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How to Regulate Radon: Case Study of Radon Exposure in Korea and Indonesia

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1. Introduction

Radon (^{222}Rn) is part of the uranium decay chain and, being a noble gas, can escape the matrix of the rock and soil in which it is formed. As a gas or dissolved in water, it moves through fractures in rock or pore spaces in soil. Radon decays with a half-life of 3.8 days to a series of radionuclide referred to as radon progeny.

When radon reaches open air, it disperses quickly. Typically, the average radon concentration in outdoor air is around 10 Bq/m^3. However, when radon enters an enclosed space, such as a cave, mine, or building, it can't disperse as easily, so is usually found at higher levels than outdoors. The worldwide average indoor radon concentration is about 50 Bq/m^3, although there is a wide variation.

One of the biggest concerns about radon is its radiological hazardousness, which is suspected to cause lung cancer and stomach cancer [4].

Generally, the International Commission on Radiological Protection (ICRP) recommended that the radiation dose limit for public is 1 mSv in a year. In addition, the ICRP limits for occupational workers are 20 mSv per year, averaged over defined periods of five years, with the further provision that the dose should not exceed 50 mSv in any single year [13, 15].

To have a better understanding in regulating radon, case study analysis on radon exposure of Korea and Indonesia has been done. In addition, considerations on natural sources of exposure, international standard, and radiation protection principles were done to see the appropriate way in regulating radon.

2. Methods and Results

In this study, some important considerations and scientific judgments will be discussed to give more perspective on the way to regulate radon in an appropriate manner. In addition, result of radon exposure measurements is used to support the analysis.

2.1 Radon Exposure in Korea and Indonesia

Radon exposure is influenced by geological characteristics such as altitude variation and earthquake prone areas. Exposure analysis between Korea with less altitude variation and relatively safe from earthquake and Indonesia with significant altitude variation and prone to earthquake can be a good example to learn radon profile.

Table 1 and Table 2 show the distribution of radon concentration values in provinces in both countries.

Table I: Distribution of Radon Concentration by Province in Public Buildings in Korea

Province (No)	Range (Bq/m^3)	Mean + SD (Bq/m^3)
Gangwon.(45)	22.3-133.7	55.0±29.2
Gyeonggi.(56)	19.0-169.3	47.5±23.3
Gyeongsangnam.(42)	19.1-87.3	37.3±14.6
Gyeongsangbuk (66)	18.6-317.7	53.8±40.7
Jeollanam (43)	21.6-194.5	58.8±39.1
Jeollabuk (26)	25.2-103.9	55.8±21.6
Jeju (9)	15.2-53.5	28.2±11.2
Chungcheongnam (37)	24.4-202.5	56.7±33.1
Chungcheongbuk (27)	31.6-236.5	70.0±53.2
Total average	15.2-317.7	52.6±33.1
Effective Dose (mSv/y)		0.37

Table 2: Distribution of Radon Concentration in Public Buildings in Indonesia

Province (No)	Range (Bq/m^3)	Mean (Bq/m^3)
Lampung (32)	16.0-33.0	23.5
Bengkulu (12)	20.0-125.0	50.0
Riau (29)	33.3-83.3	56.2
Banten (80)	5.5-55.5	28.2
Jawa Barat (187)	3.0-155.0	43.0
Jakarta (255)	2.0-127.3	27.0
Jawa Timur (32)	4.7-168	17.3
Sulawesi Selatan		200
Bali		208.3
Total average		72.6
Effective Dose (mSv/y)		0.52

It can be seen that the concentration in Korea is relatively uniform while in Indonesia has a significant range of radon concentration.

To inspect more detail about radon, three main radon source types were investigated; they were indoor radon, outdoor radon, and radon from building materials. Nowadays, radon from building materials has become a big issue and is suspected to give high exposure. Table 3 and Table 4 give information about three radon source types from both countries.

Table 3. Radon and effective dose from indoor, outdoor, and building materials in Korea

	Samples	Mean	Effective Dose (mSv/y)
Indoor	Public buildings [1] Houses [2] College rooms [3] Elementary school [4]	52.6±33.1 Bq/m^3 129.0±29 Bq/m^3 59.7±6.0 Bq/m^3 49.0 Bq/m^3	0.37 0.9 0.43 0.41
Outdoor	Atmosphere [5]	3.2 nGy/h	0.28
Building materials	Frame construction materials Finishing materials [6]	287.8 Bq/m^3 83.81 Bq/m^3	2.07 0.6
Reference value: • 1 mSv (ICRP: public dose limit) • 148 Bq/m^3 (EPA: radon concentration) • 4 pCi/l (EPA: radon concentration) • 26.2 mBq/m^{2}s (UNSCEAR, 2000: radon exhalation)			

Table 4. Radon and or effective dose from indoor, outdoor, and building materials in Indonesia

	Samples	Mean	Effective Dose (mSv/y)
Indoor	Public buildings [7] Research Buildings [8] Caves [9]	35.1 Bq/m^3 40.0 Bq/m^3 200 Bq/m^3	0.37 0.37 >5
Outdoor	Bangka Belitung soil [10] Atmosphere [9]	48.11 mBq/m^{2}s 351.5 Bq/m^3	- 2.53
Building materials	Bricks [11] Gypsum, <100cm from ceiling [12]	66.6 Bq/m^3 208.3 Bq/m^3	0.48 1.5
Reference value: • 1 mSv (ICRP: public dose limit) • 148 Bq/m^3 (EPA: radon concentration) • 4 pCi/l (EPA: radon concentration) • 26.2 mBq/m^{2}s (UNSCEAR, 2000: radon exhalation)			

Table 3 shows that there are few areas exceed standard exposure, however it is still reasonable since it comes only from the building materials. Table 4 shows that Indonesia has several areas with excessive exposure in each type of exposure, both indoor, outdoor and building materials.

2.2 Consideration on Natural Sources of Exposure

Discussion about radon can never be separated from natural exposure. Radon itself is a significant contributor to natural exposure. Natural sources of exposure consist of:

- External terrestrial
- Cosmic radiation
- Ingestion
- Radon gas (inhalation)

From all above radiations, radon is estimated to contribute above 50%. The total average of natural radiation is about 2.4 mSv per year [14]. Approximately, 65% of world population receive this amount of dose, and 10% others receive more than 3 mSv effective dose.

Since the world average dose and the majority of the population in the world receiving a dose of 2.4 mSv, it can be concluded that the dose value is a dose that is safe for humans. Even more, the radiation dose limit for workers of 20 mSv per year [13, 15] is considered as a safe dose, so basically a value below 20 mSv is already a tightened value. Based on average radon dose values in Korea and Indonesia (tables 3 and 4), which are below 2.4 mSv (0.7 mSv and 1.7 mSv respectively); we can state that this value is a safe value.

Based on this consideration, regulation of radon can be integrated within the public exposure regulation. However, individual exposures, particularly to radon, can vary significantly. Therefore, government should make a provision on real-time monitoring in every area to supervise the updated concentration and to minimize public concern.

For establishing radiation safety regime, the government must keep monitoring and using radon international standards as a secondary safety reference.

2.3 Consideration on International Standard

In GSR part 3 paragraph 5 [15], IAEA has limited the scope of natural sources of radiation as the following:

(a) ^{222}Rn and its progeny and ^{220}Rn and its progeny, in workplaces other than those workplaces for which exposure due to other radionuclide in the uranium decay chain or the thorium decay chain is controlled as a planned exposure situation, in dwellings and in other buildings with high occupancy factors for members of the public;
(b) Radionuclide of natural origin, regardless of activity concentration, in commodities, including food, feed, drinking water, agricultural fertilizer and soil amendments, and construction materials, and residual radioactive material in the environment;
(c) Materials, other than those stated above, in which the activity concentration of no radionuclide in either the uranium decay chain or the thorium decay chain exceeds 1 Bq/g and the activity concentration of 40K does not exceed 10 Bq/g;
(d) Exposure of aircrew and space crew to cosmic radiation.

It is often not straightforward to differentiate between normal exposures and enhanced exposures to natural sources of radiation, and between these and exposures to man-made sources. An illustrative example is the common assessment of radiation exposure indoors, where the natural background radiation exposure is influenced by the presence of natural radioactivity in building materials.

Based on the IAEA Safety Fundamental 1 Principle 2 [16], government has a role to establish effective legal and framework for safety of public, worker, and environment. On the other hand, government also has a responsibility to increase and stabilize the economy.

Here, it can be seen the opposite thing. In this case, the government is expected to act wisely in regulating and managing radon. From radon exposure analysis in previous part, especially for Indonesia, it might be better to have a specific regulation to regulate radon in particular areas. The specific regulation can be used to manage some special case like some areas with high exposure.

There are two possible way in establishing the specific regulation. First, it can be issued by the top government as a supporting regulation and should be understood by all local government. Second, the establishment of the specific regulation can be mandated to local government which has high radon exposure in their areas.

2.4 Consideration on Radiation Protection Principle

The principle of radiological protection established by the ICRP is based on scientific knowledge and data as well as societal and economic considerations. ICRP Publication 103 states: "the primary aim in the Commission's Recommendations is to contribute an appropriate level of protection for people and the environment against the detrimental effects of radiation exposure without unduly limiting the desirable human actions that may be associated with such exposure [13]."

Radiation protection principles should always be the main consideration on radiation-related analysis. So do the government, since the top priority is safety of public, worker, and environment, the development of radon regulation should prioritize radiation protection principle as well.

Since radon exposure not only comes from nature, but also from man-made materials, the application of radiation protection principles is still appropriate.

For justification principle, the individual or societal benefit should be more significant than the radon exposure.

For optimization principle, the radon doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.

In case of dose limit application, the radon exposure to any individual should consider the average background exposure in the country and should not exceed the appropriate limits recommended.

3. Conclusions

The management of radon in a country is a complex process that should be done by any government for the safety of public, worker, and environment.

By doing comprehensive radon exposure analysis government can regulate and manage radon more appropriate. To develop better regulation on radon, government is recommended to consider natural sources of exposure, international standard on radon, and radiation protection principles.

From radon exposure analysis in Korea and Indonesia, it can be concluded that geological characteristics play a significant contribution in country radon profile.

By considering on natural sources of exposure and international standard on radon, and supported by radon exposure analysis, it can be inferred that radon regulation can be integrated within the general natural exposure. In case of Indonesia which has several areas with high exposure, specific regulations can be made to support the main regulation.

Establishment of radiation safety regime is one of government role. To maintain the safety regime, government must keep monitoring and using radon international standards as a secondary safety reference.

Radiation protection principles should always be the main consideration on radiation-related analysis. So, government should develop radon regulation by applying radiation protection principle as one of the main consideration.

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REFERENCES

[1] J. S. Jung, J. H. Yoo, K. S. Lee, J. W. Lee, I. K. Shim, S. Y. Seo, B. W. Kim, and M. H. Kwon, Study on Characteristics of Radon Concentration and Effective Dose at Public Buildings in Korea, Journal of the Korean Society of Living Environment System, Vol.23, p. 767, 2016.

[2] I. S. Kim, H. S. Oh, K. H. Lee, and C. G. Kim, Study of Radon Management in the Environmental Impact Assessment Stage, Journal of Environmental Impact Assessment, Vol.27, p.241, 2018.

[3] H. H. Park, E. Jeong, H J. Kim, J. Lee, and K. Y. Liu, Assessment of Indoor Radon Gas Concentration Change of College, Journal of Radiological Science and Technology, Vol.40, p.127, 2017.

[4] C. W. Lie, S Y. Choi, and H. R. Kim, Analysis and Radiation Dose Assessment of ^{222}Rn in Indoor Air at Schools: Case Study at Ulju County, Korea, Nuclear Engineering and Technology, Vol.50, p.806, 2018.

[5] S. W. Choi, J. W. Row, H. M. Park, C. K. Kim, B. H. Rho, and J. Y. Yun, Fluctuations of Exposure Rate at Regional Radiation Monitoring Stations in Korea, Journal of Environmental Radioactivity, Vol.66, p.271, 2003.

[6] C. M. Lee, S. W. Jung, D. H. Lee, Y. B. Kim, D. J. Lee, Y. S. Cho, and Y. H. Jin, Investigation of Radon Emanation of Domestic Building Materials, Journal of Odor Indoor Enironment, Vol.14, p.50, 2015.

[7] Bunawas and A. Warsona, Distribution of Radon Concentration in Dwelling and Lung Cancer Risk, National Seminar on Safety, Health, and Environment, Vol.1, p.131, 2001.

[8] Rasito, S. Sofyan, and T. Desita Radon Concentration in the Atmosphere of PTNBR-BATAN Bandung, National Seminar of Science and Nuclear Technology, Bandung, 2007.

[9] S. Dewang, A. S. Akmal, B. Abdullah, and Syarbaini, Measurement of Radiation Distribution for Radon (Rn) and Thoron (Th) Concentrations in Heritage Gua Batu and Gua Mimpi of Maros Regency, South Sulawesi, AIP Conference, Vol.1801, p.060004, 2017.

[10] Syarbaini, and E. Pudjadi, Radon and Thoron Exhalation Rates from Surface Soil of Bangka - Belitung Islands, Indonesia, Indonesian Journal on Geoscience, Vol.2, p.35, 2015.

[11] E. Yufita, and R. Syafitri, Identification of Radon (Rn-222) Content in Brick at Aceh Besar Area, Journal of Physical Theory and Application, Vol.1, p.02, 2013.

[12] G. A. A. Ratnawati, and N. N. Ratini, Effects of Radon Gas Radiation from Buildings Made of Gypsum Potentially Cause Lung Cancer, National Seminar of Science and Technology, Vol.1, p.76, 2016.

[13] ICRP, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Annals of the ICRP, Vol. 37 , p. 2-4, 2007.

[14] UNSCEAR, Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report, Vol. 1, 2010.

[15] IAEA, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standard, GSR Part 3, 2014.

[16] IAEA, Fundamental Safety Principles, IAEA Safety Standard, Safety Fundamentals SF-1, 2006.