NEW IMAGE ANALYSIS SYSTEM FOR NUCLEAR TRACK DETECTOR RADON DOSIMETER, DEVELOPED IN THE CENTRAL LABORATORY OF THE ITALIAN RED CROSS

C. Fontana*, P. Bennati*, A. Zoffranieri*, T. Papetti*, A. Marchetti*, J. Light*, A. Dawodu*, F. Cardellini**, P. De Felice**

*Laboratory of Environmental Radioactivity, Central Laboratory, Italian Red Cross, Rome, Italy
** ENEA, National Institute of Meterology of Ionizing Radiation, Anguillara, Italy

claudia.fontana@cri.it francesco.cardellini@casaccia.enea.it

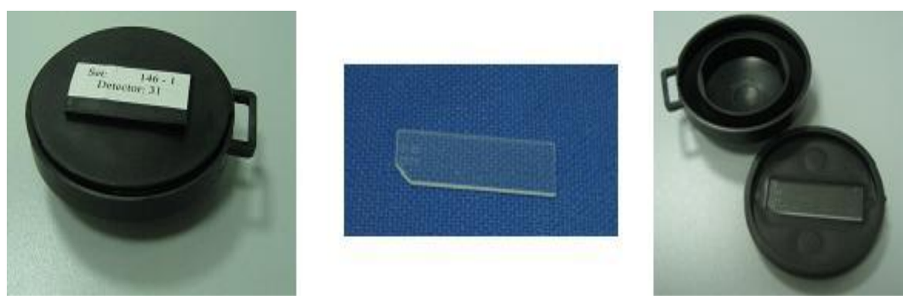
1. INTRODUCTION

In Italy, following the Decree 241/2000 for the protection of workers and the public from the risks of ionizing radiation from natural sources, the practice of monitoring surveys of indoor radon concentration has become more prevalent.
The method most commonly used for radon measurements makes use of detection systems with passive dosimeters in nuclear tracks that are left in the environment to be monitored for several months. The detectors of this type are made of special polymers that are damaged microscopically by alpha particles produced by the decay of ^{222}Rn present in the environment. The damage generated by alpha particles is called "tracks", their density is proportional to radon exposure experienced by dosimeters.
In 2004, the Service of Environmental Radioactivity Measurement of Central Laboratory of the Italian Red Cross (SMRA / LC / CRI) established a Radon Laboratory for monitoring natural ionizing radiation sources (underground workplaces, schools, public buildings and private wells, land, etc.). For the past 8 years, the lab has performed active measurements of radon with ALPHA GUARD PQ 2000 PRO and has applied measurement techniques using passive nuclear track detectors CR-39. During this period, activities were held to monitor the Indoor Radon extended to particular workplaces for the assessment of the risk of worker exposure to Rn 222 (Monitoring sites CRI 2002/2004 - Monitoring in some mushroom farms in Italy 2007/2009).
For the first time in Italy, the SMRA Service has developed a new experimental scanning system for radon dosimetry, using the platform modular software "Leica QWin Plus". This software allows for the analysis and automatic processing of images and related data acquired. We were able to test and evaluate the quality standards of our laboratory by participating in an international comparison of radon data.
The experience this lab has gained in developing techniques, reading the detectors, processing the results, and participating in international comparison has allowed us to validate the procedures for radon detection.

2. OBJECTIVES

The paper presents the results of a series of experiments carried out in conjunction with the INMRI (National Institute of Metrology of Ionizing Radiation) and carried out with the new scanning system "Leica QWin Plus", aimed at improving standards of quality and the accuracy of performance of the Service SMRA.
In particular, eight exposures were made of the detectors CR-39 to the concentration values of radon note; the experiments were carried out in INMRI ENEA radon rooms.
The dosimeters used come from two different batches, chosen randomly, but they are representative of the entire lot. After exposures were made in the Radon Laboratory SMRA / LC / CRI, the dosimeters were developed and read. The data analysis has allowed us to calculate the sensitivity of the system as well as the reliability and reproducibility of the operational procedures: the quality control of the material used, the method for development of the pre-attack chemical, and the reading system for counting the tracks.

3. METHODS



Picture 1: Dosimeter Radon: particular holder and the detector CR-39

1. Quality Control Protocol of the Radon Laboratory SMRA CRI :

1. Identification and control codes for CR-39 producer sent from the house (about 100 detectors for sheet);
2. Random monitoring of the detectors under a microscope for the detection of any imperfections;
3. Sample testing microscope at 5 for sheet detectors to examine the intrinsic background;
4. Registration codes of detectors with the corresponding sheet number and batch production from which they were derived (eg 12-01, 12-02, 12-03 etc.), the results arising from controls relating to the items listed above and analysis of data acquired.

Picture 2: The preparation of dosimeters _ *Radon Laboratory SMRA/LC/CRI*

2. Preparation of CR-39 to exposure:

1. Quality Control is performed following the Protocol described in point 1;
2. The detectors are subjected to a chemical pre-attack. This operation provides for the detection of possible intrinsic fabric damage or dosimeter background not due to radon exposure;
3. Detectors are assembled in their holder and placed in an aluminized sealed envelope, impermeable to radon, both duly sealed with sealer and sent for exposure.

3. Exposure procedure:

1. At INMBRI-ENEA laboratories the dosimeters to be exposed to radon are placed directly in the radon chamber, while the transit are kept in a vessel at low radon concentration throughout the exposure period.
2. Eight exposures were performed: five exposures were made in a radon chamber with volume of 216 L and radon concentration increased over time. The remaining three exposure were made at a constant radon concentration in the chamber with 1027 L volume (Detectors are from 2 different lots: A and B).
3. The radon activity concentration inside the radon chamber is measured and recorded by a radon monitor calibrated in the primary radon standard of INMRI ENEA. All exposures last for more than 100 hours to reduce the uncertainty of the exposure value.
4. After the exposure, the exposed dosimeters together with the transit are placed in an environment of low concentration of radon for about 24 hours in order to allow the escape of radon trapped in the holder, avoiding unwanted additional exposures
5. Subsequently, the CR-39 are put back in aluminized bags sealed and delivered to the Radon laboratory of CRI to perform development, reading and analysis.

Picture 3a: Radon room from 216 L_ENEA INMRI

Picture 3b: Radon room from 1027 L _ENEA INMRI

Picture 4: Analysis of dosimeters after exposure _ *Radon Laboratory SMRA/LC/CRI*

4. Development of the exposed dosimeters and reading of the tracks:

1. After exposure to radon detectors are developed by etching in a solution of KOH 30% at a temperature of 80 ° C for a time of 5.5 hours. With this etching the damage due to alpha particles are enlarged and can be read with a microscope.
2. The traces from the background and defects that where already enlarged by the pre-attack undergo further expansion in order to differentiate them from those due to exposure.
3. The reading of the detectors CR-39 was carried out by means of a semiautomatic system with an optical microscope Leica DMLS connected to a camera Leica DFC 280 for the acquisition of images in digital form. The images in digital form are analyzed using special software developed in the "Laboratory Radon Plus Qwin" SMRA / LC / CRI with the cooperation of Leica Microsystems for counting of tracks.
4. In Laboratory routine 25 fields are read for each detector. Two different objectives are used: 4x (reading area 3.72 mm^2) and 10x (reading area 0.64 mm^2) depending on the density of tracks present on the detector.
5. When tracks density is high, superposition of tracks occurs. In this case images are acquired with higher resolution (10x) and the image analysis system is able to resolve the overlapping traces in two different alpha tracks. The linearity range of the system is then enhanced from the normal value of 2000 $kBq \cdot h \cdot m^{-3}$ to the value of nearly 6000 $kBq \cdot h \cdot m^{-3}$.

4. RESULTS

THE RESULTS OF THE DOSIMETER READINGS WERE REPORTED ON THE FOLLOWING CHART:

N° Exp	Radon Attivity Conc. (Bq m^{-3})	Exposition Value (kBq m^{-3})	BEAGE
1	Growing from 50 to 10300	425	A
2	Growing from 50 to 13100	694	A
			B
3	Growing from 50 to 14500	1018	A
4	Constant 20500	1924	A
5	Constant 20600	1990	B
6	Growing from 50 to 18800	2119	B
7	Constant 21300	2608	A
			B
8	Growing from 50 to 21700	4637	A

Table 1: Values of exposures

RIGHT OF SENSITIVITY

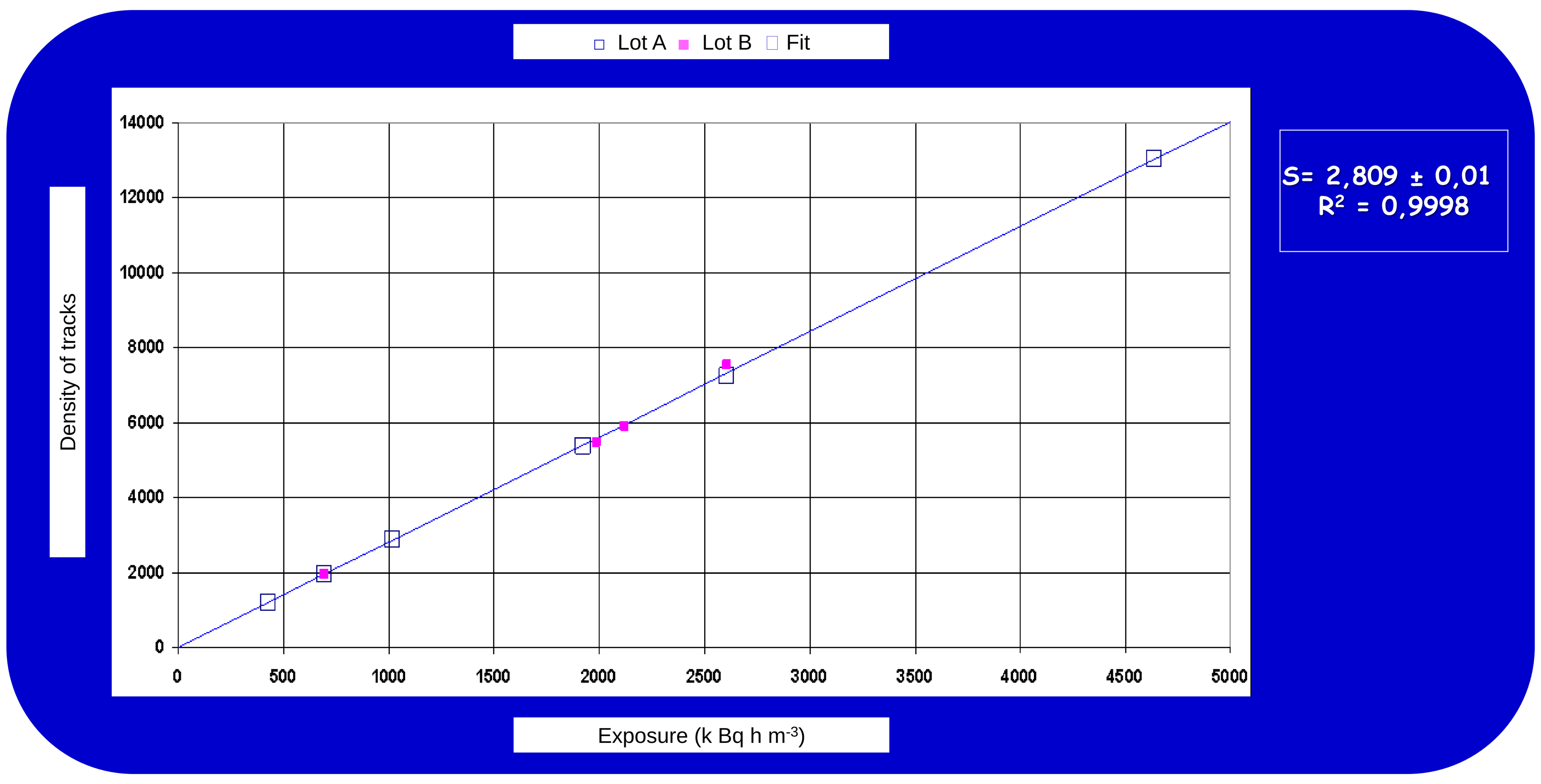


Figura 1: Graph of the density of tracks according to exposure in radon room

Results of Calibration:

1. The detectors sensitivity is linear up to 4600 $kBqm^{-3}$
2. For all exposures the difference between the density of tracks measured and that provided by the fit is within the 1,5%
3. Two batches of detectors are equivalent within experimental uncertainty
4. The low dispersion of the concentration of tracks between simultaneously exposed detectors sufficiently demonstrates that the use of one or two detectors for characterizing an environment
5. A different bath was used for the development of each detector. There were no significant differences and therefore the procedures are standardized.
6. The results of this series of experiments confirmed the overall accuracy of the exposure procedures at INMRI ENEA as well as the equivalence of the two exposure methods (constant versus increasing radon concentration).

5. DISCUSSION AND CONCLUSIONS

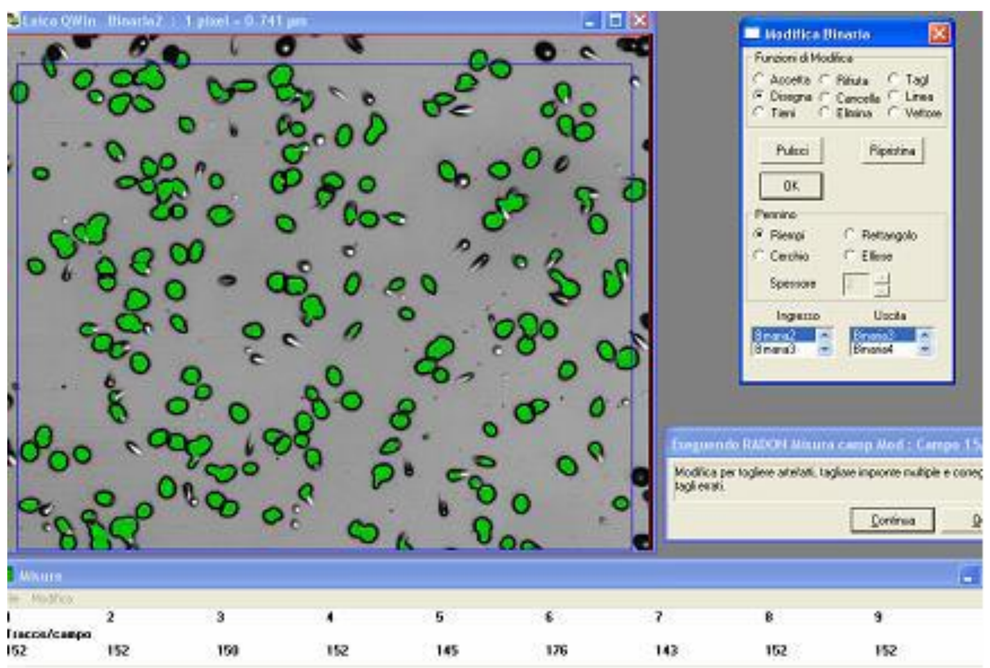
The results of the experimental tests confirm the accuracy and reliability of the internal procedures utilized by the Radon Laboratory. Furthermore, the study confirms the accuracy, precision, and repeatability of the new Leica QWin Plus **SEMI-AUTOMATIC** reading system, developed in 2006 at the Central Laboratory CRI. This system represents an evolution of the previous system and innovatively provides for the interfacing of an optical microscope directly to a personal computer. In terms of the speed of a reading, this creates a higher potential for the use of a more flexible algorithm, making this system a powerful tool for the recognition of tracks. Comparative analysis of the above is clear that the semiautomatic system, although not fully automated, reduces the time of acquisition, analysis and processing of the detectors to calculate the concentration of ^{222}radon (Bq/m^3) with measurement systems dosimetric nuclear tracks in CR-39.

Other positive elements of this measurement method include:
Reproducibility of the system over time
Elimination of random errors arising from psychological and physical conditions of the operator that may affect the results of that measure
Directly and automatically placing all the data collected on each individual CR-39 on a computer without manual errors, accurately calculating the value of the concentration of ^{222}radon (Bq/m^3)
Full traceability of the data associated with the corresponding experimental statistical errors recorded
Feedback of dosimeters used in the calibrations (ENEA-Casaccia) as well as data intercomparisons (HPA 2007 and 2011- UK) allow us to improve the quality of service of the analysis cycle control of dosimetry so that we may further refine our methodolgy

Finally, the results of this series of experiments and those of the subsequent intercomparison confirm the overall accuracy of the exposure procedures at INMRI ENEA as well as the equivalence of the two exposure methods (constant versus increasing radon concentration).
This study also confirms the usefulness of periodic calibrations and the importance of a constant experiential exchange between laboratories that perform environmental radioactivity measurements and the Calibration Service of INMRI ENEA.

Picture 5: The reading system for semi-Cr-39 "Leica QWin Plus Radon Laboratory Italian Red Cross"

Picture 6: Routine semi-automated system for acquisition, processing and analysis for Cr-39 "Leica QWin Plus – Italian Red Cross



Picture 7: Example display of tracks with software for reading Semiautomatic Cr-39 "Leica QWin Plus - CRI"