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A SHORT SUMMARY OF PAST AND RECENT ACTIVITIES ON PROTECTION FROM RADON EXPOSURE CARRIED OUT BY THE ITALIAN NATIONAL INSTITUTE OF HEALTH

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Summary: The Italian National Institute of Health (Istituto Superiore di Sanità – ISS) has a long experience of activities concerning protection from radon exposure (measuring techniques, surveys in dwellings and other environments, public information, training courses, epidemiological studies and risk evaluation, etc.) with the first activities dating back to the eighties. On the basis of this expertise, the ISS has also contributed to radon policies and regulations, in particular to the development of the first Italian National Radon Action Plan (INRAP) in 2002 and its coordination in the following years, as well as to international regulations and recommendations. Many activities have been carried out with significant collaborations not only with Italian agencies and institutes, but also with some other countries as well as with international organizations (e.g. WHO). In this paper, a short summary of the past activities carried out by the ISS on several radon issues is presented. Moreover, some of the recent and current activities and projects are shortly described, taking into account the requirements of the Council Directive 2013/59/Euratom, including design of radon surveys, quality of both active and passive measurements, evaluation of actual public exposure, and cost-effectiveness evaluations.

Keywords: radon, policy, surveys, measurement techniques, risk evaluation.

1. INTRODUCTION

The *Italian National Institute of Health* (ISS) is the technical scientific-body of the Ministry of Health responsible for public health. Since the eighties, the *National Center for Radiation Protection and Computational Physics* (former *Physics Laboratory* and *Unit of Radioactivity and related Health Effects*) of the ISS has been carrying out activities concerning the protection of the public against exposure indoors due to radon and other natural sources of radiation.

ISS has been working mostly in collaboration with other Italian agencies (both national and regional ones), especially after the start-up of the first Italian National Radon Action Plan (INRAP) – approved by the *Superior Council of Health* and *the Minister of Health* in 2002 – whose activities have been coordinated by the ISS since 2006 [1].

In this work, a brief description of the past activities carried out by ISS is presented starting from the first representative national survey carried out in the nineties. Moreover, among the recent and current activities, the following ones will be shortly described:

i) the identification of an affordable approach to perform a representative survey on radon concentration in dwellings of all the Italian Provinces;

ii) the analysis of critical issues of measurement protocols of radon concentration in specific types of workplaces;

iii) the application of cost-effectiveness analysis (CEA) as a useful tool to evaluate the public health policies aimed to reduce lung cancer risk attributable to indoor radon exposure.

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2. SUMMARY OF PAST *ISS* ACTIVITIES ON RADON ISSUES

2.1. First representative national survey in dwellings

Most of the radon-related activities in Italy started after the first representative national survey aimed to evaluate the exposure to natural sources of ionizing radiation in dwellings, including radon, and conducted in all the 21 Italian Regions (actually 19 Regions and 2 administratively independent Provinces) from 1989 to 1998 [2–5]. The coordination was in the hands of the Italian National Institute of Health and of the National Agency on Environmental Protection. The national average annual radon concentration (population-weighted) resulted to be equal to 70 Bq m^{-3}, but with regional averages ranged from about 25 Bq m^{-3} to about 120 Bq m^{-3}. Radon concentration measurements were carried out by the laboratories of the *Regional Agencies for Environmental Protection*, which gained the know-hows of the radon measurement techniques. Thanks to the expertise gained, in the following years several regional and sub-regional surveys, both in dwellings (e.g. [6–8]) and schools (e.g. [9,10]), were carried out by the regional agencies, some of them in collaboration with ISS.

2.2. Surveys on radon concentration in dwellings, schools, and workplaces

Besides the first national surveys in dwellings, ISS participated to other surveys, some of them with the aim to identify areas with greatest probability of finding high radon levels (i.e. radon prone areas) [11]. After the start-up of the first Italian National Radon Action Plan (INRAP), ISS took part to the design stage of some regional surveys in dwellings (e.g. [12]) with the aim to obtain information on radon distribution in dwellings representative of the population exposure.

The ISS also contributed to several radon surveys in kindergartens and schools – both in Italy [9] and in Balkan countries [13–16]. Even if exposure to radon in dwellings represents the main contribution to the total population exposure to radon, evaluating exposure to radon in kindergartens and schools has been considered important due to the presence of children.

Regarding workplaces, ISS gave its contribution to the design stage of a national survey in specific types of workplaces (offices and underground workplaces) of a National telephone company (*Telecom-Italia*) [17]. In the framework of a collaboration with *Telecom-Italia*, another national survey was conducted as described in Chapter 3.

According to the *National Radon Archive*, in Italy, more than 50 000 among dwellings, schools and workplaces have been measured in the framework of radon concentration surveys at national, regional or sub-regional level carried out by national or regional public institutions involved with protection from radon exposure [18,19].

2.3. Epidemiological studies and risk evaluations

Since 1988, radon has been classified as a human carcinogen by the IARC, the cancer research agency of the World Health Organization (WHO) [20], on the basis of epidemiological studies on underground miners. In Italy, ISS promoted and conducted an epidemiological case-control study to evaluate the lung cancer risk due to radon exposure in dwellings [21]. The data of this study were also used in the European pooling of case-control studies whose results showed a statistically significant increase of lung cancer risk due to residential radon exposure [22–24]. On the basis of these results as well as of analogous results from pooling of case-control studies in North-America [25] and China [26], radon exposure of the general population is now considered by WHO to be the second leading cause of lung cancer, after smoking [27]. Taking into account the risk estimates of the epidemiological studies, ISS also studied the health impact of radon exposure in Italy, estimating that about 3400 lung cancer deaths (about 10% of all lung cancers) are attributable to radon each year, mostly among smokers and ex-smokers [28].

2.4. Methods for measuring radon concentration (including retrospective techniques) and quality assurance studies

The use of passive radon devices is widespread within nationwide or regional surveys aiming to measure indoor radon concentration. Among passive devices, those relying on counting the tracks determined by the alpha particles emitted by radon and progeny (solid-state nuclear tracks detectors, i.e. CR-39 and LR 115) [29] are the most suitable due to the allowed sampling period (3 to 12 months), the low cost, and the small size of the measuring device [30]. For the passive radon devices based on LR 115 detectors whose tracks are counted using a spark counter – this technique was used for the Italian national survey and for the epidemiological case-control study – quality assurance studies were carried out [31,32]. For other passive devices based on CR-39 detectors, used for the second Italian survey (see Chapter 3), some practical improvements in corresponding measurement protocols have been found [33]. Notably, a study, aimed to evaluate the ageing and fading effects for long-term radon concentration measurements using passive radon devices, showed that these effects are negligible for devices based on LR 115 [34].

Since 1988, ^{210}Pb and ^{210}Po have been used to estimate the long-term indoor radon concentration by considering vitreous glasses as emission substrates [35]. The comparison between results of this so-called retrospective technique and those of "traditional" measurements by passive detectors has been done in different scenarios [36,37].

2.5. Rn-220 (thoron)

ISS has been performing research activities (summarized by [38]) on thoron issue since the 90s, years characterized by a lack of attention of the international community (no comments on thoron are, for example, contained in ICRP Publications 60 [39] and 65 [40]). Most of these activities regarded the monitoring of thoron and its decay products in indoor air. Thoron concentrations values higher than 1000 Bq m^{-3} near the walls [41] were found in Regions of the Center and South Italy due to the presence of building materials of natural origin (e.g., tuff and pozzolana).

ISS also studied the sensitivity to thoron (thoron interference) of the passive radon devices used for the first national radon surveys and for the epidemiological case control-studies showing that these devices are not significantly affected by the presence of thoron [42].

3. THE SECOND NATIONAL SURVEY IN DWELLINGS

The first radon national survey in dwellings showed some criticalities common to all surveys for which a sample needs to be chosen as representative of a large population. Indeed, the operative stages of national surveys are generally difficult, expensive and time-consuming. For example, it generally occurs that: *i*) sampled persons, randomly picked from national lists, should be contacted individually; *ii*) questionnaires should be filled by the participants and *iii*) data transferred to digital supports (digital archives on PCs).

Moving from the difficulties linked with the first survey, a new national survey in dwellings was designed by ISS and carried out in collaboration with an Italian telephone company (Telecom-Italia) [43]. The aim was to obtain information on radon concentration distribution in all the 110 Italian Provinces using an affordable approach.

3.1. Sampling design and procedure

The sampling base of the survey was the full list of the about 54 000 employees of the telephone company. The approach used relies on the fundamental condition that the employees' houses and workplaces are distributed over all the Italian territory.

Table 1. Number of Italian dwellings, Telecom employees' houses and relative distribution among the 110 Italian Provinces (data referring to the year 2010). As regards the Provinces distribution, the table reports the median value and, between brackets, the variation range.

	Number of dwellings		Number of towns	
	Total	Per Province	Total	Per Province
All Italian dwellings	~20 000 000	378 000 (58 000–4 100 000)	8 100	60 (6–315)
Telecom employees' houses	54 168	190 (10–12 833)	4 198	32 (6–184)

As shown in Table 1, houses of employees are 54168, distributed in about 4200 Municipalities out of the 8100 Italian Municipalities (at 2010).

A random sample was drawn for each of the 110 Italian Provinces by considering the desired estimates precision of radon distribution parameters, and several resource constraints (e.g. survey duration, available detectors and staff costs). 7000 dwellings finally constituted the overall sample size in order to assure a precision of 20% on geometric and arithmetic means by assuming a certain percentage (of about 15%) of refusals.

Cost and time required for designing, testing and implementing the sampling design strongly decreased, if compared with "traditional" survey, thanks to the availability of a database management system (DBMS), containing information on all the Telecom employees, including their workplaces and home addresses. The corporate e-mail managed by each Telecom employee was used to contact the sample.

3.2. Radon concentration measurements

Radon concentration was measured by passive measuring devices each composed by a CR-39 (manufactured by Intercast Europe srl, Parma, Italy) solid-state nuclear track detector placed inside a small dome-shaped diffusion chamber of 5-cm diameter and 2-cm height, made of conductive plastic. The chemical etching of detectors had a duration of 60 minutes and took place in a 6.25 M solution of NaOH. A fully automatic read-out system (Politrack, SW version 4.1) was then used to count tracks.

For each dwelling sampled, two rooms were monitored for a single exposure period of 12 months in order to reduce costs and intermediate replacements of devices.

Dosimeters were shipped (for sending/receiving devices to/from employees) through the company's internal mail service connecting all working sites. This choice is justified by the very significant reduction in shipment and packaging costs obtained by delivering devices only to 700 working sites, rather than to 7000 private addresses.

3.3. Evaluation of sample representativeness

Sample representativeness should be assessed by comparing some information (those considered to be related to radon concentration) on dwellings and families collected through the questionnaires, with data of the National Census. Dwelling characteristics that will certainly be considered in the analysis are: i) dwelling location; ii) floor; iii) type of housing unit; iv) year of building construction. A preliminary representativeness analysis carried out at national level showed a good agreement between the sample and the census [43]. A more detailed, province-by-province representativeness check is still ongoing.

4. ANALYSIS OF CRITICALITY IN MEASUREMENT PROTOCOLS IN WORKPLACES

In 2017, a project started from the collaboration of the ISS with the *Italian National Institute for Insurance against Accidents at Work* (INAIL) and the *Regional Agency for Environmental Protection and Prevention of Toscana* (ARPAT). The main purpose was a critical review and experimentation of methods and protocols for radon concentration measurements. In doing this, two main critical issues have been addressed, through experiments carried out on field and detailed analysis of literature findings: *i*) corrections to be applied to results from passive measurements when trying to assess the actual radon exposure of workers during the working hours; *ii*) thoron interference of continuous radon monitors when used in presence of high thoron levels.

4.1. Assessment of actual exposure in workplaces

The present Italian legislation (Decree 230/95 of Italian Government [44]) – which is going to be replaced by the upcoming transposition of the 2013/59/Euratom Directive [45] – regulates the protection from radon in workplaces (including schools) only. Remedial actions are required if the measured radon level exceeds the action level (expressed in terms of annual averaged radon concentration) of 500 Bq m^{-3} and if the annual effective dose for workers exceeds 3 mSv per year.

Measurements to verify action level exceedance are generally performed by passive devices, mainly based on solid-state nuclear track detectors. Such devices are deployed in workplaces for an overall period of one year and the so resulting concentration is averaged along such measurement period. As well acknowledged, a periodic short-time fluctuation component is associated to the day/night cycle being correlated with the diurnal rhythm of temperature and pressure [46]: thus, indoor concentration generally reaches higher levels at night than during the day. Therefore, the daily trend of indoor radon concentration generally experiences lowest daily values during the working hours due to both temperature and pressure rise and improved natural ventilation according to occupants habits. Due to this, when assessing radon exposure in workplaces from the yearly average, the actual exposure ends up being overestimated because of the same weights of nighttime and daytime levels in such average.

A survey has been conceived in order to try to develop specific measurement protocols capable of taking into account such daily variability in indoor radon concentration. 30 workplaces have been selected in Toscana Region and grouped according to five different working activities (i.e. restaurants, commercial activities, municipal offices, post offices and water managements plants). Radon concentrations have been simultaneously measured by CR-39-based devices and active detectors (i.e. Tera TSR 4 manufactured by TESLA) in at least one room per workplace. Results of active measurements will be used – the analysis is still ongoing – to determine the concentration during working hours.

4.2. Thoron interference affecting measurements by continuous radon monitor

The analysis of criticalities of active measurements has been gaining increasing attention mainly due to the large widespread on the market of newly conceived radon monitors differing from the "traditional" ones for the *smart* features and the cost significantly lower. Such new devices need to be studied in detail in terms of precision, accuracy, response linearity and interfering phenomena. Among the latter category, the interference of thoron presence when actively measuring radon needs to be analyzed in depth. Traditionally, such an interference, which reflects on overestimation of radon concentration, is generally evaluated in chambers where thoron concentration can be regulated and controlled [47]. Features of real existing atmosphere can significantly differ from the ones generally encountered in radon/thoron chamber experiments. For this reason, an experimental evaluation of thoron interference of the active detectors used for the project (Tera TSR 4) was performed. The analysis of the results (still on-going) will allow to "correct" the results of the radon concentration performed in workplaces where the presence of thoron was not negligible.

5. COST-EFFECTIVENESS ANALYSIS APPLIED TO RADON EXPOSURE IN DWELLINGS

In view of the forthcoming transposition into national regulation of the Council Directive 2013/59 Euratom, since 2017, ISS in collaboration with INAIL and the Regional Agency for Environmental Protection and Prevention of three Italian Regions (i.e. Friuli-Venezia Giulia, Calabria and Puglia) has been involved in cost-effectiveness evaluation (CEA) of the likely intervention strategy aimed to reduce radon exposure in existing dwellings [48]. In doing so, the model used has been the one developed by Prof. A. Gray and colleagues at the Oxford University [49], which has been adopted, among the others, by WHO and in the framework of the European project RADPAR. Such a model relies on policies effectiveness evaluations in terms of *Quality Adjusted Life Years* (*QALY*), i.e. life years gained and adjusted using age specific and sex specific normative weights. Referring to costs, estimates of those for basic preventive measures have been taken for new buildings, whereas for existing ones, costs for the identification of targeted by the specific policies, as well as for putting in exercise, running and maintaining remedial actions. Besides, treatment costs for patients with lung cancer, and the healthcare use of patients during any extended life expectancy are included.

5.1. Existing buildings

While defining the likely policy to be adopted for protection from radon exposure in existing buildings, two approaches have been considered both for radon concentration measurements and for remedial actions: recommended (assumed to result in 10% of acceptance) and/or mandatory (assumed to results in 90% of acceptance).

The main results of the comparison of CEAs performed on different scenarios/policies were the following ones: i) mandatory approach for radon policies are generally more effective in terms of radon-related risk reduction (and more cost-effective, too) if compared to recommendatory approach; ii) the values of (some) input parameters (e.g., the remediation rate and the reference level) have a great impact on the effectiveness and cost-effectiveness evaluations, whatever the policy considered. The latter results suggest that the acquisition of data and information regarding remedial rate (and other parameters) is necessary to monitor the policy effectiveness and to update it eventually.

5.2. New buildings

Only mandatory policies requiring both preventive measures (to reduce radon entry in the building) and radon measurements to verify their effectiveness have been considered for new buildings. The difference among the considered policies lies in the application of prevention actions and measurements to all Italian new buildings (*i*) or only to those located in *specific* areas (*ii*).

The effectiveness of policies for new buildings obviously increases with increasing application area thus resulting in better results, in terms of QALY gained, for a nationwide policy. Overall, an approach based on fully preventive measures in all the new dwellings is appealing for several reasons: i) it follows the optimization principle allowing to reduce the overall mean radon concentration; ii) it allows to standardize the techniques/protocols used for preventive measures; iii) it is cheaper than remediation in existing dwellings.

However, in Italy, a policy based only on preventive measures in new buildings is not sufficient, in terms of reduction of the number of lung cancer attributable to radon exposure, because the annual rate of new buildings is quite low. Therefore, an effective and cost-effective radon policy has to include requirements both in new and existing buildings.

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КРАТАК ПРЕГЛЕД ДОСАДАШЊИХ АКТИВНОСТИ НА ЗАШТИТИ ЗРАЧЕЊА ОД РАДОНА ИЗВРШЕНИХ У ИТАЛИЈАНСКОМ НАЦИОНАЛНОМ ИНСТИТУТУ ЗА ЗДРАВЉЕ

Сажетак: Италијански национални институт за здравље (Istituto Superiore di Sanità – ISS) посједује велико искуство у активностима везаним за заштиту од излагања радону (мјерне технике, анкете у стамбеним и другим окружењима, јавном информисању, курсеви обуке, епидемиолошке студије процјена ризика, итд.) са првим активностима још од осамдесетих година прошлог вијека. На основу ових искустава, ISS је такође допринио радонским политикама и прописима, нарочито развоју првог италијанског националног акционог плана за радон (INRAP) 2002. године и његовој координацији у наредним годинама, као и међународним прописима и препорукама. Многе активности су проведене уз значајну сарадњу не само са италијанским агенцијама и институтима, већ и са неким другим земљама као и са међународним организацијама (нпр. WHO). У овом раду представљен је кратак зажетак досадашњих активности које је ISS провео у вези са неколико питања везаних за радон. Осим тога, неке од недавних и тренутних активности и пројеката укратко су описане, узимајући у обзир захтјеве Директиве Вијећа 2013/59/Еуратом, укључујући израду радонских анкета, квалитет активних и пасивних мјера, процјену стварне јавне изложености и процјене економичности.

Кључне ријечи: радон, политика, анкета, мјерне технике, процјена ризика.

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