

# Radon Exposures in a Jerusalem Public School

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In December 1995, ambient radon levels exceeding 10,000 Bq/m<sup>3</sup> were measured in a basement shelter workroom of a multilevel East Talpiot, Jerusalem, public elementary school (six grades, 600 students). The measurements were taken after cancers (breast and multiple myeloma) were diagnosed in two workers who spent their workdays in basement rooms. The school was located on a hill that geologic maps show to be rich in phosphate deposits, which are a recognized source for radon gas and its daughter products. Levels exceeding 100,000 Bq/m<sup>3</sup> were measured at the mouth of a pipe in the basement shelter workroom, the major point of radon entry. The school was closed and charcoal and electret ion chamber detectors were used to carry out repeated 5-day measurements in all rooms in the multilevel building over a period of several months. Radon concentrations were generally higher in rooms in the four levels of the building that were below ground level. There were some ground-level rooms in the building in which levels reached up to 1300 Bq/m<sup>3</sup>. In rooms above ground level, however, peak levels did not exceed 300 Bq/m<sup>3</sup>. Exposure control based on sealing and positive pressure ventilation was inadequate. These findings suggested that radon diffused from highly contaminated basement and ground-floor rooms to other areas of the building and that sealing off the source may have led to reaccumulation of radon beneath the building. Later, subslab venting of below-ground radon pockets to the outside air was followed by more sustained reductions in indoor radon levels to levels below 75 Bq/m<sup>3</sup>. Even so, radon accumulated in certain rooms when the building was closed. This sentinel episode called attention to the need for a national radon policy requiring threshold exposure levels for response and control. A uniform nationwide standard for school buildings below 75 Bq/m<sup>3</sup> level was suggested after considering prudent avoidance, the controversies over risk assessment of prolonged low-level exposures in children, and the fact that exposures in most locations in the Talpiot school could be reduced below this level. Proposal of this stringent standard stimulated the search for a strategy of risk control and management based on control at the source. This strategy was more effective and probably more cost effective than one based on suppression of exposure based on sealing and ventilation. Because many Israeli areas and much of the West Bank area of the Palestinian National Authority sit on the same phosphate deposits, regional joint projects for surveillance and control may be indicated. — *Environ Health Perspect* 105(Suppl 6):1411–1416 (1997)

Key words: radiation, radon, school, exposure standards, exposure control

## Introduction

In 1993 and 1994 two employees of a public elementary school in East Talpiot, Jerusalem, were diagnosed with cancer. One cancer victim, who died in 1996, was

a 39-year-old female arts and crafts teacher with breast cancer. She had worked for 15 years in a basement bomb shelter that doubled as an arts and crafts workshop for

students. The second employee was a 55-year-old custodian who developed multiple myeloma, also after spending 15 years working mostly in the basement. Although tumors at sites outside the lung are not considered related to radon (1–6), the Parents' Committee of the East Talpiot public school demanded an investigation of radon exposure levels in the building.

In December 1995, spot measurements taken by city of Jerusalem officials indicated that radon levels in the shelter/arts and crafts room were in the range of 1000 to 15,000 Bq/m<sup>3</sup>. These high measurements led the Parents' Committee, officials from the city of Jerusalem, and the Ministry of Environmental Quality to close the school for several weeks and to conduct repeated short-term measurements in every room throughout the school over the next several months. The objectives of this monitoring were to determine the distribution of radon levels in the entire building, to determine when children could return to the building, and to evaluate the effectiveness of control measures on radon levels throughout individual rooms and hallways in the entire building. The U.S. Environmental Protection Agency (U.S. EPA) and Israeli action levels are 150 Bq/m<sup>3</sup> (4 pCi/liter) (6) and 200 Bq/m<sup>3</sup> (5.4 pCi/liter), respectively, with a conversion factor of 10 pCi/liter = 370 Bq/m<sup>3</sup>.

## Setting and Methods

### Setting

The school, which opened between 1981 and 1982, is located in an area on geological maps as rich in phosphate deposits (7), a recognized source for radon and its daughter products (8,9). Approximately 600 students are enrolled in grades one through six; they spend 5 to 6 hr/day inside the building.

The building itself, although only two to three floors above ground level, is constructed as an Escher-type structure with eight separate levels inside. The structure rests on a hillside so there are several different levels that exit directly on grade although inside they may be above one another. (Figures 1 and 2). The lowest below-ground level is designated E-4 and the ascending three levels that are partially or completely below grade are designated E-3, E-2, and E-1, respectively. Ground and higher levels are entrance and floors #1, #2, #3 and #4.

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Abbreviations used: Bq, becquerels; pCi, picocurie; U.S. EPA, U.S. Environmental Protection Agency.



**Figure 1.** East Talpiot public elementary school, Jerusalem: multilevel structure of school building.

Parts of the building below grade rest directly on rock and soil or above hollow crawlspaces or other portions of the building. Utility conduits in the walls of the building serve as direct connections between upper-level rooms and soil or spaces below the building. Walls in the school were double-layered with air gaps to provide heat insulation.

**Measurements**

The entire school was closed down after the original high measurements.

To determine sources and distribution of radon in the entire building, several sets of measurements were made using different sampling and analysis methods. Charcoal canister detectors (detection limit 5 Bq/m<sup>3</sup>, precision 5%) and the electret ion chamber method (detection limit 5 Bq/m<sup>3</sup>, precision 10%) were used to conduct repeated short-term measurements of the concentrations of radon gas for 5- or 7-day periods in every room in the building (6,9,10). Most results were based on readings of duplicate detectors placed in the same rooms at the same time. When conducted, the duplicate detections generally did not differ by more than 20 to 25%; the results we report are based on averages of different readings. Routine quality assurance and control procedures of the Ministry of Environmental Quality were used to assess accuracy and precision levels of both methods.



**Figure 2.** East Talpiot public elementary school, Jerusalem: exit to grade at different levels.

Long-term measurements over two 6-month periods were conducted in all classrooms, offices, teacher lounges, and meeting rooms using alpha-track detectors, which measure radon daughters. Problems with storage and collection did not permit use of the results of the first round of measurements; the results of the second round were not available at the time this manuscript was completed. The Parents' Committee worked together with the authors to review and interpret results of each batch of short-term measurements and to make decisions about when to reopen the school and which rooms to keep closed.

**Abatement Procedures**

Abatement procedures were based on methods described in standard sources (11,12) and initially included sealing pipe openings, adding polyvinyl chloride floor coverings over tiled floors, sealing cracks, covering receptacles, and massive general ventilation on a large scale. Ventilation was at first used to force air out of the building. Later, ventilation was used to force air into the sealed building, thus creating positive pressure relative to the surroundings to prevent the migration of radon gas into the building. Subsequent control measures are described below.

**Results**

Table 1 shows some of the readings of both ambient levels and conduit outlets

**Table 1.** Radon (Bq/m<sup>3</sup>) in shelter/arts and crafts room: ambient and pipes and conduits.<sup>a</sup>

Date	Results	
	Type measured	Level
10/12/1995	Ambient	13,000; 8500; 12,000
26/12/1995	Ambient	10,000
	Pipes and conduits	137,000; 10,000
18/12/1995	Pipes and conduits	12,345; 21,326
		10,250; 11,306

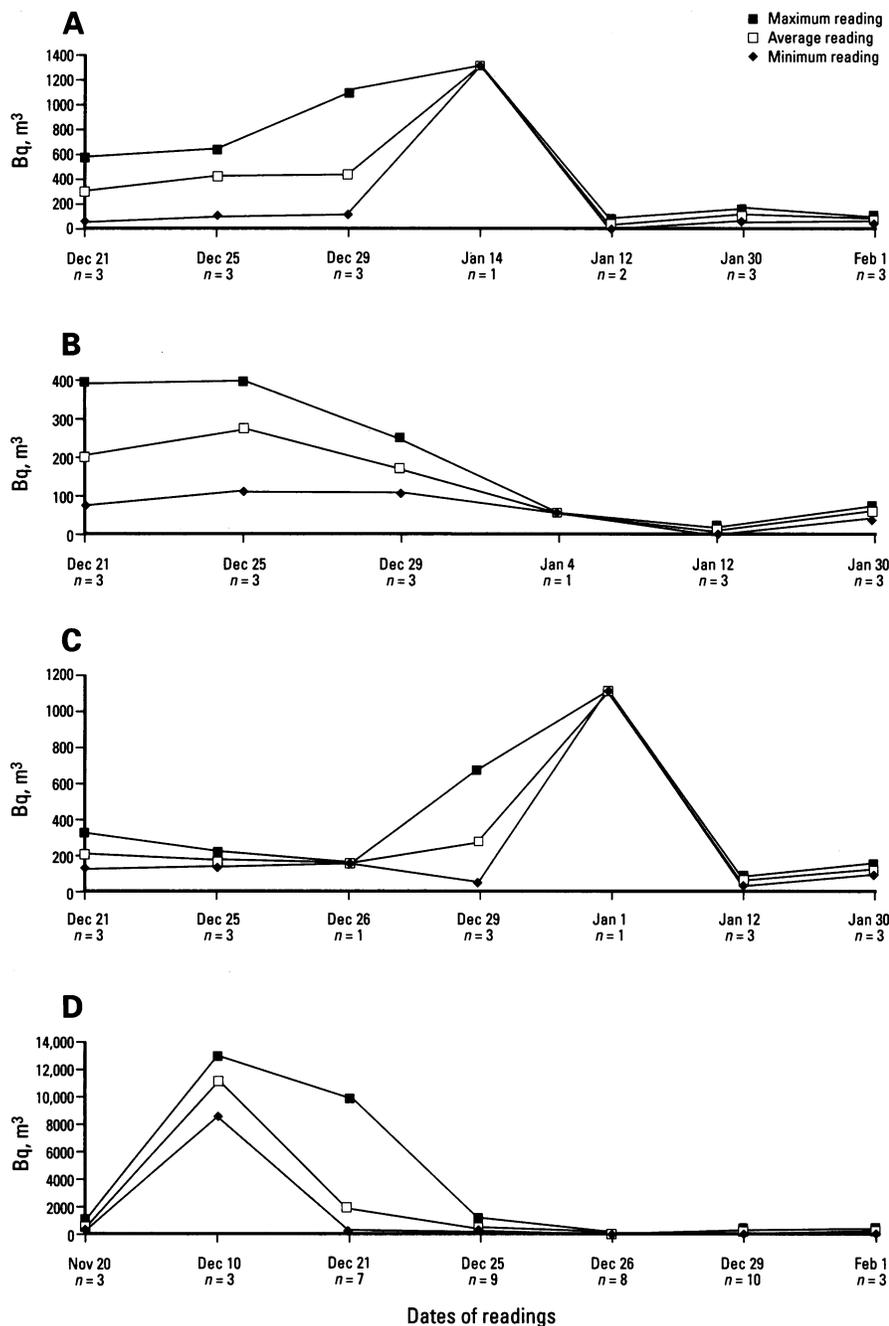
<sup>a</sup>Charcoal detector and electret ion chamber detectors: 5-day measurements.

from the shelter/arts and crafts room in the basement below grade. Ambient radon levels were an order of magnitude lower than levels measured in the pipe (originating below grade) in that room. As noted, the school was closed down after these initial measurements.

A pipe that originated underground outside the building had radon concentrations exceeding 100,000 Bq/m<sup>3</sup> at its opening. One measurement of ambient levels in the room was reported above 10,000 Bq/m<sup>3</sup> but information was lacking as to the precise height and distance of the detector providing this reading in relation to the pipe opening.

The pipe opening was sealed to block the entry of radon gas from the pipe to the room. Other rooms with high levels also had direct connections with the subslab, either by walls directly abutting the ground or by conduits.

## RADON EXPOSURE IN SCHOOLS: EXPOSURES AND CONTROL



**Figure 3.** Radon exposures in the East Talpiot public elementary school: below-grade levels. A) floor E-1; B) floor E-2; C) floor E-3; D) floor E-4. A, B, and C are all floors with classrooms; D) includes a shop, a photo lab, and home economics, music, maintenance, and teaching rooms, a gym, two bomb shelters, and bathrooms.

Figures 3 and 4 show the serial trends in radon levels over an 8-week period for classrooms on each of the eight levels in the building. In these two figures, the gradient is from E-4, the lowest level in the building, to #4, the highest level.

Figure 3 shows that radon concentrations (maximum, average, and minimum for each

floor) were highest in level E-4, where shops, a photo lab, a home economics and music room, a maintenance room, teaching rooms, a gym, bathrooms and two bomb shelters were located, and where the two individuals with cancer spent all or most of their time. The first set of control measures (sealing of pipe, sealing of cracks, general ventilation)

was implemented in mid-December 1995. In the 2 to 3 weeks thereafter, radon levels rapidly decreased in the lowest level (E-4) from the high levels first measured. In the higher floors (#1, #2, #3, #4) levels also fell, from concentrations approaching 150 Bq/m<sup>3</sup> to <75 Bq/m<sup>3</sup>. However, in early January 1996, in certain classrooms on levels E-3, E-1, and entrance, radon concentrations rose to levels as high as 1300 Bq/m<sup>3</sup> after a decrease in concentrations in E-4 (Figure 3). These intersecting time trends suggest that radon gas migrated upwards, perhaps as a consequence the fans used to blow out the gas and the creation of focal areas of low pressure.

The school was reopened 1 month after the original closure. In subsequent months isolated rooms had radon levels exceeding 200 Bq/m<sup>3</sup> during vacation periods when the building was totally closed. Rooms with radon levels exceeding 200 Bq/m<sup>3</sup> were sealed off.

After this rebound episode the Parents' Committee and city officials decided to implement a more definitive strategy of exposure control based on venting and diversion of radon from subsurface sources. During the summer of 1996 a system of subsoil vent pipes was installed to allow external venting of underground pockets of radon-rich air.

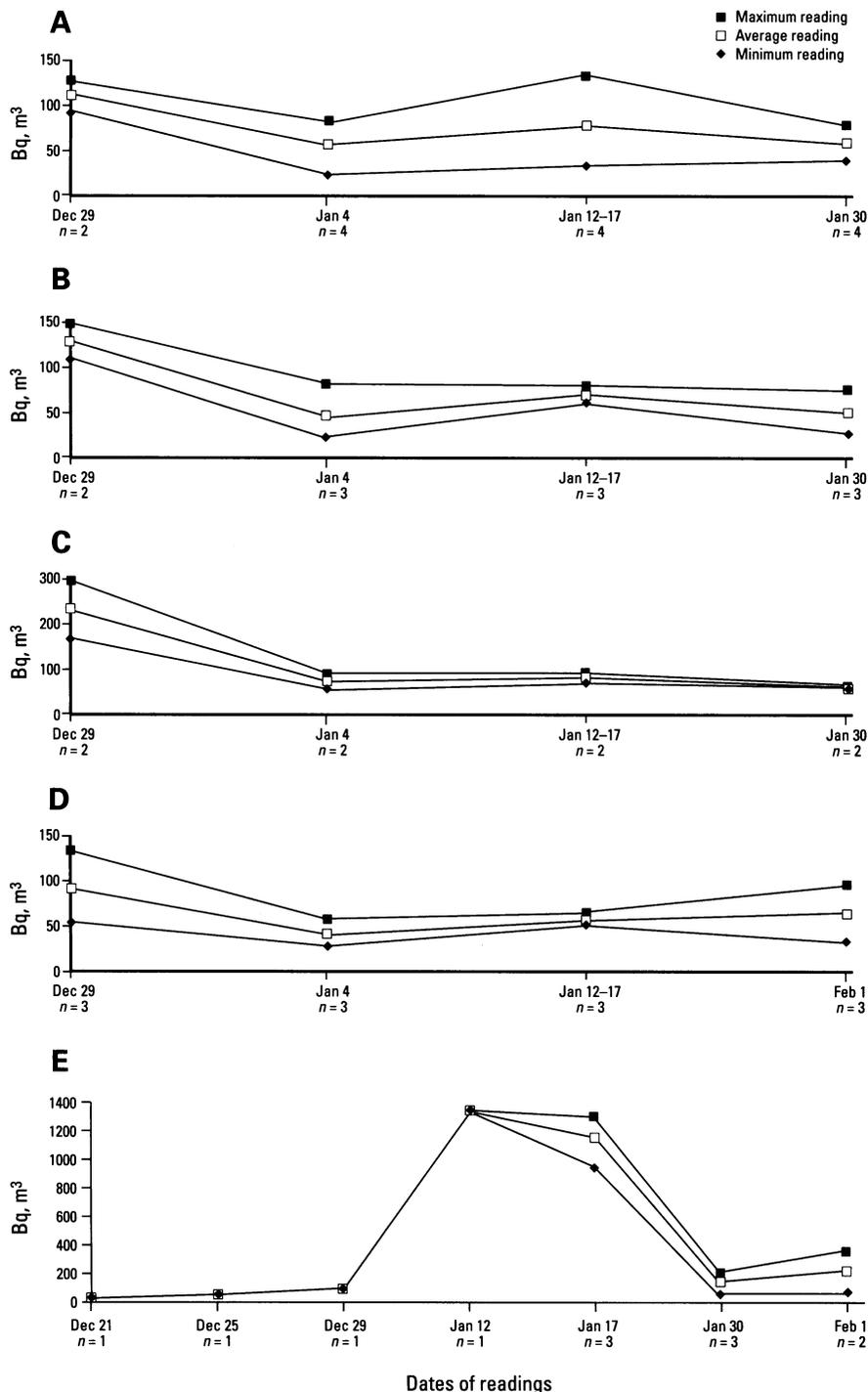
The results of 5- and 7-day radon level measurements taken from 32 rooms during the month of December 1996, after this system was already in place, were as follows. Twelve rooms <75 Bq/m<sup>3</sup>, 12 rooms 75–150 Bq/m<sup>3</sup>, 3 rooms 150–200 Bq/m<sup>3</sup>; 4 rooms 200–500 Bq/m<sup>3</sup>, and 1 room >500–1000 Bq/m<sup>3</sup>. Charcoal detectors and electret ion chamber detectors were used.

These findings show that exposure levels in 24 of 32 sites were <150 Bq/m<sup>3</sup>. Maximum levels were much lower, but isolated pockets of radon were still present in some rooms 1 year after the discovery of the hazard, even after this underground venting system was in place. On floor E-3 levels remained close to 1000 Bq/m<sup>3</sup> in one corner room when the windows and doors were closed. No abatement measures, including digging under the room, venting, and sealing produced any reduction: the room was closed off and had not been reopened as of July 1997.

## Discussion

### Action Levels and Exposure Control

This survey documented unusually high exposure levels for a nonoccupational



**Figure 4.** Radon exposures in the East Talpiot public elementary school: entrance and above-grade levels. A) floor #4, which includes science, engineering, and computer rooms and the library; B) floor #3; C) floor #2; D) floor #1; E) entrance level. B, C, and D are all floors with classrooms; E includes reception, housekeeping, and teachers' rooms.

setting. The findings showed that reducing exposure levels to  $< 75 \text{ Bq/m}^3$  (one-half the U.S. EPA action level) is an attainable goal even in high-exposure settings. The case for a uniform nationwide standard of

$< 75 \text{ Bq/m}^3$  for school buildings is suggested based on prudent avoidance, the controversies over risk assessment from prolonged low-level exposures in children (9), and feasibility—thereby bypassing the

fact that exposures at most points in the Talpiot school could be brought down below this level. The case for a low action level may be especially relevant for children studying in this school, as some of them may have had or may still have high exposures in their homes in the same neighborhood.

This low and stringent threshold for action prompted a search for a definitive solution to the problem that pockets of higher radon levels were found in certain rooms. There was a persistent effect from seepage and penetration of radon from ground sources into the building. This seepage was not completely offset by providing external venting of ground sources or by internal ventilation. A step-by-step program of local venting of underground air pockets in rock was introduced to control and eventually eliminate high levels. In retrospect, it was this stringent standard that led to a strategy of risk control and management based on control at the source. This strategy (11,12) was more effective and probably more cost effective than one based on sealing and ventilation.

### Exposure Monitoring and Control Measures

The findings underscored the importance of frequent repeated brief measurements in all rooms at all levels of the building below and above ground to evaluate appropriateness, adequacy, and efficacy of venting and other control measures. After completion of this study, radon monitoring systems were also used for online monitoring to check the effectiveness of the remediation measures. Long-term measurements would have given a more valid measure of time-weighted exposure and risk but would have missed these short-term space-time trends in radon levels inside the building in relation to control measures.

The trends shown in the level-by-level graphs (Figures 3 and 4) indicate that the abatement procedures resulted in gradual reduction of radon levels. However, later spikes in below-ground levels above E-4 suggest that radon gas entered other parts of the building from pockets of gas in high concentrations disturbed somewhere inside the underlying rock. The sealing of the pipe opening that had high concentrations of radon gas (Table 1) was followed by the penetration of gas to other below-ground rooms, perhaps as a result of the buildup of subterranean concentrations. The gases remained in the soil only to penetrate the building along new paths.

In retrospect, it would have been preferable to vent the pipe in the bomb shelter to the outside rather than seal its opening inside the room. Venting the pipe to the outside would have allowed the trapped radon gas source to bypass the entire structure. In a building with so many doors and windows, we do not know if ventilation for air exchange and dilution and elimination of indoor radon gas prior to its decomposition into particulates was preferable to using fans. The fans created negative pressure gradients that sucked radon gas and its daughter products into the building from below-ground sites of penetration. The effectiveness of using fans to create pressure gradients can be modified in ways that are not always predictable by changes in temperature and humidity. Passive or mechanically induced subterranean vents might have been preferable as a long-term solution.

In retrospect, the effects of negative and positive ventilation were never adequately assessed. Negative pressure ventilation to blow out the radon before its breakdown into daughter products may not have been sufficiently powerful to offset the effect of its penetration into the building. It is not certain that negative pressure ventilation reached all pockets in the building. In contrast, the effects of positive ventilation to counteract penetration from the earth may have been neutralized by open windows. Neither ventilation by itself was sufficient to provide a definitive solution before there was external venting of the underground radon pockets beneath the building. The subsequent buildups of radon levels during vacation time, when the windows were closed, suggests that the dilution effects of negative ventilation may have been of some value, though this by itself was not sufficient to prevent reaccumulation.

Other contaminated areas were also found in another school in the vicinity and many ground-level individual dwellings were reported to be at special risk. The problems of the second school underscored the special difficulties with construction in radon-belt areas.

### The November 1995 Earthquake

It was not certain whether radon penetration into the school in on-grade rooms with pipes and conduits directly connecting to porous subsurface rock and gravel increased after the earthquake in November 1995 as a result of subterranean

geologic disturbances (13). Nationwide surveillance programs by the Ministry of Environmental Quality indicated that there were no major sustained before-after changes in ambient indoor radon levels throughout the country that were associated with the earthquake, even though findings from the Negev suggested that this event was followed by transient rises in radon concentrations of water from certain ground sources (C Greenblatt, personal communication). A definitive answer to this question would require analysis of radon daughter products in window glass from the basement E-4 shelter (14) and would be essential for epidemiologic assessment of long-term exposure-risk relationships for the children in the school.

### The Sentinel Patients: Radon and Cancer Not in the Lung?

Breast cancer in the female teacher and multiple myeloma in the male janitor were the sentinel events that triggered the radon investigation even though epidemiologic evidence that radon produces cancer in target organs other than the lung is at best tentative and mostly inconclusive (15-18). No valid conclusions can be drawn from this observed relationship between the high basement exposures of these two individuals and their tumors. Animal studies indicating migration of radon gas to tissues with high fat content suggest a biologically plausible explanation for extrapulmonary tumors from inhalation of radon (J Shapiro, personal communication). If clusters with the same tumor types have been observed in other settings with extremely high radon exposures, it would be advisable to pool observations to assess risks.

### The Need for a Policy

The East Talpiot school radon episode was a sentinel exposure event calling attention to the need for a nationwide policy on radon exposures for school buildings, community, recreation, and day care centers, and other public and multiple-use buildings. Geologic maps of phosphate deposits in Israel and the West Bank indicate that many other sites, including residential dwellings, could be at risk for indoor radon exposure, most notably those east of the Jerusalem watershed. The need for such a policy based on periodic measurements is clear, given the findings from this paper.

Previously, a condition similar to that in the Talpiot school was noted in a school building in northern Israel; measured levels of radon gas incursion in a single room several levels above grade exceeded acceptable levels by approximately 9100 Bq/m<sup>3</sup>. This isolated room was serviced by an electrical conduit that originated below the building in the underlying soil and rock and was believed to be the source of the extremely high radon levels measured (19).

These findings indicate that it would be prudent to test all schools and public buildings and periodically retest and reevaluate high-risk schools and public buildings. Construction specifications for buildings in high radon areas might include requirements for subterranean conduits and barriers to allow radon to bypass the building and for external venting of all pipes and conduit systems that penetrate into the ground (8,9).

### Risks, Standards, and Management

A nationwide policy requires defining threshold exposure levels for control and emergency closure. Based on the experience with this episode we suggest that a community radon standard for public buildings must include surveillance and monitoring routines, prioritization of high-risk areas, construction specifications for high-risk areas with phosphate deposits, remedial guidelines, follow-up evaluation, quality control supervision of laboratories, information delivery based on right-to-know and community participation, education on the special risks from radon for smokers, and possibly governmental guarantees of compensation for future lung cancer victims with past childhood exposures to so-called hot environments.

As previously noted, setting < 75 Bq/m<sup>3</sup> as the standard for this school building resulted in a concentrated effort for exposure control directed to outward venting of the below-surface source. This definitive strategy was more effective and probably will be more cost effective than one based on permanent or intermittent ventilation and sealing alone.

Because much of the residential area in the eastern part of Jerusalem and the West Bank of the Palestinian National Authority is located on phosphate deposits, joint binational projects for surveillance and control are indicated.

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