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Natural radiation in industry - Finnish regulatory approach and experiences

R. Mustonen

Finnish Centre for Radiation and Nuclear Safety

Finland

NATURAL RADIATION IN INDUSTRY - FINNISH REGULATORY APPROACH AND EXPERIENCES

Raimo Mustonen [1]

ABSTRACT

Exposure to natural radiation of workers and members of the public in Finland is supervised on the basis of the Radiation Act and the Radiation Decree issued in 1991. Both of these statutes contain special articles on natural radiation. In the Radiation Act, activities or circumstances, where exposure to natural radiation causes or may cause health detriment, are defined as radiation practices. In separate cases, the competent authority, the Radiation and Nuclear Safety Authority (STUK), will determine whether or not the activity in question has to be considered as a practice. Utilisation of materials derived from rock and soil, mining activities, and work places where natural radiation may cause an enhanced exposure to radiation are activities or circumstances where this consideration might be necessary. If an activity is considered as a practice, the Radiation Act stipulates that the party running the practice is responsible for safety of the operations. The responsible party is obliged to ensure that the level of safety specified in the Radiation Decree and in other regulations or guides, given on the basis of Radiation Act, is attained and maintained.

The Radiation and Nuclear Safety Authority (STUK) issues general instructions, known as Radiation Safety Guides (ST-Guides), concerning the use of radiation and operations involving exposure to natural radiation. Four ST-Guides concerning exposure to natural radiation have been issued. The first one relates to application of dose limits to radon exposure in work places. The others concern radiation safety in mining and excavation work, radioactivity of construction materials, and radioactivity of household water. The Ministry of Social Affairs and Health has given an order on the upper limits for indoor radon concentration in places of residence.

This presentation deals with the Finnish legislation on natural radiation, and it's relation to the new EC-Directive of radiation protection. Some examples of activities in which exposure to natural radiation has given reason for radiation protection actions in Finland are discussed.

INTRODUCTION

The Finnish legislation on exposure to natural radiation is written in the Radiation Act [1], and in the Radiation Decree [2], issued in 1991. In the Radiation Act, activities or circumstances, where human exposure to natural radiation causes or may cause health detriment, are defined as radiation practices. The competent radiation protection authority, the Radiation and Nuclear Safety Authority (STUK), will determine whether or not the activity in question has to be considered as a practice. Definition of the radiation practice does not include activities of private members of the public, but it concerns only enterprises and individuals, engaged in industry or commerce, whose activities cause an enhanced exposure to natural radiation. According to this definition, the Finnish radiation legislation includes both occupational and population exposures to natural radiation arising from work activities. So application of the Finnish radiation protection legislation to natural radiation is consistent with that of the new European Basic Safety Standards Directive [3].

[1] Radiation and Nuclear Safety Authority (STUK)
P.O.Box 14, FIN - 00881 Helsinki, Finland

REGULATORY APPROACH

The Finnish radiation protection legislation sets down a framework for controlling exposures to natural radiation sources arising from work activities. The framework is, generally speaking, same as for practices with artificial radiation, but it does not mean that identical procedures are to be followed in the case of natural and artificial sources of radiation. This is because of some exposures to natural radiation may be regarded as intervention situations rather than practices.

Activities or circumstances which might be regarded as practices are utilisation of materials derived from rock and soil, mining activities, and work places where natural radiation may cause an enhanced exposure to radiation. If an activity is considered as a practice, the Finnish Radiation Act stipulates that the party running the practice is responsible for safety of the operations. The responsible party is obliged to ensure that the level of safety specified in the Radiation Decree and in other regulations or guides, given on the basis of Radiation Act, is attained and maintained. The responsible party has to report STUK about radiation exposure and work conditions, after which STUK has to give detailed orders or guides for limitation of radiation exposure.

The Radiation Decree defines annual occupational effective dose of 5 mSv as a level above which the work has to be regarded as radiation work. This corresponds the categorisation of exposed workers into category A and category B in the European BSS Directive [4], although the limit of effective dose is not exactly the same (it is 6 mSv/a in the BSS). The basic idea in the Finnish legislation is that if the occupational exposure to natural radiation exceeds or may exceed 5 mSv/a, the employer has to make necessary actions in order to reduce the exposure. If, despite all necessary efforts, the exposure to natural radiation still remain above 5 mSv/a, then the work shall ~~be regarded as radiation work and a scheme of radiation protection should be arranged according to that with artificial exposure to radiation, if appropriate. This approach is consistent with the new~~ European BSS Directive.

STUK issues general instructions, known as Radiation Safety Guides (ST-Guides), concerning the use of radiation and practices with natural radiation. Four of these ST-Guides concern exposure to natural radiation. The first one relates to application of dose limits to radon exposure in workplaces. The others concern radiation safety in mining and excavation work, radioactivity of construction materials, and radioactivity of household water. These ST-Guides are described in more details below. The Ministry of Social Affairs and Health has given an order on the upper limits for indoor radon concentration in places of residence [5], and these limits are identical with the recommendations of the European Commission [6].

Radon in workplaces

Dose limits to workers and to members of the public, arising from practices, are laid down in the Radiation Decree. General requirements for applying these limits in practices with artificial and natural radiation are given in the ST Guide 1.2 [7]. The limit for annual average of radon concentration at work places, during the working hours, was set at 400 Bq/m^3, if the total number of annual working hours is 1600 or greater. If the annual working time is shorter, higher radon concentrations can be applied, respectively. The limit of 400 Bq/m^3 also applies to public buildings.

Actions must be taken to reduce radon concentration if it exceeds 400 Bq/m^3. If, despite all reasonable actions, the radon concentration still exceeds twofold the limits of annual average, the work has to be regarded as radiation work. In that case, the employer has to arrange regular monitoring of occupational exposure to radiation and health surveillance of workers.

Radiation safety in mining and excavation work

Application of radiation protection requirements in mining and excavation work is given in the ST Guide 12.1 [8]. In mining conditions, average radon concentrations of 400 Bq/m^3 and 1600 Bq/m^3 are estimated to correspond to the dose limit of 5 mSv/a for classifying work as radiation work and to the annual dose limit of 20 mSv/a, respectively. Work places are divided into three categories according to radon concentrations, and radiation protection actions and requirements for these categories are given in Table 1. If workers are exposed also to other radiation sources than airborne radon, the employer is responsible to make necessary measurements and dose assessments. These doses have to be taken into account when considering exposure to radon.

Table 1. Classification of work places in mining and excavation work and corresponding radiation protection actions.

Radon concentration	**Radiation protection action**
Below 400 Bq/m^3	Regulatory control measurements in every two years in mines, at excavation sites in every half-year. Normally no other actions.
400 - 1600 Bq/m^3	Work has to regarded as radiation work. Personal dose control and health surveillance of workers have to be arranged. Person responsible for radiation protection has to be nominated.
1600 Bq/m^3	Average exposure has to be kept under this value, corresponds to annual dose limit of 20 mSv.
1600 - 4000 Bq/m^3	Concentration has to be reduced, or occupation time without any breathing mask has to be limited.
Over 4000 Bq/m^3	Immediate remediation actions necessary before proceeding the work.
	Breathing mask obligatory.

Radioactivity of construction materials

Radiation protection requirements for radioactivity in construction materials are given in ST Guide 12.2 [9]. The general safety requirement is that gamma radiation from radioactivity in construction materials of buildings may not add to the effective dose from natural radionuclides in the undisturbed earth's crust by more than 1 mSv per year. For practical implementation of the safety requirement, a special activity index for building materials of houses is given in the form;

$$I = \frac{C_{Th}}{200} + \frac{C_{Ra}}{300} + \frac{C_K}{3000} \leq 1,$$

where C_{Th}, C_{Ra} and C_K are the activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K, respectively, in the main construction material of a house, expressed in Bq/kg. If the activity index exceeds 1, it is required to show that the safety requirement will be met. Higher activity concentrations will be acceptable for materials used in minor amounts in constructions of a house. No special requirements for radon exhalation from construction materials are laid down, because there is a separate order on indoor radon issued by the Ministry of Social Affairs and Heath [5].

If industrial by-products or wastes with elevated amounts of artificial radionuclides from past radioactive fall-outs are added in construction materials (e.g. peat ash), the general safety requirement is that the additional effective dose to members of the public may not be greater than 0,1 mSv per year.

Radioactivity of household water

Natural radioactivity in household water, together with indoor radon, is a serious problem in Finland. Especially groundwater in certain areas in Finland contains high amounts of radon and other radionuclides of the ^{238}U series. Radiation protection requirements for water plants distributing water for general consumption is given in the ST Guide 12.3 [10]. The general safety requirement is that radioactivity in household water may not cause an effective dose more than 0,5 mSv per year. Radon released from water into indoor air is not taken into account in this safety requirement because the order on indoor radon issued by the Ministry of Social Affairs and Heath [5] includes also the radon released from water.

For practical implementation of the safety requirement, a special activity index is given in the form;

$$I = C_\alpha + C_\beta + \frac{C_{Rn}}{300} \leq 1,$$

where C_α, C_β and C_{Rn} are concentrations of total alpha activity, total beta activity and radon in water, expressed in Bq/l, respectively. The safety requirement will be fulfilled if value of the activity index will be below one. If the activity index exceeds 1, a more precise nuclide specific analysis has to be made and dose assessment to be done. After these actions STUK will decide whether or not further actions will be needed to limit the exposure to radiation.

It has to be noticed that this safety requirement in directed to water plants and enterprises distributing household water for general consumption or using water in food production. Major ~~problems with radioactivity in household water appear, however, in private wells, especially in wells drilled in bedrock. Recommendations and guides for private well owners are at present under~~ preparation.

EXPERIENCES

The first indications that exposure to natural radiation could be a remarkable health problem in Finland were found in early 1970s when regular control measurement on radon in mines were started and first findings on high radon concentrations in household water were done. Since then it has been proved that exposure to natural radiation in Finland is a real public health problem, the major radiation sources being indoor radon and natural radioactivity in household water. Both of these radiation sources are exposing people primarily in their homes.

It is not possible, on the basis of radiation protection legislation, to give obliged regulations to private house owners to reduce indoor radon concentrations or radioactivity in water if the water is got from his/her private well. Public health officials can declare, on the basis of Public Health Act, prohibition of using a private house for living or drinking contaminated water, if there is a clear and acute health hazard. No such prohibitions have been declared in Finland because of exposure to natural radiation. The most effective way to reduce the population exposure to indoor radon or radioactivity of household water in private homes is to provide reliable information and technical advises in order to mitigate radiation exposure, and to offer public support for implementation of countermeasures.

Regarding natural radiation in industry, there are several cases where radiation protection aspects have been taken into consideration in Finland.

They are varying from regular radon surveillance in mines to occasional cases with using raw materials containing elevated amounts of natural radioactivity. Some examples are treated below.

Radon surveillance in workplaces

Radon surveillance in workplaces, others than mines and excavations, are concentrated in regions where survey on indoor radon in detached houses has shown elevated results. This survey has indicated that especially three counties in Southern Finland are so called radon prone areas. According to about 25 000 measured houses STUK has grouped all 455 municipalities into four categories in order to identify radon prone areas [11]. Municipalities where 25% of the measured radon concentrations in dwellings exceed 400 Bq/m^3 are classified in the category I. The corresponding percentages exceeding 400 Bq/m^3 in categories II, III and IV were 10 - 25%, 1 - 10% and < 1%, respectively. There were 14 municipalities in category I, 68 in category II, 154 in category III and 224 in category IV.

STUK has estimated that there are about 2 000 - 4 000 workplaces in Finland having an indoor radon concentration above 400 Bq/m^3. Total number of workers in these workplaces may vary from 10 000 to 40 000. Since 1992 more than 8 000 workplaces in categories I and II have received a request to measure their indoor radon concentration, and up to the end of 1996 more than 7 000 radon measurements have been made in about 4 200 work places.

On the basis of measurement results STUK has requested 738 workplaces to start actions to reduce radon concentrations or to estimate the mean exposure to radon during the working hours. In most cases working conditions have been noticed to be acceptable after a more precise exposure assessment or after a remeasurement. Technical remediation actions have been performed in 150 workplaces. The mean reduction in radon concentration in these places has been about 1 500 Bq/m^3 [12]. All radon measurements have been made with alpha track detectors with exposure time of one month.

Radon surveillance in mines and excavations

Due to long traditions of radon control in mines and underground excavations the situation in these work places in Finland is at present fairly good. Since 1970s, when radon control in mines was started, the number of mines and miners has been decreased, and today mining companies and employees are well informed about risks of high exposure to radon. During the last few years STUK has made annually around ten inspections in mines and excavations, and only in few cases a radon concentration of 400 Bq/m^3 has been exceeded. In 1995 - 1996 the mean radon concentration in these work places has been varied between 90 and 230 Bq/m^3. Radon measurements in these workplaces are made during inspections.

Radioactivity in building materials

STUK has made the nation-wide survey on natural radioactivity of building materials used in Finland [13]. The main conclusion was that radioactivity in building materials used normally for house construction (wood, brick, concrete and light-weight concrete) seldom exceeds the activity index presented above. Annually few tens of material samples were analysed, and in few cases an assessment of radiation exposure has been requested. For example some granites contain natural radioactivity exceeding the activity index, but they are used in minor amounts in buildings so that the safety requirement of 1 mSv/a from external gamma radiation is however fulfilled.

By-product gypsum was used for manufacturing building elements in 1970s in Finland. The factory used mainly by-product gypsum from processing imported raw phosphate with varying amounts of uranium. By-product gypsum from some raw phosphates contained elevated amounts of radium, up to hundreds of Bq/kg. In few cases STUK gave recommendations not use certain by-product gypsums as a building material of houses. The factory closed the operation in late 1970s. At present only natural gypsum with very low radioactivity is used to this purpose.

Surveillance of radioactivity in household water

In Finland there are roughly 800 water plants delivering household water to more than 200 persons, and about same amount of water plants delivering water to 50 - 200 consumers. Roughly half of the raw water used by water plants is surface water, the rest coming from groundwater sources (groundwater in soil or bedrock or artificial groundwater). Table 2 shows the activity concentrations in different types of water used by water plants (results up to 1994) [14]. The results show clearly that groundwater in bedrock contains often radioactivity exceeding the activity index presented above.

Table 2. Results from water plants using raw water from different sources

Raw water source	Number of plants	^{222}Rn Bq/l	Gross alpha Bq/l	Gross beta Bq/l	^{226}Ra Bq/l
Surface water	129	< 3	0.029	0.11	0.003
Groundwater in soil	716	55	0.068	0.12	0.009
Artificial groundwater	12	38	0.045	0.13	0.005
Groundwater in bedrock	46	320	0.25	0.27	0.068

Since 1992 about 250 water samples from water plants were analysed for their natural radioactivity. In 43 cases the activity index for household water was exceeded. In three cases, nuclide specific analysis indicated that no remedial actions were needed. In 14 cases technical remediation actions were performed, and in the rest remediation planning is going. The present ~~estimation is that there are 100 - 200 water plants where the radiation safety requirement will not be met.~~

As mentioned above, the real radiological problem is with private wells drilled in bedrock. Table 3 shows the situation in 1994 [14]. Radon is a dominating radionuclide and most of the gross alpha activity is caused by uranium. Effective information about risks of exposure to radiation and about remediation methods to private well owners is the most effective way to reduce radiation exposure.

Table 3. Mean concentrations of natural radioactivity of water in different types of private wells.

Wells and springs in soil			Wells drilled in bedrock		
Activity	Number of samples	Arith. mean Bq/l	Activity	Number of samples	Arith. mean Bq/l
^{222}Rn	2950	76	^{222}Rn	4051	930
Gross alpha	1321	0.09	Gross alpha	2408	2.4
Gross beta	155	0.34	Gross beta	561	1.5

Raw materials in industry

A large carbonatite deposit is located in the Northern Finland. Production of phosphate from three different ores in the deposit was planned in 1980s, but at that time the production was desisted due to low market prices of phosphate. The ores contain elevated amounts of uranium, and especially thorium. Tests of ore benefication indicated that concentrations of ^{238}U and ^{232}Th in the ores varied from 400 to 1000 Bq/kg, and 400 to 4000 Bq/kg, respectively. Concentrations in phosphate enrichment were lower and most of uranium and thorium were found in the wastes. Radiation protection was taken into account in connection of planning the production, and the company was informed about the radiation protection issues. In this connection STUK also made a survey on environmental radioactivity in the surroundings of the deposit in order to investigate the natural radiological condition of the area before any industrial activities.

Within production of TiO_2 pigment in Finland has given reason for radiological considerations in 1980s. Some ores used for TiO_2 production contain elevated concentrations of uranium and thorium. Radioactivity in few ilmenite minerals used as raw materials, in wastes, and in TiO_2 were analysed and assessments of occupational doses and impact on environment were made. Results showed that concentrations of ^{238}U and ^{232}Th in ilmenite vary from few tens of Bq/kg to few thousands of Bq/kg depending on the origin of ilmenite. Final TiO_2 pigment in these investigations contained low activity concentrations, typically only tens of Bq/kg. Major part of radioactivity drifted with wastes to the waste dumping site. Estimates on occupational exposure to radiation indicated low doses, and there were no reason to any recommendations for protective actions. Also radiological impact to the environment was insignificant mainly because of isolated liquid circulation.

One factory producing cobalt and nickel uses different sources of raw material. One source is an old uranium mine in Zaire, wastes of which contain cobalt and nickel, and also uranium and especially radium. Two types of raw material are measured for their radioactivity concentrations and assessment on occupational doses and environmental impact were made. Concentrations of ^{238}U in both raw materials were around 5 000 Bq/kg and those of ^{226}Ra were 1 200 and 25 000 Bq/kg. Assessment of occupational exposures to radon, external radiation and to radioactive aerosols in the factory indicated that no provisions of radiation protection were needed. However, the employer provided dose meters to about ten workers in order to make sure that no unacceptable doses would be received. External dose rates on the piles of raw material was elevated (up to 10 μSv/h) and it was recommended to avoid unnecessary stay close to the piles. If this kind of material would be used in great amounts, also waste management would need further consideration. In this separate case, the wastes were diluted to other wastes of the factory and no significant increase in radiation was measured.

One small mine is processing ore for gold production by crushing ore into fine powder and separating gold by scavenging and gravitational separation. In this process also uranium is enriched into the final concentrate. The ore contains ^{238}U and ^{226}Ra only in small amounts (about 30 Bq/kg) but their concentrations in the final concentrate is noticed to be as high as 54 000 Bq/kg. The total amount of produced gold is however not so big that significant occupational or environmental exposures would appear. However, the uranium concentration and the total amount of uranium were so high that a special permission to export the concentrate was needed according to the Nuclear Safety Act.

CONCLUSIONS

Application principles of the Finnish radiation protection legislation to natural radiation is consistent with those of the new European Basic Safety Standards Directive. So there is no need for major revisions in Finnish legislation concerning regulatory control of exposure to natural radiation.

Regulatory control of exposure to natural radiation concerns only occupational exposures and business activities which cause enhanced exposure of population to natural radiation. However, the greatest collective and individual doses from natural radiation are received in private homes from exposure to indoor radon and radioactivity of household water. In order to effectively reduce the population exposure to natural radiation, more efforts and resources should be directed to these radiation problems. Reliable and extensive information about health risks of high exposure to these radiation sources, and public support in implementation of countermeasures are the most effective tools in mitigation of the problems.

Experiences in Finland have shown that regulatory control is needed to avoid unnecessary exposure to natural radiation. Regular control of occupational exposures to radon in workplaces has resulted positive

results. Utilisation of raw materials with high concentrations of natural radionuclides may cause enhanced exposures to radiation, if radiation protection is not taken into account.
Simple and generally accepted guides on natural radiation are needed not only for radiation protection purposes, but also to remove unnecessary barriers in trade of raw materials, and to alleviate undue fear to ionizing radiation.

REFERENCES

[1] Radiation Act 592/1991.
[2] Radiation Decree 1512/1991.
[3] Recommendations for the Implementation of Title VII of the European Basic Safety Standards Directive (BSS) Concerning Significant Increase in Exposure due to Natural Radiation Sources. Internal working document. European Commission, Directorate-General Environment, Nuclear Safety and Civil protection. December 1996.
[4] Basic Safety Standards for the protection of the Health of Workers and the General Public against the Dangers from Ionizing Radiation. Council Directive 96/29/Euratom. Official Journal of the European Communities, No L159/1, 1996.
[5] Upper Limits for Indoor Radon Concentration in Places of Residence. Order 944/1992. Ministry of Social Affairs and Health, 1992.
[6] Recommendation on the protection of the Public against indoor Exposure to Radon. Commission Recommendation 90/143/Euratom. European Commission, 1990.
[7] Application of Dose Limits and Control of Exposure to Radiation. ST Guide 1.2. Radiation and Nuclear Safety Authority (STUK), 1995 (in Finnish).
[8] Radiation Safety in Work at Mines and Excavations. ST Guide 12.1. Radiation and Nuclear Safety Authority (STUK), 1992 (in Finnish).
[9] Radioactivity of Building Materials, Fuel Peat and Peat Ash. ST Guide 12.2. Radiation and Nuclear Safety Authority (STUK), 1993 (in Finnish).
[10] Radioactivity in Household Water. ST Guide 12.3. Radiation and Nuclear Safety Authority (STUK), 1993 (in Finnish).
[11] Annanmäki M., Markkanen M. and Oksanen E. Monitoring of Radon at Workplaces - Finnish Approach. Annale de l'Association belge de Radioprotection. Vol. 21, no 1, 1996.
[12] Havukainen R. (ed.). Use of Radiation and Other Practices in 1996. Report STUK-B-STO 35. Radiation and Nuclear Safety Authority (STUK), 1997 (in Finnish).
[13] Mustonen R. Natural Radioactivity in and Radon Exhalation from Finnish Building Materials. Health Physics, vol 46, 1195-1203, 1984.
[14] Salonen L. ^{238}U Series Radionuclides as a Source of Increased Radioactivity in Groundwater Originating from Finnish Bedrock. Future Groundwater Resources at Risk (Proceedings of the Helsinki Conference, June 1994). IAHS Publication no 222, 1994.