8

INTERNATIONAL STANDARD

ISO 4037

First edition
1979-05-15

ADDENDUM 2
1989-12-01

X and γ reference radiations for calibrating dosemeters and dose ratemeters and for determining their response as a function of photon energy

ADDENDUM 2: Photon reference radiations at energies between 4 MeV and 9 MeV

Rayonnements X et gamma de référence pour l'étalonnage des dosimètres et débitmètres et pour la détermination de leur réponse en fonction de l'énergie des photons

ADDITIF 2: Rayonnements de photons de référence à des énergies comprises entre 4 MeV *et* 9 MeV

Reference number
ISO 4037 : 1979/Add. 2 : 1989 (E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

Addendum 2 to ISO 4037 : 1979 was prepared by Technical Committee ISO/TC 85, *Nuclear energy.*

Annex A of this Addendum is for information only.

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

X and γ reference radiations for calibrating dosemeters and dose ratemeters and for determining their response as a function of photon energy

ADDENDUM 2: Photon reference radiations at energies between 4 MeV and 9 MeV

1 Scope

This Addendum to ISO 4037 specifies photon reference radiations for determining the response of protection level dosemeters and dose ratemeters at photon energies between 4 MeV and 9 MeV. Reference radiations in this energy range are provided because of the 6 MeV photon fields produced by many nuclear power stations and by other nuclear reactor systems. Further energies are not specified since the variation in response of most dosemeters and dose ratemeters with photon energy shows no discontinuity over this energy range.

2 Definitions

For the purposes of this Addendum, the definitions given in ISO 4037 : 1979, 3.1.1 apply.

For the purposes of this Addendum, "air kerma" shall be used as the dosimetric quantity.

3 Reference radiations

3.1 General

Photon reference radiations shall be produced by one of the following reactions:

- de-excitation of ^{16}O in the $^{19}F(p,\alpha\gamma)^{16}O$ reaction (see 3.2);
- de-excitation of ^{12}C (see 3.3);
- thermal neutron-capture gamma radiations (see 3.4);
- decay of ^{16}N (see 3.5).

3.2 Photon reference radiations from the de-excitation of ^{16}O in the $^{19}F(p,\alpha\gamma)^{16}O$ reaction[1, 2 and 3]

These reference radiations shall be produced by using a particle accelerator to bombard a fluorine target (usually CaF_2) with protons using the $^{19}F(p,\alpha\gamma)^{16}O$ reaction.

The energy levels of the photons and their relative emission probabilities resulting from this reaction for 340,5 keV protons incident on a thin target are shown in figure 1. At this proton energy, the probability for the decay of the excited ^{16}O state, via the 6,05 MeV level, under emission of an electron-positron pair is less than 2 %; the probability for its decay by emission of 6,13 MeV photons is 97 %; the deviation from isotropic emission of these photons is less than 3,5 %. At higher proton energies, the relative contribution of the 6,13 MeV photons decreases in favour of the higher-energy photons, and there is an increase in the contribution by contaminant reactions, for example (p, p'γ) and pair production.

Relative photon-emission rate (yield) as a function of proton energy is illustrated in figure 2. As target thickness (and thus proton energy loss in the target) is increased, the yield increases and the photon spectrum changes as the protons undergoing interactions with the fluorine have decreasing energies with increasing depth. The energy of the photons emitted is high enough for their attenuation in the target to be considered negligible.

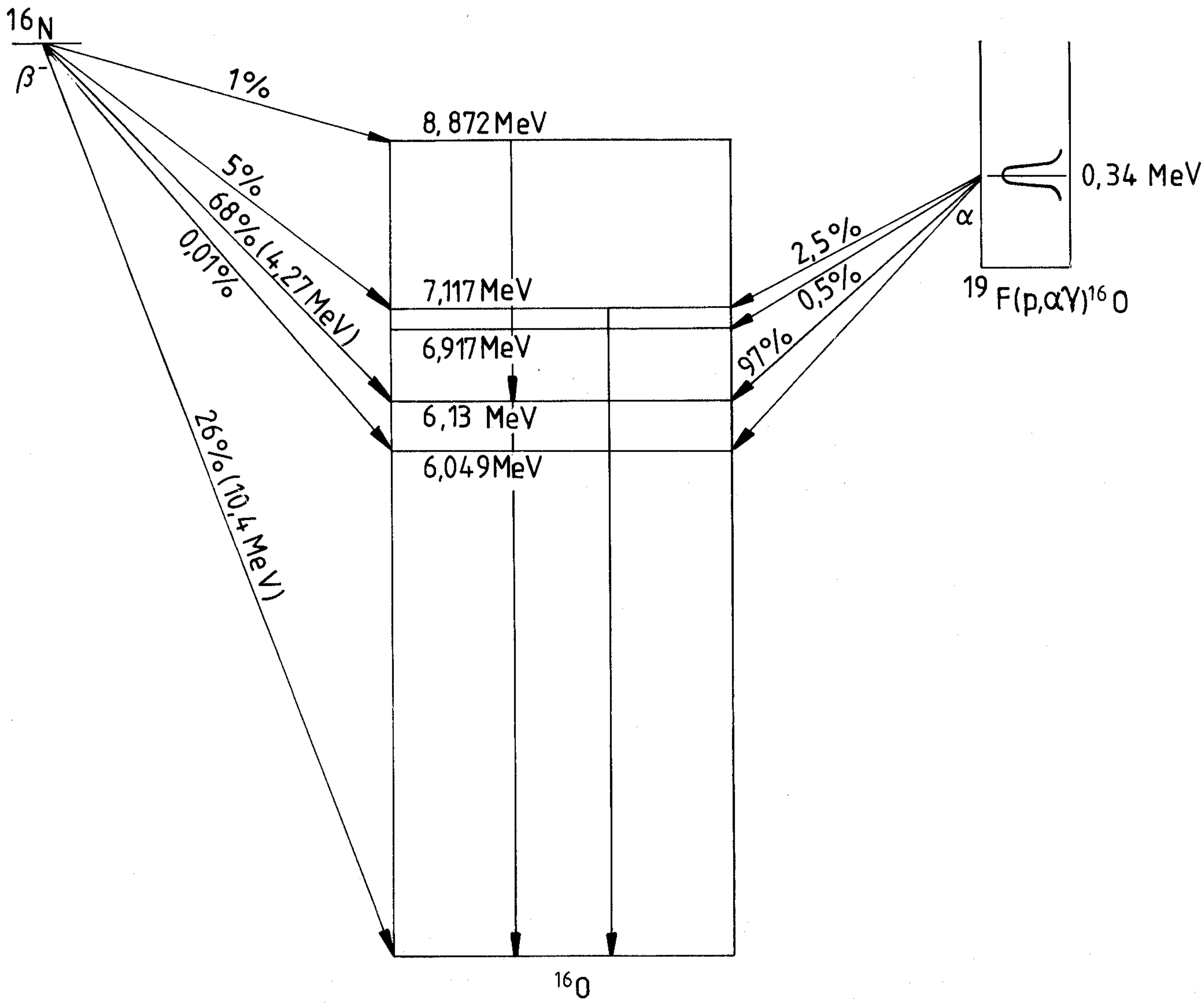

Figure 1 — Energy levels and emission probabilities of photon radiations from the decay of ^{16}N (*left*) and from the de-excitation of ^{16}O for an incident proton energy of 340,5 keV on ^{19}F (*right*)

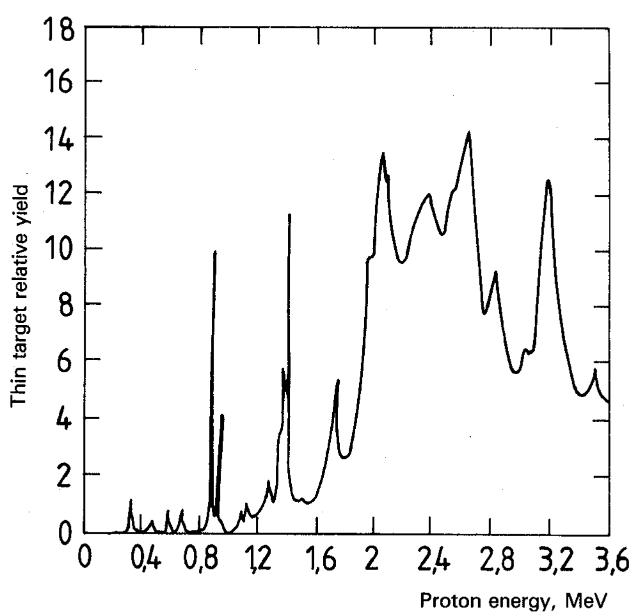

Figure 2 — Thin target photon yield as a function of proton energy for the $^{19}F(p,\alpha\gamma)^{16}O$ reaction

Depending on the required yield, the proton energy chosen for the production of the reference radiation shall be either one of the resonance energies (340,5 keV or 872,1 keV) or a convenient energy between 2 MeV and 3 MeV. If a high yield is required and a contamination contribution to the air kerma of approximately 4 % can be tolerated, protons of an energy close to 2,7 MeV, incident on a target of approximately 6 mg·cm^{-2} thickness, should be used (see also 5.3). For the purest possible reference radiation, 340,5 keV protons should be used provided that the lower air kerma rates are acceptable. For the 340,5 keV proton resonance, calibration shall be carried out both on-resonance and off-resonance by − 10 keV, in order to allow for the effect of any low-energy and non-resonant radiation originating from the accelerator. The difference between the on-resonance and the off-resonance calibrations shall be taken as due only to the 6,13 MeV photon radiation and to associated knock-on electrons. Care should be taken to prevent fluorine other than on the target from being introduced into the accelerator.

Typical yields and air kerma rates are given in table 1 for four different incident proton energies, for a proton current of 1 µA and a target thickness of approximately 6 mg·cm^{-2} (proton energy loss in the target is approximately 600 keV for a 2,7 MeV incident proton).

A typical pulse-height distribution produced with 2,7 MeV protons and a target thickness of approximately 6 $mg \cdot cm^{-2}$ is shown in figure 3.

NOTE — Figure 3 as well as figures 4, 6 and 7 show pulse-height distributions and have been included for illustrative purposes only. The distributions have not been unfolded to account for the response of the detector. The shape of the photon spectra of the reference radiation will be different since the detector photo peak efficiency decreases significantly with photon energy. Information on unfolded spectra for photons from the $^{19}F(p,\alpha\gamma)^{16}O$ reaction is given in [4].

Table 1 — Typical photon yields and air kerma dose rates for specified proton energies and a 1 μA proton current

Proton energy MeV	Photon yield s^{-1}	Typical air kerma rate at 1 m from target $\mu Gy \cdot h^{-1}$
0,340 5 (resonance)	10^5	0,05
0,872 1 (resonance)	10^6	0,5
2,05	6×10^7	30
2,7	2×10^8	100

3.3 Photon reference radiations from the de-excitation of ^{12}C [5]

These reference radiations shall be produced by using a particle accelerator to bombard a carbon target with protons resulting in the population of the lowest excited level of ^{12}C at 4,44 MeV followed by a de-excitation using the $^{12}C(p,p'\gamma)^{12}C$ reaction.

The target shall consist of a layer of high-purity carbon.

If natural carbon is used, there are two further reactions competing with the $[^{12}C(p,p'\gamma)^{12}C]$ reaction:

— $^{13}C(p,p'\gamma)^{13}C$, resulting in 3,09 MeV photon radiation;

and

— $^{13}C(p,n)^{13}N$, resulting in 0,511 MeV annihilation photons, stemming from the positron decay of ^{13}N which has a half-life of 9,96 min. A steady state between production and decay of ^{13}N is reached about 20 min after the reaction is started (i.e. after the proton beam is switched on).

The ratios of the yields of the 4,44 MeV and 3,09 MeV lines and of the 4,44 MeV and 0,511 MeV lines are independent of proton energy.

At a proton current of 1 μA, a proton energy of 5,5 MeV and a distance of 1 m from the target, the photon fluence rates are about 160 $cm^{-2} \cdot s^{-1}$, 12 $cm^{-2} \cdot s^{-1}$ and 1 800 $cm^{-2} \cdot s^{-1}$, and the corresponding air kerma rates are about 1,4 $\mu Gy \cdot h^{-1}$, 0,46 $\mu Gy \cdot h^{-1}$ and 85 $\mu Gy \cdot h^{-1}$ for the lines at 0,511 MeV, 3,09 MeV, and 4,44 MeV, respectively. A typical pulse-height distribution is shown in figure 4.

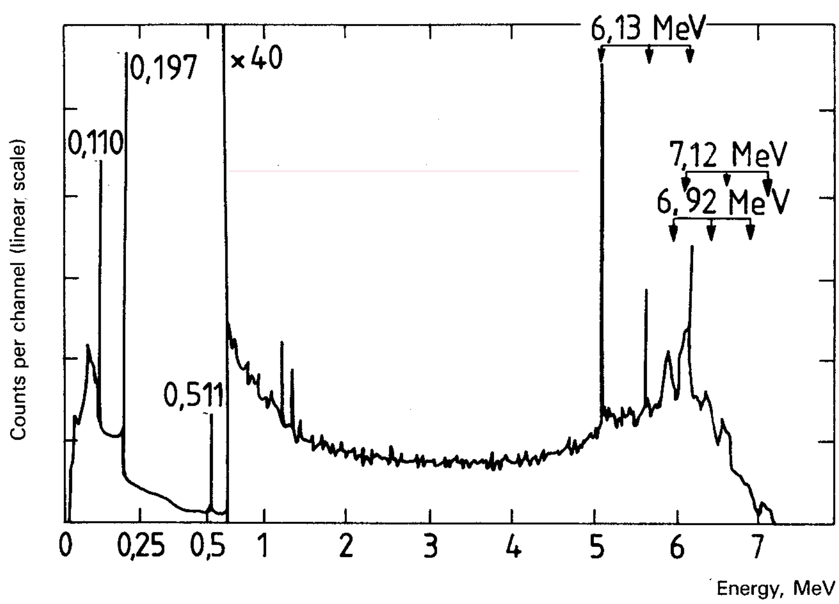

Figure 3 — Pulse-height distribution from de-excitation of ^{16}O as measured with a Ge(Li) detector[2]
[Target thickness: ≈ 6 $mg \cdot cm^{-2}$ CaF_2; proton energy: 2,7 MeV; reactions: $^{19}F(p,\alpha\gamma)^{16}O$ and $^{19}F(p,p'\gamma)^{19}F$]

3.4 Reference radiations produced by the thermal neutron-capture gamma reactions in titanium or nickel

These beams shall be produced by the (n, γ) capture reaction in a titanium or nickel target using a reactor as the neutron source. An example of an irradiation facility is shown in figure 5[6]. Multi-line spectra are produced with both the target materials. Photon yields of the main spectral components, i.e. above 3 photons per 100 neutron captures[7], are given in table 2.

For use of the resulting radiation as reference radiation between 4 MeV and 9 MeV, its low-energy components shall be reduced or eliminated by appropriate added filtration. The individual contribution of the various spectral lines to the total air kerma depends on the amount of added filtration. With suitable filtration, the effective energy of the reference radiation may be increased from an energy of 5 MeV to 6,5 MeV for titanium and from about 7 MeV to 8,5 MeV for nickel[6].

A typical pulse-height distribution is shown in figure 6 for a titanium target and in figure 7 for a nickel target, the corresponding reference energies being 6,4 MeV and 8,1 MeV, respectively[8]. The distributions of both figures 6 and 7 have not been unfolded to account for the response of the detector. In both cases, the filtration caused by the target itself, the neutron absorber (borated polyethylene, 10 cm thick) and the beam monitor is enhanced by an additional filter of aluminium, 30 cm thick.

Examples of air kerma rates and reference energies obtained with targets of nickel and titanium under the specified experimental conditions are given in table 3.

3.5 Photon reference radiations from the decay of ^{16}N

These beams shall be produced by activation of water in a reactor core by fast neutrons using the $^{16}O(n,p)^{16}N$ reaction.

The subsequent β-decay of ^{16}N (see also 3.2) with a half-life of 7,1 s leads to the excited states of ^{16}O, in this case yielding 6,13 MeV and 7,12 MeV photons, in relative emission probabilities of 68 % and 5 % respectively, and 10,4 MeV β-radiation. Photon energy levels and relative emission probabilities are shown in figure 1.

In a practical set-up, water is pumped continuously through the reactor core in a closed loop at a flow rate of 3 $l \cdot s^{-1}$. This loop is brought out through the biological shield of the reactor and acts as the radiation source[9]. The photon emission rate per 1 MW of thermal power and 1 kg of water is of the order of $1 \times 10^8\ s^{-1}$ and the associated air kerma rate is approximately 50 $\mu Gy \cdot h^{-1}$ at 1 m.

4 Beam diameter and uniformity of field

The requirements shall be identical to those specified in 3.1.3.5 of ISO 4037 : 1979, except that the term "tube focus" shall be replaced by "target". If the area of the field is not sufficient to irradiate the dosemeter or phantom completely and uniformly, they should be scanned across the beam. This technique is not always applicable to air kerma rate instruments.

Table 2 — Main photon yields of titanium and nickel per 100 neutron captures

a) Titanium

Photon energy, keV	342	1 381	1 498	1 586	1 762	4 882	4 969	6 418	6 557	6 761
Number of photons, (above 3 photons per 100 neutron captures)	26,3	69,1	4,1	8,9	5,6	5,2	3,6	30,1	4,7	24,2

b) Nickel

Photon energy, keV	283	465	878	6 837	7 537	7 819	8 121	8 533	8 999
Number of photons, (above 3 photons per 100 neutron captures)	3,3	13	3,9	10,8	4,5	8,2	3,1	17	37,7

Table 3 — Capture gamma radiations: Examples of targets and associated reference energies and air kerma rates[6]

Material	Target: Dimensions mm	Target: Mass kg	Target: Purity %	Reference energy MeV	Air kerma rate*) at a distance of 5 m for a thermal neutron fluence rate of $1,5 \times 10^{13}\ cm^{-2} \cdot s^{-1}$ $Gy \cdot h^{-1}$
Titanium	550 × 100 × 15	3,7	98	6 ± 0,5	0,8
Nickel	550 × 100 × 10	4,9	98	8,5 ± 0,5	1,2

*) These values are given only as a guide; they were obtained using beam filtration comprising 102 $g \cdot cm^{-2}$ of polyethylene plus 14 $g \cdot cm^{-2}$ of aluminium. Different filtrations will produce different air kerma rates.