

The Indoor Radon Concentration within the Tunnels of the Cholula Pyramid Through a Nuclear Tracks Methodology

A. LIMA FLORES^{1*}, R. PALOMINO-MERINO¹, E. ESPINOSA¹,
V. M. CASTAÑO², E. MERLO JUÁREZ³, M. CRUZ SANCHEZ³,
G. ESPINOSA⁴

¹Facultad de Ciencias Físico Matemáticas, Benemérita Universidad Autónoma de Puebla, Avenida San Claudio y 18 Sur, Colonia San Manuel, Ciudad Universitaria, Puebla C.P.72570, México

²Centro de Física Aplicada y Tecnología Avanzada, Universidad Nacional Autónoma de México, Boulevard Juriqulla 3001, Santiago de Querétaro, Querétaro C.P.76230, México

³Instituto Nacional de Antropología e Historia delegación Puebla, zona arqueológica de Cholula, 8 Norte No. 2 Colonia Centro, San Andrés Cholula, Puebla C.P.72760, México

⁴Instituto de Física, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica, Ciudad Universitaria, México D.F. C.P.04510, México

*Email: jaflores8630@gmail.com

Published online: August 08, 2016,

The Author(s) 2016. This article is published with open access at www.chitkara.edu.in/publications

Abstract Global organizations, including the World Health Organization (WHO), the Environmental Protection Agency of the United States (US-EPA) and the European Atomic Energy Community (EURATOM) recognize that radon gas as one of the main contributors to environmental radiation exposure for humans. Accordingly, a study and analysis of the indoors radon concentrate in the Cholula Pyramid contributes to understand the Radon dynamic inside of the Pyramid tunnels and to evaluate the radiological health risk to visitors, archaeologists, anthropologists and persons who spend extended periods inside the Pyramid. In this paper, the radon measurements along the Pyramid tunnels are presented. The Nuclear Track Methodology (NTM) was chosen for the measurements, using a close end-cup device developed at the Dosimetry Application Project (DAP) of the Physics Institute UNAM, following very well established protocols for the chemical etching and reading with the Counting Analysis Digital Imaging System (CADIS). The Cholula Pyramid consists of eight stages of constructions, each built in different periods of time. Cholula

Journal of Nuclear
Physics, Material
Sciences, Radiation and
Applications
Vol-4, No-1,
August 2016
pp. 77–88

Lima Flores, A.
Palomino-Merino, R.
Espinosa, E.
Castaño, V.M.
Merlo Juárez, E.
Cruz Sanchez, M.
Espinosa, G.

Pyramid is recognized as the pyramid with the largest base in the World, with 400 meters per side and 65 meters high. The tunnels of the pyramid were built in 1931 by architect Ignacio Marquina, with the aim of exploring and studying the structure. The results show an important indoor radon concentration in the measured tunnels, several times higher than levels recommended by United States Environmental Protection Agency (US-EPA). The recommendation will be to mitigate the radon concentration levels, in order to avoid unnecessary exposition to the people.

Keywords: Indoor radon, radon concentration, Nuclear Track Methodology, Cholula pyramid

1. INTRODUCTION

The Great Cholula Pyramid is the main building of the Cholula Archaeological Zone, historic site which is located in the valley of Puebla-Tlaxcala between the municipalities of San Pedro Cholula and San Andrés Cholula seven kilometers from the city of Puebla of Zaragoza, capital of one of the 32 states that comprise the Mexican Republic. The valley of Puebla-Tlaxcala is located in the Mexican Central Plateau at 2000 meters above sea level and is bounded on the north by the slopes of Tlaxcala block, to the west by the foothills of the Sierra Nevada where the Popocatepetl volcano is also located, on the east by the volcano La Malinche and south by the state of Puebla. Due to its geographical characteristics, the valley of Puebla-Tlaxcala, which enjoys good fertility by the presence of rivers, was the scene of an important cultural development in Mesoamerican history, forming significant part of the three great cultural horizons established by archaeologists to subdivide Mesoamerican development: Preclassic, Classic and Post Classic. Cholula Archaeological Zone has three areas equipped for public visits; First the Site Museum of the Archaeological Zone, second a travel within one of the tunnels dug inside the Great Pyramid consisting of approximately 280 meters long in the same plane artificially lit, and finally the so-called open area of Cholula Archaeological Zone that consists of the ceremonial courtyards south and west of the Great Pyramid.

1.1 Cholula, the “Holy City”

It was essentially the remarkable fertility that gave him since ancient times the Atoyac River and its tributaries to this vast valley what established the attractive, that around the VI and V centuries before the Christian era pre-

Columbian settlers chose this place to settle there and build their homes and ritual buildings and with the passage of time and the increase in population, thanks to the facilities for agriculture and trade, they managed to build a prominent prehispanic city; having as distinctive feature the construction of successive pyramidal bases, the latter of which is one of the greatest monuments of antiquity. Various explorations at the site revealed temporary depopulations by intermittent eruptions of Popocatepetl volcano, but it is the richness of this basin which led to the permanence of the inhabitants of Cholula from its origins to the present day [17].

That prehispanic city was subject to violent invasions by indigenous groups that arrived from distant regions giving rise to the presence of at least two very different ethnic groups together to establish two somewhat separate urban areas, on the one hand the original founders whose descendants recognize himself as the “colomoxcas” and other invaders coming from successive waves outside, known as cholultecas. It is not entirely clear about the meaning of the word Cholula, for the majority comes from the verb cholloa that lexicographer French Rémi Simeon interpreted as: run, jump, settle, so its meaning would be: “place of escape” [16]. It is able to interpret so if a relationship with the Toltec-Chichimec is performed, who fled from Tollan (Tula) to journey to the city of the “Great Pyramid”, then known as Tlachihualtepec, whose meaning is “where the artificial hill is”. However other people like Cayetano Reyes García, a professor at El Colegio de Michoacan, believes that originally the name of the place where rose the Great Pyramid was Achole, that means: the water that seeps from the damming or, in popular terms, water Runny [15]; in reference to the first settlers, of original still controversial, who settled on the edge of a spring which considered sacred for mysterious reasons and they called later as Aquiahuac, becoming the ideal site to build the first temple, probably with the thought -universally extended- that this water will sanctify the basement. Successive temples were built always covering the immediately preceding, at her as having magical and religious point of reference this spring. Along with this sacred structure was many other building to house the devotions of the faithful to other deities, promoting religious and sacred appeal of that city. It is not known exactly how that city was originally called but it is possible to be known as Tlachihualtepec, Machihualtépec or Tlamachihualtépetl “hill handmade earth”; the truth is that the Holy City was the natural center of all the near and far surrounding villages, attached with her in the religious and tax aspects, recognized as forced place of pilgrimage and whose prosperity invited many people to migrate to these lands. The vital center of the city, until the eighth century after the Christian era, was the colossal pyramid structure or “holy mountain” which housed the huey teocalli or the “Great Temple”

The Indoor Radon
Concentration
within the Tunnels
of the Cholula
Pyramid Through
a Nuclear Tracks
Methodology

Lima Flores, A.
Palomino-Merino, R.
Espinosa, E.
Castaño, V.M.
Merlo Juárez, E.
Cruz Sanchez, M.
Espinosa, G.

dedicated to the deity called Chiconahui Quiáhuatl (9 Rain) destroyed in a violent invasion by indigenous groups (the Toltec-Chichimec) who occupy the west side of the already ancient city. The destroyers built a new basement and teocalli (enclosure God) that much later dedicated to Yacatecuhtli, the patron of traders, with what Cholula was newly founded becoming one of the largest markets and assortments of Mesoamerica [12].

1.2 The Great Cholula Pyramid

The enigma of the original builders of the Great Pyramid has always provoked the most varied explanations from indigenous times, and with the reestablishment of Cholula by the Toltec-Chichimec these revolved around mythological events linked with the “giants”, those beings who occupied the world after the creation of the cosmos, including one called Xelhua who would have been, according to the indigenous document: Telleriano Remensis Codex, the builder of the pyramid [14]. Moreover, the Nahuatl Indians mentioned that before the arrival of the Toltecs the Olmec-Xicalanca dominate the region between what is now Cholula and Tlaxcala [9], researchers now call historical Olmecs to differentiate them from the builders of the cities of southern Veracruz and north of Tabasco.

The Great Pyramid by its splendor and dimensions, 400 meters on each side and 65 meters high, is the largest and most important construction not only of Cholula but also of the entire valley of Puebla-Tlaxcala and is ranked as the pyramid with the basement of greater volume in the world. This stunning piece of engineering is the result of centuries of accumulation of large structures identified in our time by researchers as constructive stages. Such splendor is reflected in the many written opinions that left European explorers; for example, Alexander von Humboldt, German expeditionary and prestigious scientist from the time of the Spanish conquest, that compares the magnificence of the Great Pyramid with the pyramids of Teotihuacan, Egypt and Babylon and is the first person to recommend “dig a gallery through teocalli of Cholula to study inside” [8].

In 1931, one hundred Twenty-seven years later the recommendation of the explorer, the Department of Monuments of SEP, under the direction of Engineer Jose Reygadas Vertiz commissioned the architect Emilio Cuevas, Mr. Ignacio Herrera and Mr. Marino Gomez to begin excavation work at the pyramid same start in September of that year on the north side of the pyramid. The strategy employed and successfully tested inside of the Pyramid of the Sun at Teotihuacan consisted of digging and tunneling, with an angular roof to distribute the load effectively, which allow finding the fronts of overlapping structures, following its contours and then permeating in search of the next [1].

Shortly after, the work was entrusted to the architect Ignacio Marquina Barredo, who decided to open two tunnels go through the entire pyramid, from north to south and from east to west, cutting buildings that comprise overlapping each other make up the Great Pyramid [11]. The exploration unexpectedly turned out to be more complex due to the huge number of walls that found as they advanced the excavations and unable to follow the perimeters of each of them it was favored expose portions of the contours of largest buildings. From these early excavations and the pottery found at the site, analyzed later by Mr. Eduardo Noguera to know their age [13], it came to the conclusion that the Great Pyramid consists of five overlapping or construction stages, whose age of the first four would date from the Preclassic and Classic period mainly. It can also be concluded that the material used in all stages was the adobe. The first constructive step consists in a pyramidal structure and would be oriented towards the west with a deviation from the north of 17 degrees, almost square and having its sides east and west 113 meters and in the north and south 107 meters. It also features panels decorated with yellow, black and red whose images represent human skulls. Marquina considers that this first stage was built around the year 250 after the Christian era. The second stage, also pyramidal, would consist of nine superposed bodies with steps (eleven steps by body) in all the building, symmetrically uninterrupted by drains coming from the top of the building and have a dimension of 190 meters on each side and 34 meters from height. The third stage are platforms on which are located non pyramidal structures as above, with dimensions of 52 meters north to south and 40 meters from east to west. The east side to the west also has a limited staircase by balustrades. The fourth construction stage covers entirely the three previous buildings with adobe. This platform is about 400 meters per side and 25 meters high. The fifth stage corresponds to other annexes to the Great Pyramid sets, it is about buildings belonging to Posclásico such as a tomb known as “Altar de los Craneos” where skeletal remains of a male individual were found and one female accompanied by offerings [10].

In 1966 a process starts to expand the exploration on the south side of the Great Pyramid by the so-called “Cholula Project”, this time directed by the architect Miguel Messmacher. In this new project they were opened stratigraphic wells that allowed to find four large basements near the main building, among them it highlights a building that presents decorated shaped T. This project was suspended to make way for traditional archeology that completed these works to excavate other sets in the south side of the Great Pyramid as the buildings known as “Patio de los Altares” and “Mural de los Bebedores”. The project finally ended in 1971 with over 10 kilometers of tunnels that crossed deviously the inside of the pyramid [10].

Lima Flores, A.
Palomino-Merino, R.
Espinosa, E.
Castaño, V.M.
Merlo Juárez, E.
Cruz Sanchez, M.
Espinosa, G.

The amount of data obtained with the excavation of the tunnels resulted overwhelming for the researchers of those decades so they decided to make models based more on general sketches than in the planes of each of the tunnels. But new technologies have made it possible to process all that data and by using technology called Total Station and computer assisted software (CAD) have been able to develop accurate plans so far 30% of the tunnels and modeling virtually. These new data suggest the existence of three other constructive stages. The first is around the first constructive stage, a segment that sticks out in one of the deepest tunnels not previously reported reflects a substructure which was called later as “Edificio de la Olla”. Still you cannot specify its shape and dimensions but it is known that it is built of adobe and carbon-14 dating shows that was built in the first century, and measures more than 34 meters east-west and less than 6 meters high. The second is another substructure built around 100 A.D., with a base of 107.41 meters east-west by 113 meters north-south and a height of 17 meters later known as “Edificio de los Chapulines”. This substructure if was reported by Marquina but new records modified a series of data, mainly design than originally reported. Finally, the “Edificio de los Tableros Lisos” a substructure not previously reported made of adobe in the second half of the second century, would reach 145 meters north-south by 178 meters east-west and between 18 and 19 meters high. Other materials that make up the Great Pyramid also adobe are, limestone for the flagstone and lime and sand for the finishing [18].

An accepted interpretation by most researchers to understand the reason which led to a culture to build a structure over another not only in the Great Pyramid of Cholula but in many of the Mesoamerica pyramids, was the manifestation of power of their leaders each once a significant political or ideological change occurred; thereby obtaining two advantages: get a monument larger and save on materials. It also they appropriate of the sacredness of the old building. This manifestation of power was also used by the Spanish, because in the top of the Great Pyramid was erected in the year of 1594 a sanctuary known as “Nuestra Señora de los Remedios”, also as symbol of the Spanish evangelization against the Indian world. When the Spaniards arrived to Cholula the Great Pyramid looked like a natural hill with signs of having been abandoned for centuries before, its coating showed dismantled and vegetation flourish on it, but the natives knew well that this was not an ordinary elevation of the land but an archaic and revered human work [18]. About the reason that the people who settled around the Great Pyramid of Cholula decided to leave the place continues to be debated to this day.



The Indoor Radon Concentration within the Tunnels of the Cholula Pyramid Through a Nuclear Tracks Methodology

Figure 1: Photographs taken by us. (a) Picture of the Great Pyramid of Cholula completely covered by vegetation. At the summit it's possible to observe the sanctuary of Nuestra Señora de los Remedios. (b) Scale model located at the Site Museum in Cholula Archaeological Zone showing the southeast side of the Great Pyramid.

2. METHODOLOGY AND MATERIALS

The passive method of integration by Nuclear Track Methodology (NTM) [6] was used in the evaluation of the radon levels inside of the Cholula Pyramid tunnels. The detector material was CR-39 (allyl diglycol carbonate) chosen because of its high sensitivity. This CR-39 material is $750\ \mu\text{m}$ thick, cut in $1.8 \times 0.9\ \text{cm}^2$, and labeled with a laser beam. Each polycarbonate chip comes supplied with an attached $60\ \mu\text{m}$ protective foil to reduce background exposure and damage due to handling. The device chosen to measure radon was the cup system [4], and it consists of a cup with a 330 ml volume, and a drying material to keep the relative humidity constant. In total 20 cups were placed, each hung to 20 centimeters from the ceiling. Of all the tunnels are dug into the Cholula Pyramid we choose those who are not directly connected to the main tunnels or those who are less than 25 meters long, this because such tunnels have airflow and since radon is preferably concentrated in places where there are no air currents was more probably to obtain greater concentration in these areas, besides that most of these tunnels are used by professionals to carry out research of an archaeological nature. We place the detectors in cavities and small branches that were standing inside the tunnels. It was not possible to place detectors in all tunnels that has these characteristics due to various reasons, for example, some tunnels have landslides or mudslides so it is not possible to access all areas safely, also we do not use any tunnel that had access to the general public or where special guided tours are conducted to prevent people hit or extracted detectors. Figure 2 shows a map with the lifting of the tunnels of the pyramid, also shows an

Lima Flores, A.
Palomino-Merino, R.
Espinosa, E.
Castaño, V.M.
Merlo Juárez, E.
Cruz Sanchez, M.
Espinosa, G.

approach to the area where the detectors were placed, indicating the location of each detector with a number. The CR-39 Detectors, were exposed during 3 months inside the tunnels in the winter period, choosing this period to avoid the rainy season. Finally, other detectors were attached to the measurement

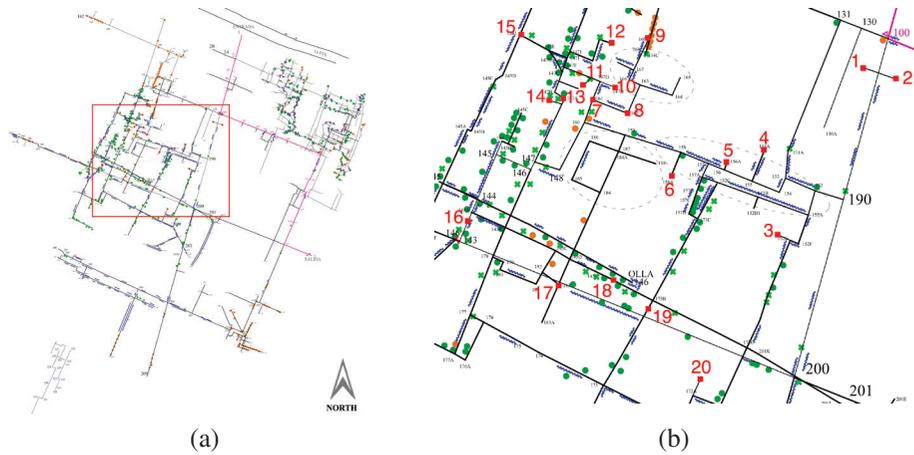


Figure 2: (a) Map of lifting of the tunnels of the Cholula Pyramid (scale 1: 750) [2]. With a box indicates the area where they were placed detectors. (b) Enlarged section of the map. A small square indicates the location of each detector placed, and a number accompanies each square to identify.



Figure 3: Photographs taken by us. (a) Picture of one of the tunnels of the Great Pyramid. (b) A device-cup placed in a cavity in one of the tunnels.

process to be used as reference samples and calibration. After their exposure, the detectors were removed and chemically etched simultaneously, for 18 h in a 6.25M KOH solution to $60^{\circ}\text{C} \pm 2^{\circ}\text{C}$. After the chemical treatment, the etched CR-39 track detectors have been washed in distilled water and dried, following an established protocol [3]. The readings of each detector were done afterwards with an automatic system [7].

3. RESULTS AND DISCUSSION

The tracks count results show a significant concentration of radon in the 20 detectors placed within the selected tunnels in the pyramid. This concentration

Table 1: Amount of radon found for each detector in Becquerels per cubic meter.

Detector Code	Average Radon Level (Bq/m^3)
01	816 ± 164
02	806 ± 92
03	925 ± 78
04	1134 ± 52
05	1048 ± 36
06	1098 ± 102
07	974 ± 83
08	1197 ± 76
09	1196 ± 46
10	961 ± 66
11	1157 ± 35
12	1053 ± 80
13	966 ± 122
14	738 ± 71
15	852 ± 52
16	717 ± 48
17	956 ± 83
18	1015 ± 114
19	855 ± 78
20	1092 ± 82

Lima Flores, A.
Palomino-Merino, R.
Espinosa, E.
Castaño, V.M.
Merlo Juárez, E.
Cruz Sanchez, M.
Espinosa, G.

of radon is mainly due to the contribution of the ^{222}Rn that emerges from underground [5]. Table 1, shows the amount of radon found for each detector number indicated on the map of Figure 2.

In Table 1 it can be seen that the detectors 8 and 9 are those with the highest concentrations of radon. In general, no identified areas showing increased activity of radon over others, neither a particular dynamics of radon behavior is observed within the tunnels, but rather a widespread concentration with some tunnels with more activity with respect to others. Although not placed detectors in all tunnels which do not have proper air circulation but because the 20 detectors placed show that significant concentration of radon, we observe the high possibility that all tunnels, forks and cavities that not have this proper ventilation can present these important concentrations. This can be understood if we observe the first conclusions proposed by Marquina and his team after finishing the first excavation; in these first conclusions Marquina noted that the fourth constructive stage consisted of a structure that covered with adobe in its entirety all previous construction stages, so practically this structure remains locked all previous buildings to this, without allowing the possibility of output air and probably of most radon coming from the subsoil, so that radon can only move through tunnels with air circulation, ie the main tunnels (to lead these with exit to the outside of the enclosure) and those having a length greater than 25 meters (that are commonly connected to the mains), and concentrated in places that do not have this air circulation. Figure 4, shows two micrographs, one belong to the detector that presents the highest average radon concentration (detector 8); and the second the lower concentration (detector 16).

Based on these results and comparing them with doses of radon recommended by the US-EPA as a limit value which may be subject a person in a closed workspace (148 Bq/m^3) [19] we recommend that archaeologists,

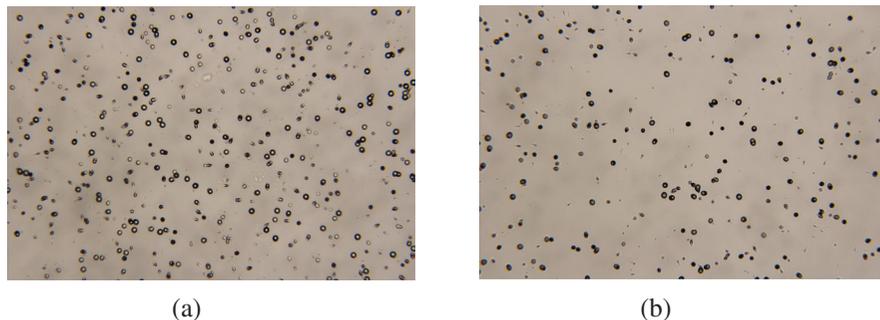


Figure 4: (a) One of the micrographs of detector 8, 10x magnification. (b) One of the micrographs of detector 16, 10x magnification.

anthropologists, architects and people in general not they must spend many hours a week inside the tunnels and cavities that lack adequate ventilation so that these are not subject to unnecessary doses of radon. If a person requires being inside the tunnels for many hours, we recommend placing fans, positioning them so as to allow circulate air in from its position toward the tunnels that having a length greater than 25 meters, that have proper ventilation. If it's not possible to place fans is recommended to use the device manufactured in the IFUNAM that allows mitigate radon levels to make them safe.

The Indoor Radon
Concentration
within the Tunnels
of the Cholula
Pyramid Through
a Nuclear Tracks
Methodology

4. CONCLUSION

The Great Pyramid of Cholula is one of the most important pre-Hispanic buildings in Mesoamerica. It is constituted by at least seven constructive stages, whose original architects possibly were the Olmec-Xicalanca, and of which the first was erected in about the first century of the Christian era. The last constructive stage confined the previous, avoiding the air outlet and the greater amount of radon gas coming from the subsoil. The tunnels dug to study the different constructive stages in 1931 by the architect Ignacio Marquina are places where they can concentrate radon; specifically, in those tunnels, cavities and bifurcations that do not have proper air circulation, so that all people who spend many hours in them will be subjected to doses above those recommended by the US-EPA values. Therefore, it is recommended to mitigate radon levels using fans or special equipment such as invented in the IFUNAM.

ACKNOWLEDGEMENTS

This work was partially supported by PAPIIT-DGAPA-UNAM Project IN103316. The authors wish thank to Jose Ignacio Golzarri, Allan Chavarría and Pablo Marco Trejo García for their technical help. Also to Instituto Nacional de Antropología e Historia-Puebla for allowing access to the tunnels of the Cholula Pyramid and for all the support on guided tours and advice on the historical background.

REFERENCES

- [1] Childs, E. Teotihuacan ceramics, chronology and cultural trends. Distrito Federal: Insti-tuto Nacional de Antropología e Historia, (2001).
- [2] Cruz, M. Levantamiento topográfico de los túneles de la Gran Pirámide de Cholula. Proyecto de Integración Arqueológico, Histórico y Urbano de Cholula, Puebla. Puebla: Instituto Nacional de Antropología e Historia, (2002).

-
- Lima Flores, A. [3] Espinosa, G. *Trazas Nucleares en Sólidos*. Distrito Federal: Universidad Nacional Autónoma de México, (1994).
- Palomino-Merino, R. Espinosa, E. [4] Espinosa, G. & Gammage, R.B. Measurements methodology for indoor radon using passive track detectors. *Appl. Radiat. Isot.*, **4**, 719-723, (1993).
- Castaño, V.M. [5] Espinosa, G., Manzanilla, L., & Gammage, R.B. Radon Concentration in the Pyramid of the Sun at Teotihuacan. *Radiation Measurements*. **28**, 667-670, (1997). [http://dx.doi.org/10.1016/S1350-4487\(97\)00161-3](http://dx.doi.org/10.1016/S1350-4487(97)00161-3)
- Merlo Juárez, E. [6] Fiescher, R.L., Price, P.B. & Walker, R.M. *Nuclear tracks in solids, principles and applications*. Berkeley: University of California Press (1975).
- Cruz Sanchez, M. [7] Gammage, R.B. & Espinosa, G. Digital Imaging System for Track Measurements. *Radiation Measurements*. **28**, 835, (1997). [http://dx.doi.org/10.1016/S1350-4487\(97\)00193-5](http://dx.doi.org/10.1016/S1350-4487(97)00193-5)
- Espinosa, G. [8] Humboldt, A. *Vistas de las cordilleras y monumentos de los pueblos indígenas de América*. Distrito Federal: Siglo XXI Editores, (1995).
- [9] Jiménez, W. *El Enigma de los Olmecas*. Distrito Federal: Cuadernos Americanos, (1942).
- [10] Matos, E. *Excavaciones en la Gran Pirámide de Cholula (1931-1970)*. Resource Document. *Arqueología Mexicana*. <http://www.arqueomex.com/S2N3nProyecto115.html>. Accessed 4 April 2016, (2012).
- [11] Marquina, I. *Exploraciones en la pirámide de Cholula, Pue.* Distrito Federal: Secretaría de Educación Pública, (1939).
- [12] Merlo, E. *Cholula, la Roma de Mesoamérica*. Resource Document. *Arqueología Mexicana*. <http://www.arqueomex.com/S2N3nCholula115.html>. Accessed 4 April 2016, (2012).
- [13] Noguera, E. *La cerámica arqueológica de Cholula*. Distrito Federal: Editorial Guaranda, (1954).
- [14] Quinones, E. *Codex Telleriano-Remensis: Ritual, Divination, and History in a Pictorial Aztec Manuscript*. Texas: University of Texas Press, (1995).
- [15] Reyes, C. *El altepetl, origen y desarrollo. Construcción de la identidad regional náhuatl*. Michoacán: El Colegio de Michoacán, (2000).
- [16] Simeon, R. *Diccionario de la lengua náhuatl o mexicana*. México: Siglo XXI Editores, (1977).
- [17] Solis, F. R., Uru-uela, M. G., Plunket, P., & Cruz, M. *La Gran Pirámide de Cholula*. Distrito Federal: Grupo Azabache, (2007).
- [18] Uru-uela, M. G., de Guevara, L. & Robles, M. A. *Las subestructuras de la Gran Pirámide de Cholula. Viejos túneles, nueva tecnología, nuevos datos*. Resource Document. *Arqueología Mexicana*, (2012). <http://www.arqueomex.com/S2N3nTuneles115.html>. Accessed 4 April 2016.
- [19] US-EPA. *Environmental Protection Agency Report No. EPA 400-R-92-011*, (1992).
-