1. INTRODUCTION

1.1. BACKGROUND

Pediatric radiology involves imaging individuals with diseases ofchildhood and adolescence. The age range involved is defined differently in different health care systems. The spectrum of diseases includes conditionsspecific to very young children and many conditions common in the adultpopulation. Figures derived from the United Nations Scientific Committee on theEffects of Atomic Radiation (UNSCEAR) suggest that about 250 million pediatric radiological examinations (including dental examinations) per year were performed worldwide between 1997 and 2007 [1]. Children undergoing these examinations require special attention, both because of the diseases specificto childhood and the additional risks to them. In addition, children need special care, in the form provided by parents, carers and comforters, as well as care that has to be provided by specially trained health professionals.

Some tissues in children are more sensitive to the damaging effects of ionizing radiation than those in adults and special attention has to be paid to the amounts of radiation used [2–8]. A useful general summary of some of the reasons for this is given in Table 1 (taken from Ref. [9]). The extent of the overall unnecessary pediatric dose and risk is uncertain but is currently a matter of considerable concern [10, 11].

Organs and tissues are closer together in small children and, hence, are harder to exclude from the primary beam and to protect from scatter. They are also distributed differently and are more susceptible to radiation damage. For example, a computed tomography (CT) study of the lower extremities in an adult will encounter almost exclusively fatty tissue in the bone marrow. In a child, a significant proportion of the red marrow will be exposed, which is a much greater cause for concern [11]. In addition, children have thinner layers of abdominal visceral fat; hence, the natural contrast usually available in adults is muchreduced. Most radiation induced neoplasms do not manifest until several years after exposure, so adult patients may die of other causes before they develop. Owing to their longer life expectancy, children have a greater chance of living long enough to develop a radiation induced neoplasm.

In practice, there is relatively little quantitative literature and audit of practice on the protection of pediatric patients from radiation during diagnostic procedures. This makes it difficult to gain knowledge and to justify whether this protection is working. The benefits of a procedure need to be balanced against the possibility of damage occurring, although this can be difficult to quantify. However, even with a

TABLE 1. REASONS FOR GREATER RISK IN PAEDIATRIC AS COMPARED WITH ADULT COMPUTED TOMOGRAPHY [9]

Reason	Explanation
Higher biological sensitivity at same dose	More proliferating tissue; different tissue distribution
Longer life expectancy	Late manifestation of radiation induced cancers
Increase in dose and effective dose due to technical factors in radiology	Equipment often poorly adapted to pediatric radiology; smaller size and close proximity of organs in children

dearth of literature, there is much that can be achieved. For example, relatively simple advice on the following will yield dose savings:

— Awareness of the special problems of patient positioning;
— The need for immobilization techniques (including help from parents, friends and technical aids);
— The use of image quality assessment;
— The importance of gonad protection;
— The value and proper use of collimation;
— The use of appropriate projections to minimize dose to high risk tissues;
— The use of appropriate filters, mA modulation and/or special pediatric factors with CT.

This publication brings together and summarizes the available advice on good practice in this area.

1.2. OBJECTIVE AND SCOPE

This publication provides guidance to radiologists, other clinicians and radiographers and/or technologists involved in diagnostic procedures using ionizing radiation with children and adolescents. It will also be of value to medical physicists and regulators. It is focused on the measures necessary to provide protection from the harmful effects of radiation by meeting the requirements established in the International Basic Safety Standards (BSS) [2] and by according the necessary priority to this area. The emphasis throughout is on the special requirements of pediatric radiology with, where it is felt to be helpful or necessary, limited restatement of operational aspects of patient and staff protection widely used elsewhere in radiology.

Facility design, the physics of equipment, and radiology information system and/or picture archiving and communication system (RIS/PACS) issues are not addressed, with the exception of the section on procurement and management of equipment in Section 3. This is included as pediatric facilities do not always enjoy the support available to larger units for procurement purposes. In keeping with current developments, additional attention is given tojustification, as is evident in IAEA and European Commission (EC) activities, and in the Image Gently Campaign [10].

The only mandatory statements in this text are the requirements quoted from the BSS [2]. Guidance provided here in the form of 'should' statements, or simply in the present tense indicative, describing good practices, represents expert opinion but does not constitute international consensus recommendations on how to meet the relevant requirements.

There are certain requirements in the BSS [2] that, when applied to specific practices, can be fulfilled mainly by means of one practical measure. In such cases, the regulatory body may need to use a 'should' statement, which means that licensees should take this measure; if another measure is intended, anequivalent level of protection and safety should be achieved. In other cases, theremay be more than one possible option. In such cases, the regulatory body would mention them or describe them.

1.3. STRUCTURE

Section 2 presents the general framework for radiation protection of patients and staff in pediatric radiology, and includes a discussion on thejustification of medical exposures, which are sometimes neglected in radiology. This section also deals with optimization; dose limits and constraints; occupationally exposed workers, carers and comforters; pregnancy; staff training;and research. Pertinent aspects of equipment procurement and/or management, and of immobilization devices are addressed in Section 3. The main body of the text is a series of sections treating the major radiological imaging modalities including:

— General, mobile and dental radiography, including film and/or digital systems (Section 4);
— Fluoroscopy and interventions, both diagnostic and/or therapeutic (Section 5);
— CT (Section 6);
— Diagnostic nuclear medicine (Section 7).

With each, the issue of justification is considered and practical information is provided, where possible, on optimization of protection and safety, including the doses involved and their moderation and/or control.