Journal of Environmental Radioactivity 187 (2018) 32–39

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Review of reduction factors by buildings for gamma radiation from radiocaesium deposited on the ground due to fallout

Hiroko Yoshida-Ohuchi[a,*], Norihiro Matsuda[b], Kimiaki Saito[b]

[a] Graduate School of Pharmaceutical Sciences, Tohoku University, 6-3 Aramaki-Aoba, Aoba-ku, Sendai, Miyagi, 980-8578, Japan
[b] Fukushima Environmental Safety Center, Japan Atomic Energy Agency, 2-2-2 Uchisaiwai-cho, Chiyoda, Tokyo, 100-8577, Japan

ARTICLE INFO

Keywords:
Fukushima Dai-ichi nuclear power plant accident
Radiocaesium
Shielding factor
Reduction factor
Location factor
Indoor contamination

ABSTRACT

In order to estimate residents' external dose due to radionuclide exposure resulting from fallout deposit on the ground, the shielding and dose reduction effects provided by structures such as houses and workplaces are taken into account as most individuals spend a large portion of their time indoors. Many works on both calculation and measurement for European and American settlements have been reported and factors such as, shielding factors, protection factors, reduction factors, and location factors have been determined. However, measurement data for Japanese settlements are lacking. Thus, the Japanese government used reduction factors given in the International Atomic Energy Agency documents from American and European settlements when Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident occurred. The United Nations Scientific Committee on the Effects of Atomic Radiation used location factors from European settlements for the same reason. Soon after the FDNPP accident, several measurements and calculations were performed to obtain specific reduction factors for Japanese settlements due to this lack of data. This research reviews previous studies that determined factors such as, shielding factors, protection factors, reduction factors, and location factors and summarizes specific results for Japan. We discuss the issues in determining these factors and in applying them to estimate indoor dose. The contribution of surface contamination to the indoor ambient dose equivalent rate is also discussed.

1. Introduction

When the release of radioactive nuclides into the atmosphere occurs during a nuclear power plant accident and subsequent dry/wet deposition follows, the reduction factor or the shielding factor, which are both the ratio of the indoor dose to the outdoor dose, is necessary to estimate residents' exposure dose.

When the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident occurred in March 2011, the Japanese Government used 0.4 as the reduction factor for one and two-storey wooden frame houses referring to the data from the International Atomic Energy Agency (IAEA) documents (IAEA, 1979, 2000), in which the representative reduction (shielding) factor for surface deposition is 0.4 as there is a lack of measurement data for Japanese houses. This value was determined for American and European houses (Burson and Profio, 1977; Jacob and Meckbach, 1987). For the same reason, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) used location factors, which were determined from the European settlements. The necessity of determining specific reduction factors for Japanese settlements has occurred in order to verify the applications of these factors for Japanese data. Soon after the FDNPP accident, in situ measurements were carried out in highly contaminated areas (Kamada et al., 2012; Yajima et al., 2012; Yoshida-Ohuchi et al., 2014), which were designated as evacuation zones in 2011, and in the peripheral areas with less contamination to evaluate the reduction factor (Monzen et al., 2014; Matsuda et al., 2016). Calculation analysis was also conducted using the Monte Carlo simulation code to study the effect of building size and construction material on dose reduction inside the structures. (Furuta and Takahashi, 2014, 2015; Oguri et al., 2014).

Due to progression of decontamination work, the evacuation order was lifted in one area followed by others up to 2017, except in the difficult-to-return zone (Prime minister of Japan and his cabinet, 2017). When residents try to decide to permanently return to their homes, they are much concerned about remaining contamination in and around their houses. Dry deposition during the period in which the radioactive plume passed over the area caused indoor contamination; however, decontamination is being conducted outdoors and not indoors (MOE, 2017). Studies regarding indoor deposition have been performed and provide measurements of indoor deposition in the Fukushima evacuation areas (Yoshida-Ohuchi et al., 2016).

---

[*] Corresponding author.
E-mail addresses: hiroko@m.tohoku.ac.jp (H. Yoshida-Ohuchi), matsuda.norihiro@jaea.go.jp (N. Matsuda), saito.kimiaki@jaea.go.jp (K. Saito).

https://doi.org/10.1016/j.jenvrad.2018.02.006
Received 30 October 2017; Received in revised form 2 February 2018; Accepted 11 February 2018

Table 1

Reduction factors (shielding factors) of buildings for deposited radionuclides (From the IAEA TECDOC-225 (IAEA, 1979) and the IAEA TECDOC-1162 (IAEA, 2000)).

Structure or location	Representative RF (IAEA, 1979)	Representative SF[a] (IAEA, 2000)	Representative range (IAEA, 2000)
One and two story wood-frame house (no basement)	0.4	0.4	0.2–0.5
One and two story block and brick house (no basement)	0.2[a]	0.2	0.04–0.4
House basement, one or two walls fully exposed	0.1[a]		
- one-story, less than 0.6 m of basement walls exposed	0.05[a]		
- two-story, less than 0.6 m of basement walls exposed	0.03[a]		
House basement, one or two walls fully exposed			
- one-story, less than 1 m of basement wall exposed		0.1	0.03–0.15
- two story, less than 1 m of basement wall exposed		0.05	0.03–0.07
Three or four story structures (500–1000 m^2 per floor)			
- first and second floor	0.05[a]	0.05	0.01–0.08
- basement	0.01[a]	0.01	0.001–0.07
Multi-story structures (> 1000 m^2 per floor)			
- upper floors	0.01[a]	0.01	0.001–0.02
- basement	0.005[a]	0.005	0.001–0.15
1 m above an infinite smooth surface	1.00	1.0	–

[a] Away from doors and windows.

Several terms such as shielding factors, protection factors, reduction factors, and location factors have been used to express the ratio of the indoor dose rate to outdoor dose rate. This research reviews previous studies that determined these factors referring to the definition of each factor and evaluates mainly ground deposited radionuclides as a source of external radiation that could contribute to whole-body dose. Recent results for Japan, which were reported after the FDNPP accident, are then summarized. We discuss issues in determining the reduction factor, particularly for wooden houses as 78.7% of constructions and 97.3% of detached houses in Fukushima Prefecture are wooden (MIC, 2008) and in applying the reduction factor to estimate the indoor dose as wrong use or application was observed (e.g. Orita et al., 2015). The contribution of surface contamination to the indoor ambient dose equivalent rate is also discussed.

2. Previous studies on the reduction factor

Shielding provided by structures against radiation from deposited radionuclides on the ground has been extensively studied since the 1950s. In the USA, a series of civil effects test operations (the CEX series) was performed using distributed and single sources of ^{60}Co and/or ^{137}Cs from the 1950s–1960s (Auxier et al., 1958; Strickler and Auxier, 1960; Burson and Borella, 1961a, 1961c, Burson et al., 1961b; Burson, 1962, 1963a, 1963b; Summers and Burson, 1966) to obtain information that could be used to evaluate the protection afforded by residences against radiation due to fallout and to develop and demonstrate practical means of improving fallout-radiation protection with economical modification of typical houses. In this series, the term shielding factor (SF) was first introduced, which is defined as the ratio of the dose rate in the open at a given height above the plane to the dose rate at the same height inside the structure (Auxier et al., 1958) as follows:

$$SF = \dot{D_{in}}/\dot{D_{out}} \tag{2.1}$$

where $\dot{D_{in}}$ is the dose rate inside the structure and $\dot{D_{out}}$ is the outdoor dose rate.

They considered the shielding of houses against radiation from a contaminated ground plane and from sources uniformly deposited on the roofs. Subsequently, the term protection factor (PF) replaced the SF in the CEX series (Strickler and Auxier, 1960; Borella et al., 1961, etc.). The protection factor is a number that indicates the protective value of a structure and provides a measure of how much less the radiation level would be at a given point inside the structure than outside in an unprotected area. Thus, the protection factor is defined as the reciprocal of the shielding factor ($PF = 1/SF$). In technical terms it is the ratio of the exposure rate 3 ft above a smooth infinite plane that is uniformly contaminated with radioactive material to the exposure rate at a specific point in question indoors, assuming the same source distribution.

Accordingly, the protection factor is defined as follows:

$$PF = \dot{D}_\infty/\dot{D} \tag{2.2}$$

where $\dot{D}_\infty$ is the total infinite plane exposure rate and $\dot{D}$ is the exposure rate at the point in question indoors.

A smooth infinite plane is assumed hypothetically for the reference position and does not exist in reality. In order to simulate the smooth infinite plane, the authors placed the source tubing on a flat open field around a house and evaluated $\dot{D}_\infty$.

The protection factor is theoretically defined as follows:

$$PF = (D_1 + D_2)/(R + G_1 + G_2) \tag{2.3}$$

where D_1 is the dose rate 3 ft above the center of a circular contaminated area of radius r, D_2 is the dose rate from the area outside the circle of radius r, R is the indoor dose rate from contamination on the roof, G_1 is the indoor dose rate from contamination on the ground around the structure within a circular area of radius r (from the center of the building), and G_2 is the indoor dose rate from more distant areas. The value of r represents the radius of the area actually covered by the source distribution. By neglecting the contributions from large distances, the protection factor is approximated as shown in the following equation:

$$PF\ (approx.) = D_1/(R + G_1) \tag{2.4}$$

In the CEX series, sources of ^{60}Co and/or ^{137}Cs were used. The protection factors for fission-product and ^{60}Co gamma radiation were compared to within 10% (Auxier et al., 1958).

These experimentally measured reduction factors and representative reduction factor (RF) range from fallout radiation in the CEX series were summarized by Burson and Profio (1977). Further theoretical studies of shielding were performed and the results were reviewed (Burson and Profio, 1977; Jensen, 1982, 1984). The IAEA TECDOC-225 (IAEA, 1979) lists representative reduction factors for deposited radioactivity (Table 1) by referring to the study reviewed by Burson and Profio (1977).

Jacob and Meckbach (1987) performed extensive Monte Carlo calculations to obtain the kerma in typical European houses in urban and suburban environments due to gamma radiation from the contamination of different deposition areas such as lawns, windows, roofs, paved areas, light-shafts, and internal surfaces. They developed a definition of the shielding factor (SF_j) for the external exposure at location j relative to lawns as follows:

$$SF_j(t) = K_j(t)/\left(A\cdot\exp(-\lambda t)\cdot y\cdot s_{lawn}(t)\cdot K_{ref}\right) \tag{2.5}$$