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Determination of Indoor Radon Concentration and Effective Dose Equivalent at Workplaces of Afyonkarahisar Province

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Abstract: It is commonly known that people are exposed to radon and its progenies since they spend about 35% of daytime at workplaces. This exposure has been reported to be more than 50% of the natural radiation. Therefore, determination of indoor radon concentration has been widely conducted by the scientists. This work presents indoor radon measurements and the associated annual dose equivalents obtained in 28 public buildings of the Afyonkarahisar province. The survey was conducted using passive nuclear track detectors and repeated quarterly during a year. The investigation focused on the seasonal and regional effects in indoor radon concentration anomalies. The measured values ranged from 13 $Bq.m^{-3}$ to 1,932 $Bq.m^{-3}$, whereas the calculated average values were in the range of 21.75 $Bq.m^{-3}$ and 1,032.50 $Bq.m^{-3}$. Moreover, the mean indoor radon concentration and the corresponding annual dose equivalent values were obtained as 158.83±13.16 $Bq.m^{-3}$ and 1.25±0.10 $mSv.y^{-1}$, respectively.

***Key words**:* Indoor radon concentration, Annual dose equivalent, Nuclear track detectors, Workplaces, Afyonkarahisar.

Afyonkarahisar'daki İşyerlerinde Kapalı Ortam Radon Konsantrasyonunun ve Etkin Doz Oranının Belirlenmesi

Özet: Günün yaklaşık %35'ini işyerlerinde geçiren insanlar, kapalı olan bu ortamlarda, toplam doğal radyasyonun %50'sinden fazla olduğu bilinen radon ve bozunum ürünlerinden kaynaklanan ışınlanmaya maruz kalırlar. Bu nedenle, kapalı ortam radon konsantrasyonunun belirlenmesi çalışmaları bilim adamları tarafından yaygın bir şekilde yürütülmüştür. Bu çalışma, Afyonkarahisar vilayetindeki 28 kamu binasında elde edilen kapalı radon ölçümlerini ve ilişkili yıllık doz eşdeğerlerini sunmaktadır. Çalışma, CR-39 pasif nükleer iz detektörleri kullanılarak gerçekleştirildi ve bir yıl içinde dört kez tekrarlandı. Araştırmada kapalı radon konsantrasyon anomalilerinde üzerindeki mevsimsel ve bölgesel etkilere odaklanmıştır. Ölçülen değerler 13 $Bq.m^{-3}$ ile 1,932 $Bq.m^{-3}$ arasında değişirken, hesaplanan ortalama değerler 21.75 $Bq.m^{-3}$ ile 1,032.50 $Bq.m^{-3}$ arasındadır. İlaveten, incelenen işyerlerindeki ortalama kapalı ortam radon konsantrasyonu ve ilişkili yıllık ortalama doz eşdeğeri değerleri sırasıyla 158.83±13.16 $Bq.m^{-3}$ ve 1.25±0.10 $mSv.y^{-1}$ olarak elde edilmiştir.

***Anahtar kelimeler**:* Kapalı ortam radon konsantrasyonu, Yıllık doz eşdeğeri, Nükleer iz detektörleri, İşyeri, Afyonkarahisar.

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1. Introduction

It is commonly known that people are exposed to radon and its progenies since they spend about 35% of daytime at workplaces. This exposure has been reported to be more than 50% of the natural radiation [1,2]. The epidemiological studies have shown that people, who live in dwellings with high radon concentrations, may have to deal with major health problems, especially a lung cancer [3]. After smoking, radon is considered as being the second leading lung cancer cause since alpha particles emitted by radon strike the lung tissues [4-8]. In order to minimize the risk of lung cancer caused by radon exposure, it is essential to determine the mean of a long-term exposure by using a suitable dosimeter [9-12]. Therefore, the indoor radon exposure problem has been widely studied by the international scientific community for several years. These studies have proved that the level of indoor radon exposure is tightly related to both the geological characteristics and the meteorological conditions of an area. The variability of radon exposure indicate that it is affected by several factors such as soil temperature and permeability [13,14], air temperature and pressure difference inside and outside of buildings [15-20], and construction materials used for buildings and the ventilation degree of closed environments [21-26]. Moreover, some studies have also pointed out that indoor radon levels vary significantly on a daily and seasonal basis [27-33].

In this discussion, ordinary places of work such as schools, libraries, hospitals, offices and stores excluding nuclear aimed facilities are defined as workplaces [34]. Although, the internationally suggested action level of radon concentration in workplaces should be set as 500-1,500 $Bq.m^{-3}$ recommended by the ICRP (International Commission on Radiological Protection) [7], it ranges from the value of 20 $Bq.m^{-3}$ in the Netherlands to the limit of 3,000 $Bq.m^{-3}$ in Switzerland [35]. The present results are discussed considering the maximum limit of 100 $Bq.m^{-3}$ allowed by the WHO (World Health Organization) [36], the limit of 400 $Bq.m^{-3}$ recommended by the TAEA (Turkish Atomic Energy Authority) [37], and the limit of 400 $Bq.m^{-3}$ defined by the ICRP for indoor radon concentration [7].

This present article deals with the indoor radon concentration measurements and the effective dose rate determinations of radon exposure in 28 public buildings of the Afyonkarahisar province of Turkey. The study is focused on the seasonal and regional effects of indoor radon concentration anomalies. The survey was carried out using CR-39 detectors and repeated four times in a one-year period. The annual dose taken by the occupants was assessed in the light of the guidelines given by the ref. [7].

2. Materials and methods

2.1. Geology of study area

This study was conducted in the Midwest Anatolia of Turkey (Figure 1). The study area was assumed to be divided into four regions according to lithological properties and tectonic structure. There are lithologies belonging to various geological times from the Paleozoic to the Quaternary in Afyonkarahisar province whose southeast and northwest part consist of the Paleozoic metamorphic rocks. The main constituents of the Paleozoic time are crystallized limestone, schist and quartzite [38,39]. Mesozoic rocks are different in the area. Due to the northern edges are composed of detrital and carbonated rocks, Triadic-Upper Cretaceous carbonated occurrences are widespread in the Southeast. Throughout the present study area, the Cenozoic units overlie in the Mesozoic and the

Paleozoic rocks unconformably and they are composed of sandy and gravel fluvial sediments and, marl and limestone mixed with sand-gravel-clay-tuff in alternation.

2.2. Indoor radon determinations

The indoor radon concentrations were determined by using passive radon dosimeters (CR-39) in 28 public buildings of Afyonkarahisar and the measurements were repeated four-times a year as aiming to obtain the seasonal indoor radon variations. On the other hand, it was assumed that the study area can be divided into four regions by taking its rock type and tectonic structure into account for defining the effect of geological structure on radon concentrations.

Figure 1. The location of Afyonkarahisar on the map of Turkey

Indoor radon measurements were done in offices and repositories of the randomly selected workplaces by placing two dosimeters at each sampling point and leaving them in their places about 80-90 days to record radon exposure. After exposure time, the dosimeters were chemically processed (Radobath system) and automatically were tracked. A detailed description about this procedure can be found in the RADOSYS User Manual and elsewhere [40-43]. The radon concentration (in $Bq.m^{-3}$) recorded by each dosimeter were calculated using the formula below:

$$C_{Rn} = CF \times \left(\frac{\rho_{Tracks}}{46.8}\right) \times \left(\frac{1000}{T}\right) \quad (1)$$

Where *CF* is calibration factor, ρ_{Tracks} is track density (number of tracks per cm^2), *T* is the exposure time in hours. Moreover, the standard deviations were obtained using the equation as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \bar{X})}{N-1}} \quad (2)$$

2.3. Annual dose equivalents

The annual dose rate estimated to be taken by people in the residential places as well as workplaces due to the radon exposure can be obtained using the following formula according to the UNSCEAR (United Nations Scientific Committee on the Effects of

Atomic Radiation) [3]. The annual dose equivalent *(ED* in $mSv.y^{-1}$) of a certain radon concentration (C_{Rn} in $Bq.m^{-3}$) is estimated using the following relation:

$$ED = C_{Rn} \times D \times F \times H \times T \tag{3}$$

Here C_{Rn} is the radon concentration (in $Bq.m^{-3}$), D is the dose conversion factor ($9x10^{-6}$ $mSv.h^{-1}$ per $Bq.m^{-3}$), F is the equilibrium factor (0.4), H is the occupancy factor (estimated 0.25 since the nominal annual occupancy should only be 2,000 *h* for offices) and T is the yearly time in hours (8,760 *hours*) [44].

3. Findings

The indoor radon concentrations were measured in two rooms of 28 public buildings spread over geologically different four parts of Afyonkarahisar province by using passive radon dosimeters (CR-39) in during a one-year period. The minimum radon concentration was measured as 13 $Bq.m^{-3}$ in the office of surgeon general in the spring season, whereas the maximum value was measured as 1,932 $Bq.m^{-3}$ in a repository without ventilation in the winter season. On the other hand, the minimum average radon concentration value was determined as 21.75 $Bq.m^{-3}$ in the same office, while the maximum was 1,032.50 $Bq.m^{-3}$ in the same repository. The measured and average maximum radon concentration values are both much higher than the limit of 400 $Bq.m^{-3}$ for indoor radon concentration in dwellings recommended by the TAEA [37] and they are in the range of the internationally action level of radon concentration in workplaces suggested by the ICRP [7].

The seasonal average radon concentrations of each region were calculated using the measured data for each sampling period and the annual mean indoor radon concentration value was determined as 158.83±15.26 $Bq.m^{-3}$ for Afyonkarahisar province. Most of the seasonal average radon concentration values in all regions and the annual mean indoor radon concentration value are higher than the maximum allowed limit of 100 $Bq.m^{-3}$ defined by the WHO [36], but they are all below the limits of 400 $Bq.m^{-3}$ recommended for indoor radon concentration in dwellings by the TAEA [37] and by the ICRP [7]. Although there does not exist an average radon concentration value defined for workplaces in Turkey, the TAEA determined the average value of 82.66 $Bq.m^{-3}$ for houses. The average value in Afyonkarahisar seems in the range of 106.7 and 180 $Bq.m^{-3}$ [37]. The present average value lies within the range defined for Afyonkarahisar houses. Moreover, the highest mean radon concentration value was obtained in the winter season as reported in the earlier studies [45-48].

The annual dose equivalent of indoor radon exposure was estimated from the present annual mean indoor radon concentration value and it was obtained as 1.25±0.10 $mSv.y^{-1}$ for Afyonkarahisar province. Although annual dose equivalent value is higher than the world average annual effective dose equivalent of 1 $mSv.y^{-1}$ for radon and its decay products [49], it is both below the value of 2.4 $mSv.y^{-1}$ for the worldwide annual effective dose from natural sources [50] and well below the action level of 3-10 $mSv.y^{-1}$ recommended by the ref. [7] for dwellings. The obtained seasonal average radon concentrations of each region, and seasonal and regional mean radon concentrations and annual dose equivalents in Afyonkarahisar province are presented in Table 1.

Table 1. The seasonal average radon concentrations of each region, and seasonal and regional mean radon concentrations and corresponding annual dose equivalent values.

	Average Radon Concentrations						**Annual Dose Equivalents**	
	1st Region	*2nd Region*	*3rd Region*	*4th Region*	***Seasonal Mean***	$\pm\sigma$	***Seasonal Mean***	$\pm\sigma$
Summer	160.20	136.14	199.21	102.11	**149.42**	6.84	**1.18**	0.05
Autumn	121.21	137.61	143.50	70.60	**118.23**	9.85	**0.93**	0.08
Winter	234.80	331.14	227.43	131.40	**231.19**	26.10	**1.82**	0.21
Spring	128.80	221.91	125.72	69.50	**136.48**	9.85	**1.08**	0.10
Annual Mean	**161.25**	**206.70**	**173.96**	**93.40**	***158.83***	***13.16***	***1.25***	***0.10***

4. Results and Discussions

This study is the first survey carried out in 28 public buildings spread over geologically different four parts of Afyonkarahisar province to obtain the indoor radon concentrations and the corresponding exposure doses at workplaces. The indoor radon concentrations were determined four times in a one-year period in offices and repositories of randomly selected workplaces. The present results can be concluded as follows:

- The maximum measured, and the average indoor radon concentration values were obtained in the same repository of a state building. This result is agreed with the expectations of radon concentrations being higher at the lower floors.
- The highest seasonal mean radon concentration value was obtained in winter. This is because of poor ventilation in winter compared with the other seasons and the higher outdoor pressure in winter due to very low seasonal temperature.
- The lowest seasonal mean radon concentration could not be obtained in the summer season in contrast with the previous studies, since the majority of the selected workplaces are schools and they are officially off due to summer vacation.
- Regional mean radon concentrations show that the values are higher in the 2nd and the 3rd regions. This result shows the dependence of radon concentration on the dominance of alluvial material having high porosity and permeability. It can also be concluded that the indoor radon activity concentration levels are strictly tied to the soil and the geological structures beneath the building and soil permeability in Afyonkarahisar province.

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References

[1] S. Oikawa, N. Kanno, T. Sanada, N. Ohashi, M. Uesugi, K. Sato, J. Abukawa, and H. Higuchi, “A nationwide survey of outdoor radon concentration in Japan,” *J. Environ. Radioact.*, vol. 65 (2), pp. 203-213, 2003.

[2] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), "Sources, effects and risks of ionizing radiations," *Report to the General Assembly on the effects of atomic radiation. United Nations,* New York, 1993.

[3] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), "Sources and Effects of Ionizing Radiation.," *In: Report to the General Assembly with Scientific Annexes, vol. I. United Nations,* New York, 2000.

[4] F. Bochicchio, F Forastiere, D. Abeni, and E. Rapiti, "Epidemiologic studies on lung cancer and residential exposure to radon in Italy and other countries," *Radiat. Prot. Dosim.,* vol. 78 (1), pp. 33-38, 1998.

[5] R.W. Field, D.J. Steck, B.J. Smith et al., "Residential gas exposure and lung cancer: the Iowa Radon Lung Cancer Study," *Am. J. Epidemiol*., vol. 151 (11), pp. 101-102, 2000.

[6] D.L. Henshaw, J.P. Eatough, and R.B. Richardson, "Radon as a causative factor in the induction of myeloid leukaemia and other cancers in adults and children?" *The Lancet,* vol. 335, pp. 1008-1015, 1990.

[7] ICRP., "Protection Against Radon-222 at Home and at Work," *ICRP Publication, Annals of the ICRP Publication,* 65, 23(2), *Pergamon Press,* Oxford, 1-262, 1993.

[8] WHO (World Health Organization), "Handbook on Indoor Radon: A Public Health Perspective," *WHO press,* Geneva, 2009.

[9] S.A. Durrani, R.K. Bull, and D.Ter. Haar, "Solid State Nuclear Track Detection: Principles, Methods and Applications," ISBN: 978-0-08-020605-9, *Pergamon Press,* Oxford, 1987.

[10] R.L. Fleischer, P.B.Price, R.M. Walker, "Nuclear Tracks in Solids, Principlesand Applications," *University of California Press, Berkeley,* USA, 1975.

[11] H.A. Khan, I.E. Qureshi, M. Tufail, "Passive dosimetry of radon and its daughters using solid state nuclear track detectors (SSNTDs)," *Radiat Prot Dosimetry,* vol. 46 (3), pp. 149–170, 1993.

[12] A.A. Qureshi, D.M. Kakar, M. Akram, N.U. Khattak, K. Mehmood, K. Jamil, and H.A. Khan, "Radon concentration in coal mines of Baluchistan. Pakistan," *J. Environ. Radioact.,* vol. 48 (2), pp. 203-209, 2000.

[13] R. Fujiyoshi, K. Sakamoto, T. Imanishi, T. Sumiyoshi, S. Sawamura, J. Vaupotic, I. Kobal, "Meteorological parameters controlling variability of ^{222}Rn activity concentration in soil gas at a site in Sapporo, Japan," *Sci. Total Environ.,* vol. 370 (1), pp. 224-234, 2006.

[14] C.Y. King and A. Minissale, "Seasonal variability of soilegas radon concentration in Central California," *Radiat. Meas.,* vol. 23 (4), pp. 683-692, 1994.

[15] B. Collignan and E. Powaga, "Procedure for the characterization of radon potential in existing dwellings and to assess the annual average indoor radon concentration," *J. Environ. Radioact.,* vol. 137, pp. 64-70, 2014.

[16] J. Dolejs and J. Hulka, "The weekly measurement deviations of indoor radon concentration from the annual arithmetic mean," *Radiat Prot Dosimetry, vol. 104 (3), pp.* 253–258, 2003.

[17] M.E. Kitto, "Interrelationship of indoor radon concentrations, soil-gas flux, and meteorological parameters," *J. Radioanal. Nucl. Chem.,* vol. 264 (2), pp. 381-385, 2005.

[18] T.N. Narasimhan, Y.W. Tsang, H.Y. Holman, "On the potential importance of transient air flow in advective radon entry into buildings," *Geophys. Res. Let.,* vol. 17 (6), pp. 821-824, 1990.

[19] H. Papaefthymiou, A. Mavroudis, P. Kritidis, "Indoor radon levels and influencing factors in houses of Patras, Greece," *J. Environ. Radioact*., vol. 65 (2), pp. 203-213, 2003.

[20] Allen L. Robinson, and Richard G. Sextro, Radon entry into buildings driven by atmospheric pressure fluctuations. *Environ. Sci. Technol.,* 31 (6), 1742-1748, 1997.

[21] H.M. Al-Khateeb, A.A. Al-Qudah, F.Y. Alzoubi, M.K. Alqadi, K.M. Aljarrah, "Radon concentration and radon effective dose rate in dwellings of some villages in the district of Ajloun, Jordan*," Applied Radiation and Isotopes*, vol. 70, 8, 1579-1582, 2012.

[22] A. Baeza, E. Navarro, C. Roldán, J.L. Ferrero, D. Juanes, J.A. Coebacho, and F.J. Guillén, "Indoor radon levels in buildi ngs in the autonomous community of Extremadura (Spain)," *Radiat. Prot. Dosim., vol.* 103, 3, pp. 263-268, 2003.

[23] A. Ulug, M.T. Karabulut, and N.Celebi, "Radon measurements with CR-39 track detectors at specific locations in Turkey," *Nucl. Technol. Radiat. Prot.,* vol. 19, pp. 46-49, 2004.

[24] S.A. Vaizoğlu, and Ç. Güler, "Indoor Radon Concentrations in Ankara Dwellings," *Indoor Built Environ.,* vol. 8, pp. 327, 1999.

[25] Y. Yarar, T. Gunaydin, and N. Celebi, "Determination of radon concentrations of the Dikili geothermal area in Western Turkey," *Radiat Prot Dosimetry,* Vol. 118 (1), pp. 78–81, 2006.

[26] Ş. Kılınçarslan, and B. Akyol, "Investigation of the Effect of Selection of Construction Materials for Radiotherapy Centers," *ACTA PHYSICA POLONICA A,* vol. 130, 1, pp. 441-443, 2016.

[27] F. Bochicchio, G. Campos-Venuti, S. Piermattei, et al., “Annual average and seasonal variations of residential radon concentration for all the Italian Regions,” *Radiat. Meas.*, vol. 40, 2-6, pp. 686-694, 2005.
[28] P. Bossew, and H. Lettner, “Investigations on indoor radon in Austria, Part 1: seasonality of indoor radon concentration,” *J. Environ. Radioact*., vol. 98 (3), pp. 329-345, 2007.
[29] F.T. Cross, N.H. Hartley, and W. Hoffmann, “Health effects and risk from radon in drinking water,” *Health Phys.*, vol. 48, 5, pp. 649-670, 1985.
[30] M.H. Magalhães, E.C. Amaral, I. Sachett, and E.R. Rochedo, “Radon-222 in Brazil: an outline of indoor and outdoor measurements,” *J. Environ. Radioact.*, vol. 67 (2), pp. 131-143, 2003.
[31] M. Mihci, A. Buyuksarac, A. Aydemir, N. Celebi, “Indoor and outdoor Radon concentration measurements in Sivas, Turkey, in comparison with geological setting,” *J. Environ. Radioact.*, vol. 101 (11), pp. 952-957, 2010.
[32] V. Moreno, C. Baixeras, L. Font, and J. Bach, “Indoor radon levels and their dynamics in relation with the geological characteristics of La Garrotxa, Spain,” *Radiat. Meas.*, vol. 43 (9-10), pp. 1532-1540, 2008.
[33] Z. Zenginerler, F. Ertugral, H. Yakut, E. Tabar, N. Demirci, and K. Gunermelikoglu, “Measurement of Seasonal Indoor Radon Concentration in Sakarya University, Turkey,” *ACTA PHYSICA POLONICA A*, vol. 130 (1), pp. 450-452, 2016.
[34] R.H. Clarke, “ICRP recommendations applicable to the mining and minerals processing industries and to natural sources,” *Health Physics,* vol. 69 (4), pp. 454-460, 1995.
[35] USEPA (United States Environmental Protection Agency), “Guidelines for Exposure to Naturally Occurring Radioactive Materials,” Washington (DC): *National Academies Press (US)*, 1999.
[36] WHO (World Health Organization), “International Radon Project Survey on Radon Guidelines, Programmes and Activities,” *WHO press,* Geneva, 2007.
[37] TAEA (Turkish Atomic Energy Authority-TAEK in Turkish acronym), “Radon gas in the indoor environment,” *Technical report 2012/3,* Ankara, 2012. (in Turkish)
[38] Y. Erkan, H. Bayhan, Ü. Tolluoğlu, and E. Aydar, “Afyon Yöresi Metamorfik ve Volkanik kayaçlarının Petrografik ve Jeokimyasal İncelenmesi,” TÜBİTAK Proje Raporu. YBAG-0044/DPT Projesi Raporu, Ankara, 1996. (in Turkish)
[39] S. Metin, Ş. Genç and V. Bulut, “Afyon ve dolayının jeolojisi,” MTA derleme No:8103, 74s. Ankara, 1987. (in Turkish)
[40] K.M. Abumurad, M.K. Kullab, B.A. Al-Bataina, A.M. Ismail, and A. Lehlooh, “Estimate of radon concentrations inside houses in some Jordanian regions,” *Mu’tah J. Res. Stud.,* vol. B9 (5), pp. 9-21, 1994.
[41] B.A. Al-Bataina., A.M. Ismail, M.K. Kullab, K.M. Abumurad, and H. Mustafa., “Radon measurements in different types of natural waters in Jordan,” *Radiat. Meas.,* vol. 28, pp. 591-594, 1997.
[42] V.A. Nikolaev and R. Ilic´, “Etched track radiometers in radon measurements: a review” *Radiat. Meas.*, vol. 30, pp. 1-13, 1999.
[43] RADOSYS, RS_Man81: User’s Manual. *Radosys Kft*, 2001.
[44] K.N. Yu, B.M.F. Lau, Z.J. Guan, T.Y. Lo and C.M. Young, “Survey of the Rn dose conversion factor for offices” *J. Environ. Radioact.*, vol. 51, pp. 379-385, 2000.
[45] M.K. Kullab, B.A. Al-Bataina, A.M. Ismail, and K.M. Abumurad, “Seasonal variation of radon-222 concentrations in specific locations in Jordan,” *Radiat. Meas.*, vol. 34, 1-6, pp. 361-364, 2001.
[46] S. Singh, A. Kumar, and B. Singh, “Radon level in dwellings and its correlation with uranium and radium content in some areas of Himachal Pradesh, India,” *Environmental International, vol.* 28, pp. 97–101, 2002.
[47] S. Singh, R. Mehra, and K. Singh, “Seasonal variation of indoor radon in dwellings of Malwa region, Punjab,” *Atmospheric Environment*, vol. 39 (40), pp. 7761-7767, 2005.
[48] N. Sulekha Rao and D. Sengupta, “Seasonal levels of radon and thoron in the dwellings along southern coastal Orissa, Eastern India,” *Applied Radiation and Isotopes*, vol. 68, 1, pp. 28-32, 2010.
[49] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), “Effects and Risks of Ionizing Radiations,” *United Nations,* New York, 2000.
[50] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), “Ionizing Radiation: Exposure due to Natural Radiation Sources,” *United Nations,* New York, 2000.

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