DISTINGUISHABL VOID SIZE AND NEUTRON DOSE-EQUIVALENT-RATE INCREASING DUE TO A VOID IN A CASK SHIELD

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SUMMARY

As a neutron shielding material of a high-burnup spent fuel shipping cask, a kind of epoxy resin, NS-4-FR, has been employed in Japan. The NS-4-FR shield is solidified by mixing the base and the hardener in the normal temperature, and or rare occasions, small voids might be produced in it during the solidifying process. The void is a defect of a shield, and as an inevitable consequence, the defect makes some deterioration of the neutron shielding ability of the shield.

In order to simulate the void produced in the NS-4-FR shield, seven plugs in which each plug has an artificially made void were prepared. The plugs with the void were set at the center of the NS-4-FR slab, alternately. The neutron dose-equivalent rates penetrated through the shielding systems were measured with a moderator-type neutron survey meter. The neutron source was a ^{252}Cf and the intensity was 5.02×10^7 n/s at the experiments. The void sizes prepared in the experiments were from the minimum size of $0.3^{\phi}\times0.3$ cm to the maximum size of $5^{\phi}\times5$ cm, and the neutron survey meter employed in the experiments has relatively large volume of $20^{\phi}\times23$ cm. Accordingly, the measured dose-equivalent rates obtained with the survey meter were the values averaged over the volume of it. Therefore, the volume of the survey meter was taken into account in the analysis by the continuous energy Monte Carlo code MCNP 4A with the NESXE (Next Event Surface Crossing Estimator). The shielding experiments were carried out to evaluate the void effects with three-types of arrangements. Arrangement 1 : only the NS-4-FR slab with a void was set, Arrangement 2 : the slab with a void was sandwiched by the slabs without a void, and Arrangement 3: Type 304 SS (stainless steel) slabs of 25 cm thick were located on the neutron source side of the NS-4-FR slab with a void. The Arrangement 3 is simulating an actual structure of a spent fuel shipping cask. The experimental results and the Monte Carlo analyzed data were indicated as the increasing ratio of neuron dose-equivalent rate as a function of the void size.

In the Arrangement 1, the increasing ratio of neutron dose-equivalent rate was observed when the void size was more than $1^{\phi}\times1$ cm by the survey meter, and the increasing ratio of the $5^{\phi}\times5$ cm void was approximately 25 % as compared with the dose -equivalent rate of the NS-4-FR slab without the void. On the other hand, in the Arrangement 3, that is Type 304 SS

slabs of 25-cm-thick was located on the source side of the NS-4-FR slab with the void, the increasing ratio was observed when the void size is more than $2^{\phi}\times 2$ cm, and the increasing ratio of the $5^{\phi}\times 5$ cm void was approximately 17.5 % by the survey meter. Due to locating the Type 304 SS slabs on the source side, most of the neutrons entering the NS-4-FR slab with the void were multi-scattered and moderated neutrons, and the dose conversion factor of the moderated neutrons is smaller than that of fast neutrons. Then, the increasing ratio of neutron dose-equivalent rate in the Arrangement 3 becomes smaller than that of the Arrangement 1.
As compared with the experiments, the Monte Carlo calculations with the NESXE showed fairly good agreement for the whole void sizes in the Arrangement 1, however, the Monte Carlo calculations were overestimated with the void size in the Arrangement 3.

INTRODUCTION

As a neutron shielding material of a high-burnup spent fuel shipping cask, a kind of epoxy resin, NS-4-FR, has been employed in Japan. The neutron shielding ability of the NS-4-FR is just slightly inferior to polyethylene (Iron-Polyethylene Shielding System, Neutron Shielding Effects). However, it can be used under 150℃ continuously, and the secondary gamma-rays produced through the capture of thermal neutrons in hydrogen contained in it can be reduced easily by adding boron. On the contrary, the softening temperature of polyethylene is less than 50℃. Accordingly, polyethylene can not satisfy the transport conditions as provided by the IAEA transport regulation (Basic Safety Standards). The NS-4-FR shield is solidified by mixing the base and the hardener in the normal temperature, and as rare occasions, small voids might be produced in it during the solidifying process. The void is a defect of a shield, and, as an inevitable consequence, the defect results in some deterioration of the shielding ability.

In order to simulate the void produced in the NS-4-FR shield seven plugs in which each plug has an artificially made void were prepared. The plugs with the voids were set at the center of the NS-4-FR slab, alternately. The size of each NS-4-FR slab and each Type 304 SS slab is $80\times 80\times 5$ cm thick. The neutron dose-equivalent rates penetrated through the shielding systems are measured with a moderator-type neutron survey meter. The neutron source was a ^{252}Cf and the intensity was 5.02×10^7 n/s at the experiments, and the void sizes prepared in the experiments were from the minimum size of $0.3^{\phi}\times 0.3$ cm to the maximum size of $5^{\phi}\times$ 5 cm. The neutron survey meter employed in the experiments has relatively large volume of $20^{\phi}\times 23$ cm. Accordingly, the measured dose-equivalent rates measured with the survey meter are the values averaged through the volume. Therefore, the volume of the survey meter was taken into account in the analysis by the continuous energy Monte Carlo code MCNP 4A with the NESXE (Next Event Surface Crossing Estimator). The NESXE has actual results reduce the fsd (fractional standard deviation) effectively, because the estimator possesses good characteristics of both the point detector and the surface crossing estimators. The shielding experiments were carried out to evaluate the void effects with three-types of arrangements. Arrangement 1: only the NS-4-FR slab with a void was set, Arrangement 2: the slab with a void was sandwiched by the slabs without a void, and Arrangement 3: Type 304 SS slab of 25 cm thick were located on the neutron source side of the NS-4-FR slab with a void. The Arrangement 3 is simulating an actual structure of a spent fuel shipping cask.

EXPERIMENTS AND MONTE CARLO ANALYSIS

In order to simulate the void produced in the NS-4-FR shield, seven plugs in which each plug has an artificially made void were prepared. The configuration and sizes of the seven plugs with a void are shown in Fig. 1. The minimum size of the void is $0.3^{\phi} \times 0.3$ cm and the maximum one is $5^{\phi} \times 5$ cm. These plugs were inserted in the center of the NS-4-FR slab, alternatively. To evaluate the void effects to the neutron shielding systematically, three-types of arrangement were provided and experimented with a ^{252}Cf neutron source. The source intensity of the ^{252}Cf was 5.02×10^{7} n/s at the experiments.

The three-types of arrangements are illustrated in Fig. 2.

Arrangement 1 : Only one NS-4-FR slab with the plug is set.

Arrangement 2 : The slab with the plug is sandwiched by the slab without the plug.

Arrangement 3 : Type 304 SS slabs of 25 cm thick are located on the neutron source side of the slab with the plug.

The side of each NS-4-FR slab and Type 304 SS slab is $80 \times 80 \times 5$ cm^{t}. The neutron survey meter employed in the experiments is shown in Fig. 3. The survey meter is a moderator-type with thick polyethylene and has relatively large volume of $20^{\phi} \times 23$ cm. Accordingly, the measured neutron dose-equivalent rates with the survey meter are the values averaged over the volume of it. Therefore, the volume of the survey meter was taken into account in the analysis of the continuous energy Monte Carlo code MCNP 4A with the NESXE, and the diameter of the survey meter was set as 20^{ϕ} cm and the effective center was as 5 cm outside from the real center in the calculations.

As shown in Fig. 2, the neutron shielding experiments were carried out with the Arrangement 1, 2, and 3. However, the results of the Arrangement 1 and 3 are discussed mainly in this study. In the Arrangement 1, most of the neutrons enter into the NS-4-FR slab with a void are the source neutrons of the ^{252}Cf source, average energy is 2.35 MeV. On the contrary, most of neutrons enter into the NS-4-FR slab with a void are intermediate neutrons (1~1000 keV) of which are slow downed in the thick Type 304 SS slabs located on the source side, and the Arrangement 3 is simulating an actual structure of a spent fuel shipping cask.

As indicated in Fig. 4 for the Arrangement 1 and in Fig. 5 for the Arrangement 3, respectively, the experimental results and the Monte Carlo calculations are exhibited as relative increasing ratio of neutron dose-equivalent rates as a function of the void sizes. The relative increasing ratio is calculated as follows.

$$\mathrm{RIR} = \frac{\text{NDER with void} - \text{NDER without void}}{\text{NDER without void}} \times 100,$$

where, RIR = relative increasing ratio of neutron dose-equivalent rate (%),

NDER = neutron dose-equivalent rate.

The error bars shown in Fig's 3 and 4 are fsd's (fractional standard deviation) are calculated as follows.

$$f\left(\frac{C}{A}\right) = \sqrt{f^2(C) + f^2(A)},$$

$$f(C) = \frac{\sqrt{\left(f(A)\cdot A\right)^2 + \left(f(B)\cdot B\right)^2}}{C},$$

where,

$C = A - B$,

A = neutron dose-equivalent rate with a void,

B = neutron dose-equivalent rate without a void,

$f(A) = $ fsd of A.

CONCLUDING REMARKS

Following remarks are obtained through the experiments and the Monte Carlo analysis. In the Arrangement 1, the increasing ratio of neutron dose-equivalent rate can be observed when the void size is more than $1^{\phi} \times 1$ cm by the survey meter, and the increasing ratio of the $5^{\phi} \times 5$ cm void is approximately 25 % as compared with the dose-equivalent rate of the NS-4-FR slab without the void. On the other hand, in the Arrangement 3, that is Type 304 SS slabs of 25 cm thick is located on the source side of the NS-4-FR slab with the void, the increasing ratio can be observed when the void size is more than $2^{\phi} \times 2$ cm , and increasing ratio of the $5^{\phi} \times 5$ cm void is approximately 17.5 % by the survey meter. Due to Type 304 SS slabs are set on the source side, most of the source neutrons entering the NS-4-FR slab with the void are multi-scattered and moderated neutrons. The dose-conversions factor of neutrons is depend on its energy and the factor of intermediate and slow neutrons are smaller than that of fast neutrons. Then, the increasing ratio of neutron dose-equivalent rate in the Arrangement 3 becomes smaller than that of the Arrangement 1.

As compared with the experimental results, the Monte Carlo calculations with the NESXE show good agreement for the whole void sizes in the Arrangement 1, however, the Monte Carlo calculations are overestimated with the void size in the Arrangement 3. Due to locating Type 304 SS slabs on the source side, multi-scattered and moderated neutrons are enter into the NS-4-FR slab with the void and intermediate and slow neutrons penetrated through the shielding system are detected by the survey meter. In consequence, the effective diameter of the survey meter in the Arrangement 3 might be larger than that of the Arrangement 1 in the Monte Carlo calculation. Because of the maximum volume of the void is $5^{\phi} \times 5$ cm, the difference of the Monte Carlo calculated neutron dose-equivalent rate between with void and without void becomes smaller with the detector size employed in the calculation.

REFERENCES

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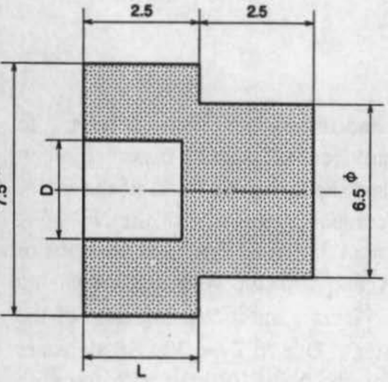


Prepared Plugs

Void Dimension	No.1	2	3	4	5	6	7	8
D φ	5.0	4.0	3.0	2.0	1.0	0.5	0.3	0
L	5.0	4.0	3.0	2.0	1.0	0.5	0.3	0

Fig. 1 Dimensions of a void simulation plug. Dimensions are all in centimetres.

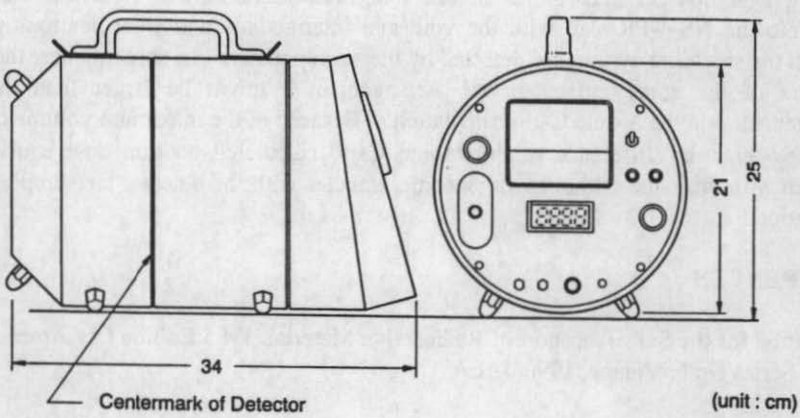
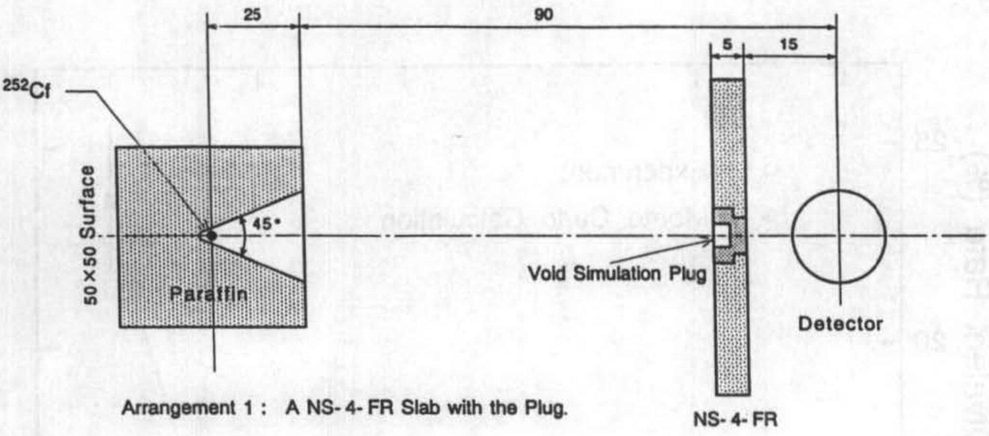
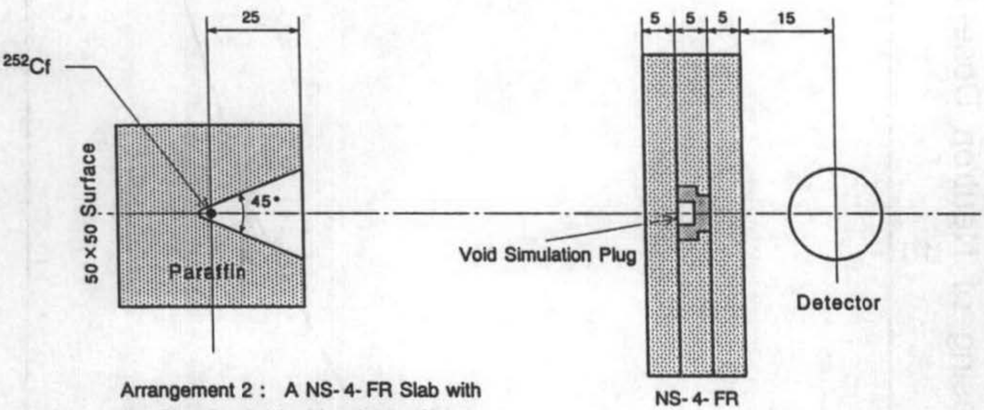


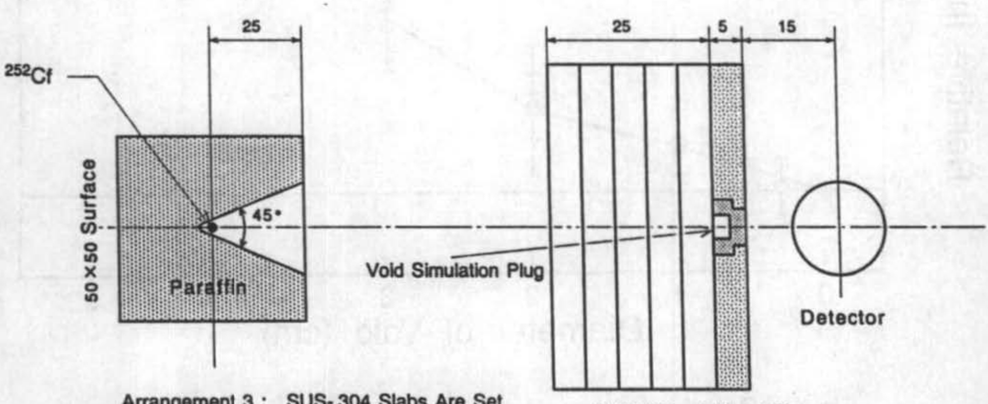
Fig.3 Dimensions of the ALOKA Moderator-Type Neutron Survey meter. The weight is about 9 kg.



Arrangement 1 : A NS-4-FR Slab with the Plug.



Arrangement 2 : A NS-4-FR Slab with the Plug Sandwiched by Normal Slabs.



Arrangement 3 : SUS-304 Slabs Are Set in front of a NS-4-FR Slab with Plug.

Fig. 2. Experimental arrangements to evaluate shielding ability reduction effect of a void in the NS-4-FR slab, systematically. Dimensions are all in centimetres.

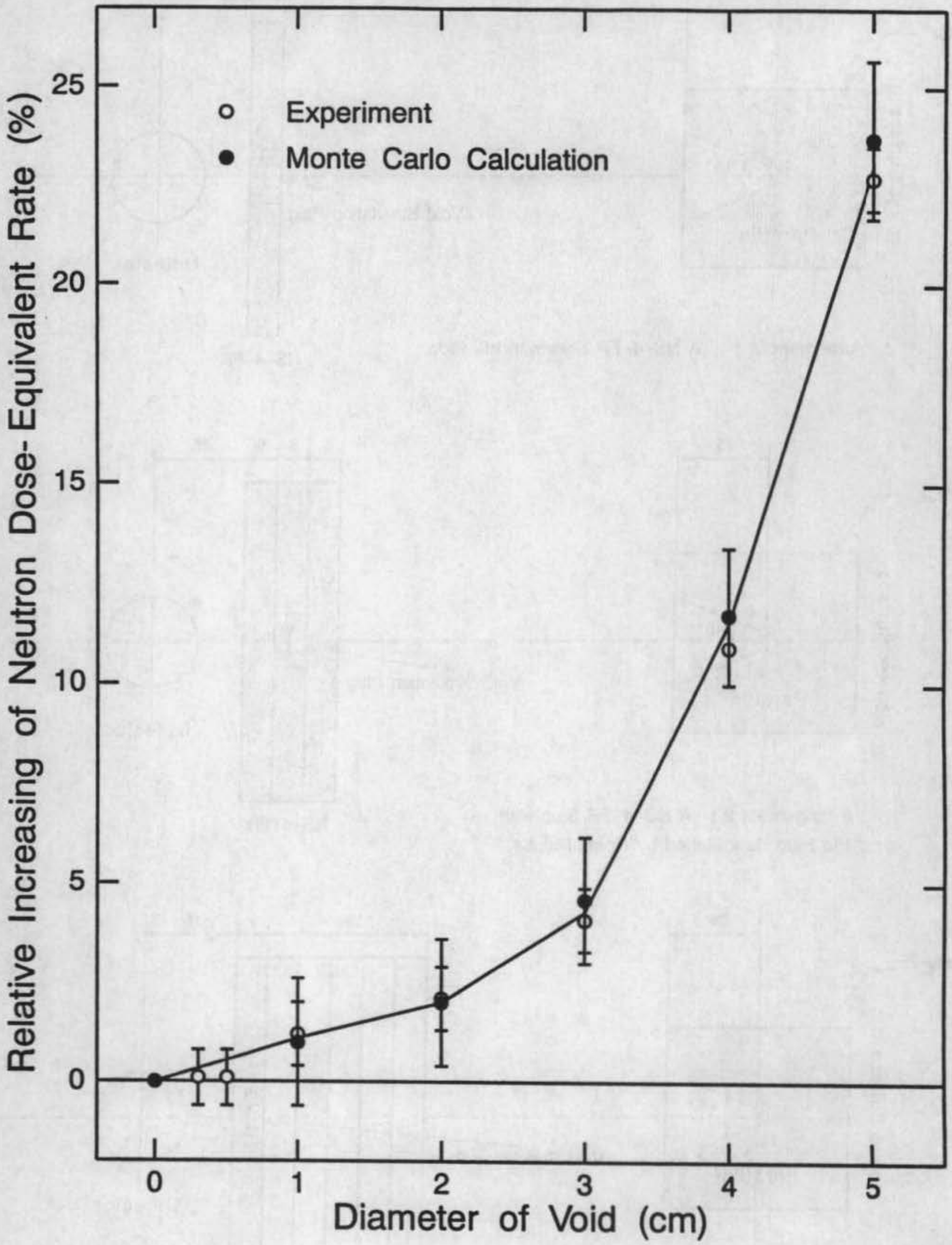


Fig.4 Relative increasing of neutron dose- equivalent rate in the Arrangement 1.

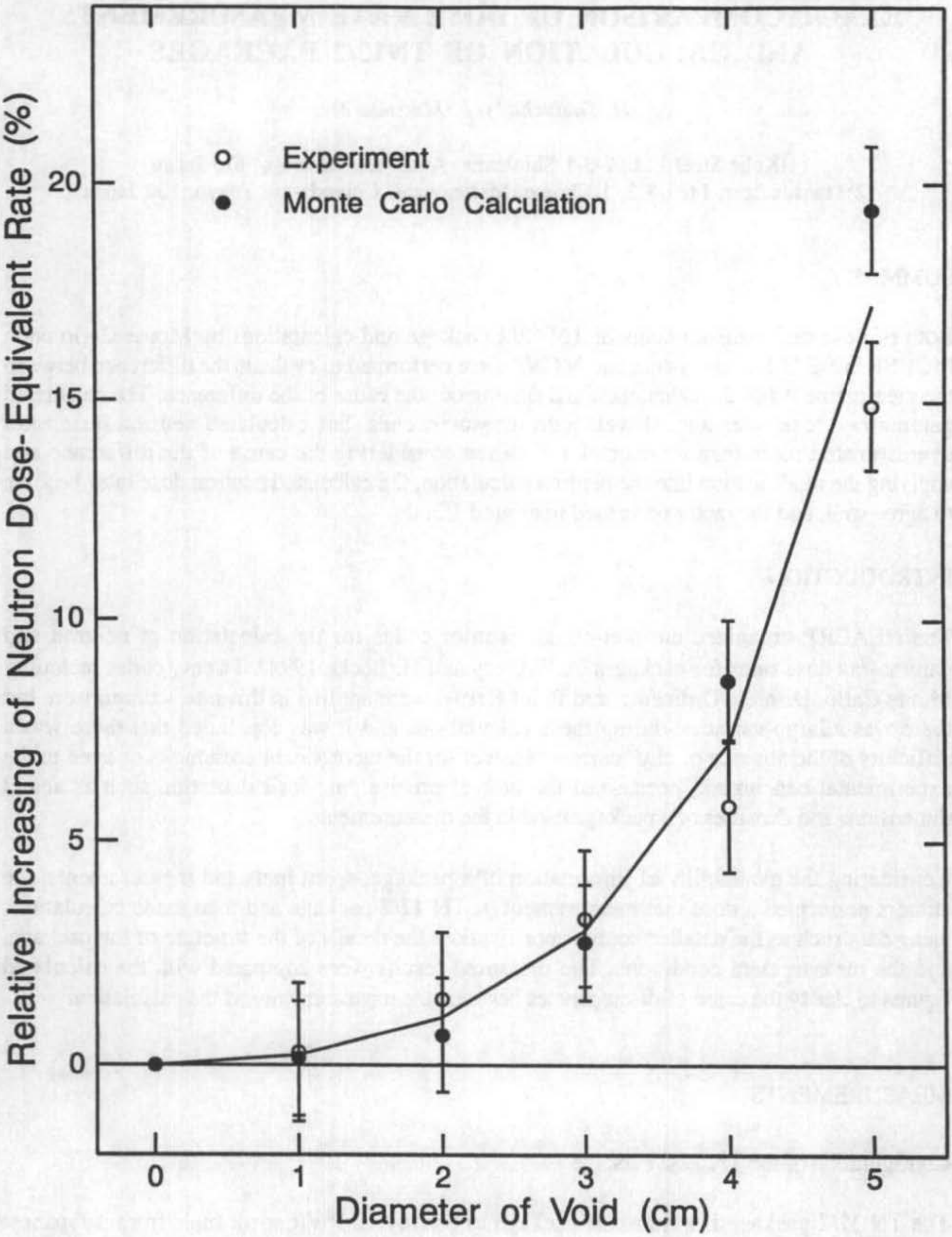


Fig.5 Relative increasing of neutron dose- equivalent rate in the Arrangement 3.