STRAIGHT TUBE NESTS IN CONCRETE WALLS FOR RADIATION SHIELDING

By

E. J. Szondi

Nuclear Training Reactor of the Technical University Budapest

Received January 7, 1982
Presented by Dir. Dr. Gy. Csom

1. Introduction

The primary-circuit installation of the Paks Nuclear Power Plant lies within the so called 'hermetic rooms system' the confining walls of which serve at the same time for radiation shielding. Since the central control room of the plant, the power switchgears, laboratories etc. lie outside this hermetic unit, a large number of measuring cables, transmission cables, sampling pipelines etc. have to be passed through these walls.

A mutual feature of the practices known from the literature (Summary: [1]) is that the wall passage tubes are L or Z-shaped or helical, preventing thus direct radiation. In contrast with this practice, *straight protective tube nests are* used at the *Paks Nuclear Power Plant* for the same purpose, the requirements of radiation attenuation being met by the use of additional fittings.

The purpose of our experiments has been to test if the building technology (first of all concreting technology) permits preparing passages which, after further assembly work, will meet the requirements of radiation protection.

2. Ideal and actual concreting

Entering the homogeneous infinite semiplane in direction $+z$, the intensity of the parallel monoenergetic gamma beam changes in accordance with the following formula:

$$I(z)=I(0)\exp\left(-\frac{z}{\lambda}\right).$$

Because of scattering of gamma photons, the parallelism condition is not fulfilled in the interior of the shielding wall. Approximating the role of multiply-scattered photons by means of the *buildup factor*:

$$I(z)=I(0)\exp\left(-\frac{z}{\lambda}\right)B\left(\frac{z}{\lambda}\right)$$

(For empirical formulae of the buildup factor see e.g. [2].)

In the above relationships, term z/λ is the dimensionless expression for wall thickness i.e. thickness measured in *mfp* (*mfp = mean free path*, or, in other words, *relaxation length*, a macroscopic material characteristic [3]).

Like the entire wall, also the different parts of the wall can be measured in *mfp*. The model described above will be true i.e. the relationship written for the homogeneous plane will apply also to this quasi-homogeneous case if the density gradient of the concrete is small, and also the heterogeneities (e.g. pebbles in concrete) of the wall are small as compared with *mfp*. Walls meeting this requirement are considered *ideal.*

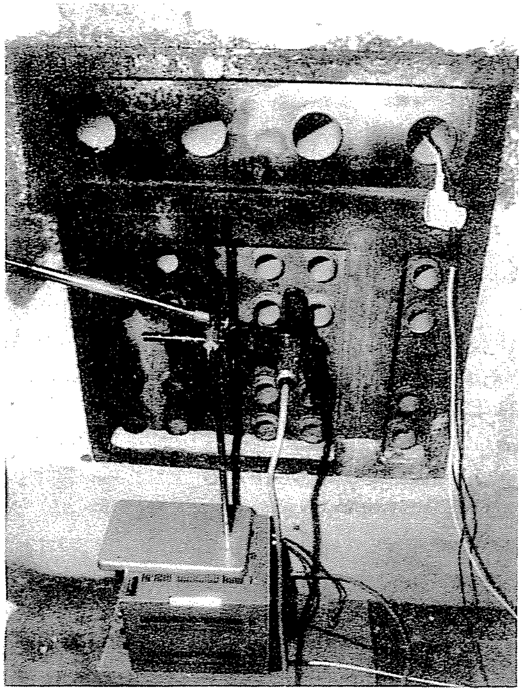

Fig. 1. Detector behind passage in in-situ measurement

However, if larger heterogeneities are present in the wall, a new model shall be applied to the semiplane. According to Coveyou [4], 'channels' are forming in the filler between larger solid lumps. Because of the fundamentally exponential nature of attenuation, the total gamma intensity passing through the wall is higher than would be if shielding were provided by a homogeneous mixture.

In the area of only a few centimeters between the passage tube nests (Fig. 1), it is difficult to compact the concrete, a fact affecting the shielding properties of the wall in the *actual* case unfavourably by

- — reducing average density,
- — worsening homogeneity.

Because of the intricate geometry (Fig. 2) and the heterogeneities, the shielding conditions can not be followed by calculations.

Assuming that, in case of *ideal* concreting and with the additional shielding elements fitted, walls with straight tube nests used as passages are *equivalent* to ambient undisturbed walls, the purpose of *qualification* is a comparison of the *actual* and *ideal* case.

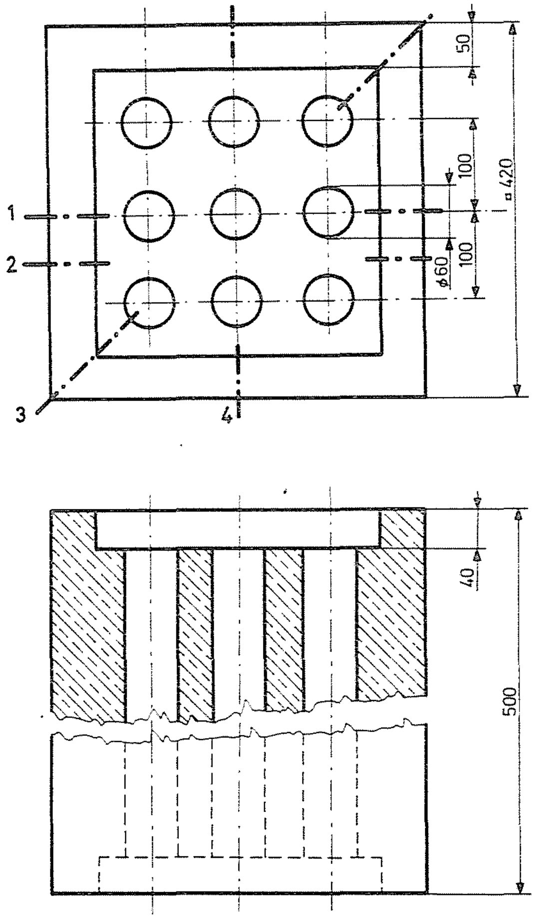

Fig. 2. Passage specimen; 1 horizontal section in the median plane of the specimen; 2 horizontal section in the area between the tubes; 3 diagonal section (along the diagonal plane); 4 vertical section in the median plane of the specimen

3. Measurement method [6]

Specimens were used to represent the *ideal* and *actual* shielding armatures. Measurements were made using extended radiation source (in the irradiation tunnel of the nuclear reactor of the Technical University Budapest, for description see [7]) and point source (see later).

Two specimens of identical rated dimensions determined by the size of the irradiation tunnel of the reactor were used in the measurements (Fig. 2).

The *ideal* specimen was prepared on the basis of the receipt of the so called 'standard concrete suited also for radiation shielding' where the maximum density is about 2300 kg/m^3. The concrete was compacted on a vibratory table. In preparing the *actual* specimen, the usual concreting technology of radiation shielding walls was used, the concrete was compacted by means of the vibrator used in the construction of the walls. (The concreting technology taking the actual operating conditions into consideration specifies a rated density of 2250 ±50 kg/m^3).

Passages are usually built into walls confining rooms which contain extensive radiation sources. However, measurements can usually be carried out by means of point sources. The purpose of the measurements was, among others, to determine the relationship between the results of tests carried out with these two different radiation sources.

As an extended radiation source, the active core of the reactor put out of service for summer overhaul was used. (In case of an operating reactor, the intensity of gamma radiation would have been too high even beyond the minimum automatic power).By the time of the measurements, the half-life of the core increase to about 800 to 900 hours because of the decay of isotopes of shorter half-life. This half-life permitted the change of source strength to be compensated by calculations.

The gamma source strength on the surface of the specimen was approximately uniform within about 20%. Since the same source was used to measure both specimens, the locus-dependence of source strength could be neglected in the comparison of the specimens. The gamma spectrum (reactor) used for the measurement is similar to the spectrum of gamma radiation entering the shielding at nuclear power plants. This similarity and the uniform source strength are favourable in that the measured data may describe the behaviour of passages to be built in at nuclear power plants also numerically.

A Model PMB-6 betatron [8] was used as the point source in the measurements. The radiation of this source is strongly oriented: practically, it acts within a cone of a semi-angle of degree 9.

The map of gamma intensity behind the cable passage was plotted by means of a small scintillation detector (with a diam. 25 × 25 mm NaI(Tl) crystal). The signals of the detector were processed by means of a single-channel

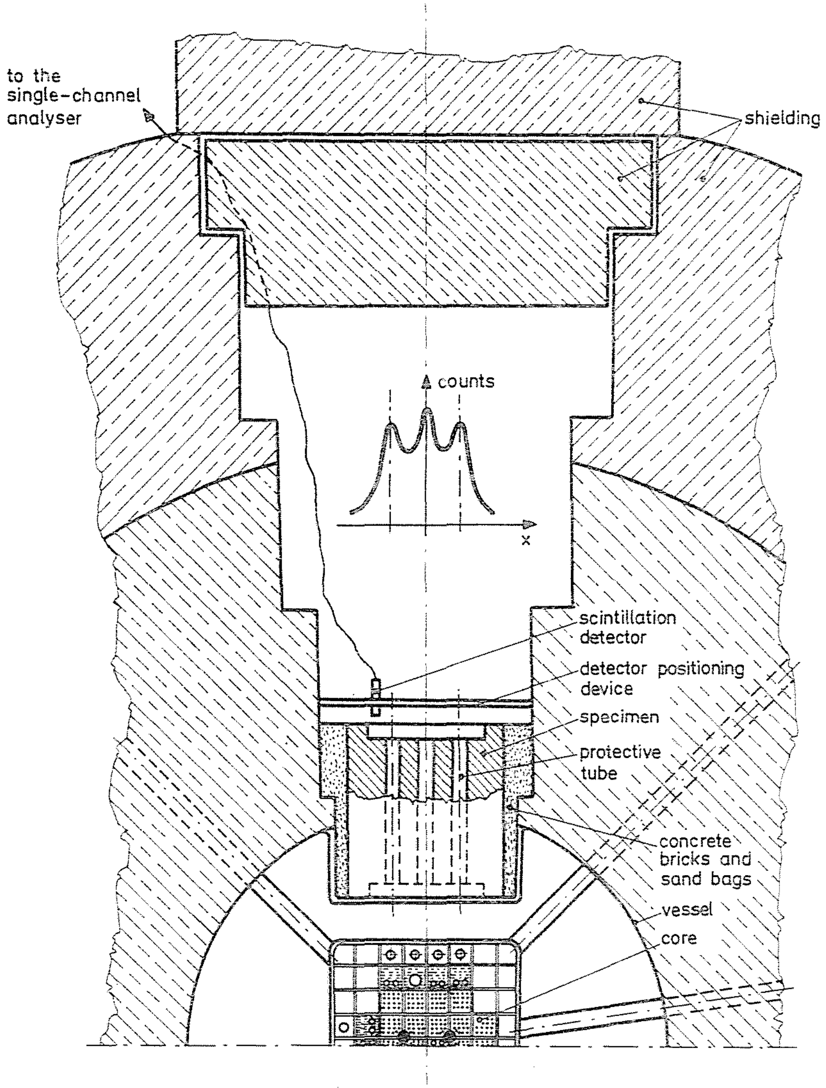

Fig. 3. Specimen in the irradiation tunnel

amplitude analyzer. The discriminator threshold was selected so as to cut pulses below about 1.4 MeV completely. In this way, it was possible to count only pulses resulting from non-scattered photons in measurements made both with the reactor and the betatron.

In measurements in the reactor, the specimen was fixed in a container on the carriage of the irradiation tunnel so that the specimen touched the face of the container (Fig. 3). The vacant space between specimen and container was filled with concrete bricks and sand bags. The detector positioning device was placed in the rear area of the container.

After calibration of the measuring chain, the carriage was sent into the irradiation tunnel. 3 measurements were made in each point along a square lattice of a side length of 1 cm. In order to obtain information on the decay of the core, the detector was left in the same point every evening in the course of the measurement of several weeks.

Then the container carrying the specimen was built into a wall built of concrete bricks in the reactor hall with a view to reduce lateral scattering. The betatron was placed so as to face the central tube of the specimen at the shortest possible distance permitted by its geometry. The detector positioning device was placed, and the measuring points were selected, in the same way as in case of measurements with the reactor.

A maximum photon energy of 2-3-4-5-6 MeV can be adjusted on the PMB-6 betatron. To improve the comparability of the two different sources, 2 MeV was adjusted because the gamma spectrum of a nonoperating reactor was best approached by the spectrum of the X-ray radiation of the betatron in this case. The time-dependence of the source strength of the betatron was monitored by means of an independent measuring chain.

4. Evaluation of the measurement results

As a result of the measurement described in the previous chapter, counts were obtained in the net points behind the passage, and these counts had to be processed to estimate the density of concrete in the passage.

In this approach, the distribution of counts behind the specimen prepared under laboratory conditions (*ideal* concreting) was considered to be the reference shape function.

Opposite to the central tube of the specimen, the counts are approximately independent of the quality of concreting, the decisive majority of the counts resulting from photons getting from the source directly into the detector so that no attenuation has to be reckoned with. Considering the shape function to be unit in this point, the difference in the number of counts behind the specimens of different concreting is the result of the different concreting.

In evaluating the reactor measurements of the attenuation by the specimen prepared under laboratory conditions, using the usual corrections (for dead time, decay etc.) we obtained the shape function of the attenuation by *ideal* passage. The measurement error was about 0.6%. The shape function is shown in Fig. 4. The 'serrated' edges can be attributed to the fact that the sides of the specimen were not completely flat so that, in spite of filling the vacancies with sand bags, there remained still gaps which slightly disturbed the

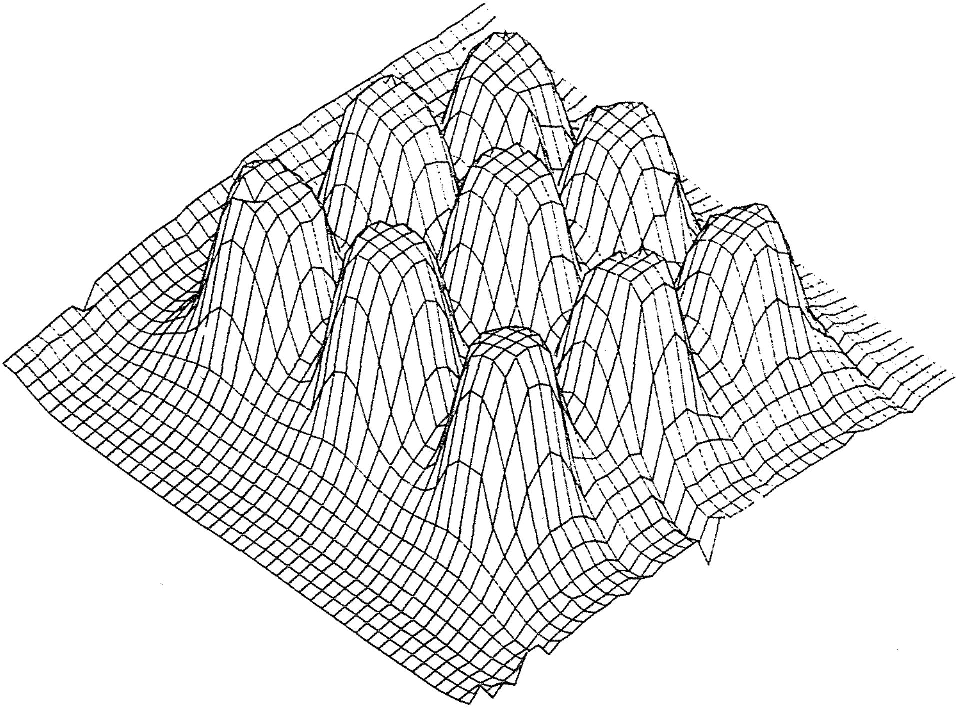

Fig. 4. Perspective drawing of the count intensity distribution developing behind the laboratory specimen in the irradiation tunnel

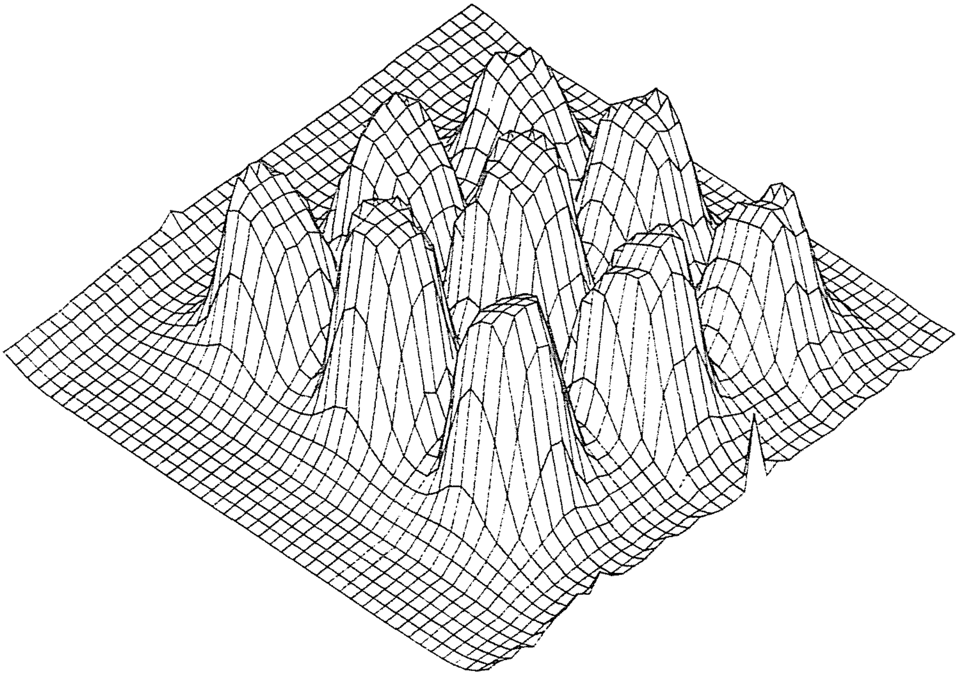

Fig. 5. Perspective drawing of the count intensity distribution developing behind the full-scale specimen in the irradiation tunnel

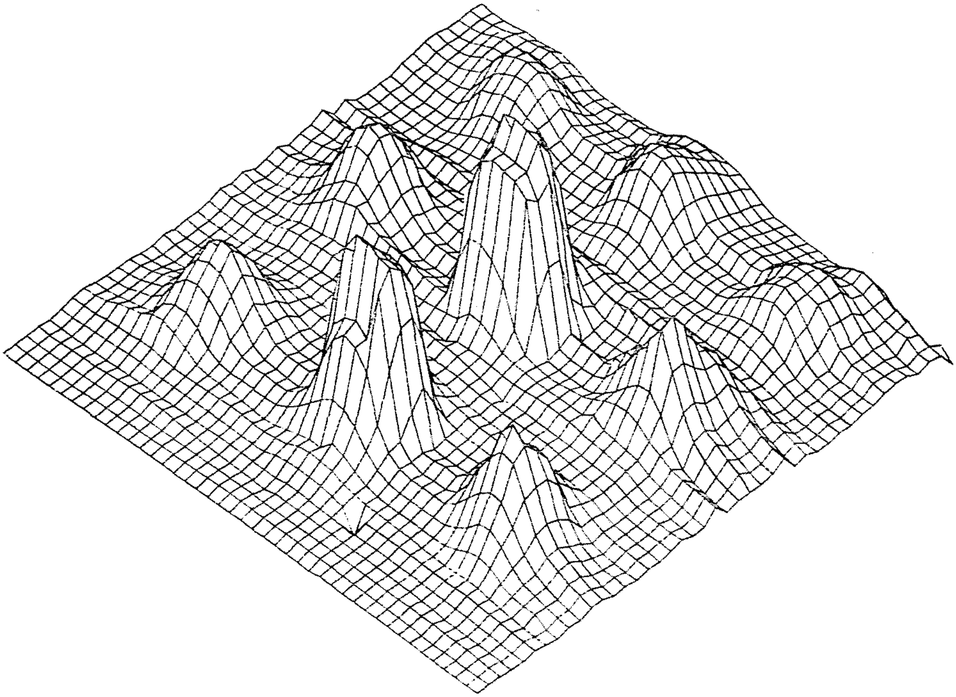

Fig. 6. Perspective drawing of the count intensity distribution developing at the betatron (point source) behind the full-scale specimen

measurement. As can be clearly seen in the Figure, attenuation by the concrete between the tubes is poorer than that by the marginal iron armatures (as has been mentioned in[5]).

The evaluation of the reactor measurement of the specimen prepared under full-scale conditions agreed with what has been said above in every respect. The distribution of counts behind the *actual* specimen can be seen in Fig. 5. It can be seen that fundamentally the diagram remained unchanged but the local number of counts increased because of the non-uniform compacting.

The betatron is a weaker radiation source as the reactor core was at the time of the measurements, its yield changing considerably with time. Therefore, also monitoring had to be taken into consideration in evaluating the measurements. Thus, the ultimate error of measurement is about 1.5%. The distribution of counts behind the passage made under full-scale conditions is given in Fig. 6.

5. Conclusions

Measurements were made to compare the gamma-attenuation properties of passages where the concreting can be considered ‘ideal’ and passages with concreting of maximum achievable density under full-scale conditions. In the latter case, the poor attenuation properties can be attributed exclusively to factors affecting concreting unfavourably under full-scale conditions. (Such factors, to mention only the most important ones, are the inaccessibility of wall passage armatures clamped between forms of a height of several meters, impossibility of vibration ramming between the tubes of multi-row or even superimposed multi-row wall passage armatures, close reinforcing bars, close arrangement of protective tubes etc.)

Tabulated below are the experiences of a comparison of the results of in-situ measurements [5] with the results of the measurement of the specimens:

Measuring points	Maximum/minimum ratio of counts
Full-scale specimen measured with betatron, section *4*	35.04
In situ measurement with betatron, tube centre, undamaged wall	37.65

Both maximum/minimum ratios correspond to the conditions of measurement. That means that the measurement method used was a good laboratory reproduction of the in-situ measurements.

In Figs 4 to 6 showing the count intensity behind the passages, the consequences of difficulties in concreting technology can be clearly seen:

— The peaks of count intensity measured over against the protective tubes of the laboratory specimen differ from each other to the extent corresponding to the uneven gamma-source distribution (Fig. 4);

— On the other hand, the change of count intensity due to the rapid change in density at the concrete layer interfaces can be clearly followed on the specimen prepared under full-sclae conditions (Fig. 5);

— the same effect can also be recognized when the measurement is made with betatron (Fig. 6).

The measurement method was developed as a comparative measurement. In full-scale application, the number of measuring points had to be reduced considerably. For this purpose, the series of counts obtained for 4 typical sections have been compared (43 points instead of 43^2 measuring points!). Since the same lattice spacing was used for all the three series of measurements, the *correlation coefficient* between the counts obtained in the corresponding lattice point series was considered to be the typical information. For the sake of comparison, the correlation with the data calculated for continuous wall was also investigated (by continuous wall we understand here the wall section in which *there is no* passage while its concreting is considered 'ideal').

Correlation coefficients r_{xy} are tabulated below, where subscripts x and y relate to the different measurements:

L results obtained in the reactor measurement of the *l*aboratory specimen
F results obtained in the reactor measurement of the *f*ull-scale specimen
B results obtained in the betatron measurement of full-scale specimen
C calculated attenuation figures of *c*ontinuous wall.

r_{xy}	Number of sections			
	1	2	3	4
r_{LF}	0.865	0.942	0.780	0.938
r_{LB}	0.755	0.856	0.649	0.632
r_{LC}	0.762	0.786	0.746	0.821
r_{FB}	0.583	0.762	0.591	0.707
r_{FC}	0.593	0.614	0.591	0.672
r_{BC}	0.661	0.934	0.502	0.493

The good correlation between the horizontal section of the measurement with betatron, relating to the concrete layer, and the calculated data for the continuous wall is conspicuous: the geometrical effect may even conceal the results of uneven compacting. Defects in the concrete are essentially detected by an analysis of the counts obtained in a *diagonal* section.

Acknowledgements

Sincere thanks are expressed here to Mrs. L. Bollók and Ms. É. Sipos for their assistance in ten thousands of measurement and in computer processing of the data.

Explanation of the symbols used

B buildup factor
I value of intensity character (such as e.g. pulse rate, dose rate etc.)
r_{xy} correlation coefficient between statistical variables x and y
z co-ordinate perpendicular to wall plane (thickness)
λ relaxation length

Summary

Measuring cables, sampling pipelines etc. starting from the rooms of the primary circuit of the Paks Nuclear Power Plant are passed through concrete shielding walls in protective armatures made of straight tube nests. The confined area between the tubes affects the homogeneity of the concrete unfavourably. Because of the intricate geometry, the actual conditions can be followed only experimentally. In these experiments, the gamma-radiation field behind the protective armature has been investigated using both extended and point sources. The attenuating effect of wall armature specimen prepared under service conditions is inferior as compared with the specimen considered ideal, prepared in laboratory. Local defects resulting from inhomogeneities in the concrete can be sufficiently detected.

References

1. JAEGER, R. G. (Ed.): Engineering Compendium on Radiation Shielding. Vol. III. Springer-Verlag Berlin, 1970. pp. 394–404.
2. STEVENS, P. N., TRUBEY, D. K.: Methods for Calculating Neutron and Gamma-Ray Attenuation. DASA-1892-3. March 1972.
3. SZONDI, E. J.: Calculation of Relaxation Length from Measured Data (in Hungarian). Energia és Atomtechnika **29** (1976). No. 7.
4. JAEGER, R. G. (Ed.): Engineering Compendium on Radiation Shielding. Vol. I. Springer-Verlag Berlin, 1968. pp. 487–497.
5. SZONDI, E. J.: Report BME-TR-67/77. Budapest Techn. Univ. 1977. (*)
6. SZONDI, E. J.: Report BME-TR-79/78. Budapest Techn. Univ. 1978. (*)
7. CSOM, GY.: The Nuclear Reactor of the Budapest Technical University. Periodica Polytechnica Electr. Eng. 26/1—2. (1982).
8. ANANJEW, L. M., TSCHACHLOW, W. L.: Ein transportables Betatron und seine Anwendung. Materialprüfung (Düsseldorf) *13*. (1971) No. 11.

* Reports for restricted distribution

Dr. Egon J. SZONDI H-1521 Budapest