as the unoptimised (which implies that doses can be reduced by improvements in procedures or equipment). The opinion of the ICRP is that radical measures should be taken to reduce unnecessary exposure, especially since this can be done without any sacrifice of the diagnostic benefit [4].

It is not clear if the same potential exists for nuclear medicine investigations, which are less frequent but for the individual patient may give an exposure of the same order of magnitude as an X-ray investigation.

In radiation therapy, the situation is much different from the diagnostic one, since the adequate irradiation of the target volume is therapeutic and that the wish to get low doses to volumes just outside the treated volume is an essential part of the process. In external beam therapy, doses to distant parts of the body may, however, be significantly influenced by for example various types of field shaping devices used.

When discussing protection in medicine, we have also to consider the irradiation of members of the staff, remembering that more than 90% of the persons, being occupationally exposed to radiation world-wide, belong to the medical field.

Current ICRP recommendations on radiological protection in medicine

The International Commission on Radiological Protection (ICRP) has a special connection to medicine due to its roots in the International Society of Radiology. It has even a special committee on "Protection in Medicine " (Committee 3) and has issued a series of documents [5-7] for the medical field: ICRP Publication 34 deals with

Protection of the Patient in Diagnostic Radiology, Publication 52 with *Protection of the Patient in Nuclear Medicine* (diagnostic and therapeutic) and Publication 44 about *Protection of the Patient in Radiation Therapy*. There is a special report, Publication 57, on the *Protection of the Worker in Medicine and Dentistry*[8]. The Publication 53, *Dose to Patients from Radiopharmaceuticals* [9] is also an important document for nuclear medicine.

After these documents were written, ICRP has published new general recommendations in Publication 60 [10], which replaces Publication 26 from 1977 [11]. There is now an urgent need to implement and apply the ideas of Publication 60 in the medical field. A first attempt to do that was the updating of the *"Summary of the Current ICRP Principles for Protection of the Patient in Diagnostic Radiology"* , which is included in the recently printed Publication 62 from 1993 [12]. A similar publication covering the field of nuclear medicine is in press and will be distributed at the International Congress of Radiology in Singapore in the beginning of 1994. The main part of Publication 62 deals with *"Protection of Humans in Biomedical Research"*. There are also an *addendum to* Publication 53 *"Dose to Patients from Radiopharmaceuticals"* in that publication.

What does ICRP Publication 60 say about radiological protection and safety in medicine

New data and new interpretations of old data indicate that the risk associated with ionising radiation is about four times higher than estimated a decade ago. The increased knowledge about the variation of risk by age at exposure has also implications for our clinical radiation protection efforts, which should make priorities for new-born, children and pregnant women.
The main principles for radiological protection still state that practices causing exposure should be justified. The new recommendations point out that together with the justification at the broad level of practices, it is necessary to justify with respect to the individual patient. Protection arrangements should be optimised. Dose limits should be applied to workers but not to medical exposures of patients. However, ICRP now recommends that consideration should be given to the use of reference dose levels for application in some common diagnostic procedures. They should be applied with flexibility to allow higher doses when indicated by sound clinical judgement. The use of such dose constraints is a part of the optimisation procedure. As a new principle, potential exposure (accidents) as well as interventions after an accident are to be treated in the same way as planned exposure. Moreover ICRP Publication 60 points out the need to control if the system used for optimisation (or justification) is good enough (assessment of effectiveness).

An important task for ICRP is to clarify how the recommended system of radiological protection should be applied in medicine. A major point to be clarified is how the ALARA-principle should be applied at investigations of patients, how reference levels should be applied to medical exposures and constraints to occupational exposure and for members of the public. Other tasks include the implications of the new dose limits for occupational exposure, potential exposures and intervention. In addition the procedures for assessment of effectiveness of the system of radiological protection will be developed. There is also a need to review the quantities used for dose and risk assessment in medical examinations.

Which parameters can be used to describe the radiation risk for patients?

One parameter is the mean absorbed dose to the whole body. It is the energy imparted (ε) divided by the weight of the person. In diagnostic radiology, the energy imparted can be estimated using measurements with a transmission ionisation chamber. This is the simplest way to get an individual dose estimate and can separate contributions from various projections and procedures.

To get a better estimate of the risk, the distribution of the absorbed dose among different organs and tissues in the body has to be known. This gives the possibility to calculate the mean absorbed dose to organs/tissues and combine those with risk figures for each organ (tissue).

The use of mean absorbed doses to organs and tissues is a simplification as the heterogeneity of absorbed dose in the tissue is not taken into consideration. In diagnostic radiology organs are often only partly irradiated or there is a sharp dose gradient within organs. Sharp dose gradients are also present at interfaces e.g. between bone and soft tissue, contrast media and soft tissue. In nuclear medicine there is often a heterogeneous uptake of the radionuclide in organs and tissues and even in cells.

There is often insufficient information on organ doses to calculate the effective dose (E). Attempts to estimate effective dose or effective dose equivalent (H_E) in diagnostic radiology normally rely on a limited number of Monte Carlo calculated organ doses for standardised phantoms [13-15]. Alm-Carlsson and Carlsson [16], Huda and Bissessur [17] and Le Heron [18] used such data and calculated effective dose values for a number of typical investigations and gave a relation to dose-area product or entrance dose. Experimentally, using measurements on phantoms, various groups have estimated the relation between H_E and ε or E and ε (e.g. Månsson et al. [19], Almén and Mattsson [20]).

In nuclear medicine, calculations of organ doses and effective dose (equivalent) have been carried out for a number of radiopharmaceuticals [9, 21] mainly using the MIRD formalism [22]. There is a large uncertainty in dose data mainly due to insufficient information on biokinetic data. It is also well-known that there are considerable differences in biokinetics from patient to patient. Children, who often show different kinetics than adults, constitute a special problem. There is also a need to establish reliable biokinetic data for new radiopharmaceuticals.

Effective dose (equivalent) for patients ?
The use of the quantity effective dose for patients has been criticised [23,24]. MIRD accepts the use of effective dose equivalent for volunteers entering investigational protocols, but not for patients [23]. The alternative proposed is the absorbed dose to various organs and tissues, for which specific risk factors can be applied. According to the authors' opinion, the effective dose is of great value if one wants to characterise and communicate on patient doses. It should not be taken as an exact number of the

risk. The effective dose, however, gives a relative number and thereby a possibility to compare techniques used at various places and laboratories. NRPB [25] has quantified levels of risk for two broad groups of patients, namely paediatric and geriatric, for which the detriment per unit effective dose is a factor of about 2 higher and at least 5 lower, respectively, than for the general population. For patients of any age between these two groups, the detriment per unit effective dose is close to the ICRP Publication 60 value for the general population.

The effective dose takes only the stochastic effects (lethal cancer and hereditary effects) into consideration. Today, there are new reasons to consider the risk for deterministic effects in diagnostic radiology again. Locally high absorbed doses to the skin can be reached for example in digital radiography in connection with interventional studies. The doses are sometimes at a level where they result in skin erythema and epilation.

Diagnostic radiology

The potential for reducing the exposure of the population from medical X-ray examinations is well established through a number of local, national and international patient dose surveys. It is generally accepted that the lowest possible dose should be delivered consistent with the clinical purpose of the investigation. A problem is to guarantee that these aspects are considered in practice. Radiation protection has often low priority in the busy clinical practise.
It is important to include patient exposure as well as image quality into the quality management system, which should be in operation at every department of diagnostic radiology. The manufacturers have a central role to build radiological protection into the system design. The WHO-Basic Radiological System (BRS) [26] is a good example of such a design!

How can patient exposure be monitored in the clinic?
There are several methods used together with the more simple estimates based on the "mAs product". The need differs considerably for various types of equipment. CT is standardised and the mean absorbed dose in a scan is very similar from patient to patient, if the same unit is used. There are, however, considerable differences between units [27] as in the number of scans used. At other investigations there is a need for more detailed studies of the large variation of doses. This can be done by:
1. Measurement of the primary beam air kerma using an ionisation chamber
2. Measurement of entrance surface absorbed dose by TLD (lithium fluoride, lithium borate) on patients or on phantoms simulating the clinical situation.
3. Assessment of total energy imparted to the patient by direct measurement of the product of the kerma in air and the area of the patient exposed using a "dose-area product meter" (transmission ionisation chamber). In this respect there is a strong need for an international agreement on quantities to be measured, calibration to be used and on a uniform data presentation. Factors to convert data on dose-area product into energy imparted, organ doses and effective dose should be given.

There is a need for further advice and a protocol for periodic patient dose measurements. UK has got such a protocol [28] and ICRU is tackling the problem [29].

Methods to carry out automated dose surveys [30] should be stimulated. Based on patient dose surveys CEC and UK have suggested guideline dose levels in terms of entrance surface dose for routine radiographs, based on the third quartile value of the observed dose distributions [31,25].
The ease with which new equipment can give the patient high doses, stresses the need to create routines which react when certain investigation levels are overdrawn!

How can image quality be described?
There are various ways to describe the image quality:
1. Imaging standard test phantoms for determination of physical parameters (contrast, resolution)
2. Imaging phantoms with diagnostically relevant structures (subjective optimisation) or patients of equal size (group mean weight within 70±5 kg).
Observer performance tests (ROC) can then be done on the images.
3. Specification of the visibility of defined anatomical structures in patient studies [31].

Relation between image quality and absorbed dose?
There are fundamental difficulties to understand the relation between measured physical parameters and what the radiologist can see in an image.
This is one of the most challenging field of research related to diagnostic radiology and nuclear medicine today. If we could make some progress in this field, our work to optimise the relation between dose and image quality will be much simplified.

Reference dose levels and image quality criteria have to be set by professional and advisory bodies after consideration of the information content gained and the ranges of average doses delivered.

Need of methods for risk comparison
It is important to be able to put the radiological risks into perspective. We also need to know the risk for the patient if the investigation is not carried out. We need better methods for risk comparison e.g. between radiation and amount of X-ray contrast agents in diagnostic radiology, and also between risks associated with X-rays and with MR, ultrasound etc. One problem for ICRP is that this organisation solely works with ionising radiation.

Which priorities should be given today in radiological protection in diagnostic radiology?:
These priorities of course differ from country to country. However, in most developed countries, the high dose/high risk investigations are:
Paediatric investigations, interventional radiology, CT and other digital techniques.

The effective dose at CT-investigations is 5-10 times higher than at ordinary X-ray images. CT, which in many European countries typically stands for 2% of the investigations, gives 20% of the total population dose from diagnostic radiology [27].

There is an increasing unintentional misuse of modern technology. This may be connected to a wish to increase the patient throughput from the user's side. For example, using helical scan CT it takes shorter time to scan 60 cm along the body with covering scans in 30 seconds than to take only the necessary 10 scans at various

positions. The misuse may also be connected to insufficient knowledge about the dose contribution from long time fluoroscopy.

Nuclear medicine

Nuclear medicine differs from diagnostic radiology in the respect that the radiation "source term", the administered activity, is well known. ICRP recommends that this should be recorded for every patient. Patient doses can then be estimated using data in ICRP Publication 53 and 62. One problem is that uptake and retention, and thus the absorbed dose, may differ considerably from patient to patient.

As part of the optimisation process, the activity, which provides an appropriate level of diagnostics and still ensure radiological protection aspects, has to be determined to be able to propose reference levels. Paediatric applications should receive special attention in this regard and recommendations given for selected body-weight intervals. There may be a need for differentiation, so that lower activity and longer measurement time are used for young patients (provided that patient movement can be controlled) and higher activity and shorter measurement time for older.

Relevant methods for dose reduction should be used [7]. Except for forced diuresis and thyroid blocking using stable iodine, this is not very much used in the clinical practise.

It is important that quality control procedures are employed to monitor the performance of all equipment used for clinical measurements.

With regard to occupational exposure, exposure of workers, who are engaged in labelling, synthesis and preparations of radiopharmaceuticals and in patient handling, is the main concern.

Exposure of the public during the patient's home travelling and when he/she is back at home with family members has to be assessed, as well as the appropriate handling and disposal of the radioactive waste. Unintended situations such as misadministration of radiopharmaceuticals or administration of certain radiopharmaceuticals to pregnant and nursing women have to be addressed.

Radiation therapy

Optimisation regarding irradiation of target volume and risk organs is a part of the radiotherapy procedure itself. Underexposure of the target volume can have as serious health consequences for the patient as overexposure. However, the dose to distant organs (uterus, second breast etc.) can be significantly influenced by the treatment technique (wedges or not, ext a collimation, shielding of organs, leakage radiation etc.) and there is no reason to trea: this differently from other types of radiological protection problems.

In radiation therapy, the main emphasis has to be given to the potential (accidental) exposures. Even if radiotherapy is the area of medicine which has the longest traditions of quality control and safety, a number of accidents and misadministrations have occurred during the recent years. In spite of improved safety systems accidents continue to occur. The type of accidents range from one single fraction up to the whole treatment of a large number of patients. There is a combination of equipment failure, a wide range of human errors as well as communication problems. High dose rate brachytherapy systems create special problems from the safety point of view.
ICRP will hopefully transfer the experiences of accidents and malfunction into recommendations for authorities, manufacturers and users. The recommendations are proposed to cover design of equipment, responsibilities and program for education and training.

As regards safety, the interlocks associated with the equipment and the facility will be reviewed and for the protection of staff and public, consideration will be given to the practical application of dose constraints. Potential exposures to the public from decommissioned radiation sources should be minimised.

Procedures to assess the effectiveness of the safety measures have also to be considered.

Immediate practical impacts

In spite of the fact that the work to translate ICRP Publication 60 into the medical field has recently started, there are several points which follow earlier ICRP recommendations being quite obvious.

The work to improve radiological protection in medicine has to be done in close co-operation between all categories of staff involved in the work. The responsibility of the operator of the various equipment used should be increased. Various persons have to be aware of their responsibilities. They should actively sign when and why levels for dose constraints are overdrawn.

The continuos dialogue between experts in diagnostic radiology and medical physics and people from various medical professions including the practitioners, who send the patients for a diagnostic investigation is essential and has to be improved.

The new economic system for health care, where the income depends on how many investigations are carried out, does not stimulate optimisation and there is a risk that the justification for a certain investigation is not always discussed as it should. There is therefore an increasing need for clear referral criteria. It is important that the responsibility in each situation is given to those who have the professional knowledge. A competent and active local radiation protection organisation is needed, including an experienced radiation protection committee. It is important that this organisation is asked for advice e.g. when new equipment is purchased. A centralised organisation and a joint laboratory, a diagnostic house or centre, for all patient bound imaging, may be one way to simplify the optimal choice of imaging technique as well as the contacts with the practitioners.

The manufacturers of equipment for X-ray diagnostics and nuclear medicine have to be more actively involved in the discussions, programs and planning than up to now. The situation is far from optimal. This is particularly problematic as far as equipment for interventional radiology and other types of digital radiology is concerned. Today most

digital radiography systems are adjusted by the manufacturers to guarantee good image quality for very different patients, giving too much exposure to the large majority. This guarantees best image quality in every situation, which is the selling argument number one. For most modern CT, one should be able to reduce the exposure (mAs) to half the recommended value without any observable degradation of image quality for almost all patients. Too little attention has hitherto been given to the patient dose aspects when designing new CT-scanners [27].

Education and training of all physicians, medical physicists, radiographers, assistants, nurses and other staff members working in radiology and nuclear medicine should be intensified. Complementary training for those who are not specialised (training in new methods) is also important. "Drivers licences" for equipment and methods should be given when training is fulfilled.

Courses in radiological protection in medicine should be given for all medical students. Examinations in radiological protection should be carried out for specialists in Diagnostic Radiology, Nuclear Medicine, Radiation Oncology and Medical Physics. Active research in the field of radiation protection and the relation between patient doses and image content should be stimulated.

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