Article

Radiation protection legislation and sustainable development of a rural green-tuff village of Ischia Island

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Abstract: Radiological risk affect the quality of the environment in buildings since population and workers can be potentially exposed to high level of dose. Radon gas emanated from both subsoil and building materials represents the most important source of radiation exposure for people. This study investigates the sustainability concept of a small rural village of Ischia Island, named Ciglio, in relation to the radiological risk. Radon activity concentration was measured in typical green tuff dwellings and in water samples collected from a local spring using E-Perm devices. Moreover, for green-tuff as building material, the radon emanation coefficient was calculated by a mixed technique based on gamma and alpha spectrometry. The results highlight the importance to perform environmental radon monitoring and to investigate the radon content of building materials, especially in geographical areas characterized by traditional use of typical stones for constructions. In conclusion, the sustainability development of rural buildings is possible if the radiological risk for inhabitants and workers was assessed.

Keywords: building materials; rural architecture; Ischia Island; radiological characterization; radon; radiological risk assessment; sustainable buildings

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1. Introduction

1.1 Concept of sustainability and rural area of Ciglio

In recent years the issue of sustainability has aroused an increasing interest in different fields of study as it involves a wide range of human activities as policy, economy, traditional culture, civil architecture [1-5]. Sustainability is a multidimensional concept with various perspectives in the natural, historical, environmental and cultural texture of the communities living in cities and rural areas as well as.

In particular, traditional rural areas and one-off built structures represent an important imprint of our cultural heritage: preserving the local architectural heritage and transferring it to future generations have a great impact on the sustainability.

Despite a wide available literature on the sustainability concept [4,6-9], to date the definitions of "sustainable building" are still unclear and biased [10]. Generally, the terminology "design and construction of sustainable buildings" usually refers to the energy efficiency, renewable materials, and reduction of emissions, wastes and pollutants in buildings, neglecting the relations between built, natural and social systems [11]. Indeed, sustainable development of villages and their buildings have a significant influence on the economy, on resource demand and consumption, building design and construction, planning and transport, communication [4].

The sustainability approach in the building sector lead the construction industry to consider economic, environmental and social aspects and not more time, cost and quality as indicators of the level of efficiency [7]. The reuse of the locally available construction materials and the enhancement of traditional rural buildings (TRBs) have been a strategic solution in favor of the sustainable policy [8].

Over the years, various European and national programs, supported by financial projects, have promoted the reuse of TRBs aiming at preserving, developing, and supporting local identities and the natural resources [12-14]. The rehabilitation of TRBs can be an opportunity for the local communities to implement different tourist attractiveness and activities: accommodation facilities, meeting places, conference halls, restaurants, hotels, museums, residential centers and much more. The phenomenon of the rural tourism is becoming increasingly popular since the visitors rediscover historical traditions, memories and social identities, enjoying at the same time the natural landscape [12,15,16]. It is clear that, as consequence of the sustainable development of rural areas, the presence of people (inhabitants, visitors and workers) involved in receptive activities or guided tour), is intensified. Consequently, sustainable planning of social, cultural and economic activities must be integrated with an appropriate planning for the safety of occupants, workers and public.

The knowledge of the territory and surrounding environment, construction techniques and materials, plays a key role in the implementation of adequate security and protection conditions.

The history of the Ischia Island (southern Italy) was mainly characterized by the volcanism activity that influenced the geological and morphological structures of the island and surrounding area. The island represents the emerged portion of a wide volcanic field including both Somma-Vesuvius and the Phlegrean Fields. As consequence, the soil composition of Ischia has peculiar mineralogical, chemical, and textural characteristics, which are then found in the building materials used for constructions. In particular, a small rural village near Serrara Fontana in Ischia, named Ciglio, is a touristic attraction thanks to its green landscape and ancient constructions.

Typical buildings of Ciglio were built with green tuff, a natural stone widely spread on the island after Mount Epomeo eruption [17]. About 55,000 years ago, there was a strong activity in a large magma chamber located under the island of Ischia. The deposits of these mighty eruptions are known as the "*Monte Epomeo Green Tuff*". The grey-green color was probably caused by the prolonged contact of the rock with seawater. The chemical composition of green tuff consists primarily of phillipsite, pyrogenic K-feldspar, and clay minerals. Mineralogical, chemical, and textural features on green-tuff as well as details on geological history of the Ciglio area were available in ref. [18].

The abundance of this material in this place has influenced the architecture and construction techniques, there are in fact two peculiar techniques: sculpting directly into the rock to obtain a habitable space or extracting blocks of tuff from the original sites and building above the street level. Buildings built with the combination of the two techniques can also be observed. Today these traditional buildings are intended for residential or tourist accommodation.

1.2 Aim of the study, radon issue and legislative background

The main topic of this study is the contribution to environmental radioactivity from the most abundant component of natural origin: radon gas. We have focused on the issue of radiation protection for the public and workers, analyzing it both based on Italian legislation and European directive [19,20]. Radon (^{222}Rn) is a radioactive gas (half-life of 3.8 days) produced by the radium-226 (^{226}Ra) in the uranium-238 (^{238}U) decay chain. It is a naturally occurring element present in soil, rocks and earth's crust. Short-living alpha emitters descents of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) with half-life of few seconds, are responsible for a natural source of internal exposure. The lungs are affected when aerosols carrying these radioactive decay products from the radon gas are inhaled. Once deposited on the surface of the lungs, the radioelements emit alpha rays which can penetrate deep enough to reach the cells of the bronchioles and lead the DNA damage that underlies mutations that could cause cancer [21]. In 1998, the International Agency for Research on Cancer (IARC) classified radon and its decay products as carcinogens of group 1 for human [22] and in 2009 the Worth Health Organization (WHO) identified in radon the second cause of lung cancer, after smoking [23]. The exposure radon risk depends on the radon concentration in homes and workplaces (radon indoor) where people spend most of their time [24,25]. Radon enters in buildings mainly through the porous basement foundations but also as radioactivity content in natural stones used as building materials [26] and accumulates especially on floor levels. Since radon mobility is influenced by the rock porosity, radon concentration in buildings tuff-constructed is potentially much higher than constructions built with materials characterized by a more compact matrix.

As it is well known, not the full amount of radon produced in the matrix (soil and building materials) has the potential to reach the environment. In fact, only a fraction of radon atoms acquires the minimum kinetic energy to leave the grain of the material where it has been generated, so to reach the empty space in the solid matrix. This process is named emanation and the emanated radon fraction is the emanation coefficient.

In addition to inhalation, another source of incorporation of radionuclides and therefore of internal radiation is the ingestion of these through drinking water which contains a level of concentration of radon enough to increase the probability of biological damage. It has been estimated that a daily consumption of 2 liters of water with a radon concentration of 100 Bq/L can provide an annual effective dose of about 0.1 mSv [27]. This value of radon activity concentration is defined "parameter value" (or "attention value") established by the current Italian Legislative Decree 28/2016 [27], which implements the Council Directive 2013/51/EURATOM, regulating the radiological control of water intended for human use. If the concentration of radon gas activity exceeds the parameter value, it is mandatory to calculate the so-called indicative dose to ensure consumer safety.

Concerning the health protection of people against the risk deriving from ionizing radiation, in particular from inhalation of radon gas, the Italian legislation is represented by the Legislative Decree 241/00 (in force at the time of measurement), that establishes an action level of mean annual radon concentration equal to 500 Bq/m^3 and an annual effective dose of 3 mSv/year in the workplaces. The Decree identifies radon risk areas: underground workplaces such as tunnels, subways, catacombs, caves and areas with specific characteristics where are implemented activities involving workers and, eventually, public as stated in the Article 10-bis, comma 1, letter a of the Legislative Decree 241/00, [19]. On the other hand, the letter b, of the same Article, indicates the "work activities during which the workers and possibly people from the public are exposed to decay products of radon or thoron, or a gamma radiation or any other exposure in places of work other than those referred to in letter a) in areas well identified or with specific characteristics". Ischia Island, due to its volcanic origin, has its own specific characteristics. Recently, in August 2020, Italy implemented Directive 2013/59/EURATOM [20] with Legislative Decree 101/2020, which repeals Legislative Decree 241/00. The greatest social and managerial impact of Legislative Decree 101/2020 lies in the updating and expansion of the recommendations for the protection of health in all closed environments, including workplaces and homes, in a monitoring program of radiation. In particular, the Legislative Decree 101/2020 at article 12 comma 1 establishes the reference level of the radon concentration equal to 300 Bq/m^3 both in buildings intended for residential use and in workplaces and raises the limit of the average annual dose effective up to 6 mSv. In this framework, our study was performed before the emanation of the current legislation, consequently the results were presented and interpreted according to the Legislative Decree 241/2000. The aim of this work was to strengthen the concept of sustainability by introducing the variable of safe work and public employment. About territorial examination, many works of literature have reported measurements of the activity indoor radon concentration in Italian homes [28,29], underground workplaces [30,31], schools [32-35] and tourist attraction sites in the island of Ischia as thermal spas centers [36]. In this work, we investigated some aspects of the exposure risk to radon deriving from the radon content in different material and environments (indoor air, water and building materials) in the village of Ciglio in Ischia Island. One church and one dwelling were selected for the measurements of radon indoor activity concentration. Six samples of water were collected in loco from an ancient waterfall to measure radon content. The average annual effective dose for the radioprotection of workers was estimated according to Decree 241/00 only when the concentration of radon activity exceeded the reference value. Finally, a preliminary radiological characterization of green tuff was performed measuring the emanation coefficient of five samples extracted from a site near the church.

2. Materials and Methods

2.1 Traditional rural buildings selected for radon concentration measurements

Ciglio is a small rupestrian village of the seventeenth century with a great landscape impact and famous for its "stone houses" carved into the rock, once used as a dwelling and today integrated with modern houses built along the road that climbs to the slopes of Mount Epomeo. The south-western side of the Ischia island, including the Ciglio, is pervaded by a large amount of green tuff, so much so that native construction techniques based on the use of this natural stone have been encouraged in this area. The buildings were used to support the economic and sustenance activities of the pre-industrial era, based on agriculture and winemaking. Often these buildings were equipped with a single opening and without windowless or with little hole above the access door. The stone houses served different purposes, both for the preservation of the products and as a shelter for the farmers and breeders, who spent much time on the mountain. These buildings date back to the 14th-15th centuries and their use has been continuous for about 500 years. To date, even if most of dwellings is abandoned, many of them have been converted in warehouse, garage, stable, accommodation as well. Furthermore, the stone houses constitute a tourist attraction together to some rock constructions of religious nature. For our investigation and radiological characterization, two TRB sites were selected as representative of the two construction techniques in use: a house, obtained by digging directly into a rock boulder and a church built with extracted tuff blocks (Figure 1 A-B). In addition, the six samples for the radiological water analysis, were collected from a tap directly connected to a cave in which a small waterfall flows from the overlooking Mount Epomeo and located inside the church.

Finally, for the radon emanation study from typical stones, tuff bricks were collected, emulating the same approach as the builders in the area who used the material found in the surrounding areas.

Figure 1. Picture of San Ciro church **(A)** and dwelling **(B)**.

2.2 Radon measurement device

Radon concentration measurements in indoor air and water, were carried out using a conventional electret passive environmental radon monitor (E-Perm) electret ion chamber (EIC) system manufactured by Rad. Elec. Inc., (Frederck, Maryland, USA) [37-40].

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The measurements were performed in the radioactivity laboratory certified UNI EN ISO 9001: 2015 for measures of concentration of activity of radon gas [41].

2.2.1. Measurement of radon activity concentration in air

E-Perm devices were used in Long–Long Term (LLT) configuration: chamber Long Term and low sensitivity electret Long Term [38].

The charge loss of the electret was measured using an electrometer (Rad. Elec. Inc. Mod. 6383-01, Frederck, Maryland, USA).

Since E-Perm are sensitive to gamma radiation, radon concentration measure requires corrections for cosmic and terrestrial radiation background. The method has been already described in detail elsewhere [36]. The gamma dose rate was measured at each site using a portable proportional counter (Berthold Technologies, Germany). The range of gamma dose rate across the monitored sites, varied from a minimum of (0.27 ± 0.01) μGy h^{-1} to a maximum of (0.31 ± 0.02) μGy h^{-1}.

The radon concentration was calculated applying the appropriate calibration factor and the exposure time, according to the equations (1) and (2) given by Kotrappa et al. [39]:

$$C_{Rn} = \left[\frac{(V_i - V_f)}{CF \ x \ T} - G_\gamma C_1\right] x \ 37 \qquad (1)$$

$$CF = C_2 + C_3 \ (V_i - V_f)/2 \qquad (2)$$

where:

V_i and V_f: electret voltage readings before and after exposure respectively;

T: exposure time in days;

G_γ: gamma dose rate in μR h^{-1};

C_1= 0.59, C_2=0.02383, C_3=0.0000112: constants given by the manufacturer depending on configuration and volume of the E-Perm chamber.

The measurement was carried out between November 2019 and July 2020.

The E-Perm devices were exposed in several places of the selected buildings in order to have a significant distribution of measured values of radon concentration. In particular, 3 measurement points were chosen in the San Ciro church and one in the living room of the dwelling, where occupants spent most of their time. The planimetry of the buildings with the scheme of exposure of the E-Perm systems was reported in Figure 2. The E-Perm devices were exposed away from windows and doors, at about 1.5 m above the floor and 0.5 m from the wall. The exposure period was long 232 days.

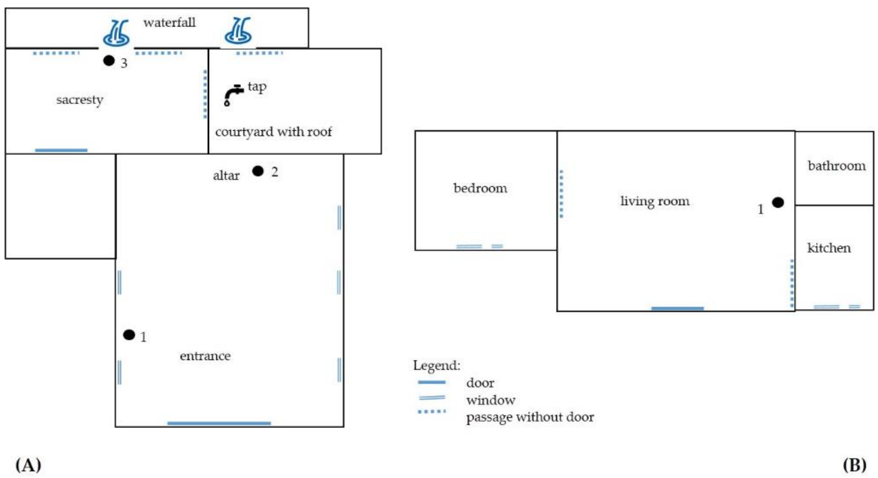

Figure 2. Exposure scheme of the E-Perm devices (marked with a numbered black spot) in San Ciro church **(A)** and dwelling **(B)**.

2.2.2 Measurement of radon activity concentration in water

Six water samples were collected directly from the tap with bottles of 140 mL each, taking care to fill them slowly in order to avoid radon lack. After transport to the laboratory, within about 24 hours of collection, each 140 mL bottle was opened and immediately placed in a 4 L glass jar with a suspended E-Perm chamber in short-short term configuration (SST). The jar containing the electret and water sample was sealed (airtight) for 94 h to allow radon to reach equilibrium with its daughters. To determine the radon concentration in the water sample, the reading of the voltage electret discharge is used with a formula (3) provided by the manufacturer [37]:

$$C_{Rn}(water) = C_{Rn} + B_1 + B_2 + B_3 \quad (3)$$

where:
C_{Rn}: radon concentration measured in the air inside the jar by equations (1) and (2) where C_1=0.097, C_2=1.670, C_3= 0.0005742;
B_1: period between the collection of the water sample and the start of the measurement;
B_2: period from the time of inserting the sampling bottle into the jar until the E-Perm is removed;
B_3: ratio between the volume of the jar and the water sample.

A more detailed description of the formula is available in ref.[31].

2.3. Calculation of annual effective radon dose

The annual effective dose (H) due to exposure of radon progeny in air has been calculated from the experimentally determined value of radon concentration using expression (4):

$$H\ (mSv\ y^{-1}) = C_{Rn} \times O \times D \quad (4)$$

where:
C_{Rn}: indoor radon concentration (Bq m^{-3});
O: occupancy factor (2,000 h y^{-1} at work);
D: dose coefficient.

Italian legislation [19] suggests using the conventional dose coefficient of 3 × 10^{-6} mSv per Bq h m^{-3} (Annex I-bis, comma 6).
D expressed in terms of ^{222}Rn gas exposure, includes the equilibrium factor F, representing the equilibrium between radon gas and its short-lived decay products. The value of the equilibrium factor is between 0.1 and 0.9 and depends on many environmental variables [42], however the environmental conditions of the buildings were standard and for this reason in this study we adopted the standard hypothesis of F = 0.4 as the Italian legislation established for most indoor situations.

2.4 Emanation coefficient

2.4.1 Sample preparation

Before analysis, each sample was processed according to the protocol UNI EN ISO 18589-2:2015 (Measurement of radioactivity environment - soil guidance for the selection of the sampling strategy, sampling and pre-treatment of samples) in order to obtain homogenous and uniform matrix. The samples were prepared reducing bricks to powder by grinding (PM 100 Retsch) and sieving, drying in an oven (DIGITRONIC Selecta 2005141) at 105°C for two hours and homogenizing the powder according to the measurement techniques [10]. The final product was weighted and sealed in a

Marinelli Beaker for 4 weeks to allow ^{226}Ra and gamma daughters to reach secular equilibrium. The number of the analyzed samples was enough to ensure statistical significance.

2.4.2 Emanation coefficient measurement

The emanation coefficient of ^{222}Rn in samples of green tuff has been obtained by the ratio between the activity concentration of emanated radon fraction and the total radon concentration in equilibrium with ^{226}Ra in the same material. The first one is measured in an electrostatic collection chamber; the total activity concentration of ^{226}Ra in the materials was measured by gamma ray spectroscopy on another sample of the same material put in a Marinelli beaker. The measured emanation coefficient is obviously referred to the characteristic of the material.

The measurement of the radon concentration released in air was measured by putting the sample into a box characterized by a diameter of 8 cm and high equal to 2.5 cm included in a chamber of 0.765 L. A positive high voltage applied between chamber wall and alpha detector produce the transport of ionized daughter of radon (^{218}Po) and Thoron (^{216}Po) on the detector surface. Therefore, the alpha particles emitted can reach the depleted zone of the diode without energy loss and in these conditions a high resolution alpha particles spectrometry can be performed, despite the presence of air in the chamber.

The energy performance of the high-resolution gamma spectrometry system, consisting of coaxial High Purity 129 Germanium (HPGe ORTEC®) detector, model GMX-45P4ST, is defined by the relative efficiency equal to 48% and energy resolution, measured as full width at half maximum (FWHM), equal to 2.16 keV at 1.33 MeV. The detector is equipped with a beryllium window that ensures a good sensitivity also at energy lower than 100 keV. The minimum detectable activity (MDA) of the system has been estimated with 95% confidence level. The detector was shielded from external background by 7.5 cm lead circular wall.

The spectra were acquired by Ortec DSPEC-LF unit plus MCA Emulator software and analyzed with GammaVision Spectrum Analysis Software.

The alpha lines for the measurement of the exhalated radon fraction was that at 7,687 keV of ^{214}Po and that at 6,030 keV of ^{218}Po. The line of ^{218}Po interferes with the line at 6,090 keV of ^{212}Bi (Thorium series) so to take into account this contribution it was subtracted from peak due to ^{214}Po and ^{214}Bi the half of the intensity of the single peak of ^{212}Po at 8,784 keV of the same series .

The gamma measurements were carried out on a sample of the same grain size characteristic in 1 L Marinelli Beaker. The gamma rays used for determining the total radon content of the green tuff were 295 keV, 352 keV (^{214}Bi) and 609 keV (^{214}Pb).

Alpha spectra data are saved in different files coming from the alpha detector, with related files included in a single directory.

3. Results

The radon activity concentrations for each measurement point in the church and dwelling were reported in Table 1.

Table 1. Radon concentration in air for each measurement point in the church and dwelling.

Measurement point	Activity radon concentration (Bq/m^3)	
	church	dwelling
#1	210 ± 20	210 ± 20
#2	120 ± 20	
#3	540 ± 40	

The mean radon concentration in the six water samples resulted to be (12 ± 1) Bq/L.
The measurement of emanation coefficient in the six samples of green-tuff stones provided the mean value of (8 ± 2) %.

4. Discussion

The results show that according to the national legislation for the workplace [19], in the church one measurement point (#3 see Table 1), corresponding to the sacristy, exceeds the action level of 500 Bq/m^3. Obviously, the value of radon concentration in the sacristy exceeds also the reference level of 300 Bq/m^3 recommended by the European Commission in the Directive 2013/59/EURATOM [20] and so the recent Italian legislation [43]. Instead, in the other measurement points of the church, the radon concentration is lower than the reference value.

The result is very interesting for the consequence concerning eventually presence of people in the building. Italian regulation requires implementing adequate remedial actions (i.e. architectural remediation, building configuration, ventilation), if the mean annual effective dose exceeds the level of 3 mSv/y. For the conventional occupancy time of 2,000 h/y in the sacristy, the mean annual effective dose results 3.3 mSv/y. In this case, the sacristan and the priest spends only 150 h/y, as they stated, corresponding to a mean annual effective dose of 0.2 mSv/y.

The study was performed independently on the intended use of the building since the dwelling and the San Ciro church are representative of local constructive techniques (carved directly into the rock and built with extracted tuff, respectively used to construct other buildings potentially intended for activities involving workers and opened to the public.

The value of radon concentration measured in the dwelling, meets the requirements of the Italian regulation [43], resulting below 300 Bq/m^3 and it is consistent with the results reported in a previous work [44], investigating the radon concentration in several dwellings of Ischia Island. However, we can assert that the occupants of this area should open frequently windows and doors in order to reduce the radon concentration and effective annual dose consequently, through natural ventilation, since the value of radon activity concentration in the dwelling resulted much higher than the regional mean (95 ± 3 Bq/m^3) reported in ref. [28]. In addition, radon mitigation should aim to achieve the WHO recommended goal of lowering the level of radon concentration in homes below 100 Bq/m^3 in order to limit the risk to individuals [23]. The effectiveness of natural ventilation on reducing radon indoor level has been already evaluated in some dwelling of Puglia region (Southern Italy) [45].

The radon activity concentration found in water samples is within the limit stated by the Italian regulation (< 100 Bq/L) [27]. Consequently, neither further screening of radioactivity content nor any risk assessments and corrective actions are mandatory. Assessed the safety of the water flow for eventually ingestion, it is interesting to note that the presence of the water flow could have an effect of the indoor radon concentration in the surrounding environment. In fact, the high value of radon concentration in the sacristy respect to the other rooms could be attribute to twofold causes: the presence of water flow which gurgling release the radon gas and the tuff-walls without plaster. We can speculate that since radon is has a solubility in water depending on the temperature and other conditions of the microenvironment, a percentage of radon reaches the surface inside the sacristy. In a future work, we are planning to estimate the contribution of the radon content in water to radon accumulation in the surrounding environment, though further measurements designed ad hoc. On the other hand, in the sacristy, the radon emanated from the green-tuff could greatly contributes to the indoor accumulation. On the contrary, in the other rooms the plaster probably acts as a screen for alpha particles, which do not reach the environment.

The emanation coefficient measured from the green-tuff samples was comparable with the values reported in ref. [46] for volcanic materials used as building material in Campania region, including tuff from Monte Epomeo in Ischia Island. In addition, the result obtained was comparable with those contained in the ISTISAN report 17/36 [47] for volcanic tuff. This report is an extensive database of emanation rate measured in approximately 1,500 samples of building materials or their components used in the construction industry in most European Countries. The estimation of radon emanation rate from building materials is crucial to assess the radon exposure hazard since the dominant contributor to indoor radon is the emanation from soil and fractured bedrock close to the surface. In this context, recent studies deal with radon exposure risk and lung cancer incidence in

South-eastern Italy [48,49], together with radiological characterization of typical stones used for constructions [26].

The findings of the study remark the importance to monitor the radon concentration in traditional buildings, that potentially could come into programs of promotion of multifunctional use of TRBs. Ciglio area is representative of the entire Italian peninsula, which increasingly promotes sites with peculiar architectural and geological characteristics. Therefore, the radiological surveillance of the environments, indicating the level of exposure risk, seems to be a priority before to take into account the development of any area leading high occupancy time for workers and general population. Similar to Ciglio, in these regions, local geology led to a widespread use of building materials potentially rich in uranium and radio.

The obtained results provide information useful to design a development planning of rural and touristic activities, in line with the sustainability concept in areas where the enhancement of local traditions was supported by national and local policy as well. To this regard, since 1999, Ciglio is included in the Landscape Plan "Ischia Island" [50] having the double aim of blocking the processes of degradation and to develop the enormous urban, landscape, environmental heritage, already present. Inhabitants, sensible to the traditional value of the local heritage, have a primary role in preserving the characteristics of the original landscape in combination with a concrete sense of innovation and renewal. In this perspective, the results of the study ensure workers, tourists and local community that Ciglio can be fully experienced in health-safety if the radioprotection isn't neglected.

5. Conclusions

For the first time the sustainability concept was evaluated in relation to the radioprotection issue in the peculiar area of Ciglio village, in Ischia Island.

The radon concentration was measured in two typical rural buildings and in water samples collected from an ancient waterfall. When mandatory, the evaluation of mean effective dose per year was calculated for workers. The emanation coefficient of green-tuff was also carried out.

In this case study emerged the need to evaluate the impact of the building materials and geological structures on radon activity concentration and to assess the radiation exposure in order to implement the sustainable planning of social and economic activities in Ciglio rural area. This study presents a scenery in which the valorization of rural landscape, involving both natural and cultural dimensions, includes also the radioprotection concept, essential to guarantee occupational safety.

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