Follow-up study on indoor radon levels in Irish schools after a National School Survey and remediation programme

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Abstract

***Background*:** A National Survey of Radon in Irish Schools was carried out by the Department of Education and the Environmental Protection Agency (EPA) (formerly the Radiological Protection Institute of Ireland) between 1998 and 2004. Then, a remediation programme was developed and implemented in the schools with elevated radon levels.

***Objectives*:** To determine the durability of the remediation systems 10–17 years post-installation and to study the effect of radon awareness on follow-up programmes, radon retests were performed in 16 schools that had some form of remediation implemented.

***Design*:** The schools were chosen based on the data of the National Survey for Irish Schools and the post-remediation survey. A total of 276 rooms were tested for radon using CR-39 etched track detectors supplied by the EPA. Short questionnaires were given to the school principals to gather information about the level of radon awareness, remediation maintenance and retesting policies.

***Results*:** An increasing trend in the radon concentration with time was found in some schools. Potential factors contributing to this rise are lack of maintenance, lack of follow-up testing programmes and knowledge lost due to staff turnover. The results showed that 26% of the rooms which had remediation installed had risen to above the Department of Education's reference level for schools of 200 Bq/m^3 again and 10% to above 400 Bq/m^3. Through case studies and questionnaires, radon awareness in schools was observed to be correlated with an ability to maintain radon concentrations below the reference level. Although the National Survey of Radon in Irish Schools is to be commended for its exhaustive completeness, many schools in this project were unaware of the remediation system installed. Only 15% of the schools in this study remember or have records of regularly checking or servicing their remediation systems.

***Conclusions*:** Retesting for radon is crucial in indicating where remediation methods are less effective or have failed. A follow-up programme to retest for radon and to ensure maintenance of remediation systems should be implemented.

Keywords: *radon*; *schools*; *radon awareness*; *remediation*; *follow-up testing*

Radon gas is considered the main source of ionising radiation exposure for the general population. It is a radioactive gas product of the decay of radium (^{226}Ra), which belongs to the decay series of the uranium (^{238}U) and is present in soils and rock of the Earth's crust. Radon originating from the ground can permeate through the soil and penetrate the indoor space of buildings, where it tends to accumulate resulting in a health risk. Recognised as the second leading cause of lung cancer by the World Health Organisation (WHO), indoor exposure to radon gas is responsible for around 300 lung cancer cases per year in Ireland (1, 2). To minimise indoor radon concentrations, there are various prevention and remediation techniques, often these remediation techniques are dependent on the gas flow through the granular fill materials used in the building construction (3–7). Measuring radon concentrations is key to controlling radon levels in any type of building (8, 9).

A survey of radon concentrations in schools was conducted in Ireland during the years 1998 and 2004 by the then Department of Education and Science (DES), with the assistance and guidance of the Environmental Protection Agency (EPA; formerly the Radiological Protection Institute of Ireland, RPII) (10). The project was called the National Survey of Radon in Irish Schools (hereafter referred to as the National School Survey or the NSS) and was carried out in over 95% of the primary and post-primary schools in Ireland. Radon concentration

was measured in a total of 3,826 schools and 38,531 rooms using CR-39 etched track detectors. The average radon concentration found was 93 Bq/m^3. A total of 984 schools presented radon concentrations over 200 Bq/m^3 in 3,028 rooms (7.9%) and 329 schools over 400 Bq/m^3 in 800 rooms (2.1%) (11).

Following the NSS, an experienced UK remediation consultant was contracted to implement a strategy for reducing the radon concentration in all rooms that were greater than 200 Bq/m^3, and local radon contractors implemented the strategy (12). The reference concentration of 200 Bq/m^3 was used because at the time the reference levels in Ireland were 200 Bq/m^3 for dwellings and 400 Bq/m^3 for workplaces, and the view was taken by the DES that 'children should expect the same level of protection while at school as in the home' (10, 11, 13, 14).

A reference level is defined to regulate indoor radon exposure, but it does not define a rigid boundary between safety and danger (1). The WHO advises setting a reference level for radon gas as low as possible and proposed 100 Bq/m^3 (1, 15). The 2013/59/EURATOM BSS Directive, mandatory since February 2018, advises that all member states of the European Union shall establish national reference levels not exceeding 300 Bq/m^3 for dwellings, buildings with public access and workplaces (16). The Directive did not state explicit advice for schools but classified them as types of workplaces or buildings with public access. The cautious approach adopted by the DES in setting the 200 Bq/m^3 reference level for schools during the NSS was warranted. In 2014, the National Radon Control Strategy (NRCS) for Ireland recommended retaining this reference level for schools (17). A radon concentration of 200 Bq/m^3 results in an equivalent dose of 5 mSv per year for a dwelling, assuming an occupancy time of 7,000 h (18). For schools, the occupancy is assumed to be a minimum of 1,000 h, which at a radon concentration of 200 Bq/m^3 would result in an equivalent dose of 0.7 mSv per year.

The remediation systems implemented were, in general, an active sump where concentrations were over 400 Bq/m^3, and for concentrations between 200–400 Bq/m^3, passive ventilation, such as window trickle vents or wall vents, was installed. Summaries of the project and the detailed remediation techniques implemented were reported, and a post-remediation survey was conducted in many schools to confirm whether the remediation was successful (11, 12). In the cases where remediation was not successful, but radon levels were in the range of 200–400 Bq/m^3, no further remediation was conducted as the results were below the statutory workplace reference level. However, in the school rooms with radon concentrations above 400 Bq/m^3 post-remediation, further remediation was implemented and then retested for confirmation.

Several countries have undertaken school radon testing programmes, and Clouvas *et al* included a summary of the studies done in Europe when publishing their work on a Greek school survey (19). The Irish NSS is considered as one of the most comprehensive undertaken in Europe due to its size and detail, which makes it ideal for a follow-up remediation study.

This article presents a follow-up radon survey conducted in a selection of schools from the NSS, with the main aim of investigating the durability of the remediation systems installed and determining the importance of follow-up programmes.

Materials and methods

The survey was conducted in a total of 16 schools that had remediation implemented after the NSS, of which 10 are located in a high radon area (HRA) as defined by the radon map for Ireland (20). Three schools were located in County Dublin, six schools in County Galway, four schools in County Kerry and three schools in County Wicklow. The schools were chosen by the percentage of rooms that had radon concentrations above 200 Bq/m^3, as measured in the NSS, in order to obtain a sufficient data set to make conclusive comparisons of rooms with radon remediation. In total, 77% of the rooms measured in this follow-up survey were greater than 200 Bq/m^3.

The radon detectors used for the survey were CR-39 etched track detectors, supplied and analysed by the EPA. Detectors were placed and collected in person to allow *in situ* examination of the rooms and to avoid non-returning of the detectors when posted, as the NSS reported a 26% non-return rate of detectors (11).

The survey was conducted in two phases. Phase one was a pilot survey undertaken in six schools that were contacted and asked to participate in a radon review process initiated by the EPA and DES. CR-39 etched track detectors were placed in each occupied ground floor room of the schools and collected after a 3-month period (March–June). Short questionnaires were given to the principals to determine the level of radon awareness asking:

- Whether the school had a radon retesting policy and if so to provide the results
- If any maintenance had been carried out on the currently installed remediation
- If any retrofitting had been done to the school
- If new extensions have been tested for radon or fitted with any remediation.

One of the issues highlighted in the pilot survey was the lack of consistency of room names over periods of time. This made it difficult to correlate the rooms listed in the NSS to the current rooms tested. Subsequently, for phase 2 of this study, schools were chosen from a report compiled by the radon adviser in the NSS. The report detailed

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the radon concentration in each room and the type of remediation implemented, which together with school photographs and floor-plans made it possible to correlate rooms for comparison.

The second phase was conducted the following year on an additional 10 schools. CR-39 etched track detectors were placed in person and left for 6 months (January–June). The remediation works were inspected where possible, and similar to phase one, a questionnaire was completed.

Results and discussion

Results from the follow-up study

The radon measurements from the NSS and the post-remediation survey for the 16 schools tested in this study were provided by the EPA. The summary statistics for the three stages of the survey, the initial NSS, the post-remediation survey (completed between 1998 and 2004) and the follow-up survey completed in 2014–2015, are presented in Table 1. No school reported a concentration lower than 10 Bq/m^3 in the follow-up study, as this is the lower limit of detection of the CR-39 etched track detectors supplied by the EPA (11). Seasonal correction factors were not applied to these results. At the time of this survey and until 2018, seasonal correction factors were derived from measurements carried out in homes and therefore were only applied to home measurements as per the EPA protocol.

The number of rooms measured in the three stages is different; some rooms initially measured in the NSS were not measured post-remediation because the radon concentration initially recorded was below 200 Bq/m^3. In the follow-up study, additional rooms that were not measured in the NSS were tested, possibly due to unreturned detectors in the initial survey or because they were built in the interim.

Synnott et al. (5) found that the nationwide arithmetic mean (AM) in schools was 93 Bq/m^3, but here a higher AM of 520 Bq/m^3 is reported; this is due to the bias in selecting schools with an elevated radon concentration. The NSS post-remediation AM was 79 Bq/m^3, meaning that remediation was successful. In the follow-up study, the AM has risen to 111 Bq/m^3 which indicates that some remediation methods are not working as efficiently as when first installed or that some have failed. By looking at the geometric mean (GM), post-remediation and follow-up values are almost the same, and similarly, the median reported for each stage correlates quite closely with the respective GM.

The arithmetic standard deviation (ASD) is a parameter indicative of the data set dispersion, and it is valuable to identify possible outliers of high radon concentration that can skew the AM. The ASD for the follow-up survey is 136 Bq/m^3 indicating a large spread of values in the data set. Consequently, it can be deduced that some of the remediation works failed in time, resulting in outliers in the data.

A total of 224 rooms measured in the NSS were correlated with the rooms tested in this follow-up study. About 52 of the rooms measured in the follow-up study could not be correlated with the rooms in the NSS, and this was due to the building of new rooms, the combining of rooms or rooms that were not measured in the NSS as a result of unreturned detector. Table 2 compares the data from the NSS to the correlated and un-correlated data from the follow-up survey with respect to three reference levels; 200 Bq/m^3 is the reference level for dwellings and schools in Ireland, 300 Bq/m^3 is the reference level for workplaces following the European Union Directive 2013/59/Euratom and 400 Bq/m^3 is the former Irish workplace reference level (13, 14, 16). The rooms for the correlated and uncorrelated data are different, but their close agreement confirms the trend for the percentage of rooms exceeding the reference levels.

Table 1. Summary of radon surveys' statistical data results

	National school survey	Post-remediation survey	Follow-up survey
	250 rooms (16 schools)	209 rooms (16 schools)	276 rooms (16 schools)
AM ± SE (Bq/m^3)	520 ± 33	79 ± 5	111 ± 8
ASD (Bq/m^3)	525	69	136
GM (Bq/m^3)	370	58	60
GSD (Bq/m^3)	2	2	3
Median (Bq/m^3)	356	57	51
Range	3,809	489	687
(min, max) (Bq/m^3)	(3,93,848)	(10,499)	(10,697)

Note: AM is the arithmetic mean of the radon concentration with standard error (SE), ASD is the arithmetic standard deviation, GM is the geometric mean of the radon concentration and GSD is the geometric standard deviation. The range indicates the difference between the minimum and maximum radon concentrations.

Table 2. Percentage of rooms exceeding the reference level in the NSS and the follow-up survey

Reference level	NSS (%)	Follow-up survey	
		Correlated rooms (%)	Uncorrelated rooms (%)
>200 Bq/m^3	77	16	14
>300 Bq/m^3	60	8	9
>400 Bq/m^3	44	5	5

Note: The correlated rooms column refers to those rooms tested in the NSS which were matched with rooms tested in the follow-up study and similarly for the uncorrelated rooms column.

The follow-up survey also highlighted 8 rooms with radon measurements above the 200 Bq/m^3 reference level that did not have a previous radon measurement, possibly because of unreturned detectors.

Post-remediation radon tests were not conducted in all the schools remediated, and hence, post-remediation measurements were not available for all the rooms tested in the follow-up survey, and it is not possible to be certain that the 224 correlated NSS and follow-up survey rooms were below 200 Bq/m^3 following the remediation works. A data set of 146 rooms could be correlated for the three stages of the survey: NSS, post-remediation and follow-up, of which 129 were above 200 Bq/m^3 during the NSS and had remediation implemented. Data are summarised in Table 3.

Based on data from Table 3, the remediation works implemented after the NSS were successful in reducing radon concentration below 400 Bq/m^3 for the totality of the rooms tested and below 200 Bq/m^3 in a 97% of the rooms measured. The follow-up survey conducted 10–17 years after the remediation shows that 26% of the rooms are above 200 Bq/m^3 reference level and 10% of the rooms are above 400 Bq/m^3, indicating failures of remediation works with time.

After the National Survey of Irish Schools, it was reported that radon concentrations above 200 Bq/m^3 were measured in 3,028 school rooms, and radon concentrations above 400 Bq/m^3 were measured in 800 rooms (11). Based on these data and extrapolating data from Table 3 regarding the follow-up survey, it is predicted that approximately 790 rooms are currently above the Irish reference level for schools (see Table 4). This prediction disregards the 5% of schools not tested during the NSS and schools built since the NSS. However, the DES now require all newly built schools to be tested for radon, and where the reference level is exceeded, remediation must be carried out by the building contractor. Consequently, the number of new schools with radon concentrations above the reference level is likely to be very low.

Radon awareness in schools

In order to ascertain the level of radon awareness in the schools, a summary of the results from the short questionnaires was given to the school principals, presented in Table 5. From the first contact with schools during the follow-up survey, it was noticed that radon awareness and radon interest varied widely; 63% of the schools had retested for radon since the end of the NSS programme, of which 60% are located in HRAs of Co. Kerry and Co. Galway. The level of awareness due to media attention, EPA awareness campaigns and journal publications is likely to contribute to these schools implementing a retesting programme (20, 21). Among the remediated schools, only 15% of these had a protocol in place for the maintenance of the installed remediation.

Some schools had built extensions, and among them, it was noticed that a high percentage (83%) had installed a radon remediation system. Upon further investigation, it was found that in each circumstance, window trickle vents were installed. These are a ventilation requirement set out in the building regulations, and therefore, a remediation system was not intentionally installed (22). Of the schools which had built extensions, only two had measured the radon concentration in the new extension, and again, these were located in HRAs of Co. Kerry, showing the influence of radon awareness in the protection against radon.

Fifty per cent of the schools tested in the follow-up survey had been energy retrofitted since the NSS, involving window replacement, wall insulation, roof replacement or heating system replacement. Among the seven schools where an increased radon concentration was found in the follow-up survey, four of them had been retrofitted after the NSS. It is difficult to state with certainty the impact of the retrofitting modifications in the radon concentrations, due to the small data set and the time lapse between post-remediation and the follow-up survey. However, recent studies have shown the correlation of various energy retrofit programmes and increased indoor radon concentrations (23, 24). Also, remediation failure would

Table 3. Number of rooms exceeding the reference level in the NSS, post-remediation and follow-up survey

Reference level	Correlated NSS, no. of rooms	Correlated post-remediation survey, no. of rooms	Correlated follow-up survey, no. of rooms
>200 Bq/m^3	129	5	34 (26%)
>300 Bq/m^3	106	2	23 (18%)
>400 Bq/m^3	79	0	13 (10%)

Note: The correlated rooms column refers to those rooms tested in the NSS which were matched with rooms tested in the follow-up study.

Table 4. Prediction for number of rooms above the reference level in Irish schools currently, based on the results of the follow-up survey and NSS (11)

Reference level	NSS (1998–2004), no. of rooms	Prediction, no. of rooms
>200 Bq/m^3	3,028	790 (26%)
>400 Bq/m^3	800	80 (10%)

Table 5. Summary of radon awareness questionnaire results

	Percentage of schools
Retesting programme	63
Remediation system maintained	15
Retrofitting installed since NSS	50
Remediation installed in extensions	83

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have to be excluded as the cause of the radon concentration increase before it could be attributed to the energy retrofit works.

Case studies

To investigate the influence of radon awareness campaigns and radon programmes in schools, three schools are analysed separately as case studies. The first school (case study 1) is in a HRA with a limited radon programme in place considering retesting only, the second school (case study 2) is in a HRA with a comprehensive radon programme including retesting and remediation maintenance. Lastly, the third school (case study 3) is in a low radon area with no radon programme in place.

Case study 1

The school is a large secondary school in a HRA of Co. Kerry that was remediated after the NSS. Remediation works consisted of the installation of eight sub-slab pressurisation sumps as advised by the radon contractor. The principal indicated that, to his knowledge, maintenance was not carried out on the remediation works but radon measurements were conducted in 2013 and the results were provided. Figure 1 shows a boxplot of the radon concentration in the school at the different stages. The mean radon concentration reported in the NSS was 580 Bq/m^3, and two remediation attempts were needed to reduce radon concentration below the reference level, achieving a mean radon concentration of 80 Bq/m^3 (post-remediation 2). However, the radon measurement conducted in 2013 (Intermediate 1) and the follow-up survey measurement reported an increase in the mean radon concentration over the reference level, reaching a mean radon concentration of 430 Bq/m^3 in 2015.

Case study 2

The school is a medium size secondary school located in a HRA of Co. Kerry remediated after the NSS. Remediation works consisted of the installation of seven sub-slab depressurisation sumps. The principal indicated that a local radon adviser was contracted by the school for the maintenance of the remediation works and that radon measurements were conducted on two occasions after the NSS in years 2011 and 2012. The results of both measurements were provided. Figure 2 shows a boxplot of the radon concentration in the school at the different stages. Mean radon concentration reported in the NSS was 813 Bq/m^3, and after the remediation, it was reduced to 70 Bq/m^3. In 2011, it was found that radon levels had risen (Intermediate 1) and the school repaired the remediation system in the affected rooms. The following year radon tests were repeated (Intermediate 2) and confirmed the success of the repair works, achieving a mean radon concentration of 124 Bq/m^3, well below the reference level. The follow-up survey measurements reported a slight increase in the mean radon concentration but still below the reference level for schools.

Case study 3

The third school is a school located in a low radon area of Co. Wicklow. It was remediated after the NSS by installing, according to the radon consultants' advisory report, three radon sumps to serve six rooms and permanent trickle vents in the rooms above 200 Bq/m^3. These were confirmed at the time of detector placement, but one sump was found unintentionally switched off and did not seem to be functioning (no noise when it was turned on). The principal was not aware of the remediation system installed, and thus, maintenance was not carried out and intermediate measurements were not conducted. A new room had been

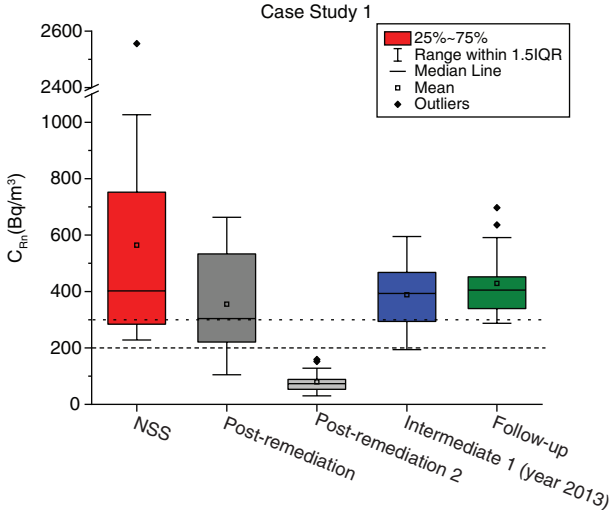

Fig. 1. Boxplot of radon concentration measurements for case study 1 – Co. Kerry.

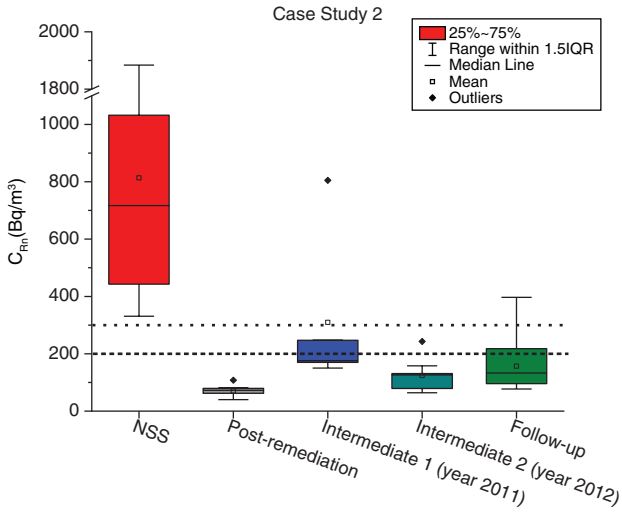

Fig. 2. Boxplot of radon concentration measurements for case study 2 – Co. Kerry.

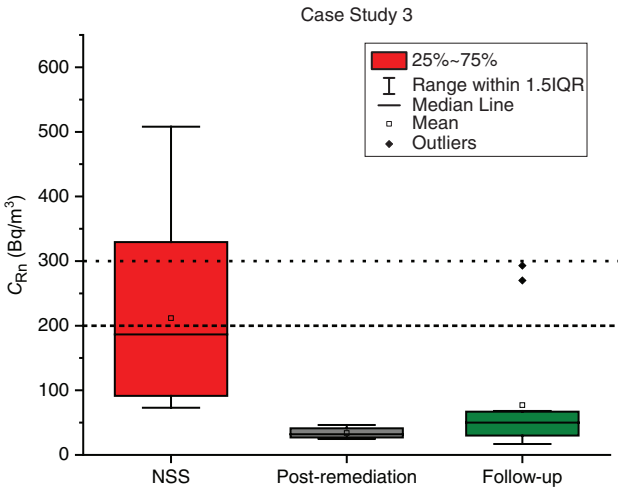

Fig. 3. Boxplot of radon concentration measurements for case study 3 – Co. Wicklow.

added to the school, and trickle vents were present in accordance with building regulations (11). Figure 3 shows a boxplot of the radon concentration in the school at the different stages. Mean radon concentration reported in the NSS was 212 Bq/m^3, and after the remediation, it was reduced to 34 Bq/m^3. In the follow-up survey, it was found that mean radon concentration doubled, reaching 77 Bq/m^3, and that radon concentration in two rooms was above the reference level as a result of the mentioned sump failure.

During the school visits, most school principals showed a high degree of interest in radon and facilitated the follow-up survey. The case studies presented point out the significance of radon awareness in schools and the key role of radon programmes in keeping levels below the reference level radon concentrations in schools. In particular, case study 1 highlights the importance of schools being actively involved in radon remediation maintenance and in responding to high radon levels to prevent radon exposure of the staff and students.

Conclusions

A follow-up survey was conducted in Irish schools to test indoor radon concentrations after they were remediated 10–17 years previously following a NSS. The study was motivated by the aim to determine the durability of the remediation works and the importance of radon awareness and structured follow-up programmes. The follow-up survey was conducted in a sample of 16 schools. Radon concentrations were tested using CR-39 etched track detectors in a total of 276 rooms, and questionnaires were given to the school principals to determine the level of radon awareness.

From the results of the follow-up survey, an increasing trend in the radon concentration was found in schools because of the lack of maintenance and follow-up testing programmes in place. In rooms where remediation was installed, it is seen that 26% of the rooms have risen to above the reference level of 200 Bq/m^3 and 10% are now above 400 Bq/m^3. It is difficult to accurately extrapolate these results; however, if one was to do so, it would lead to the prediction that currently 790 school rooms are potentially above 200 Bq/m^3 within the 3,826 schools originally tested.

Radon awareness was assessed through case studies and short questionnaires. It was observed that a correlation existed between the level of awareness and the ability to maintain radon concentrations under the reference level. As a consequence of media attention and publications, HRAs demonstrated higher radon awareness leading to a higher retesting rate, which is a unique finding from this study. Despite this, media attention is not constant and should not be relied on in isolation to raise radon awareness.

The questionnaires revealed that only 15% of the schools tested in the follow-up survey had checked or serviced their remediation systems. Case study 1 illustrated what can happen when remediation works fail and radon concentrations return to elevated levels. Students and staff were possibly exposed to radon concentrations over 400 Bq/m^3 because no action was taken to maintain the remediation system. As a direct result of this study, the EPA now recommend retesting every 5 years of any workplace or home that has been remediated.

Measuring for radon is essential not only to determine radon levels but also to check the effectiveness of remediation systems with time. Policies for schools to retest for radon and to ensure maintenance of remediation systems should be implemented to respond to the rising radon concentration trend reported in this follow-up study.

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