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Track distributions on LR-115 detector for radon measurements using diffusion chambers*

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Abstract

Analytic calculations and Monte Carlo simulations of track distributions induced by radon and its alpha emitter daughters, for different chamber geometries and critical incidence angles, were carried out. It was assumed uniform distribution of ^{222}Rn and its daughters in chamber volume and inner wall, respectively. By both methods similar results were obtained. It was determined that, in dependence of chamber diameter, uniform and non-uniform track distributions will take place in detector. Two types of non-uniform distributions can be presented: higher track concentration toward the central area of the detector or the opposite, with higher concentration near the borders. Alpha particle emissions occurring in effective volume or effective surface lead to non-uniform track distributions with errors in track density calculation higher than 30%. Optimum diameters for higher density and more uniform distribution of tracks were determined. The influence of non-uniform distribution of radon daughters in chamber wall on track density and its distribution is discussed.

Key words: Diffusion chamber; LR-115 detector; radon daughters; track distribution.

Distribuciones de trazas en el detector LR-115 para las mediciones de Radón usando cámaras de difunsión

Resumen

Se realizaron cálculos analíticos y simulaciones por Monte Carlo de las distribuciones de trazas inducidas por el Radón y sus hijas alfa emisoras, para varios diámetros de la cámara de difusión y diferentes ángulos críticos de incidencia de las partículas alfa. Se asumió distribución uniforme del ^{222}Rn y sus hijas en el volumen y pared interior de la cámara, respectivamente. Por ambos métodos se obtuvieron resultados similares y se demostró que en dependencia del diámetro de la cámara se pueden inducir distribuciones uniformes y no uniformes de trazas en el detector. Se pueden presentar dos tipos de distribuciones no uniformes: mayor concentración de trazas hacia la parte central del detector, comparada con la de sus bordes, y viceversa. Las emisiones de partículas alfa desde los volúmenes y superfi-

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cies efectivas pueden conducir a distribuciones no uniformes de trazas provocando errores en el cálculo de la densidad de trazas que pueden superar el 30%. En dependencia del valor del ángulo crítico asumido se determinaron los diámetros óptimos que condicionan la mayor densidad de trazas con distribución más uniforme. Se discute la influencia de distribución no uniforme de las hijas del Radón en la pared de la cámara sobre la densidad de trazas y su distribución en el detector.

Palabras clave*:* Cámara de difusión; detector LR-115; distribución de trazas; hijas del Radón*.*

Introduction

In the past has been recognized that non-uniformity of track distribution on a CR-39 detector is attributed to the unequal “plate-out” of radon daughters on its surface. In this passive detector latent tracks can be induced by high-energy alpha particles impinging on detector. Experimental data have shown higher concentration of deposited atoms near surface borders of CR-39 detectors, accounting non uniform track distribution (1-3). For LR-115 detector this effect is negligible since surface deposition of radon daughters don’t produce tracks to be visualized under standard etching conditions (100 minutes of chemical etching at 60°C using 2.5 M NaOH). However, experimental results have shown that depending on measurement system geometry, non-uniform track distributions can be induced (4, 5). This effect is very important since it can lead to erroneous results in track density calculations and consequently in radon concentrations. Nevertheless, so far we have not found theoretical explanation for this phenomenon. In LR-115 detector the cause of non-uniform track distribution may be related with the geometric disposition of effective volumes and surfaces, which depend on dimensions of diffusion chamber, regarding the form, dimensions and location of detector. With the objective of finding a possible explanation of this effect, track distributions on a LR-115 detector (placed inside a diffusion camera) induced by alpha emissions of radon and its daughters (^{218}Po and ^{214}Po) were simulated. Effective volumes and surfaces, as well as the influence of chamber diameters and critical angles on track distribution were considered.

Simulation and results

Assuming radon daughters with the same deposition probability and uniform distributed in chamber inner wall, ^{218}Po and ^{214}Po effective surfaces can be determined from restrictions of distances, between alpha particle emission and detector, energy and critical angle of incident alpha particles (6).

In order to analyze how geometric disposition of effective surfaces regarding the detector location influence on detector track distribution, an analytic simulation procedure of track distributions for different chamber diameters was carried out. Calculations were simplified making the analysis in two dimensions through a program that executed the following operations: for a given diameter, the symmetrical effective segments calculated to both chamber sides were subdivided in a large number of cells (10^3) and for alpha particles coming from each cell to the detector surface, etched track induction probabilities were analyzed. The times a track is induced in detector, and its position, are accumulated in variable indexes. Detector dimensions, its height over the open end, and chamber diameter are the inputs of the program, while the output are the effective surfaces in chamber inner walls, their geometric relationship with detector, the contributions of symmetrical effective segments to track distributions for each radon daughter and the resulting de-

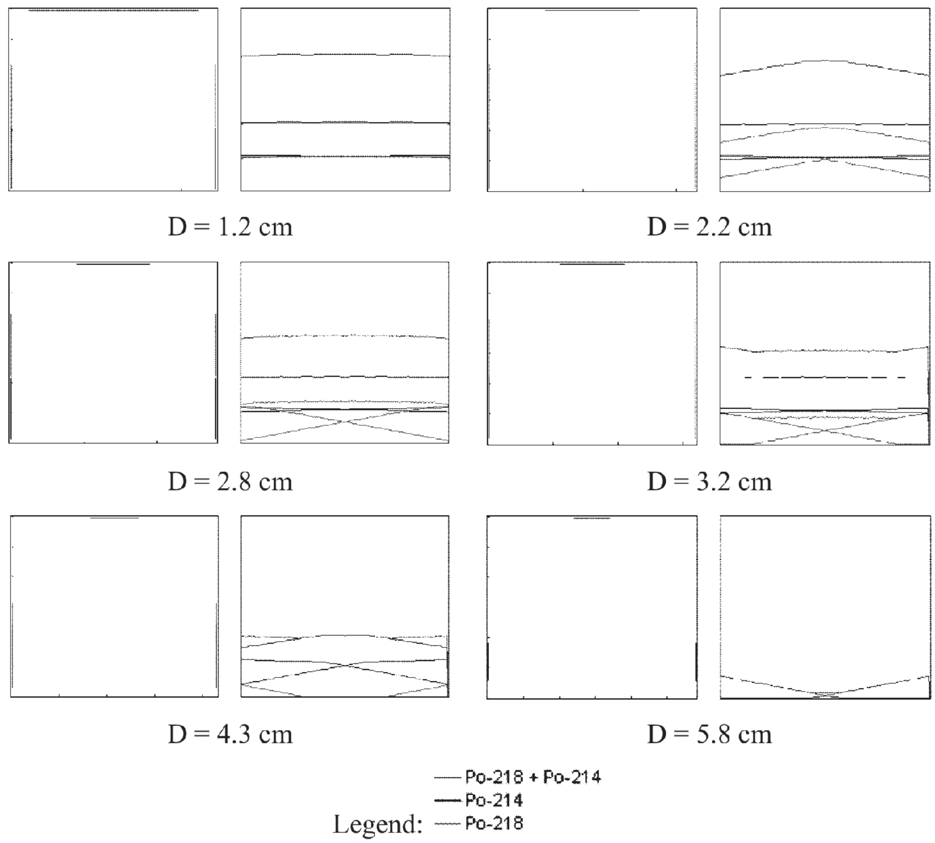


Figure 1. Effective surfaces in chamber inner walls (coloured segments at both sides of rectangles), and their contributions to track distributions for each radon daughter, as well as resulting distribution for different chamber diameters. A critical angle of 30° and circular detector of 1-cm diameter was assumed.

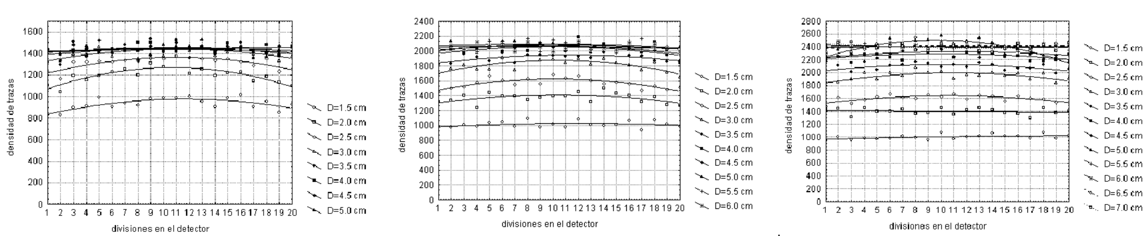
tector track distribution. In Figure 1 examples of such calculations are shown.

These results evidence that both, track quantity and form in which tracks are distributed in detector, strongly depend on dimensions and positions of effective surfaces, which depend at the same time on chamber diameter. Increasing the diameters, a decrease on total number of tracks and less uniform track distribution were observed, conditioning higher track density to the central area of detector. This effect was observed until a diameter of 2.8 cm, where total track distribution (sum of ^{218}Po and ^{214}Po track distributions) was approximately uniform. Larger diameters condition inverse effect, i.e., higher track density to detector borders compared with that in its central part. For diameters 5.3 cm or larger, alpha particles emitted by ^{218}Po are not detected, and for diameter around 7.0 cm ^{214}Po alpha particles are neither detected. Qualitatively similar results, although for other chamber diameters, were obtained assuming critical angle $\theta_c = 45°$ or energy-dependent according to experimental results of (7).

In order to verify in which extent these analytic results approach the reality, another simulation using the Monte Carlo method was carried out and the analysis was extended to the contribution of ^{222}Rn effective volume to track density. The methodology used to determine the ^{222}Rn effective volume and effective surfaces of ^{218}Po and ^{214}Po soon will be published [8]. In a program the set of cells contained in effective volume was obtained, then polar angles formed by lines that join the central point of each cell with detector ends ($\theta_{\min}$ and $\theta_{\max}$) were calculated. After that an angle between 0 and 2 was randomly generated; if generated angle(θ_g) satisfies the condition $\theta_{\min} < \theta_g < \theta_{\max}$, then the distance to detector, incidence alpha particle energy and incidence angle are calculated. If the same requirements as for effective volume calculation are satisfied, then the track counter is increased by one and program registers the positions where alpha particle impacts the imaginary LR-115 detector surface. This process is carried out for all the cells included in the effective volume and cycle repeats until detector track density is 10^3 cm^{-2}. To study how tracks are distributed on detector surface, it was divided in 20 concentric rings of the same thickness. In Figure 2 the obtained results are shown, assuming increasing diameter with a step of 0.05 cm. The diffusion chamber height was 6.0 cm and assumed incidence critical angles (θ_c) of alpha particles were 30°, 45° and energy-dependent according to experimental results given in Ref. (7).

The results presented in Figure 2 demonstrate that maximum values of track density depend on assumed critical angle, being higher for larger magnitudes of effective volumes (V_e). It was demonstrated (6) that V_e (θ_c = energy − dependent) $> V_e(\theta_c = 45°) > V_e$ ($\theta_c = 30°$). In all cases track density increases as chamber diameter grows, and practically for diameters of approximately 3.5, 4.0 and 5.0 cm their maximum values are obtained when assuming critical angles of 30°, 45° and energy-dependent, respectively, i.e., larger diameters do not condition increment in track density (Figure 3). The choice of chamber diameter that generates the most uniform track distribution depends on assumed critical angle.

In general, track density is determined by an optical microscope, counting tracks over several fields of view randomly chosen (either manually or by any automated system). To evaluate the track distribution uniformity on detector surface we took as criteria, the parameter that defines the dispersion of track density values around the mean one, i.e., their standard deviation. Only by geometric disposition of effective volumes regarding detector location, errors overcoming 10% can be achieved as can be seen in Figure 4. Although there are not very marked differences in standard errors, if precise measurements are required this effect should be kept in mind when designing a diffusion chamber. From results shown in Figure 4, if we only take into account the ^{222}Rn contribution to track density, the most uniform distributions will be expected in



$_c$ = 30° $_c$ = 45° $_c$ = energy-dependent

Figure 2. Track distributions in a circular LR-115 detector (1-cm diameter), for different diffusion chamber diameters, induced by alpha particles coming from ^{222}Rn effective volumes.

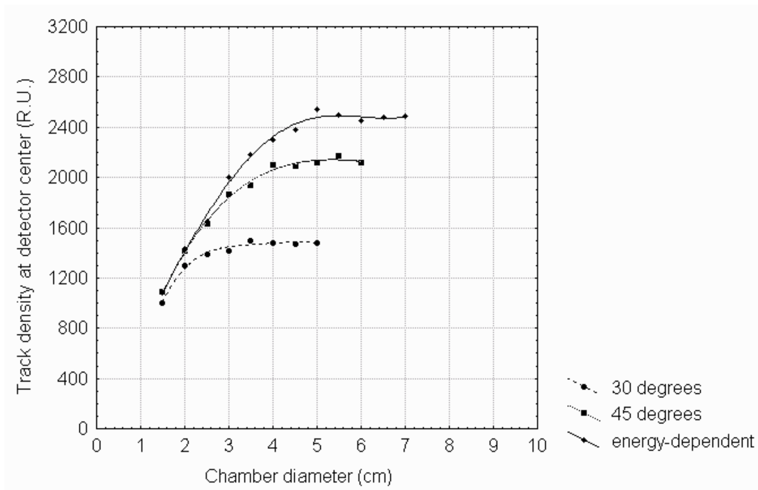


Figure 3. Track densities on detector central region, induced by ^{222}Rn in volume, as function of chamber diameter for different assumed critical angle.

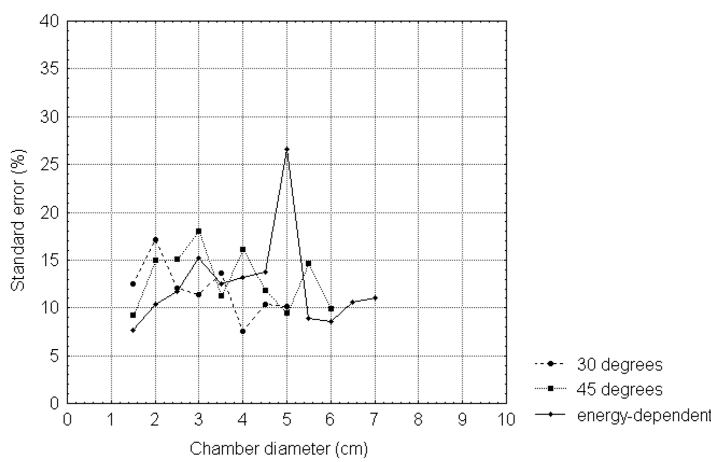


Figure 4. Standard errors of mean track densities (confidence interval = 95%), induced by ^{222}Rn effective volumes, in dependence of chamber diameters and assumed critical angles.

chambers with diameters of approximately 4.0, 5.0 or 6.0 cm assuming critical angles of 30°, 45° or energy-dependent, respectively.

The ^{222}Rn daughters deposited in chamber wall also contribute to the total track density according to their effective surfaces. To obtain their contributions, the developed program was slightly modified, since the analysis was only carried out in lateral chamber wall. In Figure 5 the resulting contributions of alpha emitter daughters (^{218}Po + ^{214}Po) to track density are shown, assuming for calculation the same variables that were used to determine the ^{222}Rn contribution from effective volumes. These results show that maximum value of track density doesn't depend on assumed critical angle if chamber diameter is very small (1.5 cm), however, for larger diameters marked difference in the contribution to track density is evidenced, being higher for larger effective

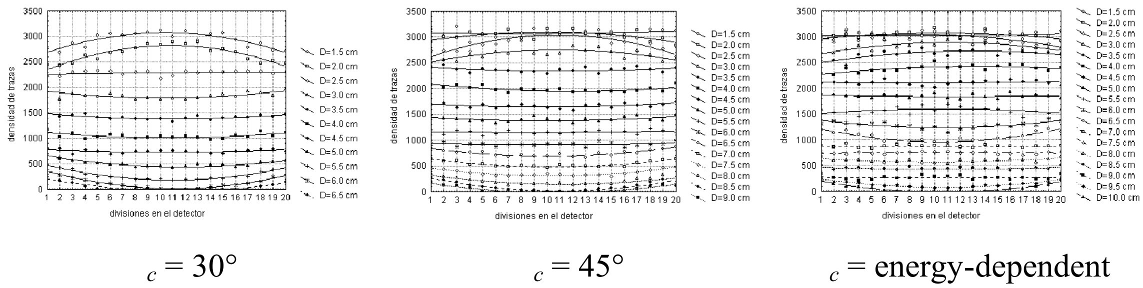


Figure 5. Track distributions in an LR-115 detector, for different chamber diameters, induced by alpha particles coming from ^{218}Po and ^{214}Po effective surfaces.

surfaces (S_e). It was demonstrated (6) that S_e ($\theta_c = f(E)$) > S_e ($\theta_c = 45°$) > ($\theta_c = 30°$). Independently of assumed critical angle, the increase of chamber diameter results in track density diminution (Figure 6), however, for diameters between 1.5 and 2.0 cm approximately similar contributions to track density are obtained when assuming critical angles of 45° and energy-dependent.

In general, as chamber diameter increase the following track distribution are induced (in that same order): higher concentration to the central area, approximately uniform distribution, higher concentration to the borders, approximately uniform distribution, and higher concentration to the borders. The diameters where these distributions took place depended on the assumed critical angle. For 30° the best uniformity was achieved with diameter of approximately 4.5 cm, for $\theta_c = 45°$ with diameters about 5.5 cm, while for $\theta_c = f(E)$ the diameters around 7.5 cm. Only by geometric disposition of effective surfaces regarding detector location, errors in mean track density calculation can overcome 30% as can be seen in Figure 7.

If we assume that detector track density is induced only by the contributions of ^{218}Po and ^{214}Po deposited in chamber wall and ^{222}Rn in volume, then the choice of optimum diameter should be a commitment solution that implies both, uniformity in track distribution and sufficiently high track density. For errors around 10%, due to non uniformity of track distribution, and track density as high as possible, the commitment solution is D= 3.5 cm ($\theta_c = 30°$), D= 4.5 cm ($\theta_c = 45°$) and D= 5.5 cm ($\theta_c = f(E)$). Nevertheless, the election of a 4.5 cm chamber diameter will lead to errors in track distribution, smaller than 15% independently of the assumed critical angle.

Limitations

We should not forget that contribution of deposited radon daughters to track density has been presented as a sum effect of their individual contributions. However, distribution of deposited radon daughters is not uniform and depends on chamber diameter (9). This fact would affect the quantity of induced tracks as well as their distribution in detector surface. As an illustration, we will analyze the case when the chamber diameter is 4.0 cm and assumed as valid a 30° critical angle (Figure 8A).

For a diffusion chamber of 4.0-cm diameter, the interval of heights in the inner wall, where radon daughters are uniformly distributed, is approximately from 1.8 to 4.2 cm (9), taking as zero the edge of the chamber open end (Figure 8B). However, in another work (7) was demonstrated that interval of heights limiting the ^{218}Po and ^{214}Po effective areas were 2.2 - 4.3 cm and 0.1 - 2.2 cm, respectively. This means ^{218}Po uniform distribution in its effective surface, while ^{214}Po atoms pres-

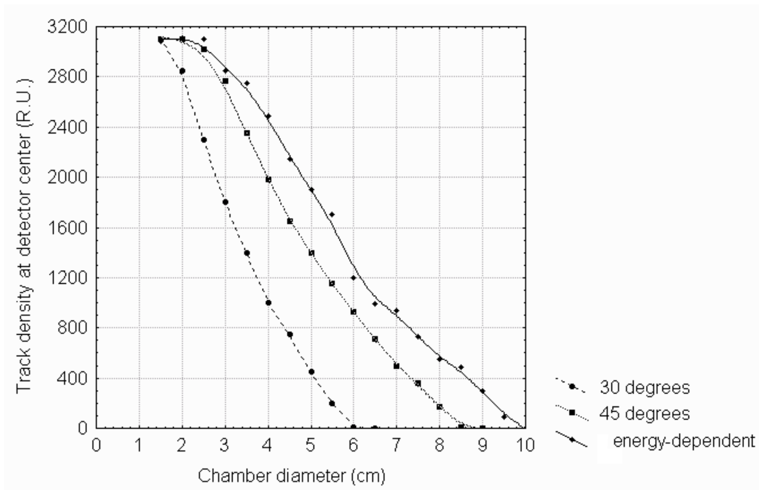


Figure 6. Track densities in central region of detector, induced by ^{218}Po and ^{214}Po deposited in chamber wall, as function of chamber diameter for different assumed critical angles.

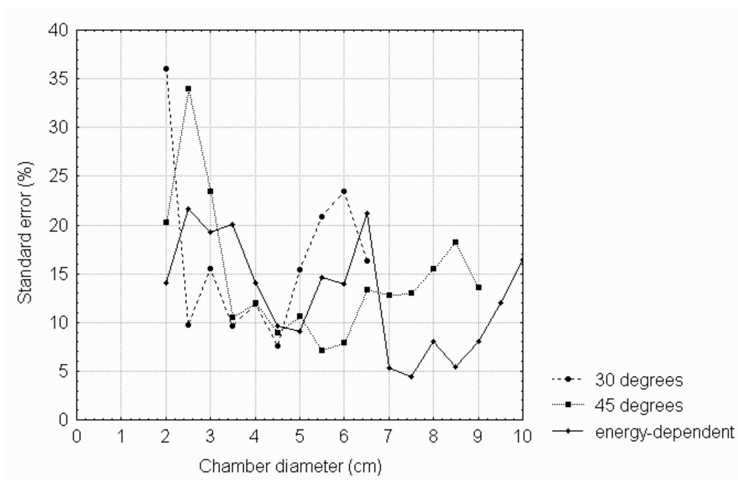
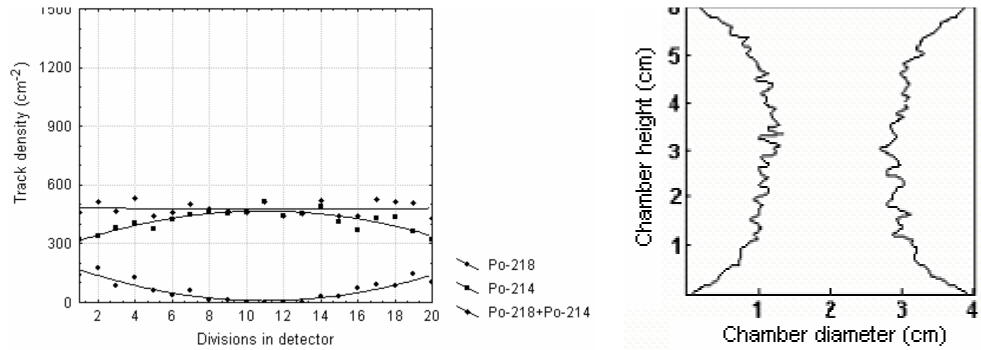


Figure 7. Standard errors of mean track densities (confidence interval= 95%), induced by ^{218}Po and ^{214}Po effective surfaces, in dependence of chamber diameters and assumed critical angles.

ent a distribution very far from the uniform. In particular, below 1.5 cm ^{214}Po concentration diminishes in an approximately lineal way until almost zero at the beginning of its effective surface. As track distribution induced by an effective surface depends on positions from where alpha particles are emitted, the presence of smaller quantity of atoms in its lower end (and unequally distributed), will condition a much smaller contribution to track density and different to that shown in Figure 8A. In consequence, track distribution will be practically determined by ^{218}Po contributions and instead of being presented an almost uniform track distribution (by the sum effect when supposing ^{214}Po uniform distribution), higher track concentration will appear near detector borders.

With the experimental determination of optimum diameter we will be able to make



A B

Figure 8. ^{218}Po and ^{214}Po contributions to track distribution for a 4-cm chamber diameter and assumed critical angle of 30° (A). Vertical distribution of ^{222}Rn daughters deposited in chamber wall (B).

inferences on which of the suppositions used in preceding calculations reflect better the reality.

Conclusions

Through analytic simulation and using the Monte Carlo method it was demonstrated that the cause of non uniform track distribution in LR-115 detectors is related with the geometric disposition of effective volumes and surfaces regarding the detector form, dimensions and position. To achieve errors around 10% in track density calculations (due to non uniformity of track distribution), and track density as high as possible, the commitment solution is D = 3.5 cm ($\theta_c = 30°$), D = 4.5 cm ($\theta_c = 45°$) and D= 5.5 cm ($\theta_c = f(E)$). Independently of the assumed critical angle we can consider that diffusion chambers with diameters around 4.5 cm condition uniform track distribution on the detector surface and relative high track density. Obtained results may be affected when considering non-uniform distribution of deposited radon daughters in chamber inner wall.

Acknowledgements

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