

ELECTRICAL ENGINEERING

Investigation of the Radiation Shielding Capacity of Asphalt and Sand for Fast Neutron Sources

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Abstract. The internal wall of the cavity of experimental assemblies, involved with high energy fusion neutrons, can be covered by an asphalt-sand layer for radiation protection purposes. The calculations have demonstrated that asphalt has a radiation protection capability superior to that of concrete, on equivalent weight basis.

For an experimental cavity using a 10^{12} neutrons/sec neutron generator, the best structure has been found to be a 10% asphalt - 90% red sand homogeneous mixture, against neutron + gamma energies, with a protection capability of more than 200% compared to the same thickness of a concrete structure.

This work has proved that the local and cheap asphalt and sand can replace the relatively expensive concrete in constructing biological radiation shielding of experimental assemblies on fusion neutronics.

Introduction

Neutronic experiments require bulky biological radiation shielding especially because highly energetic (D,T) fusion neutrons with 14.1 MeV have a very high penetration capability. Usually, an experimental facility that is covered with concrete walls of about 2.5 m over a space angle of 4π requires more financial investment for the shielding than for the enclosed experimental assembly.

As the asphalt is rich in hydrogen and carbon, and sand is rich with silicon and some other heavy elements, it is worthwhile to investigate their shielding potential against high energy fusion neutrons and induced gamma rays. This work has been done within the framework of a project on experimental fusion neutronics [1]. The asphalt that is used in this project is paving asphalt grade 60/70, a black semi-solid

sticky substance, obtained from Riyadh Refinery, and its origin is Ras Tanura. The red sand is collected from Nofod desert beside Shaqra city. The chemical composition of asphalt is $(C_{89}H_{104}S_3N_2O_2)_2$ [2,3].

Method of Calculation

The incident neutron and induced gamma-ray fluence transport calculations were performed by solving the Boltzmann transport equation [4], with the aid of the computer code ANISN [5] in $S_8 - P_3$ approximation using mainly the 30-neutron and 12-gamma-ray group data library CLAW-B [6].

The biological human tissue dose equivalent along and beyond the experiment cavity wall was calculated as recommended by ref. [7]:

$$D_c = \int_E \Sigma^D(E) W(E) \phi(E) dE \quad (1)$$

where

E = neutron energy

t = time of exposure

$\Sigma^D(E)$: macroscopic cross section of the human tissue, corresponding to incident neutron

$W(E)$: weight function for the dose unit.

The values of the dose response function, $R(E)$, can be calculated as follows [8]:

$$R(E) = \Sigma^D(E) W(E) \quad (2)$$

and were taken from ref. [9] to be implemented into the data library CLAW-B in order to calculate the dose equivalent with the help of the activity tables in the code ANISN.

On the other hand, a common method of fast neutron measurement is to use threshold detectors. We calculated the total number neutron induced events per cm^2 foils of $^{238}U(n,f)$, $^{232}Th(n,f)$, $^{10}B(n,\alpha)$, $^{27}Al(n,\alpha)$ and $^{56}Fe(n,p)$ detectors as follows:

$$D = \int_E \Sigma(E) \left[\int_t \phi(E,t) dt \right] dE \quad (3)$$

where

$\Sigma(E)$: macroscopic cross section of the corresponding detector material,
 $\int \phi(E,t) dt$: neutron fluence in the experimental cavity wall.

In case of ^{10}B and ^{27}Al detectors,

$$A_0 = \lambda D \quad (4)$$

A_0 corresponds to the initial activity of the irradiated foil, λ being the decay constant of the isotope, produced by activation.

In case of fission detectors, D is equivalent to the number of fission events (fissions/cm²) for the ^{238}U and ^{232}Th foils.

Evaluation of the Shielding Structures for Experimental Cavity

In the course of this study, the experimental cavity for the generation of fusion neutrons is approximated by a sphere of 5 m radius. The yield of the neutron generator is taken as 10^{12} neutrons/sec at 14 MeV.

The neutron transport through the asphalt, red sand, and concrete layers of 50, 75, 100, 125, 150, 175 and 200 cm was calculated with the help of the computer code ANISN in $S_8\text{-P}_3$ approximation. For the sake of comparison, two different data blocks have been utilized. The first one contains DLC-2F [10] and DLC-24 [11] data libraries with the implementation of neutron dose response factors of Snyder-Neufeld [8]. The second one contains coupled 30 neutrons + 12 gamma-ray data library CLAW-B, mainly DLC-36 CLAW [12]. Both libraries, DLC-24 and DLC-36, contain neutron reaction cross-section data; and implementing Los Alamos neutron and gamma-ray dose factors [13]. The biological neutron and gamma ray doses, are added to the above libraries to facilitate the possibility of calculating human exposure to the radiation doses, within different thicknesses of the developed structures.

Assessment of Layered Shielding Structures

The experimental cavity, using different combinations of asphalt and concrete layers is shown in Fig. 1. The atomic densities that were used in calculating the different neutronic effectivities of the shielding structures are listed in Table 1.

In Fig. 2 the biological dose response functions against the asphalt wall thickness for only neutron dose as well as for the coupled neutron and gamma-ray dose are shown. Using the neutron and gamma-ray dose transmission factors [13], it has been possible to assess the neutron and gamma-ray doses behind a 75 cm and 100 cm concrete shielding followed by an asphalt zone of various thickness.

It can be shown from the curves of Fig. 2, that for incident 14 MeV fusion neutrons, an asphalt wall of 50, 75 and 100 cm thickness offers a reduction in neutron and gamma-ray doses by a factor (protection factor) of 23, 76 and 315, respectively.

Table I. Mass and atomic densities of materials used in calculations

Material and mass density (g/cm ³)	Element	Atomic density (10 ²⁴ /cm ³)
Air on the ground 0.0012	Nitrogen	0.4076E-4
	Oxygen	0.9486E-5
Asphalt 0.98	Hydrogen	0.4481E-1
	Carbon	0.3835E-1
	Sulfur	0.1293E-2
	Nitrogen	0.8617E-3
	Oxygen	0.8617E-3
Red Sand 2.65	Hydrogen	0.9613E-2
	Oxygen	0.3573E-1
	Sodium	0.4452E-3
	Magnesium	0.4901E-3
	Aluminum	0.4508E-3
	Silicon	0.1164E-2
	Potassium	0.5481E-3
	Iron	0.3427E-3
Concrete 2.33	Hydrogen	0.9600E-2
	Oxygen	0.3980E-1
	Sodium	0.1300E-2
	Aluminum	0.3100E-2
	Silicon	0.1250E-1
	Calcium	0.4400E-2
	Iron	0.2100E-2

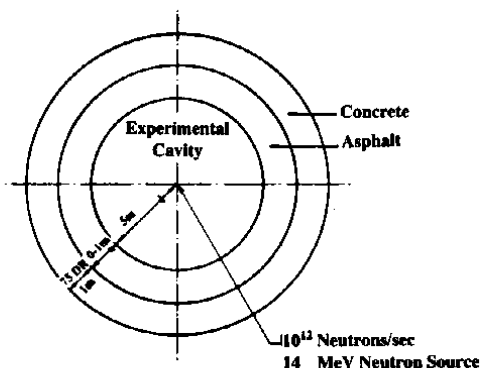


Fig. 1. One-dimensional calculational model for the biological shielding of the experimental cavity for fusion neutronics

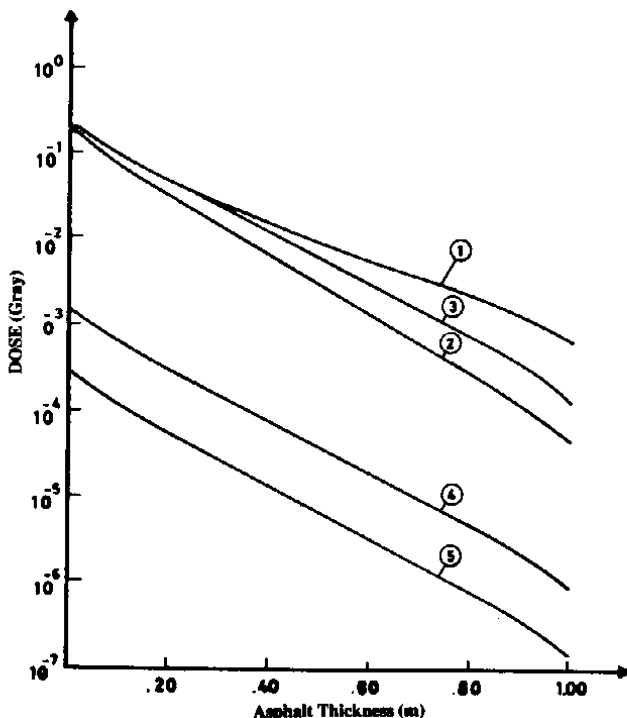


Fig. 2. The biological dose response against the asphalt wall thickness

1. Neutron + gamma-ray dose, CLAW-B Library
2. Neutron dose, CLAW-B
3. Neutron dose, DLC-2F/24
4. Neutron + gamma-ray dose behind a 75 cm concrete shielding followed by an asphalt of variable thickness, DLC-2F/24
5. Neutron + gamma-ray dose behind a 1000m concrete shielding following by an asphalt zone of variable thickness, DLC-2F/24

A comparison of the curves 1 and 2 shows clearly that the contribution of the induced gamma-rays increases with the thickness of the asphalt zone. For example, the gamma-ray dose at the end of the 100 cm asphalt wall is about 16 times higher than the neutron dose. Hence, a primary asphalt zone represents a very effective shielding against incident fast neutrons, but a secondary shielding made of high Z concrete to give structural strength is needed to absorb the induced gamma-rays.

The neutron dose through variable asphalt thickness has been calculated using different cross section data libraries for comparison and is presented in curves 2 and

3. The DLC-2F/24 library gives higher dose values (amongst the libraries available for computation at King Saud University such as: DLC-36, DLC-47); hence, for future studies, this library will be preferred to obtain apparently conservative results.

By comparing the biological dose at 0 cm asphalt on curves 3 and 4, one can determine that the protection of a concrete wall of 75 cm against the fusion neutrons is around 150, *i.e.*, concrete has a better radiation protection than asphalt on equivalent thickness basis. However, on equivalent weight basis asphalt has a superior radiation protection than concrete. For example, 184 cm thick asphalt wall ($\rho_{\text{asphalt}} = 0.98 \text{ g/cm}^3$) would have the weight of a 75 cm concrete wall ($\rho_{\text{concrete}} = 2.33 \text{ g/cm}^3$), but its radiation protection capability would be more than 100 times higher than that of the latter one, due to the availability of H&C moderators in the asphalt with high atomic densities.

Curves 4 and 5 in Fig. 2 show that an increase of the concrete wall thickness from 75 cm to 100 cm, (*i.e.* 33%), the radiation dose protection will increase by a factor of only 5.2

The neutron leakage from the asphalt walls of thicknesses 50, 75 and 100 cm are 6.6%, 1.27% and 0.236% of the incident 14 MeV neutron flux with an average neutron energy of 4.67, 4.31 and 4.09 MeV, respectively.

It was felt that, it would be worthwhile to compare both library sets, DLC-2F/24 and CLAW-B, on a broader basis. For this purpose the responses of different threshold detectors have been calculated for a source strength of 10^{12} neutrons/sec at 14 MeV in the center of the experimental cavity and for detector locations at different places in the asphalt layer.

The activity concentrations A for the $\text{Fe}(n,p)$ and $\text{Al}(n,\alpha)$ detectors were calculated according to (per gram foil material) [1]

$$A = \sum_i \phi (1 - e^{-\lambda_i T}) \quad (5)$$

where

- Σ_i : macroscopic reaction cross-section
- ϕ : the neutron flux density
- λ_i : the decay constant of the isotope produced by activation
- T : irradiation time (8 hours)

The activity concentration for the $^{238}\text{U}(n,f)$, $^{232}\text{Th}(n,f)$ represent the fission rate per gram of the corresponding fissionable material.

Figures 3 and 4 depict the above-mentioned response functions, calculated by different data blocks. They are comparable in general. The slope in threshold detector responses calculated with the CLAW-B library is higher. One can conclude that both libraries give consistent results for similar studies.

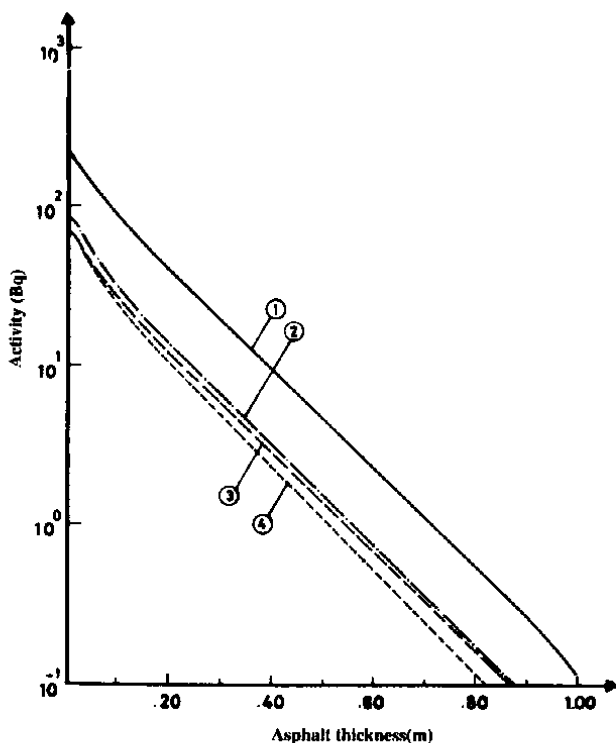


Fig. 3. Selected threshold detector response functions through the asphalt zone, calculated with DLC-2F and DLC-C24

1. $^{238}\text{U}(n,f)$
2. $^{56}\text{Fe}(n,p)$
3. $^{232}\text{Th}(n,f)$
4. $^{27}\text{Al}(n,\alpha)$

For fast neutronic measurements the $^{103}\text{Rh}(n,n')$, $^{103\text{m}}\text{Rh}$ reaction is widely used [14]. However, with this reaction, the thermal flux in the experimental cavity can be an obstacle, because it becomes difficult to distinguish the conversion electrons emitted from $^{103\text{m}}\text{Rh}$ and the β -rays emitted from ^{104}Rh (the latter is produced mainly

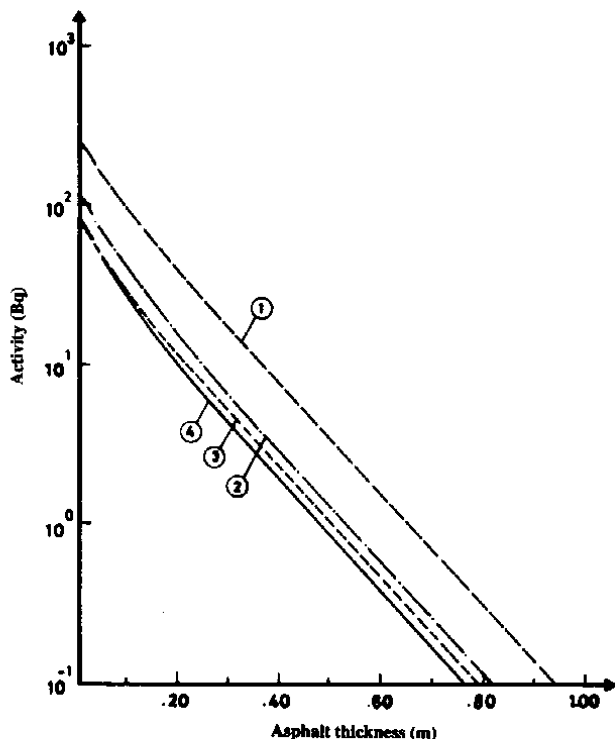


Fig. 4. Selected threshold detector response functions through the asphalt zone, calculated with CLAW-B

1. ^{238}U (n,f)
2. ^{56}Fe (n,p)
3. ^{232}Th (n,f)
4. ^{27}Al (n, α)

through thermal capture in ^{103}Rh). At this point, it is important to note that during this study the ratio of the thermal flux (< 0.414 eV) to the 14 MeV-flux in a cavity surrounded by thick asphalt walls was calculated as 1.36, while, this ratio was 1.84 in a cavity with concrete wall. In experiments dealing with fast neutron measurements a lower thermal flux background causes a reduced disturbance. Therefore, it is another advantage to use asphalt as internal cavity walls instead of concrete.

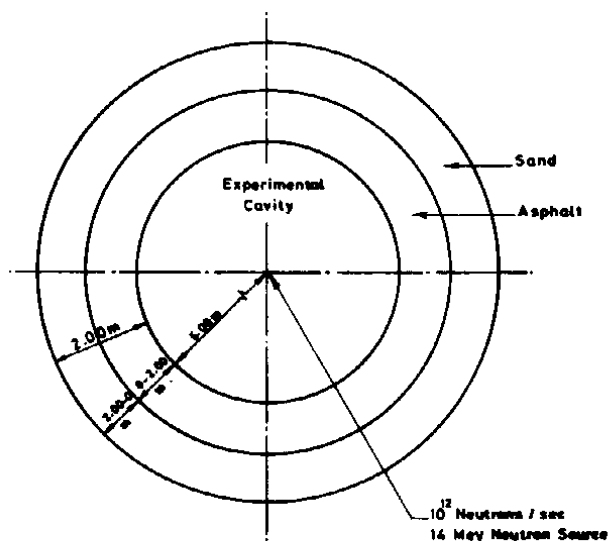


Fig. 5. Asphalt-sand calculational model for the biological shielding of the experimental cavity for fusion neutronics

Another structure using asphalt-red sand layers has been examined for a total of 200 cm thickness for the experimental cavity walls. The new calculational model is shown in Fig. 5. The computer calculations were performed by starting with 0 cm asphalt inside, and 200 cm sand outside, then increasing the thickness of inner asphalt layers by 20 cm steps up to 200 cm asphalt and 0 cm sand layers. Table 2 presents the protection factors for different asphalt-sand layers with two cases where we have whole sand or asphalt. The concrete, given at the top of the table, was used as reference. It can be seen that, the protection factor against neutron is increased with increasing sand layer thickness. For the induced gamma, the maximum protection factor has reached 1.48×10^5 for 80 cm asphalt and 120 cm sand.

The opposite arrangement has been investigated by starting with 0 cm sand inside and 200 cm asphalt outside and increasing the thickness of the sand by 20 cm steps with decreasing the thickness of the asphalt with same amount as shown in Table 3.

The maximum protection factor of 1.5×10^8 against neutron energies has been found for the 180 cm sand and 20 cm asphalt. This protection factors for sand-asphalt layer is 18% over the concrete protection factor for the same shielding thickness (200 cm).

Table 2. The protection factors against neutron and induced gamma energies across *different thicknesses* of inside-asphalt outside-sand structures of the experimental cavity.

Shielding	Structure thickness cm	LASL*		
		n + γ	n	γ
Concrete**	50	9.233E0	6.835E1	9.357E0
	100	2.653E2	7.787E3	2.656E2
	150	8.062E3	8.934E5	7.871E3
	200	2.281E5	1.240E8	2.062E5
00 cm Asphalt 200 cm Sand	50	1.259E1	5.473E1	1.278E1
	100	1.219E2	4.969E3	1.173E2
	150	1.151E3	4.767E5	1.108E3
	200	2.619E4	6.642E7	2.429E4
20 cm Asphalt 180 cm Sand	50	1.256E1	4.453E1	1.318E1
	100	2.927E2	3.787E3	2.819E2
	150	2.535E3	3.551E5	2.378E3
	200	4.890E4	4.905E7	4.422E4
40 cm Asphalt 160 cm Sand	50	6.214E0	3.878E1	6.531E0
	100	3.469E2	2.978E3	3.468E2
	150	4.678E3	2.672E5	4.346E3
	200	8.436E4	3.593E7	7.505E4
60 cm Asphalt 140 cm Sand	50	3.694E0	4.094E1	4.168E0
	100	1.979E2	2.481E3	2.062E2
	150	6.638E3	2.080E5	6.327E3
	200	1.427E5	2.692E7	1.268E5
80 cm Asphalt 120 cm Sand	50	3.599E0	4.101E1	4.144E0
	100	7.201E1	2.197E3	7.653E1
	150	4.581E3	1.666E5	4.540E3
	200	1.646E5	2.047E7	1.482E5
100 cm Asphalt 100 cm Sand	50	3.581E0	4.101E1	4.139E0
	100	2.326E1	2.242E3	2.726E1
	150	1.902E3	1.378E5	1.927E3
	200	9.866E4	1.579E7	9.025E4
120 cm Asphalt 80 cm Sand	50	3.578E0	4.101E1	4.138E0
	100	2.102E1	2.311E3	2.645E1
	150	6.741E2	1.195E5	6.955E2
	200	4.164E4	1.238E7	3.846E4
140 cm Asphalt 60 cm Sand	50	3.578E0	4.101E1	4.138E0
	100	2.070E1	2.311E3	2.632E1
	150	2.205E2	1.110E5	2.342E2
	200	1.605E4	9.935E6	1.497E4

Table 2. Cont.

Shielding	Structure thickness cm	LASL*		
		n + γ	n	γ
160 cm Asphalt 40 cm Sand	50	3.578E0	4.101E1	4.138E0
	100	2.065E1	2.311E3	2.629E1
	150	1.193E2	1.211E5	1.482E2
	200	6.022E3	8.233E6	5.680E3
180 cm Asphalt 20 cm Sand	50	3.578E0	4.101E1	4.138E0
	100	2.064E1	2.311E3	2.629E1
	150	1.147E2	1.214E5	1.464E2
	200	2.186E3	7.153E6	2.100E3
200 cm Asphalt 00 cm Sand	50	3.577E0	4.101E1	4.138E0
	100	2.064E1	2.311E3	2.629E1
	150	1.146E2	1.214E5	1.467E2
	200	8.698E2	6.860E6	9.092E2

*By using Los Alamos Scientific Laboratory (LASL) neutron and gamma-ray dose factors.

**The protection factors for different thicknesses of concrete are presented as reference for comparison only.

Table 3. The protection factors against neutron and induced gamma energies across different thicknesses of inside-sand outside-asphalt structures of the experimental cavity.

Shielding	Structure thickness cm	LASL		
		n + γ	n	γ
00 cm Sand 200 cm Asphalt	50	3.577E0	4.101E1	4.138E0
	100	2.064E1	2.311E3	2.629E1
	150	1.146E2	1.214E5	1.467E2
	200	8.698E2	6.860E6	9.092E2
20 cm Sand 180 cm Asphalt	50	4.019E0	5.766E1	4.692E0
	100	2.320E1	3.117E3	2.921E1
	150	1.226E2	1.609E5	1.470E2
	200	8.096E2	9.021E6	7.477E2
40 cm Sand 160 cm Asphalt	50	4.657E0	7.956E1	4.984E0
	100	2.916E1	4.554E3	3.719E1
	150	1.600E2	2.323E5	2.016E2
	200	1.151E3	1.295E7	1.123E3
60 cm Sand 140 cm Asphalt	50	1.125E1	5.582E1	1.158E1
	100	3.487E1	6.574E3	4.303E1
	150	1.994E2	3.336E5	2.597E2
	200	1.552E3	1.853E7	1.610E3
80 cm Sand 120 cm Asphalt	50	1.275E1	5.476E1	1.298E1
	100	3.571E1	9.142E3	3.972E1
	150	2.380E2	4.789E5	3.102E2
	200	1.941E3	2.652E7	2.100E3

Table 3. Cont.

Shielding	Structure thickness cm	LASL		
		$n + \gamma$	n	γ
100 cm Sand 100 cm Asphalt	50	1.264E1	5.473E1	1.284E1
	100	6.754E1	5.996E3	6.835E1
	150	2.842E2	6.853E3	3.596E2
	200	2.374E3	3.794E7	2.621E3
120 cm Sand 80 cm Asphalt	50	1.260E1	5.473E1	1.279E1
	100	1.215E2	4.988E3	1.177E2
	150	3.472E2	9.655E5	4.083E2
	200	3.048E3	5.423E7	3.360E3
140 cm Sand 60 cm Asphalt	50	1.259E1	5.473E1	1.278E1
	100	1.226E2	4.969E3	1.180E2
	150	4.232E2	1.142E6	4.440E2
	200	4.092E3	7.734E7	4.437E3
160 cm Sand 40 cm Asphalt	50	1.259E1	5.473E1	1.278E1
	100	1.220E2	4.969E3	1.174E2
	150	1.069E3	4.908E5	1.043E3
	200	5.694E3	1.093E8	5.968E3
180 cm Sand 20 cm Asphalt	50	1.259E1	5.473E1	1.278E1
	100	1.219E2	4.969E3	1.173E2
	150	1.154E3	4.770E5	1.111E3
	200	7.442E3	1.462E8	7.340E3
200 cm Sand 00 cm Asphalt	50	1.259E1	5.473E1	1.278E1
	100	1.219E2	4.969E3	1.173E2
	150	1.151E3	4.767E5	1.108E3
	200	2.619E3	6.642E7	2.429E4

Table 4 lists the protection factors against neutron and induced gamma energies across 200 cm concrete sandwiched with inside asphalt and outside-sand structures to form a biological shielding for the experimental cavity as it is presented graphically in Fig. 6. The maximum protection factor of 6.03×10^4 against induced gamma energies has been found for the 60 cm asphalt, 100 cm sand across 200 cm biological shielding. The maximum protection factor against neutron energies was found as 1.25×10^8 for a sandwich structure of 0 cm asphalt and 160 cm sand. This protection factor is equivalent to 200 cm of whole concrete structure.

Other calculations have shown the maximum protection factor as 3.36×10^4 against induced gamma energies for 140 cm sand - 20 cm asphalt, and 1.25×10^8 protection factor against neutron energies for 160 cm sand - 0 cm asphalt sandwich structures of inside-sand and outside - asphalt as shown in Table 5

Table 4. The protection factors against neutron and induced gamma energies across *different thicknesses* of inside-asphalt outside-sand Sandwiched by 20 cm in/out concrete structures for the experimental cavity.

Shielding	Structure thickness cm	LASL		
		n + γ	n	γ
00 cm Asphalt 160 cm Sand	50	1.685E1	5.639E1	1.868E1
	100	3.120E2	5.021E3	3.278E2
	150	2.879E3	4.808E5	3.012E3
	200	1.885E4	1.252E8	1.808E4
20 cm Asphalt 140 cm Sand	50	1.218E1	8.376E1	1.343E1
	100	4.019E2	4.191E3	4.226E2
	150	6.743E3	3.759E5	6.918E3
	200	4.148E4	8.646E7	3.938E4
40 cm Asphalt 120 cm Sand	50	4.800E0	5.799E1	5.609E0
	100	1.951E2	3.488E3	2.058E2
	150	6.221E3	2.918E5	6.259E3
	200	6.234E4	6.056E7	5.847E4
60 cm Asphalt 100 cm Sand	50	4.695E0	5.809E1	5.580E0
	100	7.311E1	3.070E3	7.810E1
	150	3.188E3	2.323E5	3.187E3
	200	6.569E4	4.288E7	6.027E4
80 cm Asphalt 80 cm Sand	50	4.675E0	5.809E1	5.580E0
	100	2.646E1	3.116E3	3.092E1
	150	1.316E3	1.913E5	1.321E3
	200	4.076E4	3.072E7	3.678E4
100 cm Asphalt 60 cm Sand	50	4.671E0	5.809E1	5.579E0
	100	2.436E1	3.211E3	3.032E1
	150	5.120E2	1.652E5	5.197E2
	200	1.869E4	2.234E7	1.681E4
120 cm Asphalt 40 cm Sand	50	4.671E0	5.809E1	5.579E0
	100	2.406E1	3.211E3	3.023E1
	150	1.913E2	1.530E5	1.986E2
	200	7.835E3	1.654E7	7.064E3
140 cm Asphalt 20 cm Sand	50	4.671E0	5.809E1	5.579E0
	100	2.401E1	3.211E3	3.022E1
	150	1.158E2	1.668E5	1.359E2
	200	3.212E3	1.260E7	2.909E3
160 cm Asphalt 00 cm Sand	50	4.671E0	5.809E1	5.579E0
	100	2.400E1	3.211E3	3.022E1
	150	1.127E2	1.671E5	1.352E2
	200	1.304E3	1.004E7	1.189E3

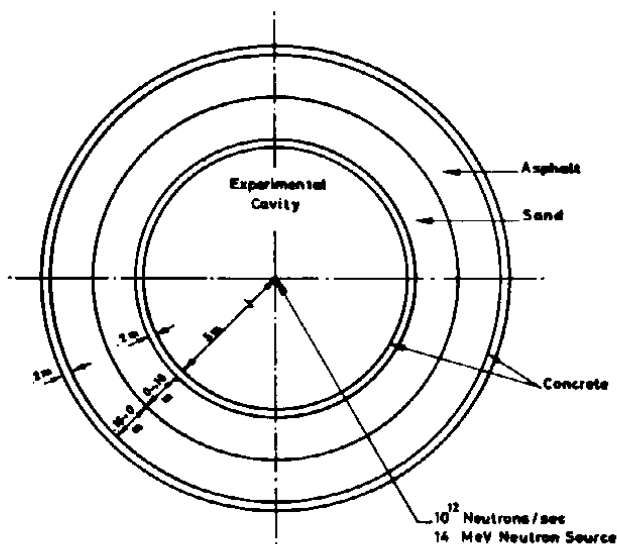


Fig. 6. Calculational model of concrete sandwiched with asphalt-sand layers for the biological shielding of the experimental cavity for fusion neutronics

Main Results and Conclusions

Six types of structures have been examined for the best protection factor (PF) for experimental cavity walls, the following results have been obtained.

- 1) The 200 cm thickness asphalt-red sand homogenous mixtures, of 10% asphalt - 90% sand has provided the following protection factors (PF):
 - a) 4.681E5 against neutron and gamma energies, or 2.05 times more than the PF of concrete for same thickness.
 - b) 4.045E5 against all gamma energies, or 1.96 times more than the PF of concrete.
 - c) 2.487E5 against high energy gamma, or 1.79 times more than the PF of concrete.
 - d) 7.622E5 against low energy gamma, or 2.10 times more than the PF of concrete.

Table 5. The protection factors against neutron and induced gamma energies across *different thicknesses of inside-sand outside-asphalt Sandwiched by 20 cm in/out concrete structures for the experimental cavity.*

Shielding	Structure thickness cm	LASL		
		n + γ	n	γ
00 cm Sand 160 cm Asphalt	50	4.671E0	5.809E1	1.579E0
	100	2.400E1	3.211E3	3.022E1
	150	1.127E2	1.671E5	1.352E2
	200	1.304E3	1.004E7	1.189E3
20 cm Sand 140 cm Asphalt	50	8.623E0	7.926E1	9.995E0
	100	4.616E1	4.653E3	5.972E1
	150	2.244E2	2.398E5	2.787E2
	200	2.762E3	1.436E7	2.549E3
40 cm Sand 120 cm Asphalt	50	1.601E1	5.746E1	1.784E1
	100	7.607E1	6.683E3	9.815E1
	150	3.915E2	3.438E5	5.079E2
	200	5.466E3	2.054E7	5.172E3
60 cm Sand 100 cm Asphalt	50	1.694E1	5.641E1	1.881E1
	100	9.314E1	9.211E3	1.120E2
	150	5.701E2	4.925E5	7.676E2
	200	9.435E3	2.942E7	9.304E3
80 cm Sand 80 cm Asphalt	50	1.689E1	5.639E1	1.873E1
	100	1.767E2	6.039E3	1.947E2
	150	7.358E2	7.026E5	9.902E2
	200	1.405E4	4.209E7	1.449E4
100 cm Sand 60 cm Asphalt	50	1.686E1	5.639E1	1.869E1
	100	3.110E2	5.040E3	3.291E2
	150	8.749E2	9.833E5	1.112E3
	200	1.904E4	6.010E7	2.036E4
120 cm Sand 40 cm Asphalt	50	1.685E1	5.639E1	1.868E1
	100	3.140E2	5.021E3	3.301E2
	150	1.025E3	1.152E6	1.170E3
	200	2.521E4	8.530E7	2.750E4
140 cm Sand 20 cm Asphalt	50	1.685E1	5.639E1	1.868E1
	100	3.123E2	5.021E3	3.282E2
	150	2.657E3	4.948E5	2.825E3
	200	3.113E4	1.177E8	3.363E4
160 cm Sand 00 cm Asphalt	50	1.685E1	5.639E1	1.868E1
	100	3.120E2	5.021E3	3.278E2
	150	2.879E3	4.808E5	3.012E3
	200	1.885E4	1.252E8	1.808E4

- 2) The 200 cm structure of inside-asphalt with outside-sand layers has provided the following protection factors:
 - a) $2.397E7$ for 160 cm asphalt -40cm sand layers against low energy neutron, which is 3.23 times better than the PF of concrete for same thickness.
 - b) $2.210E6$ for 80 cm asphalt -120 cm sand layers against low energy gamma, which is 6.09 times better than the PF of concrete.
- 3) The 200 cm structure of inside-sand with outside-asphalt layers, has provided a protection of $1.462E8$ for 180 cm sand -20 cm asphalt layers against all neutron energies, which is 1.18 times better than the PF of concrete for same thickness. But for the high energy neutron, the best structure (out of the non-concrete structures) can provide a protection factor of $4.633E8$ or 47% of the protection capability of concrete for the same thickness.

This work has demonstrated that a proper combination of cheap and abundant desert sand and asphalt can replace the relatively expensive concrete in constructing biological radiation shielding of experiment facilities for fusion neutronics.

The amount of concrete required for a dome of 30 m diameter, and 2 m concrete thickness, as an example, is about 4.072 m^3 . The concrete cost in Saudi Arabia, is about 255% more of the local asphalt and sand cost [15]. It should be stated here, that 2 m structure thickness of the investigated materials (sand and asphalt) is quite efficient for work places, using high energetic neutron source [2].

Furthermore, they are even more appropriate from both the economic point of view and neutronic considerations (higher protection factor) than concrete, to construct a biological shielding for a research installation, dealing with fusion neutronics, in a country like Saudi Arabia. Concrete would be needed for both sides of an asphalt-sand wall only to provide structural strength.

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التحقق من قدرة الحجب الإشعاعي للرمل والأزفلت لمصادر النيوترونات السريعة

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ملخص البحث. يمكن تغطية الجدران الداخلية لمصادر الإشعاع التجريبية ذات النيوترونات الاندماجية العالية بواسطة طبقة من الأزفلت والرمل، وذلك لأغراض الحماية من الإشعاع. لقد أظهرت الحسابات، أن للأزفلت والرمل قدرة حجب إشعاعي تفوق قدرة الخرسانة، على أساس تساوي الأوزان.

إن أحسن تركيب تم التوصل إليه لحجب الإشعاع الصادر من ^{110}Ni نيوترون/ الثانية مصدر نيوتروني، هو لخليط متجانس من ١٠٪ أزفلت و ٩٠٪ رمل أحمر، وذلك ضد طاقتي النيوترون وأشعة جاما بكفاءة تتجاوز ٢٠٠٪ مقارنة بالسلك نفسه لتركيب خرساني.

لقد أثبت هذا العمل، أن مادتي الأزفلت والرمل المحلية والرخيصة التكاليف، يمكنها أن تحل محل الخرسانة المكلفة نسبياً، في بناء حجب الوقاية الإشعاعية للمنشآت التجريبية المنتجة للنيوترونات الاندماجية.