# NATURAL RADIOACTIVITY EXPOSURE: RISK ASSESSMENT OF WORKERS IN ITALIAN QUARRIES

**E. Marchetti[1], R. Trevisi[1], S. Tonnarini[1], C. Orlando[1], M. Bruno[2], M. Amici[2], C. Paolelli[2], B. M. Antonelli[3], E. Incocciati[3], F. Nappi[3], P. La Pegna[3]**

[1]*Istituto Superiore per la Prevenzione e la Sicurezza del lavoro (ISPESL) – Department of Occupational Hygiene – Monteporzio Catone (Rome), Italy*
[2]*Università Cattolica del Sacro Cuore UCSC – Central Service of Radioisotopes – Rome, Italy*
[3]*Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL) – Technical Advisory Department for Risk Assessment and Prevention (CONTARP) – Rome, Italy*

**Abstract.** In alignment to the Title VII of EU BSS, the new legislative regulation introduced in Italy in 2000 dedicates a special section to working activities carried out in quarries where the presence of sources of natural radioactivity leads to a significant increase in the exposure of workers or members of the public which cannot be disregarded from the radiation protection point of view. [1,2]

In some of the activities mentioned by Italian regulation, such as the ones carried out in quarries, the workers and potentially the public might be exposed to radon or thoron decay products and gamma radiation.

The present work reports the outcome of a study performed in about 20 quarries, located in different Italian districts, to estimate the radiation dose received by the employees due to the exposure to radon, radon progeny and gamma emission of natural radionuclides such as $^{40}$K and the ones originated from $^{238}$U and $^{232}$Th. The measurements were performed both where materials are extracted and in the processing laboratories. A measurement protocol has been designed and the investigated quarries have been monitored by means of personal and environmental dosimeters. In particular, for indoor radon monitoring, radon passive devices have been used (NRPB/SSI type dosimeter and PADC/CR-39 as detector), while for gamma dose assessing personal electronic and thermoluminescence dosimeters have been used.

Samples of natural quarried materials have been analysed by gamma spectrometry. Spectrometric data have been processed to estimate the gamma dose rate in air due to gamma emission.

This paper provides a description of a measurement campaign carried out to estimate the risk of occupational exposure to natural radioactivity.

## Introduction

Primordial radionuclides contribute significantly to the exposure to natural radioactivity for people. Among these, major players are Potassium-40 and the radionuclides originated from the decay chains of Uranium-238 and Thorium-232, both widely spread in soil and rocks of the earth's crust. Naturally occurring radionuclides exposure may be internal or external. External exposure is caused prevalently by gamma radiation from radionuclides in the $^{238}$U and $^{232}$Th series and from $^{40}$K. Higher radiation levels are associated with igneous rocks, such as granite, tuff and lower levels with sedimentary rocks. Internal exposure is linked to radionuclides intake but the main cause is the inhalation of $^{222}$Rn and its short-lived decay products. $^{222}$Rn is the gaseous radioactive product of $^{226}$Ra decay in the $^{238}$U series. Inhalation of the short lived decay products of $^{222}$Rn provide the main pathway for radiation exposure of the lung.

There is a number of circumstances in which materials containing natural radionuclides are recovered, processed or brought into position that results in exposure to radiation. This human intervention causes enhanced exposures [3].

In August 2000, the Italian authorities implemented the EU BSS [1] laying down safety standards for the protection of the health of workers and the general public against the dangers from ionizing radiation into national legislative regulation [2]. According to the Title VII of EU BSS, the new legislative regulation introduces a special section regarding working activities carried out in quarries where the processing of extracted materials is a source of potential exposure because of natural radioactivity high levels arising from a large amount of primordial radionuclides in the $^{238}$U and $^{232}$Th series and $^{40}$K. For those working activities Italian regulation has fixed the action level of 1 mSv/y in terms of effective dose. If the effective dose to workers exceeds the action level of 1 mSv/y a radiation protection system must be applied.

In order to assess worker exposure risk many quarries, particularly interesting from a geological point of view, located in some of the Italian districts as Lazio, Toscana, Trentino Alto Adige, and Liguria, have been covered.

### Quarry working place features

The quarries selected for this survey are those producing “ornamental stones”. The stony materials included in this group are marbles, granites and stones. Stones category includes many rocks with different mineralogical structures as peperinos, tuffs, slates, basalts, etc. In Italy there are about 2,000 factories producing “ornamental stones” with about 10,000 working employees [4]. Usually factories have a quarry where materials are extracted and laboratories where materials are processed. In some cases the company work activity is just processing the materials coming from other quarries placed in different Italian districts and sometimes in different nations. Two typologies of quarries are the most common: underground and open air quarries. The laboratory premises are usually very wide with large entrances in order to facilitate material flow. Processing operations require high water amount for both drill cooling and air dust concentration reduction causing high humidity rate environments.

## MATERIALS AND METHODS

### $^{222}$Rn exposure evaluation

The estimation of exposure to radon and its decay products involves radon indoor concentration measurements and equilibrium factor F calculation.

The evaluation of average radon concentration requires time integrated measurement, which has been performed with passive radon devices (NRPB/SSI type diffusion chamber) and nuclear tracks detectors (PADC/CR-39). The monitoring of $^{222}$Rn indoor concentration has been done both in processing laboratories and offices. One or more passive devices for measurement location have been placed depending on premises wideness. Radon passive devices have been placed at 1.5-2 meters above the floor for a time of about six months and at the end of the acquisition data period, the monitors have been processed and analyzed by a semi-automatic evaluation system developed in our laboratory. In particular PADC/CR-39 detectors have been treated with a potassium hydroxide solution (30%) at a temperature of 80°C for 5.5 hours. These etching conditions combined with a low power microscope with magnification of 50× and an imaging analysis system allowed the evaluation of radon average concentration [5]. The quality assurance of this measurements methodology is granted by radon passive monitors calibration to the NRPB facilities and by periodic participations to radon passive monitors intercomparison.

Equilibrium factor F measurement has been carried out by continuous monitoring with ionization chamber system AlphaGUARD PQ 2000PRO and Working Level Meter Thomson & Nielsen. The measurement period is at least one week. The instruments have been positioned in processing laboratories and office premises at one meter above the floor, in active mode. To avoid air current influence, the AlphaGUARD and the WL Meter Thomson & Nielsen have been used in a sheltered place and all environmental parameters (humidity, temperature and pressure) have been registered during measure time. All measurements have been carried out during working time.

### Measurement of natural radionuclides concentrations in quarry materials

Quarry materials, extracted or processed in the selected caves, have been analyzed by gamma spectrometry in order to determine their primordial radionuclides contents. Samples undergoing gamma spectrometry analysis have been prepared with the following protocol:

a) fracturing
b) drying process (60°C for 12 h)
c) milling
d) sieving
e) drying process (60°C for 12 h).

The treatment was completed when samples reached constant weight, then they were placed in a Marinelli beaker. The samples were sealed up and stocked in a dry place for 22 days in order to achieve secular equilibrium between $^{226}$Ra and its progeny.

Samples have been analyzed by a coaxial HPGe gamma spectrometer in Marinelli geometry (38% efficiency, 1.95 keV resolution, and 65x$10^3$ sec data acquisition time). Radionuclides activity concentrations have been determined as shown:

- $^{40}$K - spectrum line at 1460 keV of energy;
- $^{238}$U - spectrum line at 1001 keV of energy of radionuclide $^{234m}$Pa;
- $^{226}$Ra - average of main spectrum line of radionuclides $^{214}$Bi (609 keV) and $^{214}$Pb (352 keV);
- $^{232}$Th - spectrum line at 911 keV of energy of radionuclide $^{228}$Ac.

Emission spectrum lines without any interference with other radionuclides energy emissions have been selected and quantitative analysis has been done by comparing with efficiency calibration curve (standard solution of nine radionuclides QCY.44, Amersham) [6]. The results are expressed in Bq·kg$^{-1}$ (dried weight).

### External radiation exposure: individual monitoring

The estimation of gamma dose has been carried out monitoring employees whose working activities can cause an enhanced external exposure (such as people processing materials or quarrymen, etc.). Two different personal dosimeters have been used: thermoluminescence personal dosimeters because of their extensive use in dose rate evaluations and electronic personal dosimeters whose quality and accuracy is improving rapidly. The aim is a comparison of dose response [7].

Electronic personal dosimeters are DMC 2000S type of MGP Instruments (radiation detected X and gamma from 50 keV). The energy response varies within 20% in the measurement range from background to 10 Sv dose equivalent.

TLD dosimeters are GR-200A. The chips are small crystal of LiF:Mg, Cu, P (diameter 4.5 mm and thickness 0.8 mm), with lower detection limit < 2 μGy. The energy response varies within 30%.

Employees have been monitored by means of both electronic and TLD dosimeters. Two locations have been selected in order to assess indoor and outdoor background levels. The measurement period is one month.

## RESULTS AND DISCUSSION

### $^{222}$Rn exposure evaluation

The values of average radon concentration determined by integrated measurements are listed in table 1. The degree of uncertainty connected to measurement is lower than 10%.

The values of indoor radon concentration are low, between 15 and 380 Bq/m$^3$ for laboratory premises where materials are processed and between 40 and 500 Bq/m$^3$ for office spaces. These cases highlight that radon concentration values are lower in laboratory premises than in offices. This can be explained considering that laboratories' structural layout and materials processing modalities allow a higher air circulation in premises. As shown in table 1, in the case of quarry labelled with *F*, located in Lazio district, indoor radon concentration is the highest observed. The evidence that indoor radon concentration levels are high in all the studied premises (laboratories and offices) points out that quarry *F* is located in a radon risk area.

These findings reveal that processing operations of quarried materials are not directly connected to the risks associated to radon exposure. Even if Lazio is one of the Italian districts where geological data show a potential radon exposure risk, indoor radon concentrations are low, with the exception of quarry *F*. Same results have been achieved for the other surveyed districts.

The presence of a high humidity rate connected to the materials processing modalities required equilibrium factor F calculation. Nevertheless results are not presented because radon concentrations are very low and the uncertainty connected to equilibrium factor measurement is too high. Effective dose values calculated from radon exposure are in the range of natural background, with the assumption that the measurement period of six months is representative of the whole year and using an average equilibrium factor value of 0.4.

**Table 1:** *radon-222 indoor average concentration values*

| Quarry | Area District | measurement location | radon concentration ($Bq/m^3$) |
|---|---|---|---|
| | **LAZIO** | | |
| ***A*** | *Vitorchiano (Viterbo)* | lab. 1 position 1 | 34±3 |
| | | lab. 1 position 2 | 21±2 |
| | | office | 40±3 |
| ***B*** | *Vitorchiano (Viterbo)* | lab. 1 position 1 | 29±2 |
| | | lab. 2 position 1 | 16±2 |
| | | lab. 2 position 2 | 15±2 |
| | | office | 193±18 |
| ***C*** | *Vitorchiano (Viterbo)* | lab. 1 | 181±16 |
| | | lab. 2 | 44±4 |
| | | office | 67±6 |
| ***E*** | *Bagnoregio (Viterbo)* | lab. 1 | 226±21 |
| | | office | 72±7 |
| ***F*** | *Bagnoregio (Viterbo)* | lab. 1 position 1 | 200±18 |
| | | lab. 1 position 2 | 245±23 |
| | | lab. 1 position 3 | 388±37 |
| | | office 1 | 140±13 |
| | | office 2 | 420±41 |
| | | office 3 | 501±49 |
| | | show-room pos 1 | 1035±100 |
| | | show-room pos 2 | 967±95 |
| ***G*** | *Civita Castellana (Viterbo)* | office 1 | 81±8 |
| | | office 2 | 86±8 |
| ***H*** | *Guidonia (Roma)* | lab. 1 | 35±3 |
| | | lab. 2 | 28±2 |
| | | lab. 3 | 18±2 |
| | | office | 199±15 |
| ***I*** | *Guidonia (Roma)* | lab. 1 | 27±2 |
| | | office | 122±11 |
| ***J*** | *Guidonia (Roma)* | lab. 1 position 1 | 107±11 |
| | | lab. 1 position 2 | 21±2 |
| | | lab. 1 position 3 | 23±2 |
| ***K*** | *Manziana (Roma)* | lab. 1 position 1 | 74±7 |
| | | lab. 1 position 2 | 45±4 |
| | | lab. 1 position 3 | 48±4 |
| | | office | 52±5 |
| | **TOSCANA** | | |
| ***L*** | *Monte Calocara (Carrara)* | tunnel pos. 1 | 20±2 |
| | | tunnel pos. 2 | 18±2 |
| ***M*** | *Monte Calocara (Carrara)* | tunnel pos. 1 | 30±2 |
| | | tunnel pos. 2 | 36±3 |
| ***N*** | *Monte La Capraia (Massa)* | tunnel pos. 1 | 15±2 |
| | | tunnel pos. 2 | 13±1 |
| ***O*** | *Pitigliano (Grosseto)* | office 1 | 56±8 |
| | | office 2 | 55±8 |
| ***P*** | *Pietrasanta (Lucca)* | lab. 1 position 1 | 15±3 |
| | | lab. 1 position 2 | 15±4 |
| ***Q*** | *Stezzema (Lucca)* | lab. 1 position 1 | 26±4 |
| | | lab. 1 position 2 | 28±6 |

### Gamma Spectrometry measurements.

The values of activity concentration (Bq/kg) measured by gamma spectrometry are shown in table 2a, 2b, 2c and 2d. Quarry materials labelled with * come from caves located in different districts or nations. Spectrometric measurements have revealed high levels of natural radionuclides in the materials of many selected quarries. As expected the specific levels of activity concentration are related to the geological nature of rocks from which the soils originate. In particular spectrometric data confirm that volcanic materials have high naturally occurring radionuclides contents. Spectrometric data for Tuscany marbles are lower than minimum radionuclides activity concentration detectable by the spectrometer (MDA). This result is consistent with the chemical nature of marbles. Anyway these quarries are of particular interest from the exposure risk assessment point of view because of their particular structural layout since they are underground quarries (in tunnel). So even if marbles have no naturally occurring radionuclides contents, exposure risk could derive from exposure to radon.

The results are consistent with medium values reported for building materials used in Italy [8].

**Table 2a:** *natural radionuclides activity concentrations in quarried materials*

| **quarry** | **Lazio district** | **analyzed materials** | **K-40 (Bq/kg)** | **Th-232 (Bq/kg)** | **Ra-226 (Bq/kg)** | **U-238 (Bq/kg)** |
|---|---|---|---|---|---|---|
| ***A*** | *Vitorchiano (Viterbo)* | basalt* | 2268.4±85.9 | 625.8±21.9 | 435.1±15.4 | 508.6±29.8 |
| | | grey peperino | 1304.2±43.1 | 158.1±4.7 | 108.8±3.2 | 168.3±14.2 |
| | | pink peperino* | 1354.8±49.7 | 159.4±5.4 | 111.6±3.7 | 147.4±13.3 |
| | | travertine* | 4.4±1.0 | < MDA | 0.8±0.1 | < MDA |
| ***B*** | *Vitorchiano (Viterbo)* | red peperino | 1386.9±50.9 | 161.8±5.5 | 115.4±4.1 | 156.7±13.5 |
| | | dark grey peperino | 1282.6±47.24 | 147.4±5.1 | 104.2±3.5 | 138.8±13.2 |
| | | light grey peperino | 74.6±17.7 | 53.7±1.9 | 45.3±1.5 | 68.4±8.3 |
| | | sandstone | 437.5±16.3 | 6.2±0.4 | 6.2±0.3 | < MDA |
| ***C*** | *Vitorchiano (Viterbo)* | grey peperino | 1350.1±48.8 | 151.1±5.1 | 103.2±3.5 | 134.6±11.6 |
| | | pink peperino | 1370.9±50.1 | 150.9±5.1 | 109.2±3.8 | 150.3±13.3 |
| ***D*** | *Tarquinia (Viterbo)* | basalt | 2268.4±85.9 | 625.8±21.9 | 435.1±15.4 | 508.6±29.8 |
| ***E*** | *Bagnoregio (Viterbo)* | trachytic lava | 2164.8±77.8 | 246.8±8.2 | 117.0±3.9 | 145.4±14.3 |
| ***F*** | *Bagnoregio (Viterbo)* | trachytic lava* | 2164.8±77.8 | 246.8±8.2 | 117.0±3.9 | 145.4±14.3 |
| ***G*** | *Civita Castellana (Roma)* | tuff | 2161.2±179.3 | 383.5±33.6 | 315.9±27.1 | < MDA |
| ***H*** | *Guidonia (Roma)* | travertine | 5.6±1.4 | < MDA | 0.5±0.1 | 11.4±2.9 |
| ***I*** | *Guidonia (Roma)* | travertine | 5.8±1.4 | 0.9±0.2 | 0.7±0,1 | < MDA |
| ***J*** | *Guidonia (Roma)* | travertine (classic) | 3.7±1.3 | < MDA | 0.4±0.1 | 9.2±2.6 |
| | | travertine (veined) | 7.9±1.4 | 1.2±0.2 | 0.7±0.1 | < MDA |
| ***K*** | *Manziana (Roma)* | tuff | 1264.0±42.4 | 172.9±5.5 | 329.3±12.0 | 422.8±25.7 |

**Table 2b:** *natural radionuclides activity concentrations in quarried materials of Toscana*

| quarry | Toscana district | analyzed materials | K-40 (Bq/kg) | Th-232 (Bq/kg) | Ra-226 (Bq/kg) | U-238 (Bq/kg) |
|---|---|---|---|---|---|---|
| ***L*** | *Monte Calocara (Carrara)* | white marble | < MDA | < MDA | < MDA | < MDA |
| ***M*** | *Monte Calocara (Carrara)* | white marble<br>veined marble | < MDA | < MDA | < MDA | < MDA |
| ***N*** | *Monte La Capraia (Massa)* | white marble<br>arabesque marble | < MDA | < MDA | < MDA | < MDA |
| ***O*** | *Pitigliano (Grosseto)* | pumice<br>lapillus | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| ***P*** | *Pietrasanta (Lucca)* | royal red granite* | 1385.1±35.6 | 30.2±0.9 | 7.8±0.3 | 76.5±35.2 |
| | | grey granite* | 1016.5±26.2 | 43.1±1.2 | 67.3±1.4 | 107.9±22.5 |
| | | pink granite * | 1019.1±26.2 | 87.6±2.3 | 84.5±1.7 | 184.7±24.8 |
| | | sandstone | 496.7±13.7 | 10.7±0.5 | 8.1±0.3 | 32.4±13.9 |
| | | black granite | 375.0±9.8 | 30.7±0.9 | 19.0±0.4 | 49.9±14.8 |
| | | yellow pearl granite* | 48.9±1.8 | 2.6±0.2 | 11.5±0.3 | < MDA |
| | | red travertine | 10.4±2.9 | < MDA | 5.2±0.2 | 14.6±7.2 |
| ***Q*** | *Stezzema (Lucca)* | Cardoso stone | 583.2±15.3 | 50.43±1.4 | 39.1±1.7 | 86.9±36.6 |
| ***R*** | *Viareggio (Lucca)* | green granite* | 1408.8±36.5 | 137.4±3.5 | 22.4±0.7 | < MDA |
| | | napoleon red granite* | 1335.9±34.2 | 199.90±4.9 | 177.1±3.4 | 337.6±19.7 |
| | | salisbury pink granite* | 1063.2±27.7 | 89.2±2.3 | 53.4±1.18 | 131.8±22.1 |
| | | samoa granite* | 1311.4±33.7 | 53.7±1.5 | 27.7±0.7 | < MDA |
| | | cecil yellow granite* | 1302.6±33.7 | 59.0±1.6 | 110.3±2.2 | 217.0±26.5 |
| | | pink granite* | 1381.7±35.9 | 324.0±8.6 | 63.2±1.4 | 104.9±23.2 |
| | | granite conq. dorado* | 945.4±24.6 | 52.7±1.9 | 30.0±0.7 | < MDA |

**Table 2c:** *natural radionuclides activity concentrations in quarried materials of Trentino Alto Adige*

| quarry | Trentino Alto Adige district | materials analyzed | K-40 (Bq/kg) | Th-232 (Bq/kg) | Ra-226 (Bq/kg) | U-238 (Bq/kg) |
|---|---|---|---|---|---|---|
| ***S*** | *Fornace (Trento)* | porphyry | 1543.9±41.3 | 86.8±3.1 | 48.2±1.3 | 79.4±20.9 |
| ***T*** | *Albiano (Trento)* | porphyry | 1421.7±38.2 | 84.9±2.5 | 54.1±1.1 | 73.6±18.3 |

**Table 2d:** *natural radionuclides activity concentrations in quarried materials of Liguria*

| quarry | Liguria district | materials analyzed | K-40 (Bq/kg) | Th-232 (Bq/kg) | Ra-226 (Bq/kg) | U-238 (Bq/kg) |
|---|---|---|---|---|---|---|
| ***U*** | *Orero (Genova)* | slate | 763.2±20.4 | 31.3±0.9 | 20.7±0.5 | 53.7±21.5 |

### Estimation of the enhanced exposure

As shown in tables 3 and 4, the individual monitoring survey took place in six different quarries where spectrometric data pointed out significant natural radionuclides activity concentrations which could have led to an increase in the exposure of workers (enhanced exposure). Employees have been monitored by means of both electronic and TLD dosimeters. The measurement period has been one month. In order to assess indoor and outdoor background levels, two measurement locations have been chosen in each of the selected quarries. As shown, in some cases there are no data of indoor dose rate because of the structural layout of the factories (laboratories are open air spaces). The values of effective dose rate obtained both with individual monitoring by TLD and electronic personal dosimeters are listed respectively in tables 3 and 4. The contribution of cosmic radiation must be subtracted from these data. Cosmic ray contribution dose rate is 0.032 μGy/h and has been assumed to be numerically equal to the effective dose rate [3].

The data show that in most of the case, workers are exposed just to gamma background. Anyway the gamma dose values are below the value fixed by Italian regulation (1 mSv/y).

**Table 3:** *effective dose rate values (TLD dosimeters)*

| Quarry | employees | effective dose (mSv/year) | | |
|---|---|---|---|---|
| | | personal | indoor | outdoor |
| ***A*** | quarrymen<br>cutters (laboratory) | 0.55±0.16<br>0.72±0.21 | 0.68±0.20 | 0.66±0.19 |
| ***B*** | quarrymen<br>laboratory operators | 0.78±0.23<br>0.63±0.18 | 0.78±0.23 | 0.61±0.18 |
| ***D*** | quarrymen | 0.40±0.12 | - | 0.38±0.11 |
| ***F*** | quarrymen<br>laboratory operators | 0.55±0.16<br>0.54±0.16 | 0.51±0.15 | 0.48±0.14 |
| ***S*** | tile makers<br>pickers | 0.44±0.13<br>0.44±0.13 | - | 0.41±0.12 |
| ***T*** | tile makers<br>pickers | 0.44±0.13<br>0.41±0.12 | - | 0.41±0.12 |

**Table 4:** *effective dose rate values( electronic personal dosimeters)*

| Quarry | employees | effective dose (mSv/year) | | |
|---|---|---|---|---|
| | | personal | indoor | outdoor |
| ***A*** | quarrymen<br>cutters (laboratory) | 0.73±0.15<br>0.40±0.08 | 0.50±0.10 | 0.45±0.09 |
| ***B*** | quarrymen<br>laboratory operators | 0.60±0.12<br>0.46±0.09 | 0.48±0.09 | 0.42±0.08 |
| ***D*** | quarrymen | 0.63±0.12 | - | 0.40±0.08 |
| ***F*** | quarrymen<br>laboratory operators | 0.50±0.10<br>0.36±0.07 | 0.35±0.07 | 0.30±0.06 |
| ***S*** | tile makers<br>pickers | 0.25±0.05<br>0.36±0.07 | 0.30±0.06 | 0.28±0.05 |
| ***T*** | tile makers<br>pickers | 0.36±0.07<br>0.35±0.07 | 0.30±0.06 | 0.32±0.06 |

Spectrometry data can be related to the absorbed dose rates in air and to effective dose. In particular annual effective dose can be calculated applying the conversion coefficient from absorbed dose in air to effective dose according to the following equation [3]:

$$D_{eff,out} = D_{outdoor} \times 0.7 \times 2000 \times 10^{-6}$$

where 0.7 is the conversion coefficient from absorbed dose in air to effective dose (Sv/Gy), 2000 are the annual working hours and $10^{-6}$ is a multiplicative factor accounting measurement unit.

Outdoor absorbed dose (expressed in nGy/h) can be calculated using spectrometric data as follow:

$$D_{outdoor} = C_K \times 0.0417 + C_{Ra} \times 0.462 + C_{Th} \times 0.604$$

where $C_K$, $C_{Ra}$ and $C_{Th}$ are, respectively, potassium, radium and thorium activity concentrations (Bq/kg), and the multiplicative coefficients indicate the contribution of each nuclide to absorbed dose (nGy/h per Bq/kg). The dose values are listed in table 5.

As shown, when the value obtained from the activity concentrations of soil samples is added to that of cosmic rays (0.032 µGy/h, [3]), the dose rate becomes similar to that obtained with individual monitoring, with the exception of quarry *D* where empirical calculations show a dose rate of about 1 mSv/y while individual monitoring show that dose rate is lower than 1 mSv/y.

In the case of quarry *A,* basalt contribution is not included in the effective dose calculation because the material is extracted in another quarry and the processing is not continuous during the year.

**Table 5:** *values of the dose rate calculated empirically*

| Quarry | material | background gamma dose (mSv/y) | background gamma dose plus cosmic ray contribution (mSv/y) |
|---|---|---|---|
| ***A*** | grey peperino<br>pink peperino | 0.56 | 0.64 |
| ***B*** | light grey peperino<br>dark grey peperino<br>red peperino | 0.66 | 0.73 |
| ***D*** | basalt | 0.94 | 1.01 |
| ***F*** | trachytic lava | 0.41 | 0.48 |
| ***S*** | porphyry | 0.20 | 0.27 |
| ***T*** | porphyry | 0.19 | 0.26 |

## CONCLUSIONS

The present work reports the outcome of a study performed in about 20 quarries, located in different Italian districts, to estimate the radiation dose received by the employees due to the exposure to radon, radon progeny and gamma emission of natural radionuclides such as $^{40}$K and radionuclides originated from $^{238}$U and $^{232}$Th. The measurements were performed both where materials are extracted and in the processing laboratories. A measurement protocol has been designed and the investigated quarries have been monitored by means of personal and environmental dosimeters. In particular, for indoor radon monitoring, radon passive devices have been used (NRPB/SSI type dosimeter and PADC/CR-39 as detector), while for gamma dose assessing personal electronic and thermoluminescence dosimeters have been used.

The measurement campaign points out that the values of radon gas concentration obtained by passive monitoring are low, as well as the results of instantaneous measurements. Nevertheless, there are some exceptions due to the geological nature of the quarry areas. These findings reveal that the processing operations of quarried materials are not directly connected to the risks associated to radon exposure.

Even if Lazio is one of the Italian districts where geological data show a potential radon exposure risk, in the selected quarries indoor radon concentrations are low.

A lower value of radon gas concentration in laboratory premises than in offices can be attributed to the materials processing modalities that facilitate air circulation.

Spectrometric analysis of volcanic materials shows, as expected, high natural radionuclides activity concentrations. On the other hand, the results obtained for travertine and sandstones highlight their low radiation emission.

Individual monitoring data by both TLD and electronic personal dosimeters show a low dose rate. With the exception of quarry *D*, the effective dose values obtained by individual monitoring are in a good agreement with theoretical data. All data collected within this study seem to point out that quarry working activities do not represent a cause of enhanced exposure for workers.

## Acknowledgement

The authors wish to acknowledge the contribution of M. Pellegri, F. Gilli, G. Angotzi, A. Giomarelli, Mr. Nicolaci, Mr. Vanelli and the owners of the quarries for making available the facilities for this study. Special thanks to professor Paolo Orlando for providing continuous scientific advise.

## REFERENCES

1. Council Directive 96/29/Euratom of 13 May 1996 Laying Down the Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionizing Radiation. Official Journal of EC, Series L, No 159 of 1996.
2. D. Lgs. 26 maggio 2000, n. 241 “Attuazione della direttiva 96/29/EURATOM in materia di protezione sanitaria della popolazione e dei lavoratori contro i rischi derivanti dalle radiazioni ionizzanti”, G.U.R.I. 31 Agosto 2000, n.140/L, Serie Generale.
3. UNSCEAR Report, *Sources and Effects of Ionizing Radiation* (2000)
4. INAIL (Italian Workers’ Compensation Authority) - Technical Directorate for Actuarial and Statistical Research - Data (2001).
5. C. Orlando, P. Orlando, L. Patrizii, L. Tommasino, S. Tonnarini, R. Trevisi, P.Viola *“A passive radon dosimeter suitable for workplaces”* Rad. Prot. Dosimetry Vol. 102 (2) pp.163-168, (2002).
6. P. Orlando, M. Amici, P. Massari, C. Paolelli, R. Trenta, R. Trevisi “*The evaluation of $^{222}$Radon emanation from building materials”*, Healthy Buildings ’95, (Milano, Italy), Vol 2, pp. 677-681 (1995).
7. M. C. Losana, M. Magnoni, F. Righino *“Comparison of different methods for the assessment of the environmental gamma dose”* Rad. Prot. Dosimetry Vol. 97 (4) pp.333-336, (2001).
8. S.Risica, C.Bolzan, C.Nuccetelli, “*Radioactivity in building materials: experimental methods, calculations and an overview of the Italian situation*”, Radon in the Living Environment, 19-23 April 1999, Athens, Greece, pp. 415-428.