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SANDIA SYSTEMATIC DECLASSIFICATION REVIEW	
1st Review Date: 5-07-80 Authority: ☐ ADC ☒ ADD Name: CCRP-RR 2nd Review Date: 5-06-97 Authority: ADD Name: W Layne	Determination (Circle Numbers): 1. Classification Retained 2. Classification Changed to: U 3. Contains No DOE Classified Information 4. Coordinate With: 5. Contains UCAI? 6. Comments:

33-56-51

INVENTORIED 6-28-59

NEUTRON AND GAMMA HAZARD RELATED TO ABOVE- AND BELOW-GROUND STRUCTURES

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INVENTORIED

MAY 19 '56

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ABSTRACT

Present experimental knowledge of radiation dose versus distance and the effect of shielding from gamma and neutron radiation is interpreted for above- and below-ground structures.

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW DOWNGRADING OR DECLASSIFICATION STAMP	
CLASSIFICATION CHANGED TO: U Emelda Selph 5-6-97 PERSON CHANGING MARKING & DATE Carmela M Gallegos PERSON VERIFYING MARKING & DATE 5/20/97	AUTHORITY: W. C. Layne RECORD ID: 97SN1726 DATED: 5-6-97

INVENTORIED

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BY ORG.

Case No. 407.09

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February 13, 1956

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NEUTRON AND GAMMA HAZARD RELATED TO ABOVE- AND BELOW-GROUND STRUCTURES

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Introduction

By letter of December 8, 1955, the Federal Civil Defense Administration requested from the Division of Biology and Medicine information on the following:

"a. Neutron dose versus distance for various ranges of energy release.

b. The current knowledge of the neutron hazard in underground and above-ground shelter construction, and its effect upon the practicality of shelter in basements and shielded floors of existing buildings.

c. The shielding coefficients of typical building materials and assemblies of materials against neutrons, with considerations of the structural geometry.

d. Similar information on prompt gamma radiation."

Radiation Dose

The importance of the immediate nuclear irradiations (neutrons and gamma rays) from atomic weapons depends upon several factors. These factors are: (a) the design of the weapon; (b) the yield of the weapon; and (c) the influence of the environment surrounding the weapon.

For the purposes of Federal Civil Defense, an energy capability may be broken down into four types of weapons. These are, first, the strategic fission weapon. The strategic fission weapon may be considered to be any weapon with yield up to 500 kt which must be carried by bombers of the B-29 or larger type or possibly by a long-range missile. A second design could be called the tactical fission-type weapon. Generally, the yield of a tactical fission weapon is less than 50 kt and can be carried by delivery vehicles as small as fighter-type jet aircraft or short-range ballistic or guided missiles similar to the Honest John, Matador, etc. A third distinct type is the gun weapon which, as its name implies, is of short-range ground-to-ground delivery in nature. The fourth type is the thermonuclear weapon with yields greater than 1 mt, which can be carried by intercontinental missiles and heavy bombers of both jet and propeller-driven types.

The design itself is primarily important concerning the total neutron dose delivered. It may categorically be stated that as the actual size, in kilotons, of the weapon decreases, the neutron dose per kiloton of yield

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increases insofar as fission weapons are concerned. Although the data are extremely deficient and perhaps suspect, it appears that thermonuclear weapons may give the highest neutron dose yields per kiloton of any type. The constants necessary for determining dose from any of these types are shown in Table 1, in units of rep per kiloton of yield, at a theoretical zero distance from point of detonation.

Considering the gamma ray dose, it has been found that design does not directly change the dose per kiloton of yield. There are other factors which are more important insofar as gamma ray dose is concerned. Yield is only important insofar as it influences gamma ray dose. In other words, direct scaling may be applied for all type weapons in the same yield range. As the yield gets large, hydrodynamic effects occur which are important insofar as gamma ray dose is concerned. This is because the gamma ray dose is delivered over a relatively long period of time after the time of detonation. The hydrodynamic effects are such that as the total energy, and thus the blast energy, increases, more and more air is pushed out of the way by the blast wave, leaving a partial vacuum behind the shock front. Since there is no absorbing material between the shock front and the point of detonation, gamma rays emitted at late times only fall off as inverse square, and the absorption function is zero. Thus, the total gamma dose per kiloton can be increased. This effect does not become too important until yields greater than 100 kt are reached. Therefore, a yield variation applies to extremely large strategic fission weapons and thermonuclear weapons.

Hydrodynamic considerations do not affect neutron dose because the total neutron dose is delivered within a few milliseconds.

The yield effect on gamma rays may be more accurately considered by reference to Figs. 23a and 23b of Ref 1. The more important aspects of the environment surrounding the weapon are, of course, air density and the influence of the surrounding terrain. Generally, the target region may be considered to be a plane and the height of burst to be such that serious ground effects need not be considered. Air density, of course, influences the absorption portion of the decrease of gamma or neutron dose with distance. Roughly, the air density varies inversely as the altitude of the target. The functional relationship of the neutron dose or gamma dose differs for any specific air density but is reasonably calculated. Assuming sea level conditions, the mean free path for neutron dose is about 220 yards, while that for gamma dose is about 340 yards. In both cases this mean free path (the distance to fall-off to 37 per cent by absorption processes alone) increases as the altitude increases. By using the K factors shown in Table 1 (in which the gamma K factor is included for yields up to 100 kt) and a standard formula, it is possible to determine dose versus distance curves in air in terms of rep for both neutrons and gamma rays. In order to determine neutron doses in terms of roentgens equivalent, it is necessary to multiply all rep doses by 1.6 which appears to be a reasonable relative biological effectiveness factor

for neutrons using acute response of humans as the endpoint. This standard formula is:

$$r = \frac{KWe^{-D/\lambda}}{D^2} ,$$

where K is shown in Table 1, W is the yield in kt, D is slant distance in yards, and λ is the mean free path in yards.

In the information following, in which various shielding considerations are made, the "in air" dose yields may be reduced directly by the applicable shielding factor. Even though the shield may change the neutron spectrum and the gamma spectrum appreciably, the biological response curve per rep does not vary significantly over a wide spectral region. In certain cases thermal neutron flux, which is unimportant insofar as dose production in air is concerned, may become important when a shield is interposed. A consideration of thermal neutrons has not been made in this short report, since the controlling factors, such as yield and design, are much more complex than those for either gamma rays or fast neutron dose.

TABLE 1

Type	"K" value in rep/kt Gamma	"K" value in rep/kt (Extrapolated to zero distance) Neutron
Strategic fission	2×10^9	1×10^9
Tactical fission	2×10^9	6×10^9
Gun	2×10^9	8×10^9
Thermonuclear	10^{10} to 2×10^{10}	1×10^{11} to 2×10^{11}

Shielding

Information reported on shielding in WT's 42, 360, 383, 549, 560, 795, and IPR's 1121 and 1161 (see Bibliography) was reviewed. Only a limited amount of information is available on the radiation shielding provided by structures other than foxholes.

Variables and Uncertainties

Certain variables and uncertainties combine to make the spread in the data quite wide. The more significant of these variables and uncertainties are:

1. Detector limitations.—Each of the detectors is designed to measure radiation above or below a given threshold. If the actual radiation is beyond the threshold, the reading is doubtful; and as limits are reached in the case of neutron detectors, the accuracy of the reading decreases rapidly.

2. Position within a structure.—The reading is sensitive to the exact location within a structure, particularly with respect to windows or doors and to the amount and kind of line-of-sight material between the detector and source.

3. Type of structure.—Types of structures included in the material reported herein were foxholes, open structures below ground (generally field fortifications with earth cover), closed structures below ground, open and closed structures above ground, and earth and masonry houses and basements of houses. Materials included some wood and metal but primarily earth and reinforced concrete. If enough data existed for each type of structure it would be possible to categorize structure types so as to reduce the spread for any one category.

4. Radiation energy.—If the radiation spectrum were divided into bands of different energies, the bands of lower energy would be shielded more effectively than those of higher energy. The gamma spectrum was not broken down into bands of different energies. The neutron spectrum was broken down into three energy bands measured by gold, plutonium, neptunium, uranium, and sulphur. The data from gold detectors are shown separately. Differences between the other energy bands were so small that they were hidden in the other uncertainties.

5. Height-of-burst vs distance.—For open structures or foxholes the height-of-burst and the distances from the weapon at which a given level of radiation occurs is an important factor in the amount of radiation scattering into the structure.

6. Open-ness.—If there were sufficient samples it would be possible to break down open structures into groups depending upon the degree of open-ness and reduce the scatter for any one group.

The data reported herein are confined to those structures in which common construction materials have been used.

Density Index

The results of this survey are described in terms of an index of density (ρt) (obtained by multiplying the weight of each material in pounds per ft³ by the number of line-of-sight feet of the material penetrated) and plotted against a shielding factor (G) which is the ratio of the flux incident on a structure location to that measured inside the structure. The density of soil at Frenchman Flat was taken as 70 and that at Yucca Flat as 50 pounds per cubic foot.

Gamma Radiation

Results of gamma radiation are shown in Fig. 1 for structures other than uncovered foxholes. As would be expected, the scatter is greater for the open than for the closed structures. These results indicate that after a certain density index is reached, large amounts of additional protection result from small increases in the density index. Gamma radiation shielding for concrete, wood frame, and masonry houses and the basements of houses fell within the area labeled houses in Fig. 1. Again, as would be expected, houses and basements provide about the same degree of protection as open foxholes, Fig. 2.

From Figs. 1 and 2, conclusions and recommendations can be made:

a. Houses and the basements of houses furnish little protection from prompt gamma radiation. The basement of a house could not be expected to have a shielding factor in excess of 10.

b. The following is recommended for evaluating houses and basements of houses:

$$S = 0.4\,\rho^{0.3}$$

c. For evaluating underground structures, it is suggested that the midpoints between the curves of Fig. 1 be used.

d. For designing underground protective structures, it is recommended that a density index of 1500 be provided for closed structures and 2400 for open structures.

Two plots of gamma radiation shielding in free earth (no structure) are included in Fig. 1 to show the relation to the structure data. The lower curve was measured at 730 yards from TUMBLER-SNAPPER Shot 2 where the angle of incidence was about 30°. The upper curve was measured 1000 yards from TUMBLER-SNAPPER Shot 5 where the angle of incidence was only 6°, and where, accordingly, the line-of-sight thickness of earth was greater.

Neutron Radiation

No measurements of neutron radiation inside houses have been made. For purposes of this analysis, slow and fast neutrons are considered separately where the slow neutrons are those indicated by activation of gold and the fast are those indicated by activation of uranium, neptunium, plutonium, and sulphur.

Results from slow neutron radiation are shown in Fig. 3. Results from open and closed structures overlap, but those from the open tend to be higher than the closed because of the greater amount of scattered radiation entering the open structures. Results from concrete-covered foxholes lie between the upper limit for open structures and the lower limit for closed structures and between shielding factors of 3 at the greater distance to 20 at the closer locations.

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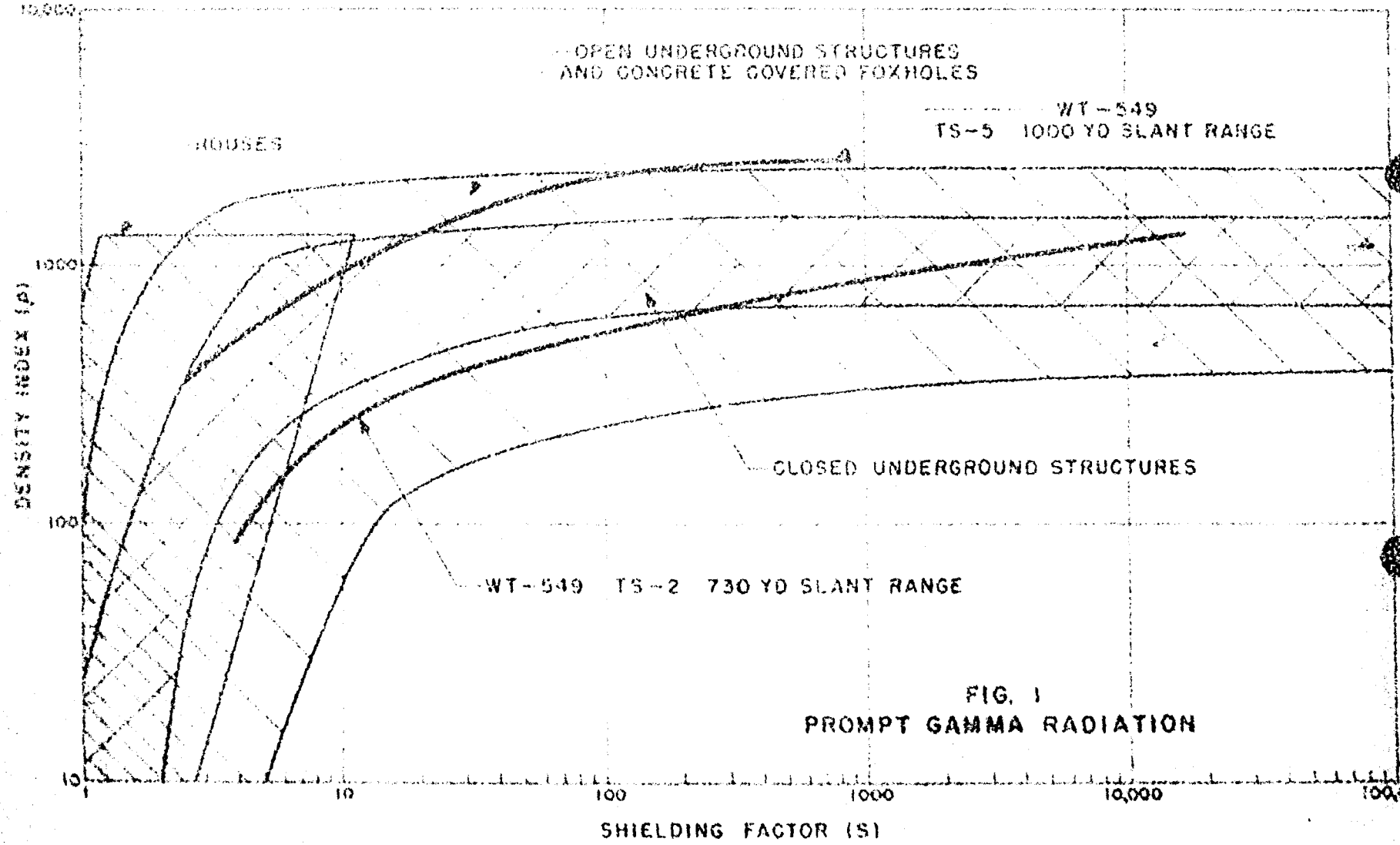

FIG. 1
PROMPT GAMMA RADIATION

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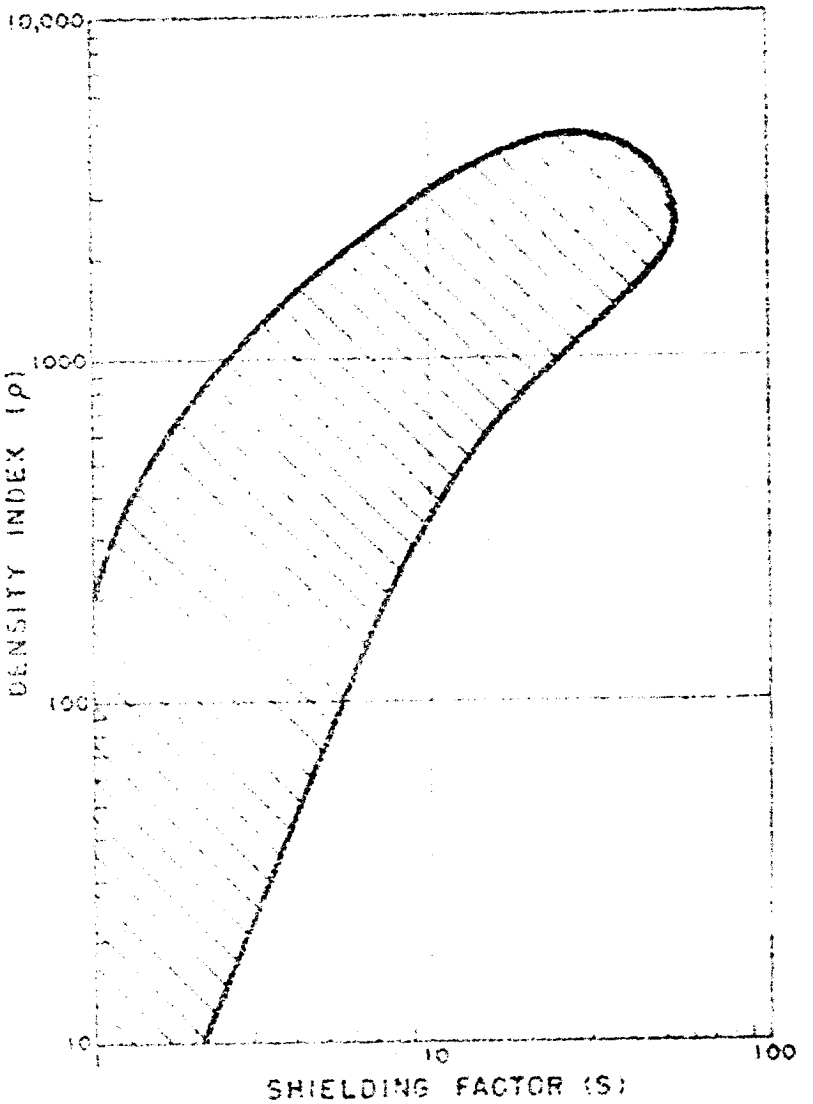

FIG. 2

PROMPT GAMMA RADIATION IN FOXHOLES

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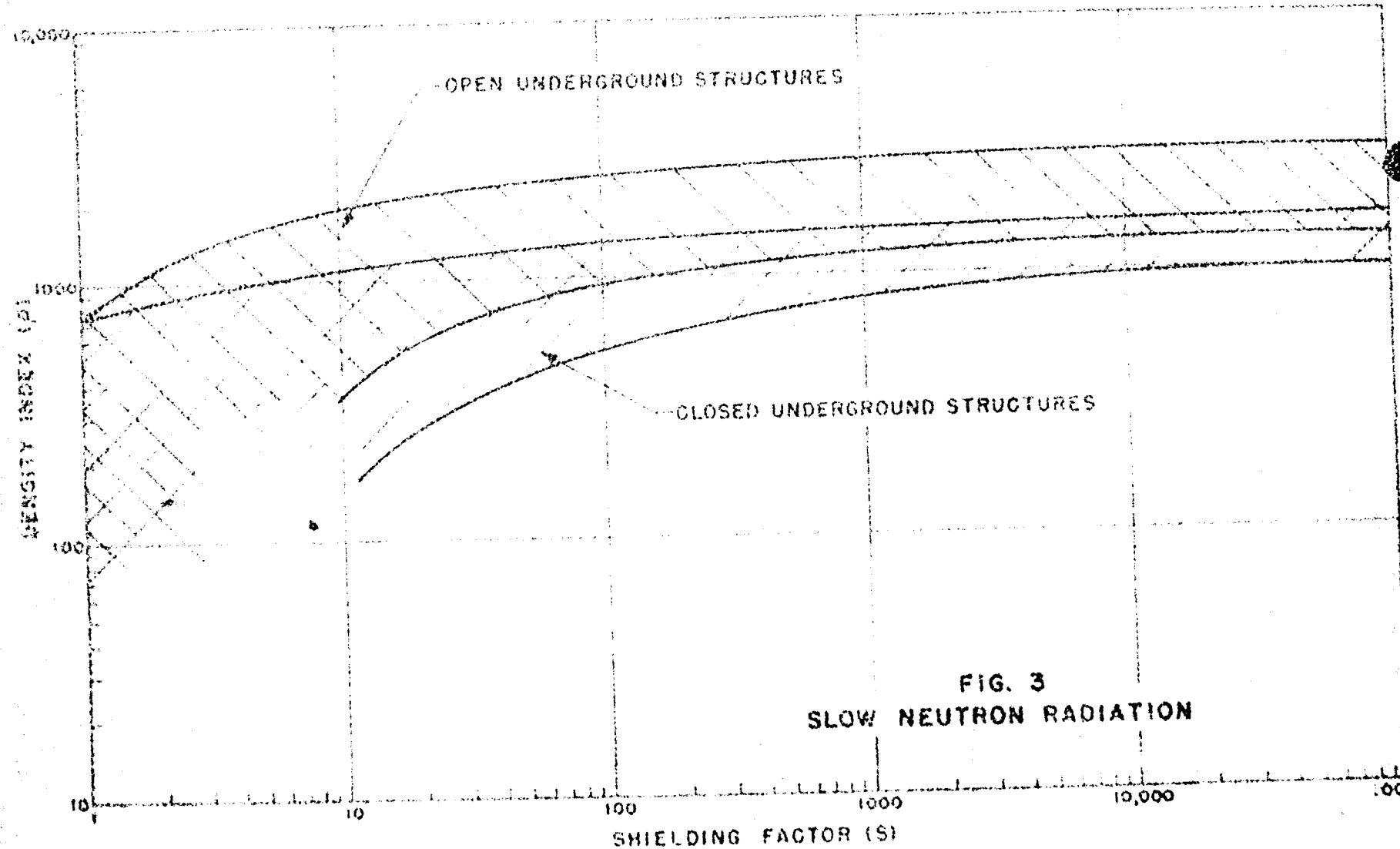

FIG. 3
SLOW NEUTRON RADIATION

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For evaluation of shielding provided by existing structures, it is suggested that values between upper and lower limits be used. For design of protective structures, it is recommended that a density index minima of 1500 for closed structures and 3000 for open structures be used.

Fast neutron radiation results are shown in Fig. 4. As would be expected, the spread is greater in the case of the open structure. The steeper slope for low values of shielding factor is probably due to the greater dependence of fast contrasted to slow neutrons on line-of-sight penetration. Data for tanks taken from Capabilities of Atomic Weapons (see Bibliography) and converted to equivalent concrete thickness (assuming 1 inch of steel equals 4 inches of concrete*) are shown because they are the only measurements made in what amounts to a closed, above-ground structure. Capabilities of Atomic Weapons does not distinguish between fast and slow neutrons. A value of shielding for concrete given by The Effects of Atomic Weapons (see Bibliography) is included in Fig. 4. Results of measurements made within the concrete-covered foxholes lie within the spread of data for open underground structures with shielding factors between 3 for the farther stations and 150 for the closer ones.

For the evaluation of shielding provided by existing structures, it is suggested that values between the upper and lower limits be used. For design of protective structures, it is recommended that either a density index minimum of 2800 or the upper limit of Fig. 4 be used.

Results of neutron penetration inside foxholes are summarized in Fig. 5. This information may be of interest to FCDA only to show the greater dependence of fast rather than slow neutron shielding on the line-of-sight thickness of material. More data exist for foxholes than for other configurations, and analysis of these in greater detail may be found in Total Nuclear Radiation on the Surface and in Foxholes from Mk 7 and Mk 12 Weapons (see Bibliography).

Remarks

The data furnished above do not answer in detail the questions asked by FCDA. However, the boundaries which encompass experimental data may be worthwhile if used discriminately. First, when it is desirable to design a structure to provide a given amount of shielding the upper limit provides an amount of covering which certainly will guarantee the degree of protection desired. Obviously, if more or better information were available, the same degree of protection might be provided with less material and hence less expense. Second, when existing structures are being evaluated as to their ability to furnish radiation protection, the average value between the upper and lower limits would give values which are as valid as available experimental information would justify.

* Reference 12 gives an average of 3.4 inches for 1, 3, and 6 mev neutrons.

Case No. [illegible]
February 1[illegible], 1956

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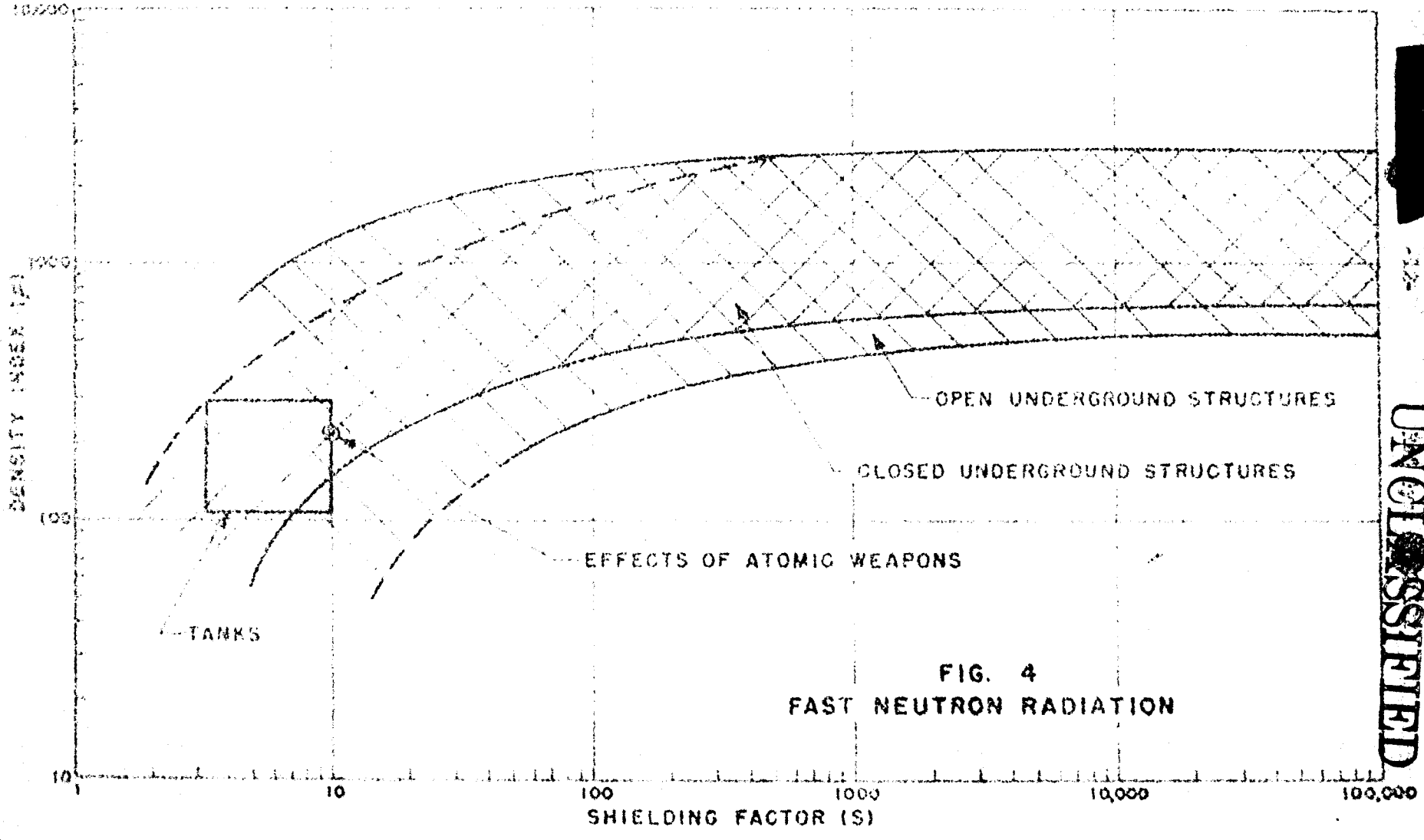

FIG. 4
FAST NEUTRON RADIATION

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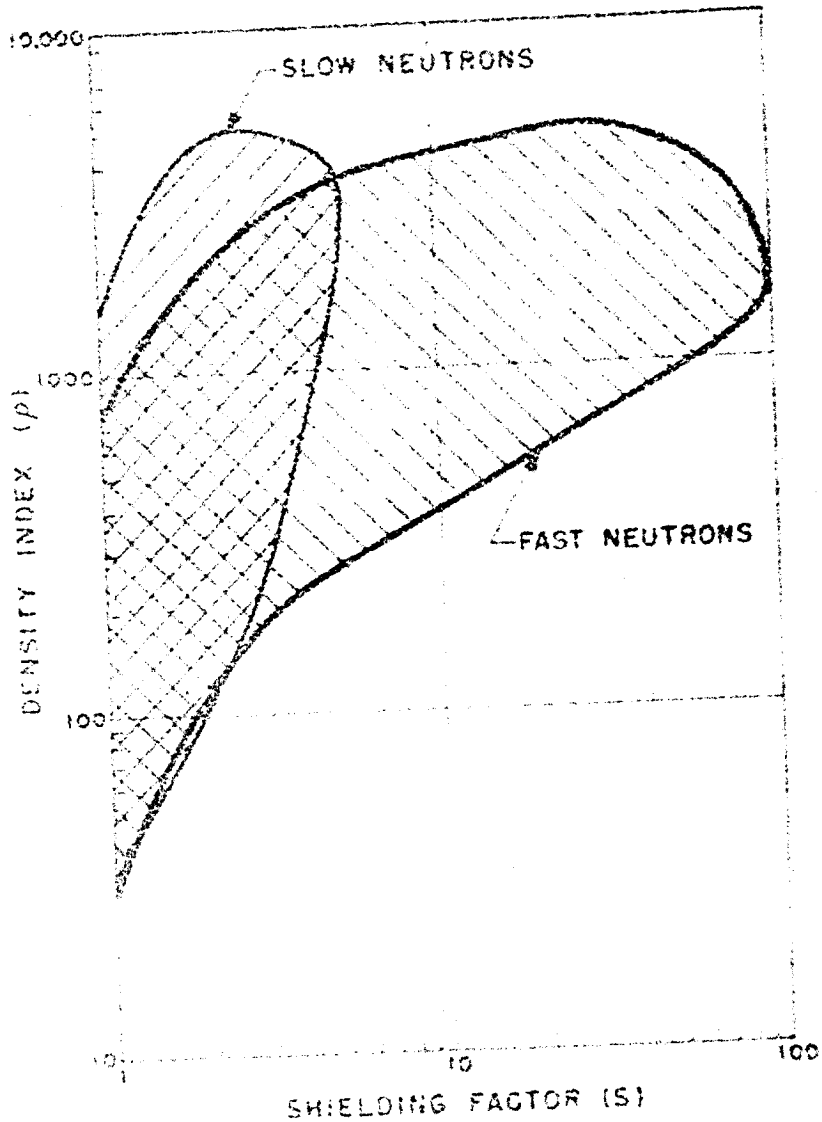

FIG. 5

NEUTRON RADIATION IN FOXHOLES

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BIBLIOGRAPHY

1. Capabilities of Atomic Weapons, prepared by Armed Forces Special Weapons Project, TM-23-200, revised edition, June 1955 (SRD).

2. Ort, Frank L., and Mears, Merton D., Evaluation of Collective-Protector Equipment, Operation GREENHOUSE report WT-42, April 1952 (SRD).

3. Gorshie, S. L., AEC Communal Shelter Evaluation, Operation BUSTER-JANGLE report WT-[illegible], July [illegible] (SRD).

4. Walsh, Thomas G., The Protective Effects of Field Fortifications Against Neutron and Gamma Ray Flux, Operation BUSTER-JANGLE report WT-383, June [illegible] (SRD).

5. Storm, Ellery, Gamma Radiation Exposure as a Function of Distance, Operation TUMBLER-SNAPPER report WT-[illegible], September 1952 (SRD).

6. [illegible], [illegible], Cavity-Type Air Feed Shelters, Operation TUMBLER-SNAPPER report WT-[illegible], January [illegible] (SRD).

7. [illegible], [illegible], et al., Neutron-Flux Measurements in AEC Communal Shelters and Lead Hemispheres, Operation UPSHOT-KNOTHOLE report WT-795, December [illegible] (SRD).

8. [illegible], [illegible], et al., Shielding Studies, Operation TEAPOT report [illegible], [illegible] (SRD).

9. [illegible], [illegible], Effects of an Atomic Explosion on Group- and Family-Type Personnel Shelters, Operation TEAPOT report ITR-1161, May 1955 (SRD).

10. [illegible], [illegible], The Effects of Atomic Weapons, McGraw-Hill Book Co., [illegible] [illegible] (SRD).

11. [illegible], [illegible], [illegible] Radiation on the Surface and in Samples from [illegible] [illegible] (SRD).

12. [illegible], [illegible], [illegible], [illegible] [illegible] (SRD).

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