An overview on the new recommendations and requirements on radon protection (2013/59/Euratom) and the actual state of art: the case-study of the Campania Region, Southern Italy

SIMONA MANCINI1 *, MICHELE GUIDA1, DOMENICO GUIDA3, ALBINA CUOMO3
1 Laboratory for Environmental Radioactivity (AmbRA), Department of Physics and National Institute for Nuclear Physics (INFN), via Giovanni Paolo II, 132, University of Salerno, 84084 Fisciano, ITALY miguida@unisa.it
2 Laboratory for Environmental Radioactivity (AmbRA), via Giovanni Paolo II, 132, University of Salerno, 84084 Fisciano, ITALY simonamancini85@tiscali.it
3 Department of Civil Engineering (DICIV), via Giovanni Paolo II, 132, University of Salerno, 84084 Fisciano, ITALY dguida@unisa.it, acuomo@unisa.it.

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INTRODUCTION

The shared awareness that inside dwellings the most prevalent contribution to the indoor Radon levels is provided by exhalation from soil has induced many public institutions, responsible in matter of public health and environmental protection, to issue regulatory bodies considering Radon exhalation from soils a relevant issue in the assessment of the radiogenic risk associated to occupational and public exposure in residential buildings and working places.

However, on one side, the existing lack of consolidated methodologies and procedures, shared among the experts’ community, has produced a valuable intense investigation research activity; while, on the other one, it led to the development of different procedures, starting from diversified approaches, which could be classified into: indoor Radon measurements campaign-based approaches, geology-based and geology-indoor correlation based, integrated ones.

On the base of this last approach, the authors have constructed an interdisciplinary research program, RAD_CAMPANIA, with contributions from different disciplines (Geology, Geomorphology, Soil Science, Environmental Physics, Building Engineering, Radiology and Epidemiology). The program, aimed to the development of a standard methodology, is based on a multi-scale hierarchical (regional - provincial - sector-zone site) procedure of assessment of the impact of Radon on natural and anthropic environments. It consists of three main projects, related to the different environmental matrices (water, soil and air) and the anthropic systems. One interrelated issue among the three projects is the geo-genic approach to the assessment of the indoor Radon risk for workers and population, by means of the evaluation Radon exhalation from soil and water. The research is supported by a built-in regional database, consisting of both suitable territorial information and experimental data provided by Radon activity concentration measurements in soil-gas performed in several sites and indoor measurements, integrated in a GIS-based management procedure. A methodology like the one described in this chapter turns out to be a very powerful tool in many environmental and territorial planning approaches, especially wherever a “vast area” approach is needed to the environmental issues, i.e., the case of the urban acoustical or the electromagnetic pollution zoning. The “vast area” is an emerging concept and it regards a systemic approach to urban and regional planning methodology of analysis, design and management.

Starting from the results achieved by RAD_CAMPANIA Program, in the framework of the Buildings sub-project, at local site level, a simplified approach, the Salerno Indoor Radon Emanation Model (S.I.R.E.M.) procedure, to assess indoor Radon activity concentrations based upon on-site experimental evaluations of Radon emanation by building materials, has been formulated with the aim to realize a tool not only with a scientific valence but also useful and precious for its applications to real situations. The
model, in fact, could be used as tool to identify the areas, and so the buildings whose ground floor or basement level is expected to exceed the relevant national reference level. The use of S.I.R.E.M. Model opens the research to important perspectives: its potentiality, in fact, aligns with the new directives of the 2013/59/Euratom (“Member States are required to promote actions to identify dwellings with CNR (as an annual average) exceeding the reference level”).

**GENERAL FEATURES**

Accumulation of Indoor Radon activity concentration inside residential dwellings and workplaces is the result of a quite complex process which has many contributing sources (entry from soil, emission by building materials, from water and gas supplies). As it undergoes different physical mechanisms all occurring at the same time, thus, it turns out to depend on many parameters. They make the realization of a realistic and complete physic-mathematical model, that could be used on-site also by professionals, a really hard task to achieve.

Therefore, in the framework of an Interdisciplinary Strategic Program of Applied Research for the Assessment of Naturally Occurring Radioactive Materials in Natural and Anthropic Environments, called RAD_CAMPANIA, carried out in Italy at the University of Salerno, by environmental physicists, geologists, environmental and building engineers, using an adaptive hierarchical multiscalar approach, an innovative procedure of assessing and modeling the contribution to Indoor Radon from the building materials: The S.I.R.E.M.© Model”, has been realized. It has been applied a realistic case of a single-detached slab-on-grade house, made with concrete.

The procedure is simple and easy-to-use. It is entirely based on on-site experimental measurements of indoor Radon-in-air activity concentrations and Radon-in-air emissions by Building Materials, performed through the spectrometry of Radon short-lived alpha-emitting progenies. From the application of the S.I.R.E.M. procedure, interesting and useful indications can be derived about the dependence of the Indoor Radon values with the age of the concrete materials used for construction, the ventilation rate and the prediction about the goodness of the installation of engineering remedies to reduce the Indoor Radon levels.

**MANAGEMENT OF INDOOR RADON RISK FOR POPULATION AND WORKERS IN EUROPE: THE STATE-OF-ART**

Human exposure to Naturally Occurring Radioactivity (NOR) represents a large percentage of the total one to ionizing radiation from artificial and natural sources. In particular, among the natural sources, Radon (Radon-222) and its progeny, a radioactive gas produced during the decay chain of the primordial radionuclide Uranium-238, provides a contribution of almost 40%, in terms of world annual average value. Accordingly, since 1990 extensive epidemiological investigations have been performed and have demonstrated a statistically significant increase in the lung cancer risk from prolonged exposure to indoor Radon. Consequently, it has been established by the World Health Organization (WHO), that exposure to Radon, claimed by the International Agency for Research on Cancer (IARC) to be a carcinogenic substance of Group I, has to be considered as one of the major risk factors for lung cancer, when people are exposed to it inside confined spaces like residential buildings, workplaces and underground places like mines and caves.

Actually, the current legislation about the assessment of the population and workers exposure to natural ionizing radiation, due to Radon and its progeny, existing in the different European state members, fulfills the European Recommendation CEC 90/143/Euratom (1990) and the Council Directive 96/29/Euratom (1996). The first one has only recommended some Reference Level (RL) values for dwellings (200 Bq/m³ and 400 Bq/m³ in new and old residential buildings, respectively) while, for workplaces, EC recommended Member States to establish an Action Level (AL) value within the range 500-1000 Bq/m³. Consequently, the different transposed national regulatory bodies require that, inside residential buildings and workplaces, the overall indoor Radon activity concentrations, averaged over a period of one year, only have to be lower than specific levels, without any consideration about the contribution of the different Radon sources (entry from underneath soil, emanation by building materials, entry from water and gas supplies), presence of artificial or natural ventilation and the geological features of the dwelling location, that could cause those values of concentration.

In particular, the most recent residential investigations show also that the risk increase can be relevant even at concentration levels of the
order of 100 Bq/m³, lower than the level values prescribed previously by and transposed into the different national legislations. These outcomes have been analyzed by a special committee of European experts, within the European project RADPAR, to put the basis of recommendations for a new comprehensive European Union radiation protection directive that takes into account the population’s and workers’ exposure to both natural and artificial sources of radiation inside a unified framework of norms and prescriptions, indicating “... a new concept of exposure situations …”, such that “… the provisions of Commission Recommendation 90/143/Euratom are enabled to be incorporated into the binding requirements of the Basic Safety Standards while leaving enough flexibility for implementation …”.

Thus, this European Council Directive 2013/59/Euratom of 5 December 2013, laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, gives more precise indications to the European Member States in matter of radioprotection from exposure to different sources of ionizing radiation. It poses, for the first time, in a harmonized framework, the issue of the human exposure to ionizing radiation in the most complete and general way, considering all the possible kind of sources (artificial and natural) and the different human targets (population and workers) in the same regulatory framework. As it has been underlined by F. Bochicchio requirements for Radon protection for workers turn out to be much more tightening than in the previous Recommendation, while for the first time exposures to Radon in dwellings are regulated in a Directive.

In such a context it is also considered the role of the exposure due to indoor Radon and to the gamma radiation and Radon emanation by building materials, both of natural and artificial origin. The latter ones can be industrial products containing Naturally Occurring Radioactive Materials (NORM), eventually Technologically Enhanced (TE-NORM) in some cases. About that, the Directive states:

“... building materials emitting gamma radiation should be within the scope of this Directive but should also be regarded as construction products as defined in Regulation (EU) No 305/2011, in the sense that that Regulation applies to construction works emitting dangerous substances or dangerous radiation...”, and “... Industries processing naturally-occurring radioactive material extracted from the earth’s crust subject workers and, if material is released into the environment, members of the public to increased exposure …”, “... Protection against natural radiation sources, rather than being addressed separately in a specific title, should be fully integrated within the overall requirements. In particular, industries processing materials containing naturally-occurring radionuclides should be managed within the same regulatory framework as other practices ...”.

The unified approach of this Directive suggests that an interdisciplinary approach to the issues of the risk assessment associated to the exposure to ionizing radiations can be the right one to address such a complex issue and in the long term the only one really successful in achieving solutions and remedies to radioprotection of population and workers. A very accurate and detailed evaluation of the consequences of the issue of Directive 2013/59/Euratom with a particular concern to Radon exposure is given by F. Bochicchio, 2014.

For what it concerns exposure to indoor Radon that means that the intertwined roles played by the different Radon sources (soil, building materials, etc.) together with ventilation and living uses cannot be neglected any longer. Therefore, it turns not anymore irrelevant that solutions and remedies to the health issues consequences to Radon exposure, that amounts to nearly the half of our total yearly exposure to natural ionizing radiation for the world population, cannot be achieved without involving necessarily different expertise and skills like building and industrial engineering, geology, environmental physics.

In order to guarantee low levels of Radon activity concentrations inside a working or a living place, first of all it is necessary to be able to predict the maximum value of indoor Radon to which people can be exposed and which are the main sources causing it, and only then to be able to identify the most appropriate and cost-effective technique of mitigation that, when installed will guarantee the respect of the regulatory reference limits imposed by the national laws and will work efficiently to keep the occupants safe.

In order to do that, it is important the availability of Radon maps and to have a detailed knowledge of the Radon dynamics in a confined space.

For such reasons an Interdisciplinary Strategic Programme of Applied Research for the
Assessment of Naturally Occurring Radioactive Materials in Natural and Anthropic Environments, called RAD_CAMPANIA, with particular attention to Radon, has been started in Italy at the University of Salerno, in collaboration with the interUniversity Centre for Applied Research on the Prediction and Prevention of Major Hazards (C.U.G.R.I.), and the Regional Agency for the Environmental Protection of Campania (A.R.P.A. Campania). The project is carried out by environmental physicists, geologists, environmental and building engineers, using an adaptive hierarchical multiscale approach to investigate several sub-projects: Soils, Waters and Buildings. The work that have been done so far shows that the environmental quality monitoring in workplaces or housings, can, no more, be only limited to integrated measurements, but must be necessarily capable to identify which is the main source (soil, building material, water or natural gas) responsible for the accumulation of indoor Radon to perform the most appropriate mitigation remedies (for an existing building) and/or design new buildings in an innovative way in order to reduce the possible activity concentrations to the reference limits prescribed by the legislation and to be conformal also to the requirements of energy-efficient modern buildings, as it has been recently underlined by A. V. Vasilyev.

Regarding the contribution to the indoor Radon activity concentrations provided by the building Materials its direct evaluation from the activity of the naturally occurring radionuclides contained in walls, ceilings and structural elements, which is expressed usually, both in the regulatory bodies and in the scientific literature, in terms of the activity concentration index (I) or the radium equivalent activity (Ra-eq), is extremely difficult if not impossible.

Therefore, for such reasons, in the framework of the Buildings sub-project a simplified approach, the Salerno Indoor Radon Emanation Model (S.I.R.E.M.) procedure, to assess indoor Radon activity concentrations based on on-site experimental evaluations of Radon emanation by building materials, has been formulated with the aim to realize a tool not only with a scientific valence but also useful and precious for its applications to real situations.

THE RAD_CAMPANIA PROGRAM

The Program (Figure 1) develops interdisciplinary researches (Projects and Sub project), concerning the role and utility of the Radon in environmental and building studies; in particular, focusing on the human interrelations and impacts in life sites and styles.

Figure 1: RAD_CAMPANIA PROGRAM STRUCTURE

The Program deals with the main themes of operative research in environmental studies for the improvement in the actions and activities of the institutionally competent Authorities and Agencies of Campania Region in the soil, water and human health monitoring and protection, according to the national and regional regulations concerning the “Radon Risk”.

The Program RAD_Campania constitutes the methodological and procedural framework of the more extensive process of planning which responds, from the institutional point of view, to the fulfilsments required by the Radon National Plan. This program foresee techniques of differentiated analysis at different scales of territorial analysis, which are interactive and progressively more specific and in depth: from the zoning at a regional scale to the physical-mathematical modelling at a site scale, adopting an approach called “Hierarchical and Multi-scale Areas Zoning”, already widely used in environmental planning and landscape ecology (Guida et al., 1996; Blasi et al., 2007). This approach, is finalized to the individuation and the multi-scale classification of the Radon-prone Areas, organized in coherently hierarchical terms. Therefore, different hierarchical levels of multi-scale assessment of Radon-prone Areas have been identified (Figure 2).
The Regional Level of analysis and mapping provides specific tools, at the scale 1:250,000, suitable for the regional planning, i.e. Radon Regional Plan, and liable to implementation in more general regulation of territorial policy, like the Regional Territorial Plan (PTR).

The Provincial Level of analysis, and mapping at the scale 1:100,000 (Figure 3), can be suitable and useful for the sub-regional territorial planning, like the Province Coordination Territorial Plan (PTCP).

At the District level (Settore), the scales of analysis between 1:50,000 and 1:25,000 is suitable for Inter-municipal Plans, where high levels of Radon have been noticed in the previous analysis scales, and it is suitable for the Territorial Planning of municipality aggregates (Strategic Town Plans) and for subjects with epidemiological aims like the Local Sanitary Authorities.

The Zone (Ambito) level of analysis, represents the Radon-soil gas spatial distribution at the scales of 1:5,000-2,000; it is useful for a Planning like Municipal Town Plan (PUC in the Campania region regulation).

Finally, the Site analysis is useful for Executive Planning, at the scale 1:2,000, like Executive Plans (PEEP, PIP) and for Radon-soil gas and Indoor Modelling. The Physical Radon Entry and Accumulation Modelling (the so called Radon dynamics), completes the procedure at level site, giving the basis for and physically-based planning in order to programming an optimized, also in economic terms, epidemiologic inquiries in domestic environments and in work places.

For this purpose at this level the RAD_CAMPANIA work group has developed the S.I.R.E. Model© with the purpose to individuate and control indoor Radon maximum concentrations in all the potential domestic environments exposed.

THE S.I.R.E.M.© MODEL AS TOOL OF ANALYSIS AT SITE LEVEL

The global model sector developed christened S.I.R.E.M.© (Salerno Indoor Radon Emanation Model) (Figure 4) developed in the framework of the software development environment STELLA Software (isee systems), takes into account all the known Radon sources and each process has been modeled in a very simple way.

The S.I.R.E.M.© model is characterized to be:
1. evaluated in case of steady state conditions
2. semi-experimental
3. not site-specific. The resolution of this sector model needs the measurements of the different emissions from all Radon sources and the knowledge of the soil parameters and the geometric characteristics of the room. The model is divided into a number of groups representing as
Figure 4 - Structure of the S.I.R.E.M.© Model realized with the STELLA software development environment.

Many Radon sources (soil, building material, water, gas supply) as are present in the case study.

**Materials and Methods**

All the data necessary to run the model come from measurements obtained with the Radon-in-air analyzer, RAD7, manufactured by DURRIDGE Company, Inc. (Bedford, MA.) which provides a continuous monitoring of the Radon-in-air activity concentrations through a spectral analysis of their alpha-emitting short-live progenies.

The set-up that has been made to measure on-site Radon emanation by Building Materials is made by a RAD7 unit in line connected to a 0.6 L Hard Surface Emission Chamber (HSEC), manufactured by DURRIDGE Company, Inc. (Bedford, MA.), designed specifically for measuring Radon emanations from walls and floors directly on-site (figure 5).

**Analysis at Site Level: A Case – Study on a Test-House**

In order to verify the validity of the above approach the S.I.R.E.M.© model has been applied to a test-house. The chosen test-house, entirely constructed with concrete, is a single-family detached house with a slab-on-grade foundation, located in Baronissi, in the province of Salerno, Southern Italy.

The geology of the site is characterized by alluvial and volcanic deposit on a limestone base. The house is built on a site with a medium-high level of risk on the Regional Radon map, that is characterized by a soil Radon concentrations from 20,000 to 50,000 Bq/m³.

Regarding the geometry the house has a rectangular plant on three levels: the basement with a garage of about 30 m², the groundfloor of about 150 m² and, finally, the area under the roof used as warehouse. The type of construction is typical of the Italian tradition of the 20th century: a framed concrete structure with external walls in concrete bricks.

The experimental set-up for Radon activity concentrations measurements consisting in the RAD7 unit equipped with HSEC for Radon emanation measurements from BM has been installed in the garage, which is principle the one more exposed to accumulation of indoor Radon,
because closer to the main Radon entry source, the soil. This room is characterized by the absence of windows, just only a small opening on the front door of the garage, and the absence of a pavement. The floor in fact is made up of only a small slab of concrete. Two of the four perimetrical walls are in contact with the soil and so built totally in concrete because of their function is also that to contain the soil stress on them. The total volume of the test-structure is of about 100 m³.

The procedure is summarized as indicated in the following steps:

Step I: Individuation of all the Radon sources.

Step II. Choice of the measurement locations.

Step III. Choice of the data acquisition protocol.

Step IV. Performance of the measurements in the Radon production sectors (soil, BM) that have been individuated in Step I.

Step V. Introduction of all the required parameters into the model, see Table 2.

Some of them (labeled with code 1 in Table 2) can be measured on-site (as the room volume, the BM surface in contact with soil, the BM coverage, etc.), others (labeled with code 2 in Table 3) can be taken from numerous cases and experiments reported in the scientific literature (e.g., concrete efficacy diffusion coefficient, soil efficacy diffusion coefficient, etc.), others (like the pressure difference soil-external air) (labeled with 3) can be easily calculated with well-known basic equations.

After performing the algorithms contained in the procedure the obtained calculated output (111 Bqm⁻³) turns out to be the maximum (steady-state) indoor Radon activity concentration that can be reached in the actual structure condition when equilibrium is achieved.

As it can be noticed in Table 1 the calculated value (111 Bqm⁻³) is very close to the experimental value of the measured overall indoor Radon activity concentration (119 Bqm⁻³) on-site with the Radon detector RAD7. So, it confirms the validity of our approach, the goodness and the accurate construction of the S.I.R.E.M.© model and its equations describing the processes of indoor Radon accumulation.

Further, the outputs of the application of the model can be further elaborated also to predict the variability of Radon indoor activity concentration, if, for example, the structure conditions change due to the material ageing. In fact, it is possible to simulate this evolution changing the parameters regarding the building material like the open area fraction, Figure 7 or the ventilation of the room, Figure 8.
Finally, it has been evaluated also the efficacy, in reducing high Radon indoor activity concentrations, of recent Radon remediation techniques based on the installation of flexible-thin barriers (PETG, Polyethylene Naphthalate) that are simply mounted on the surface of the building materials, in direct contact with soil, in the case of fractured surface. The effective diffusion coefficient of the flexible-thin barriers are indicated in the several experimental cases reported in the scientific literature.

5 CONCLUDING REMARKS

The latest European Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom gives accurate and severe indications to the European member states in matter of the exposure to natural ionizing radiation with particular attention to public’s and workers’ exposure to Radon. In order to accomplish the requirements that each state member legislation will indicate through national Radon plans it is not anymore possible to underestimate the roles and the interconnection played by the different Radon entry sources (soil, building materials, etc.) together with ventilation and dwellers’ living habits. Also, it turns out to be more and more fundamental to design and realize buildings more and more compliant with the energy efficiency requirements. Therefore, solutions and remedies to the health issues consequences to Radon exposure, that amounts to nearly the half of our total yearly exposure to natural ionizing radiation for the world population, cannot be achieved without a purely interdisciplinary approach in which different expertise and skills are necessarily involved (building and industrial engineering, geology, environmental physics). In this interdisciplinary context a simple and easy-to-use procedure, the S.I.R.E.M. model, for the assessment of the different contribution to Indoor Radon accumulation in residential and workplaces has been implemented on the basis of experimental measurements that can be done directly on-site. The application to a test-site and the comparison, regarding the contribution from Building...
Materials, between the S.I.R.E.M. procedure predictions for the cumulative Indoor Radon activity concentration and the experimental results shows a very good agreement.

Besides that the S.I.R.E.M. results show also that it is possible to evaluate in quantitativ way the role of the ventilation and of the age of the Building Materials (concrete in the examined case-study).

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