TRANSFER FACTOR: CAN THE PARAMETER BE USED TO PREDICT THE INDOOR RADON CONCENTRATION IN AN INDIVIDUAL HOUSE?

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ABSTRACT

A transfer factor describing the ratio between the indoor radon concentration and the soil-gas radon concentration was studied in real houses. An applicability of average transfer factors derived from large data sets for a prediction of the indoor radon concentration in an individual house is weak.

INTRODUCTION

In the field of the protection of houses against radon penetration from the ground, the term „transfer factor" should describe a relation between soil-gas and indoor radon concentrations. The applicability range of the term is wide. In practice, it is often used on a regional level: to compare geological data and results of long term indoor radon measurements, to classify large areas from the radon potential point of view, to define radon prone areas, or to direct a distribution of radon detectors during the search for houses with high indoor radon concentration. It is possible to determine an average transfer factor for a region that is defined geographically, using administrative units, or geological boundaries. The transfer factor is then derived from average values of measured parameters - for example it can be defined as a ratio of the geometric mean of annual average indoor radon concentrations vs. the geometric mean of soil-gas radon concentrations at a given region. Another possibility is to apply a numerically expressed radon potential of the building area (Neznal et al. 2004). In the latter case, the influence of soil permeability is also taken into account.

The concept of transfer factor is often used in the field of radon risk mapping. A large survey evaluating an applicability of the transfer factor has been realized in Germany (Kemski et al. 2003, Kemski et al. 2005). Assuming the soil is the main source of indoor radon, measurements of indoor radon concentrations have been carried out in a large number of exactly located houses. In every dwelling, two places were measured: a living room in the ground floor, and the basement. Beside measurement results, specifications of the house characteristics reported by the occupants were collected - a comprehensive questionnaire had been sent together with radon detectors. Geological units attributed to the house locations were classified and corresponding values of soil-gas radon concentrations were interpolated from available data, or measured in the field. The transfer factor characterizing every house (its basement, and/or its ground floor) was then calculated as a ratio of the indoor radon concentration and of the soil-gas radon concentration. Obtained data were grouped and analyzed using different criteria: geological conditions, presence of basement, soil-gas radon concentration, morphological situation, construction type, house type, age of house, depth of foundation, ventilation, etc. Average transfer factor values corresponding to different groups of houses were compared with the goal to discover general influences and tendencies. Finally, to be able to predict average indoor radon concentrations in regions, where no measuring campaign was carried out, a concept of a most common house type were used. The influence of a real state of the house on the indoor radon concentration was thus suppressed. A similar study has been realized in the Czech Republic (Barnet 2004). Results of indoor radon concentration measurements and soil-gas radon data from a database of the Czech Geological Service were used for the determination of average transfer factor values characterising different geological settings. No information on the state of houses, in which the indoor radon radon measurements were performed, was available. Both studies resulted in some identical, or similar conclusions. For example, a moderate decrease of transfer factor with increasing soil-gas radon concentration was observed. On the other hand, the average transfer factor values corresponding to different geological types were generally higher in the Czech study than in the German one. The difference might be caused by a worse state of foundations of houses in the Czech Republic.

As can be seen, the transfer factor concept is well-applicable at a regional scale. But other questions remain: Is it possible to use an average transfer factor derived from large data sets to predict the indoor radon concentration in an individual house? Or: Is it really useful to define a transfer factor for an individual house? How should it be defined, when the indoor radon concentration varies in time? In 2004 - 2005, a large research containing detailed radon surveys of 15 houses in different parts of the Czech Republic was carried out. One of the goals of the research project was to solve the above mentioned problems.

METHODS

The research project was focused on the study of radon transport from the ground into the indoor environment and on solving practical problems connected with the protection of houses against radon penetration from the ground. The preventive protection of new houses was studied as well as the effectiveness of remedial measures in existing buildings.

The choice of appropriate houses for detailed measurements represented the first step of the project. Potential „objects of interest“ were divided into three basic groups: (a) new houses (built after 1991); (b) old houses without remediation; (c) old houses after remediation. Many criteria were taken into account, mainly: readiness of the owners and/or of the occupants of the house to co-operate in the project; availability and quality of basic information on the house and on protective, or remedial measures; possibility to study the effectiveness of different types of preventive and remedial measures; sufficiently high indoor radon concentrations allowing to prove important effects. In the group of chosen new buildings, the majority of cases were therefore represented by houses, in which the preventive measures had failed.

In every house, a study of available information and a detailled survey of the construction itself preceded a preparation of the measurement plan. Detailed radon measurements were finally realized in 15 houses, location of which is given in Fig. 1. Following diagnostic methods were used:
- determination of radon potential of building areas using in-situ permeability and soil-gas radon concentration measurements;
- measurement of temporal changes of different parameters (soil-gas radon concentration, temperature, pressure difference) in the subfloor region using a system of probes;
- continual monitors of radon concentration in air to determine changes of indoor radon concentration under different conditions (changes in ventilation, heating, meteorological conditions, etc.); due to a prototype of a new radon monitor RADONIC with a fast response even fast changes of indoor radon concentrations could be monitored;
- smoke-pipes, a thermographic camera and flowmeters to identify cracks in the basement;
- determination of radon entry rate and ventilation rate using the blower door method.

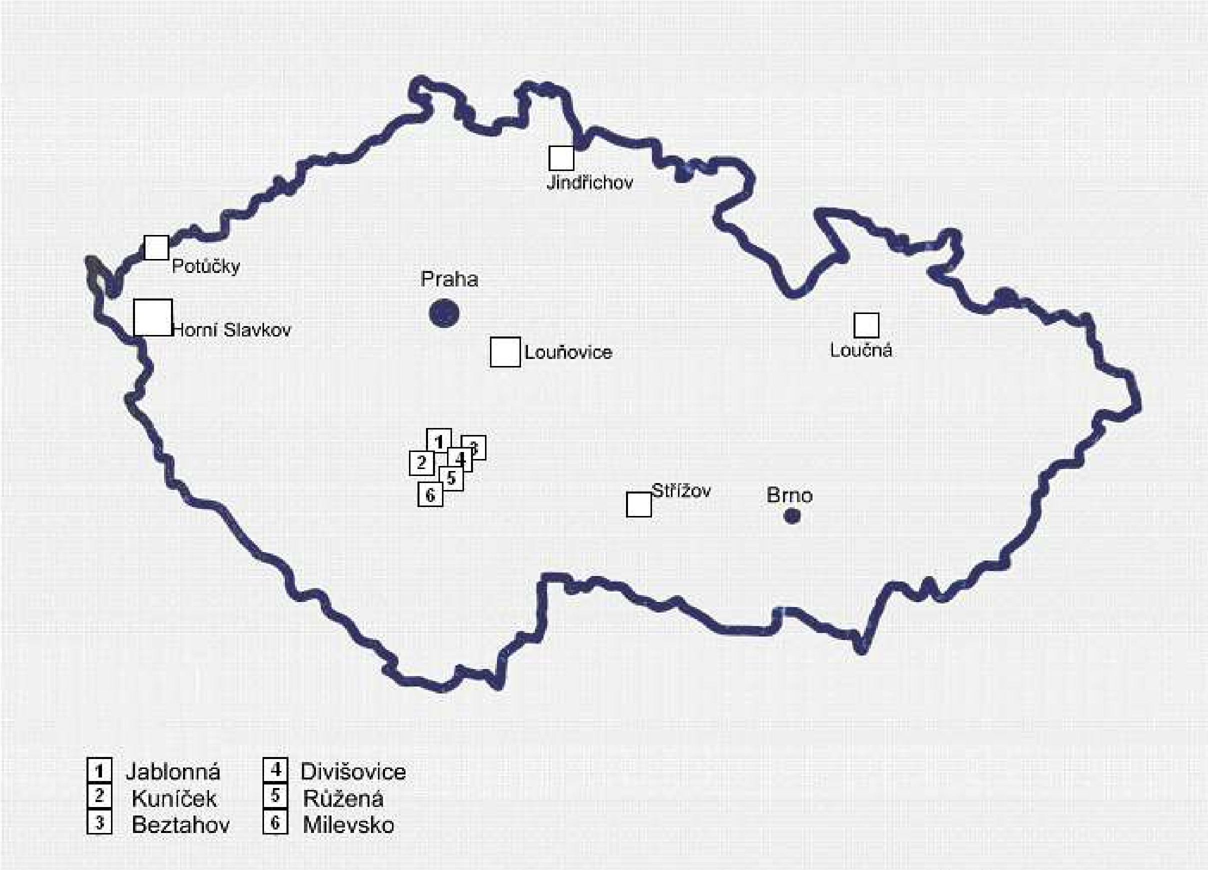

Figure 1. Location of measured houses (two houses in Louňovice; three houses in Horní Slavkov)

RESULTS AND DISCUSSION

As the final report on the research project contains several hundred of pages, only results relating to the problem of a transfer factor applicability will be presented and discussed in the paper. Four practical examples will be given.

The first example illustrates a strong influence of the quallity of preventive protective measures on the indoor radon concentration, i. e. on the tranfer factor value, too. Two new houses - „A“ and „B“ - located in the village Louňovice on areas with a high radon potential were studied. As for the foundation soils, the external conditions are comparable in both cases. Both houses were built on areas with bedrock formed by granodiorites, on highly permeable soils characterized by high soil-gas radon concentrations (see Table 1). Both houses were protected against radon penetration from the ground, in both houses a passive protection based on an application of radon-proof membrane was used. But very different indoor radon concentrations were measured. While the average indoor radon concetrations lower than 100 Bq/m^3 have been found in the house „A“, average indoor radon concentrations exceeding 400 Bq/m^3 in several rooms and short time periods with indoor radon concentrations higher than 2000 Bq/m^3 have been observed in the house „B“.

The reason for the discrepancy was simple. While the protective measures was effective in the house „A“, they failed in the house „B“. Three main failures have been found during the detailed survey of the second house: (i) a non-adequate type of the radon-proof membrane was used; (ii) the subslab drainage layer of gravel was not ventilated; (iii) imperfections occurred during the construction, some joints of the membrane were not sealed perfectly and the membrane was probably also punctured during the construction of the floor in some places.

Table 1. Building area characteristics of two new family houses in Louňovice; c_{A75} = the third quartile of the set of soil gas radon concentration values; k_{75} = the third quartile of the set of permeability measurements; radon potential and radon index were determined in accordance with the uniform method for assessing the radon risk of building sites (Neznal et al. 2004)

House / parameter	soil-gas radon concentration c_{A75} (kBq.m^{-3})	permeability k_{75} (m^2)	radon potential	radon index
Louňovice „A“	143,6	1,4.10^{-11}	167,0	High
Louňovice „B“	122,3	1,1.10^{-11}	126,5	High

The second interesting **example** of a significant difference between measured indoor radon concentrations in two similar houses results from a comparison of two old houses without remediation in the western part of the Czech Republic: the house in the village Potůčky and one of three houses that were studied in the village Horní Slavkov (marked as Horní Slavkov „B“). The radon potential of both building sites (see Table 2), as well as the state of the constructions were comparable again.

Table 2. Building area characteristics of two old houses: Potůčky and Horní Slavkov „B“; c_{A75} = the third quartile of the set of soil gas radon concentration values; k_{75} = the third quartile of the set of permeability measurements; radon potential and radon index were determined in accordance with the uniform method for assessing the radon risk of building sites (Neznal et al. 2004)

House / parameter	soil-gas radon concentration c_{A75} (kBq.m^{-3})	permeability k_{75} (m^2)	radon potential	radon index
Potůčky	70,7	1,6.10^{-11}	87,6	High
Horní Slavkov „B“	114,1	5,7.10^{-12}	90,9	High

As for the indoor radon concentration, extremely high values were observed in the house Potůčky. The annual mean values measured using solid state nuclear track detectors have reached almost 20000 Bq.m^{-3}. During the detailed diagnostic survey of the house in October 2004, the average indoor radon values were about 35000 Bq.m^{-3} in habitable rooms and 77000 Bq.m^{-3} in the cellar, that means the indoor radon concentration in the cellar was the same as the soil-gas radon concentration in the surroundings of the building. As can be seen in Fig. 2, very fast changes of indoor radon concentration were observed. On the other hand, the average indoor radon concentrations not greater than 700 were found in the house Horní Slavkov „B“.

The exact reason, why the indoor radon concentrations in the first house were extermely high, more than ten times higher than in the second one, is not known. Fast changes of indoor radon in the house Potůčky could indicate an extremaly high permeability of some parts of the subfloor region, or even presence of cavities in the surroundings of the foundations. The cavities could play the role of reservoirs of contaminated air.

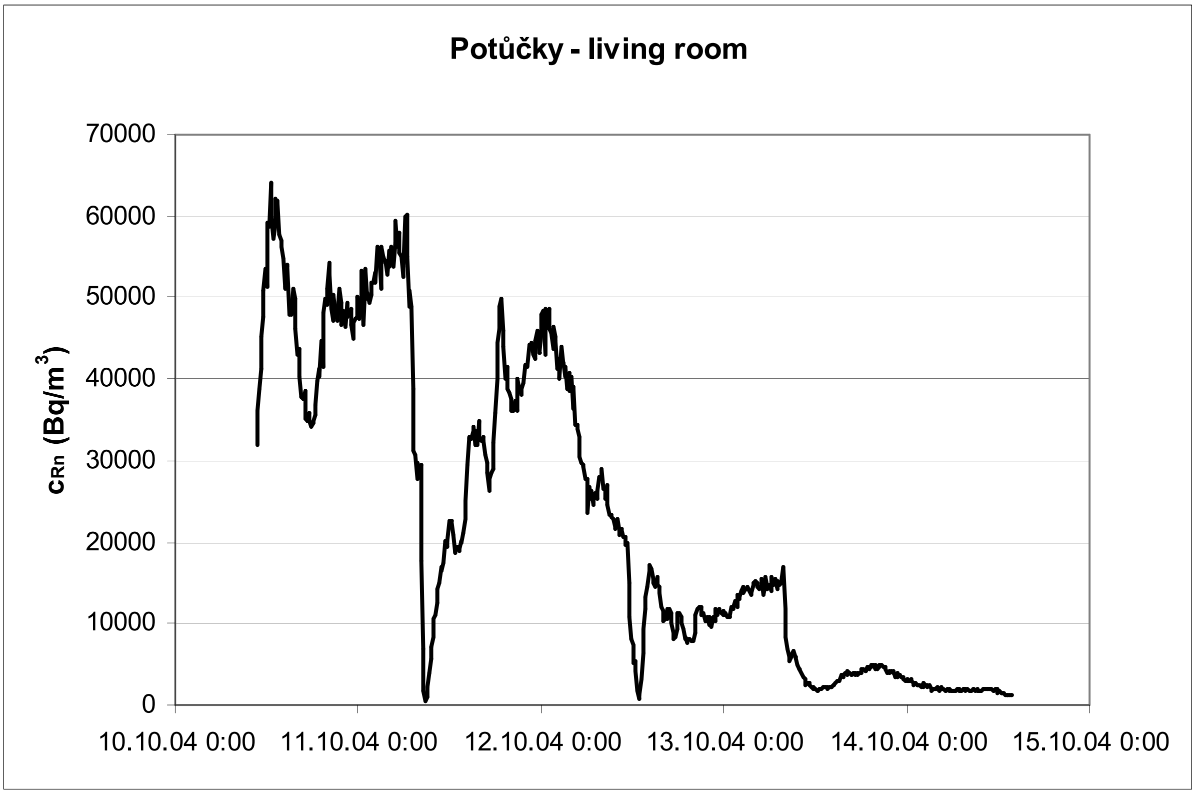

Figure 2. Continual measurement of indoor radon concentration (c_{Rn}); meas. interval 10 min

The third example illustrates the fact that the indoor radon concentration (and the transfer factor, too) may be strongly influenced by human behaviour.

The family house Horní Slavkov „A“ is one of the buildings, in which remedial measures were realized in the past. Original indoor radon values had ranged from 2000 to 10000 Bq/m^3. In 2003, the installation of a sub-slab depressurization system and the reconstruction of floors resulted in a substantial decrease of indoor radon concentration. A positive effect of the sub-slab ventilation is shown in Fig. 3.

To get some information on a long-term average values of indoor radon concentrations after remediation, electret detectors were installed in the house for a period of two months. During the exposure period, two unexpected visits in the house occured. In both cases, the SSD system was switched-off. Due to this experience, the results given in Table 3 were not surprising.

The indoor radon concentrations generally depend on the way of inhabitants' living. **The fourth example** shows changes of radon concentration in ground floor after opening the door from the cellar in the house Louňovice „B“. The measurement was performed under controlled conditions, when only one person was inside.

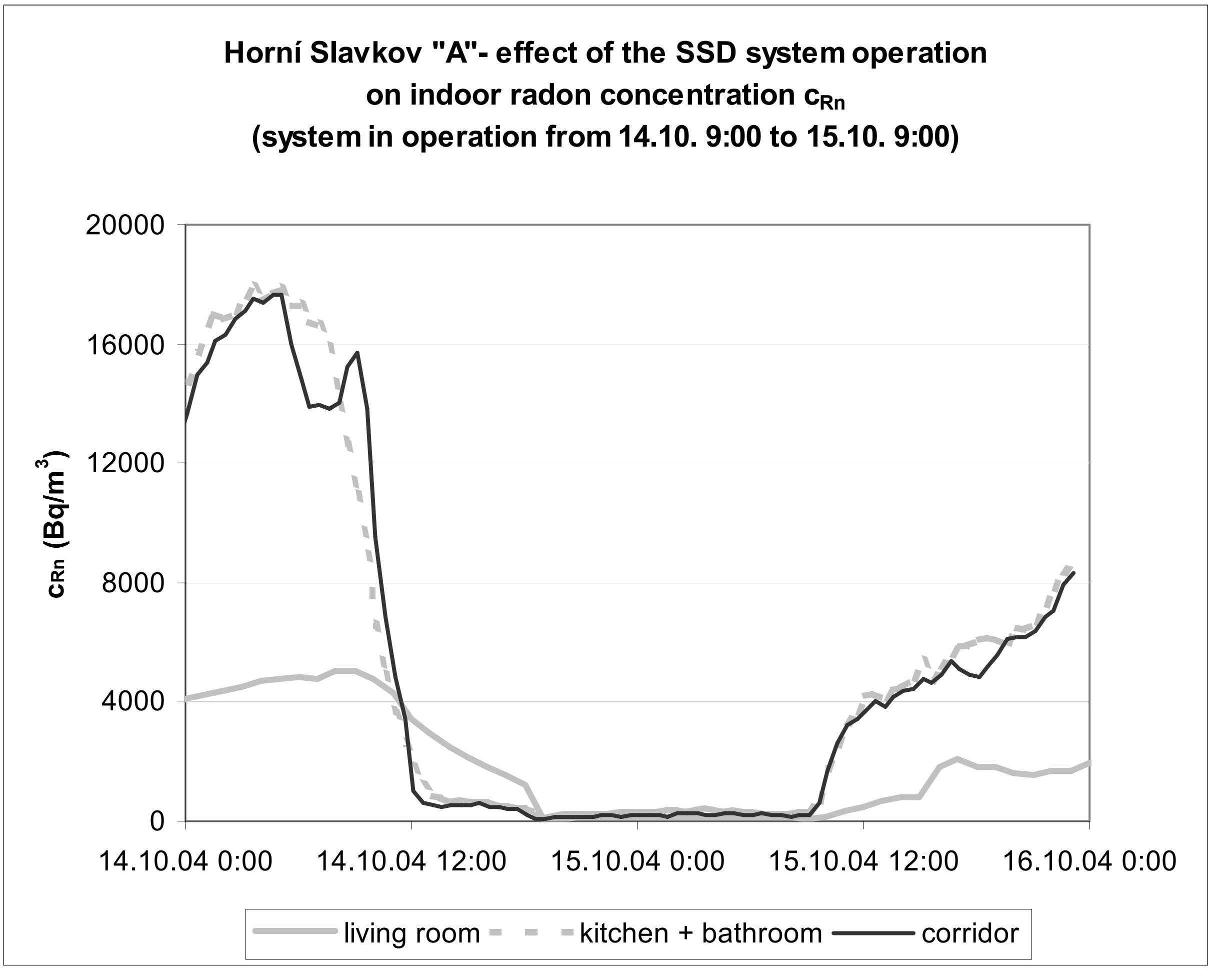

Figure 3. Influence of the sub-slab ventilation on the indoor radon concentration (c_{Rn}); meas. interval 30 min

Table 3. Indoor radon concentrations in the house Horní Slavkov „A“; long-term measurement using electret detectors, exposure period from 13.10.2004 to 13.12.2004

Room	indoor radon concentration ($Bq.m^{-3}$)
living room	>2505
bedroom	>2272
corridor	>2567
kitchen	>2483

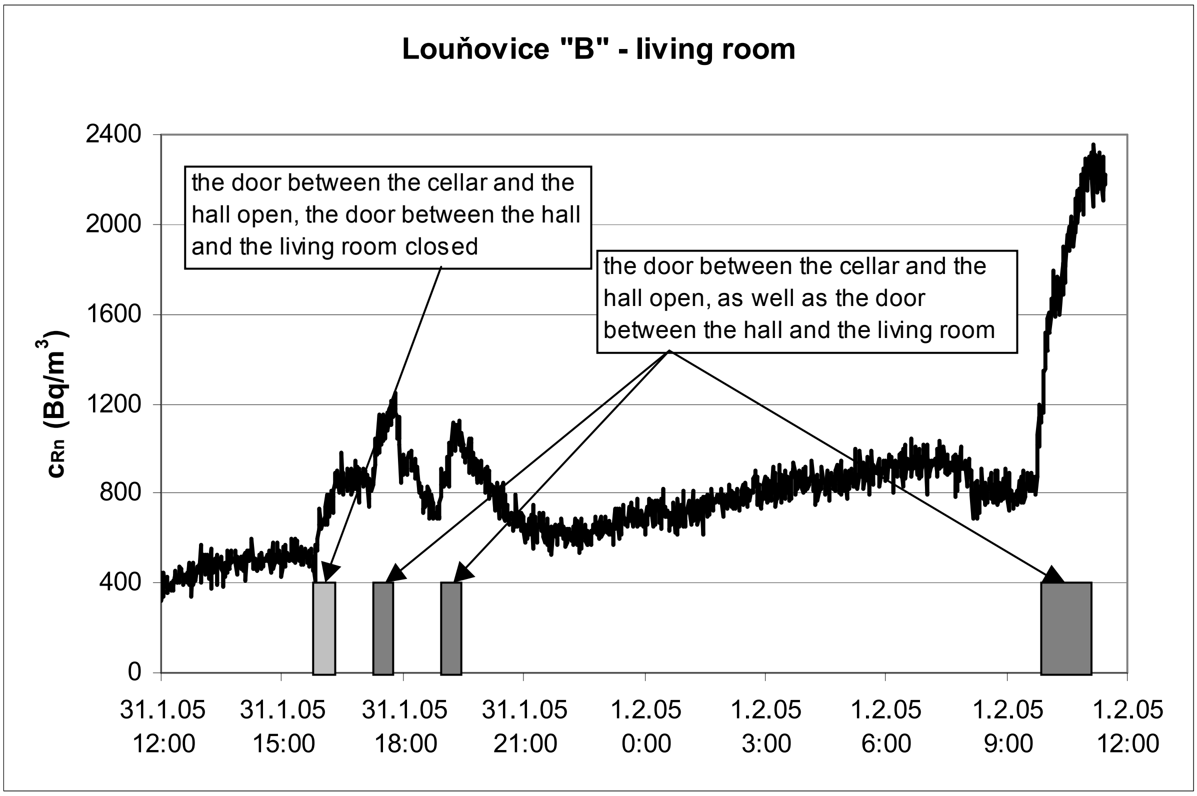

Figure 4. Influence of opening the doors between the cellar and the hall and between the hall and the living room on the radon concentration in the living room (c_{Rn}); meas. interval 1 min

It is evident that the indoor radon concentration is influenced by many factors, such as state of building foundations, ventilation, behaviour of inhabitants, and meteorological conditions.

A prediction of the indoor radon concentration in an individual house based on a statistically derived transfer factor can be wrong very often. The main reason is given by the fact, that the variability of many parameters affecting the indoor radon concentration and the transfer factor is large. Not only the variability in time is important, but also the variability in space. If we substitute an average value for a real range of any parameter, we do not take into account that inhomogenities characterized by maximal values of the parameter (for example inhomogenities of the permeability in the subfloor region) may be decisive for various consequences (for example for the radon entry into the house).

CONCLUSIONS

The average transfer factor derived from large data sets cannot be used to predict the indoor radon concentration in an individual house.

Of course, it is possible to determine a specific transfer factor for a specific room in a given time (i.e. for specific indoor and outdoor characteristics), but the usefulness of this parameter is disputable.

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