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CEX-62.11

OPERATION BREN

DISTRIBUTION OF WEAPONS RADIATION IN JAPANESE RESIDENTIAL STRUCTURES

J. S. Cheka, F. W. Sanders,
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DISTRIBUTION OF WEAPONS RADIATION IN JAPANESE RESIDENTIAL STRUCTURES

By

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March 1965

NOTICE

This report is published in the interest of providing information which may prove of value to the reader in his study of effects data derived principally from nuclear weapons tests and from experiments designed to duplicate various characteristics of nuclear weapons.

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ABSTRACT

The Oak Ridge National Laboratory Health Physics Research Reactor, attached to a hoist platform on a 1500-ft tower at the Nevada Test Site, was used in a continuation of studies to evaluate radiation doses of persons exposed to nuclear weapons. As a part of the operation, distribution of radiation in radiation analogs of Japanese residences was studied. Measurements of neutron and gamma radiation were made in single houses and in group configurations. Formulae describing the radiation patterns with respect to house parameters were derived by the use of multiple regression analysis. Nine parameters were found to predict the radiation exposures at the measured points so that 50% of the predictions were in error by less than ±6% and 90% of the predictions were in error by less than ±17%. These formulae can be used to evaluate individual exposures in Hiroshima and Nagasaki.

ACKNOWLEDGMENTS

The authors wish to extend their gratitude to the following members of the Health Physics Division, Oak Ridge National Laboratory: Mr. J. A. Auxier, Mr. J. H. Thorngate, Dr. R. H. Ritchie, Dr. G. S. Hurst, Mr. F. F. Haywood, Mr. E. T. Loy, and Mrs. Brenda Hickey. Their support and assistance in this study made it possible to complete the project in the most expedient fashion. Thanks are also extended to Mr. Samuel Helf of Picatinny Arsenal, Mr. John Andrews of General Electric Company, and Mr. Jack Knight of Edgerton, Germeshausen and Grier, Inc.

This work was done under the auspices of the Civil Effects Test Operations, Division of Biology and Medicine, U. S. Atomic Energy Commission. Thanks are expressed to Mr. L. J. Deal, Chief of the Civil Effects Branch, and to Mr. R. L. Corsbie, formerly of CETO, for their continued support and guidance in this project.

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES

Operation BREN[1] (Bare Reactor Experiment Nevada) was a continuation of studies begun in 1956 for evaluating the radiation doses sustained by persons exposed to nuclear weapons, especially the residents of Hiroshima and Nagasaki, Japan. Program 1 of BREN comprised the determination of the spectra, angular distributions,[2] and effect of air-ground interface on radiation patterns from a nuclear reactor above an extended air-ground interface.[3] Further, the neutron and gamma radiation dose distributions in radiation analogs of Japanese dwellings were evaluated as functions of house size, orientation, and position relative to neighboring houses. Projects 1.1 and 1.3, herein reported, were concerned with those phases of Program 1 which dealt with the dose distribution of gamma and neutron radiation, respectively, in Japanese domicile-type structures. Dose distribution measurements were made in "radiation equivalent" Japanese houses of several sizes. Measurements inside houses were compared with air doses* at the same distances. Comparisons were made with respect to house size and orientation. The houses were then arranged in various group configurations to test effects of mutual shielding.

1.2 BACKGROUND

Preliminary measurements were made on two facsimile Japanese houses during a weapons test in 1957,[4,5] and more extensive measurements were made during weapons tests in 1958.[6] As a result of difficulties encountered in the use of chemical dosimeters for gamma measurements, consistent values for gamma dose distributions were not obtained in 1958. The present operation yielded better gamma dose data.

Data had been obtained for neutron dose distributions in simple house configurations; additional data obtained during Operation BREN extended information to include more complex geometries.

*"Air doses" as used herein refer to first collision neutron doses in the sense of NBS Handbook 63 and to exposure gamma doses, both being measured in the open, 3 ft above the ground.

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Chapter 2

MATERIALS, INSTRUMENTATION, AND EXPERIMENTAL TECHNIQUES

2.1 RADIATION SOURCES

The source of mixed radiation was the Health Physics Research Reactor,[1] mounted on a hoist car which could be positioned at any elevation between 27 ft and 1500 ft on a steel tower (Fig. 2.1). The reactor (Fig. 2.2) has an unshielded metal core and can be operated at constant power up to 10 kw, or in bursts of 10^{17} fissions, maximum. Projects 1.1 and 1.3 utilized the constant power mode of operation.[2]

Such a reactor provides a good energy and spatial simulation of the neutron field due to a nuclear detonation because in both devices the leakage neutrons escape from the assembled fissile material and are moderated by air. At distances from the source greater than a few hundred yards, the neutron number vs energy spectrum achieves an equilibrium which does not change appreciably at greater distances. Energy and angular distributions are not strongly influenced by the design of the neutron source.[3]

Several components of the gamma-ray field of a nuclear bomb are well simulated by means of a bare reactor. Because the neutron field so closely approximates that from a weapon, the gamma rays originating through neutron interactions in air, primarily from ^{16}N (6.13 and 7.10 Mev), will have the same energy and angular distributions as the corresponding gamma rays from the weapons. Prompt gammas from fission leak through the assembled fissile material as do those from fission in weapons; attenuation in nominal yield bombs approximates that of the reactor core.[4] The lower energy gamma rays from fission products in a reactor, however, leak from the assembled fissile material with considerable attenuation, whereas fission products from a weapon detonation are distributed in an expanding and rising cloud.

In addition, a 1.2-kc ^{60}Co source was used to simulate the fission product gamma rays which had been absorbed in the reactor core (Fig. 2.3). The cobalt was, essentially, a point source at the distance utilized, while that part of the gamma radiation due to reactor operation was of a diffuse origin due to the interaction of neutrons with air.

The radiation sources were positioned at the 500-, 1125-, or 1500-ft levels on the tower for most house exposures.

2.2 JAPANESE HOUSES

Three "radiation equivalent" Japanese residences were used in these projects (Figs. 2.4-2.6). These were identical with types A, B, and C as used in Hardtack II.[5] Japanese-type wood framing was used, but the Japanese clay mixture on a split bamboo lattice for walls and wood-clay-tile structure for roofs was not used; a cement asbestos board of proper thickness was substituted for the Japanese materials other than wood. This material was tested at ORNL and found to be close (±10%) in relative gamma and neutron attenuation to both classes of Japanese structural materials.[6] Thin wood and/or paper partitions and glass in the windows were omitted, having been found to introduce perturbations of the order of but 1 or 2%.[7] The thicknesses used for external walls, internal walls, and roofs, respectively, were determined by gamma penetration measurements in several typical Japanese houses in Hiroshima and Nagasaki.

In addition, three external wall sections were utilized, Fig. 2.7. These were, respectively, silhouettes of the three houses used and were placed in proximity to the houses, when grouped, to simulate neighboring houses.

2.3 INSTRUMENTATION

Gamma dose measurements were made with the "Phil" dosimeter.[8] This instrument utilizes a miniature G-M counter inside a Pb-Sn shield which minimizes the dependence of the response per unit dose on photon energy. It has a low fast neutron response (less than 0.5%) and was shielded against thermal neutrons with a ^{6}Li shield.

Special power supplies and preamplifiers were provided to facilitate operation with the detectors and readout instruments connected by 250-ft cables. The readout equipment was located in a van-type instrument trailer in a revetment behind each experimental area.

Neutron dose measurements were made with a modified verson of Radsan.[9] Radsan consists of a polyethylene-lined, cyclopropane-filled proportional counter; high voltage supply; preamplifier; amplifier; integrator; timer; and readout scaler. The modification to the stock Radsan consisted of providing an a.c. or battery-operated transistorized preamplifier capable of operation with long (250 ft) signal cables, and changing the input of the main amplifier to make it compatible with the preamplifier.

The Radsan detector is a proportional counter which produces pulses proportional in amplitude to the energy deposited. Therefore, a summation of pulse heights is proportional to dose in C_nH_{2n}, from which conversion to tissue-rad can be made by dividing by 1.45.[9] The integrator unit weights pulses according to amplitude and sums the products. An automatic timer terminates the counting period so that the dose rate can be read directly from the scaler unit.

The response of the instrument to gamma radiation is negligible for dose rates of less than 2 r/hr.

Two normalizing channels were operated at fixed locations to provide "standard" values of reactor output for the normalization of all other instrument readings.[10] One consisted of a BF_3 tube encased in a cylinder of paraffin (Fig. 2.8), and the other of a BF_3 tube in a cylinder of wood. In each case, the axis of the cylinder was horizontal and perpendicular to the direction of a line between the detector and the reactor.

Measurements were made with the instruments mounted in pairs consisting of one Phil and one Radsan on racks (Fig. 2.9) at points 3 and 5 ft above points laid out on the floor of each house in grids identical with those used in Hardtack II. Additional readings at 1 and 7 ft were taken at selected points. The grids for all houses are shown in Figs. 2.10 through 2.13.

These values were compared with the respective air doses for neutrons and gamma rays at the corresponding distances. Air doses were determined at a sufficient distance from all houses so that perturbation of the radiation field by the structures was negligible.

Most of the measurements were made at a distance of 750 yds from the tower base, and some were made at 1000 yds.

2.4 TECHNIQUES

The house measurements were all evaluated as fractions of air dose to allow analysis to ascertain the effect of house size, house orientation, and the additional shielding due to the juxtaposition of two or more houses.

Analyses were also made, as in Hardtack II, of the effect of individual parameters of house geometry; i.e., the presence and location of house elements, such as walls, roofs, windows, and partitions, and also the proximity of external structures. Such analyses make possible the estimation of shielding factors in structures which have not been tested.

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Fig. 2.1--1500-ft steel tower used in Operation BREN.

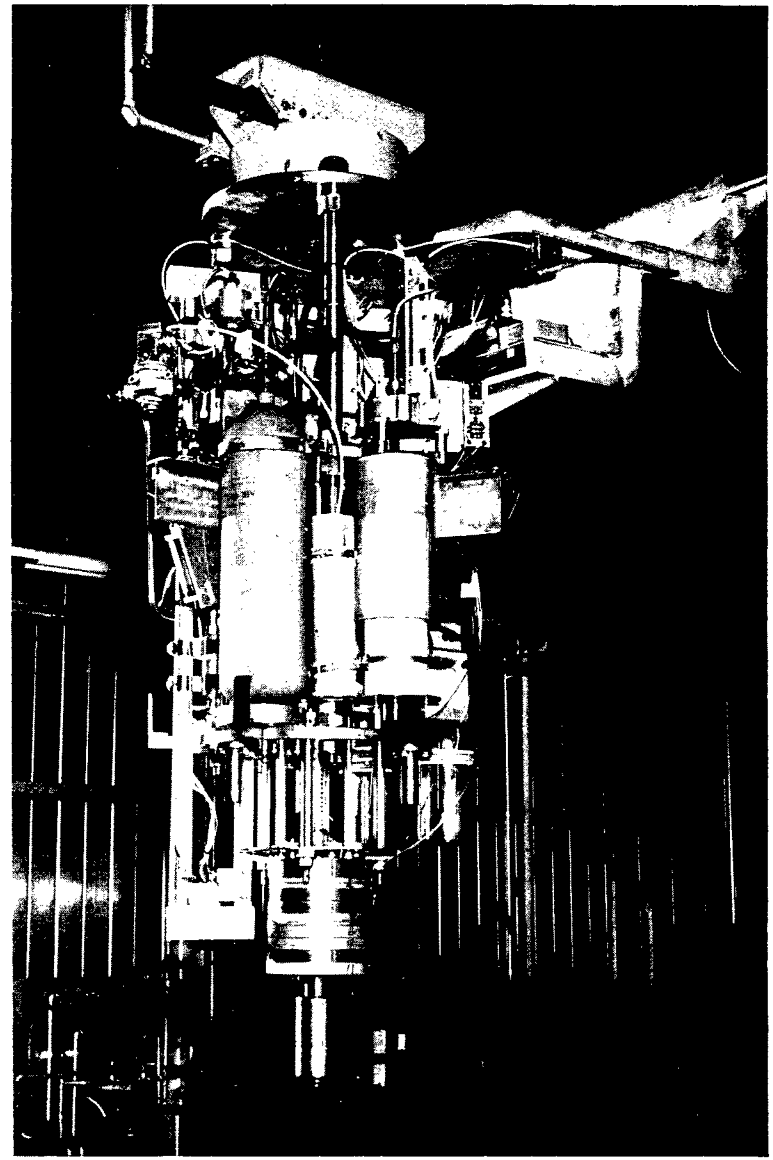


Fig. 2.2--The HPRR used in Operation BREN.

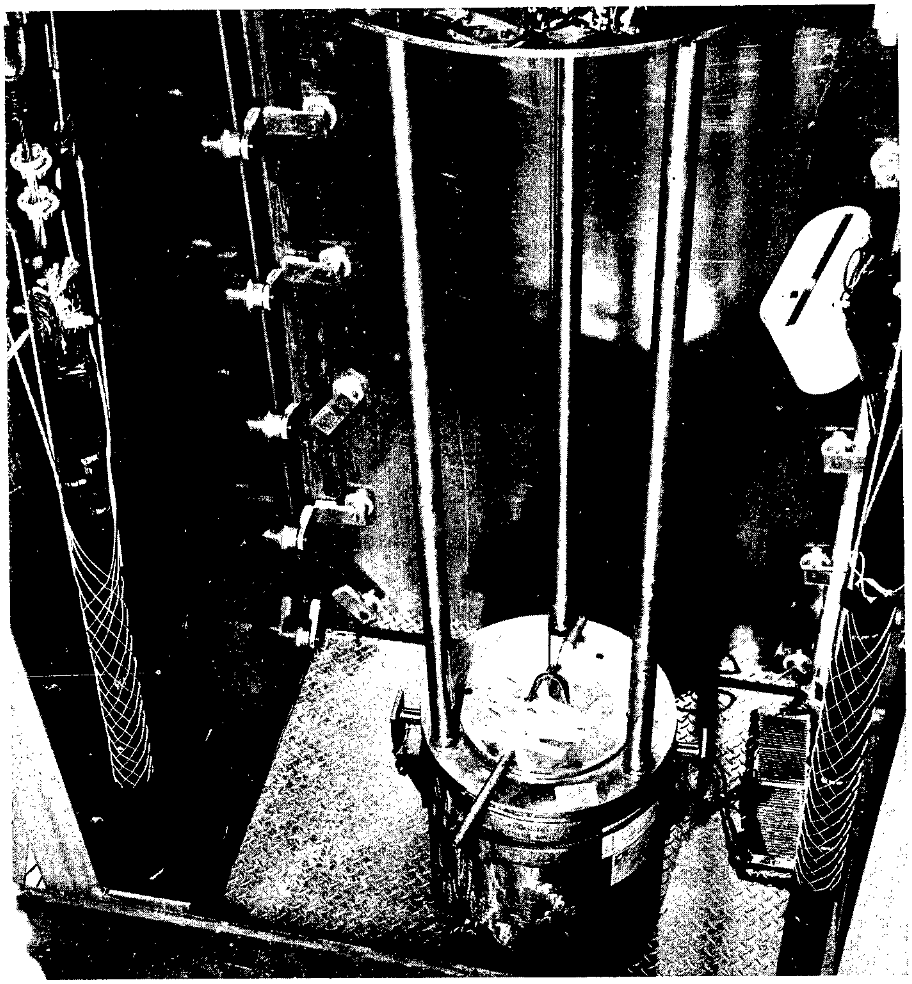


Fig. 2.3--^{60}Co source in pig on hoist platform.

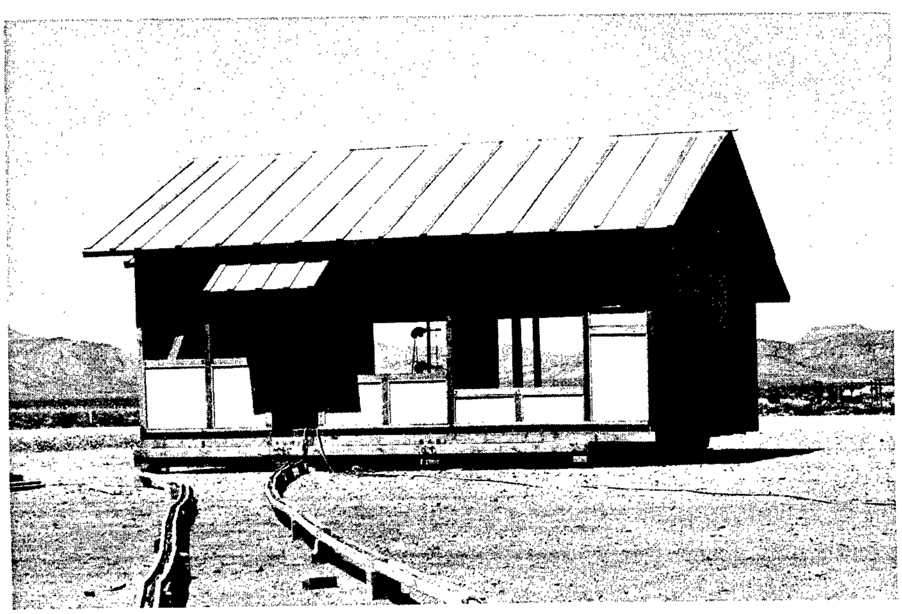


Fig. 2.4--House type A.

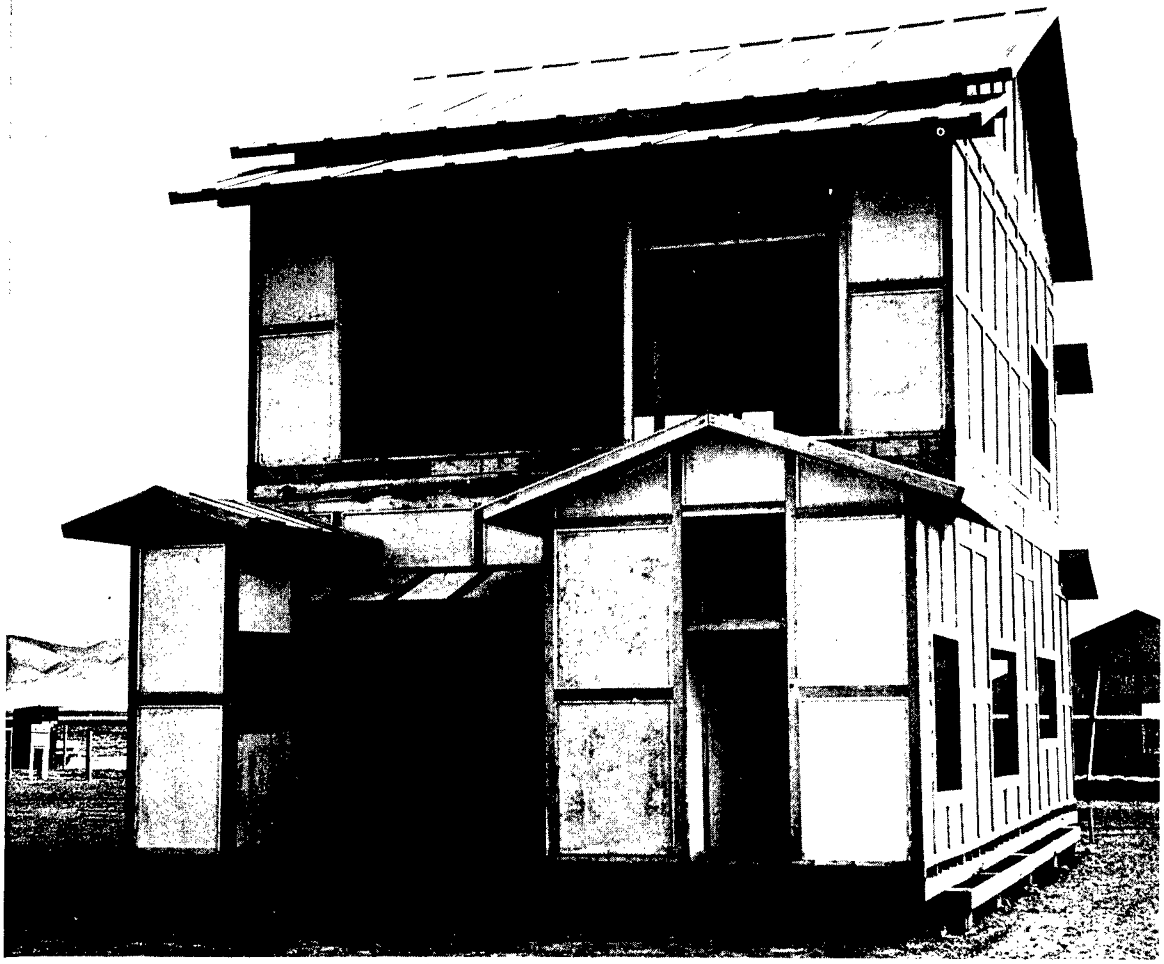


Fig. 2.5--House type B.

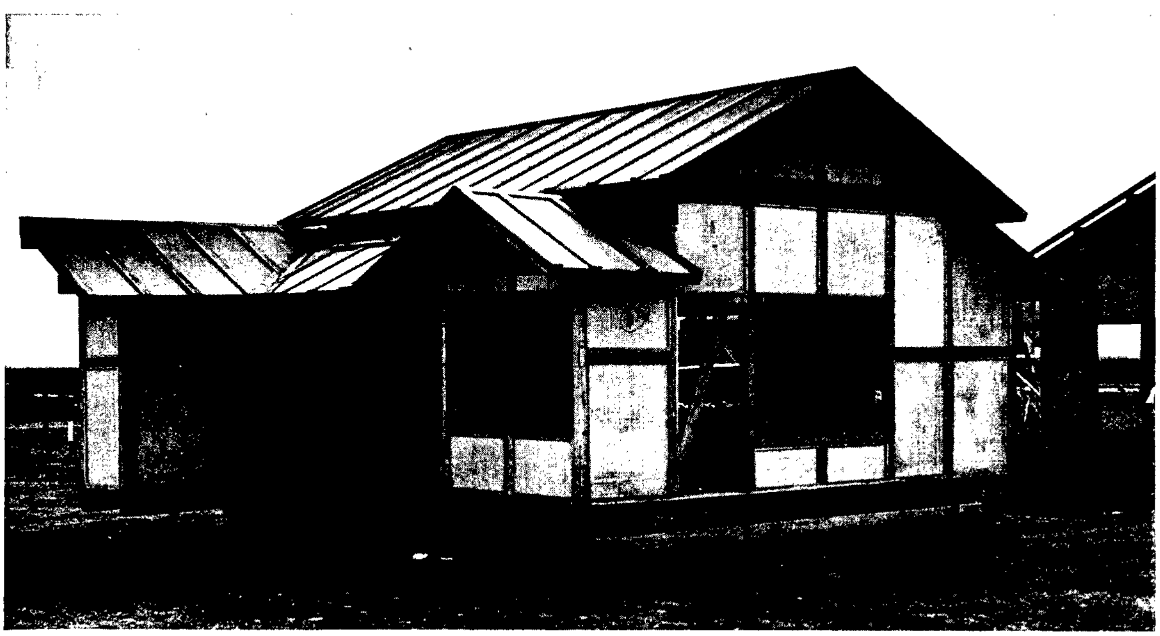


Fig. 2.6--House type C.

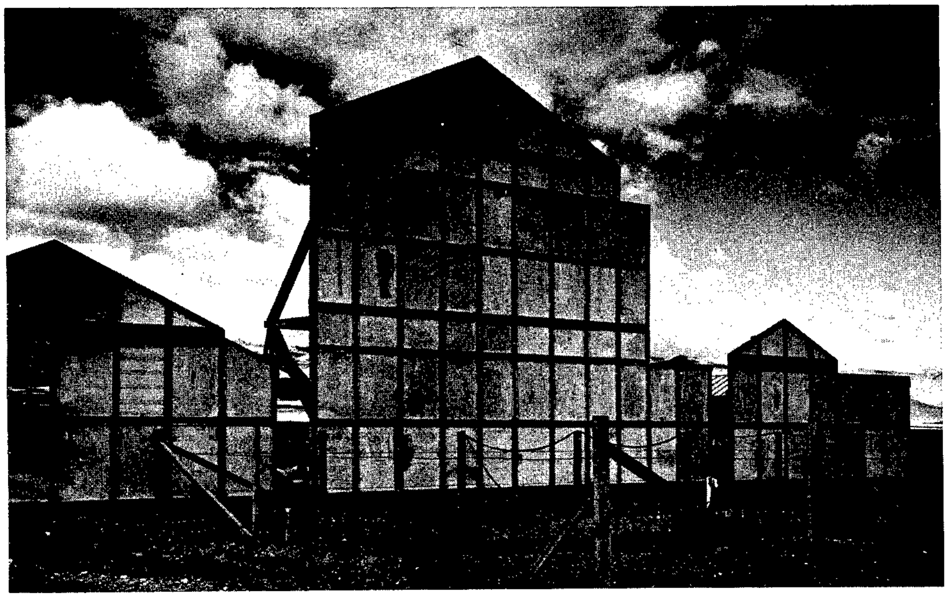


Fig. 2.7--Wall silhouettes.

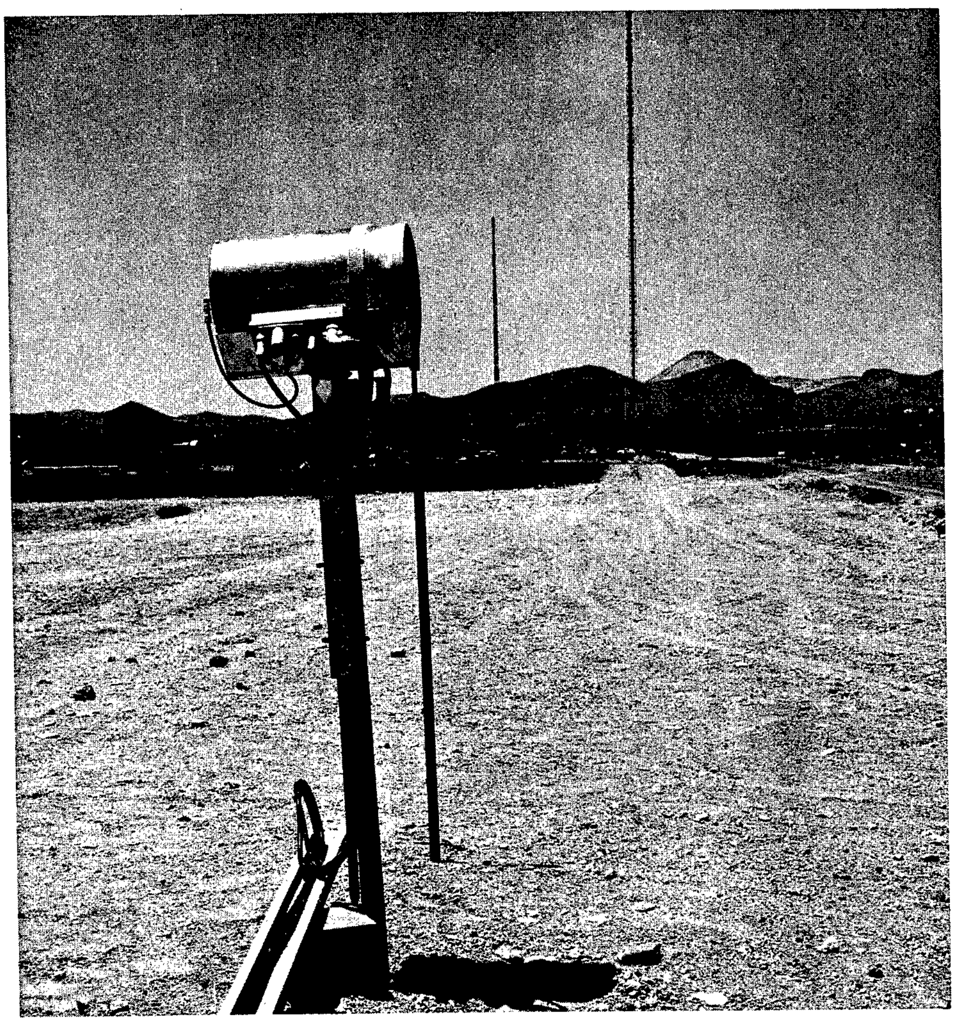


Fig. 2.8--Paraffin jacketed normalizing channel. 100-ft-high instrument tower on left in background. Reactor tower on right.

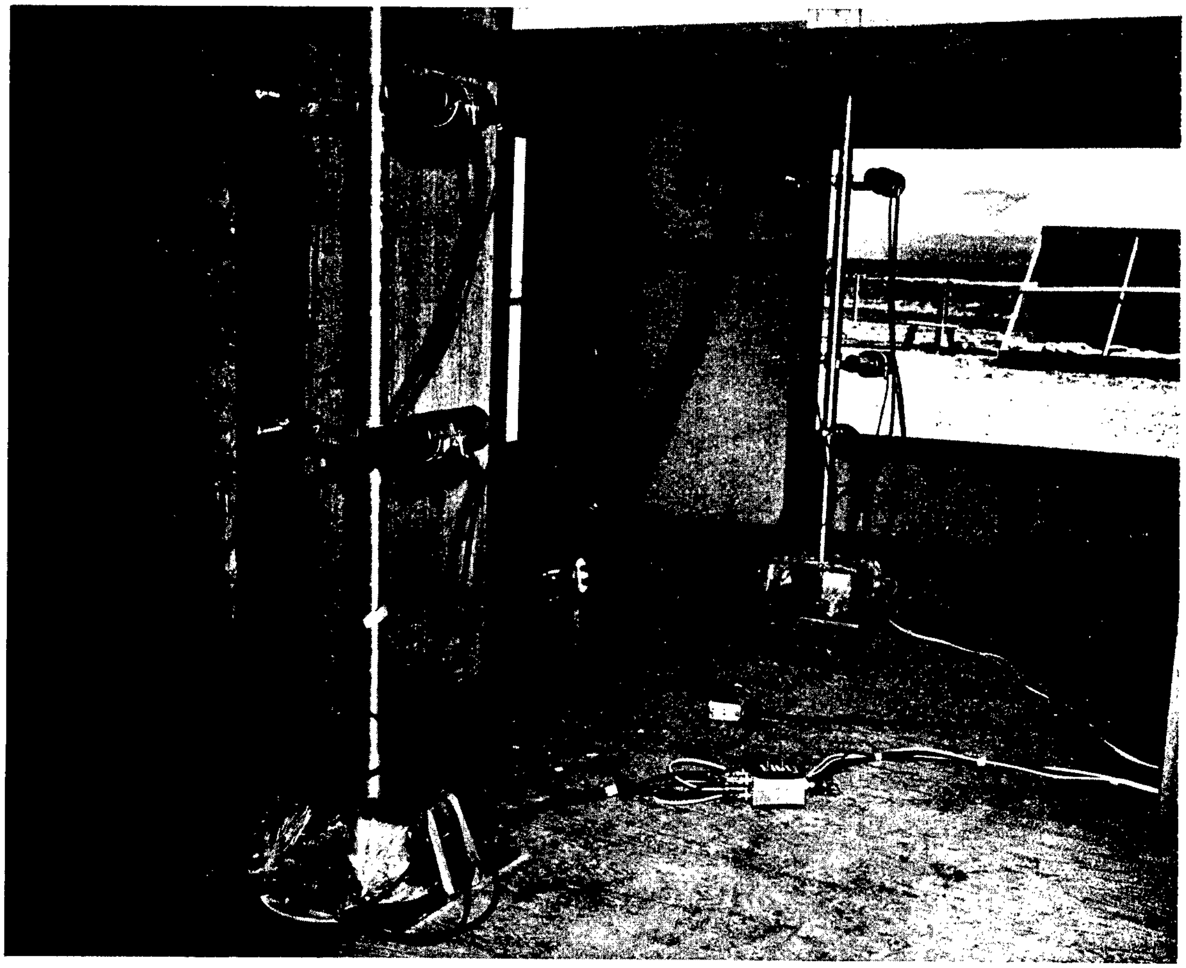


Fig. 2.9--Instrument pairs (1 Phil and 1 Radsan) mounted on stands in house.

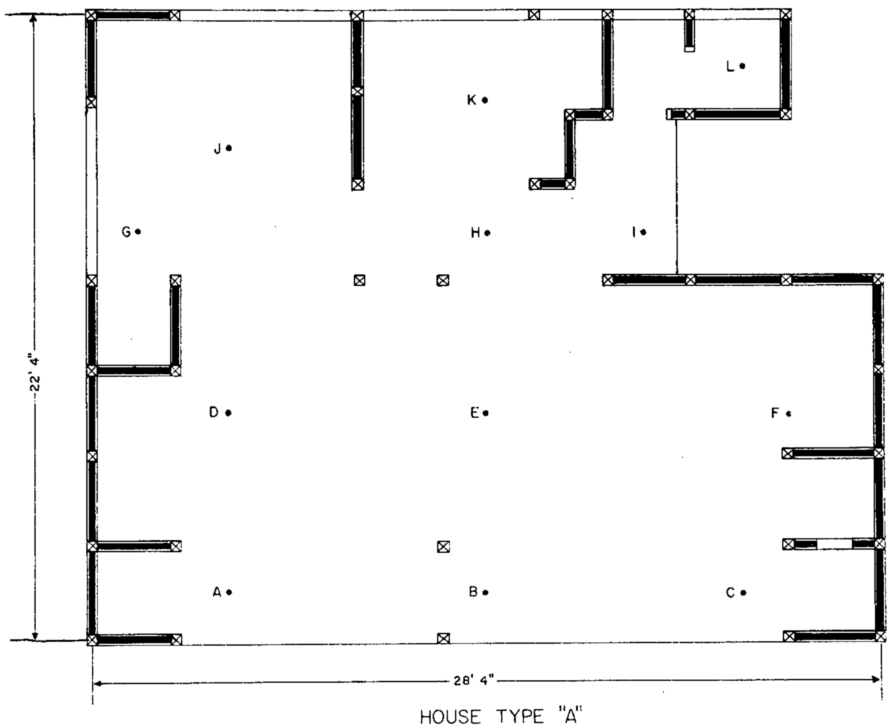


Fig. 2.10--Floor plan of house type A showing station locations.

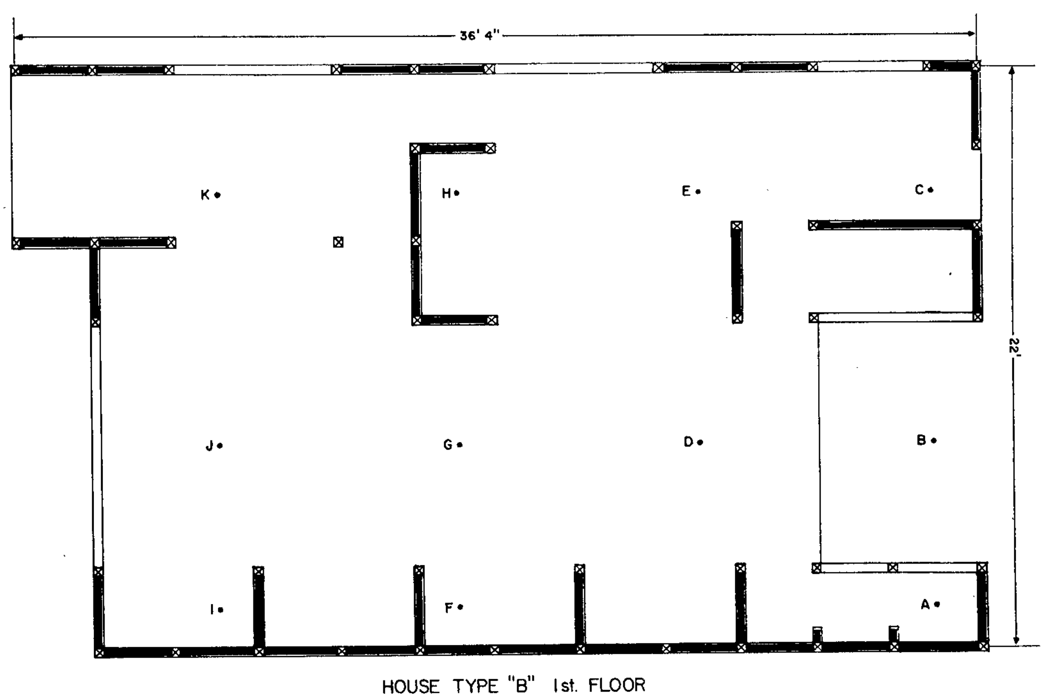


Fig. 2.11--Floor plan of lower floor of house type B showing station locations.

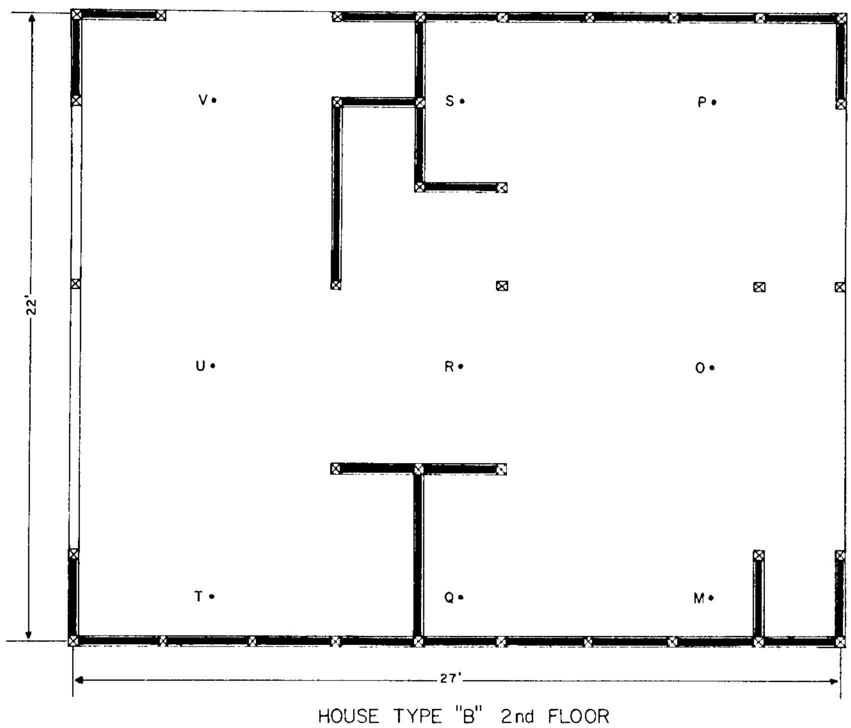


Fig. 2.12--Floor plan of upper floor of house type B showing station locations.

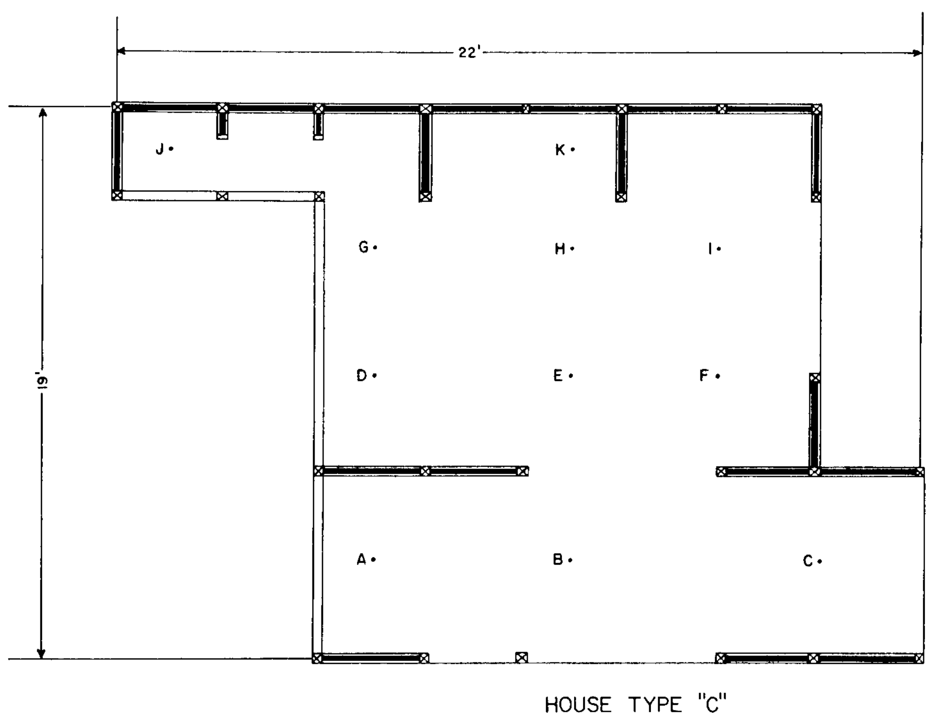


Fig. 2.13--Floor plan of house type C showing station locations.

Chapter 3

PROCEDURES

3.1 STANDARDIZATION AND CALIBRATION

The Phil dosimeters were tested for angular response with a view to evaluating calibration figures. It was found that not only was there an angular dependence of about 10% but also that this differed from instrument to instrument, as shown in Fig. 3.1. In view of this characteristic, it is difficult to calibrate for dose response with a point source.

The purpose of this study was a comparison of the doses in various shielding configurations with "air dose". As the shielding increased, the radiation field became more nearly isotropic. Therefore, cross calibrations were made with diffuse radiations under conditions similar to those of the actual measurements. To accomplish this, a "round robin" of calibration measurements was taken inside a house, wherein each of the group of instruments was successively placed in each of a series of positions of differing radiation intensity. The Phil counter correction factors were derived from this series by intercomparison and then applied to the field readings.

There may be an error due to the difference in angular distribution of radiation inside and outside the houses. However, each of the cones of 20° half angle at the ends of the detector tube, where the sensitivity is depressed, contains only 3% of the 4π solid angle. The angular variation in sensitivity is not over 16% (Fig. 3.1). A comparison was made between calculated values of the responses of these ends to the measured angular distribution in air when the reactor was at 26.5° elevation, the most usual case, and to an isotropic distribution, which was approached in the houses. The difference was between 1 and 2%.

Measurements were made in series of three or four, depending on the radiation intensity, and the averages are reported. Standard deviations were on the order of 2%. Stability of the counters was periodically checked by exposure to a ^{60}Co source at 90° to the axis. Reproducibility was excellent throughout the test period.

The normal standardization and calibration procedure for the Radsan dosimeters was modified slightly because of modifications in the instruments for use at NTS. The 5-volt discriminators were adjusted using a pulser and oscilloscope. Normal procedure prescribes adjusting the 10-volt, 20-volt, and 40-volt discriminators using the internal alpha source and scaler. It was found, however, to be faster and more accurate to adjust all four discriminators using the pulser and oscilloscope method. The discriminator settings were checked and adjusted, when necessary, at least once each operating day.

After alignment of the discriminators, the gain of the amplifier was adjusted to yield 1/2 the count rate of the particular alpha source. The gain adjustment was rechecked at least once during each half hour of operation. Drift rarely exceeded 2%.

The resolution of the proportional counters was monitored using the internal ^{239}Pu alpha sources, the amplifiers of the respective units, and a 256-channel analyzer.

In order to obtain more accurate calibration of the instruments than is possible using only the internal alpha source, a one-curie PuBe neutron source was positioned on the axis of each proportional counter at a distance of 75 cm forward from the centers of the sensitive volumes. The averages of series of five 212-sec measurements were used to calculate calibration factors for each instrument. These calibration factors were redetermined periodically and changed when they varied by more than 3%. The gamma-ray sensitivity of the counters was monitored using a ^{60}Co source. In order to minimize the effects of scattered radiation, calibration was performed in open air several meters from any large structure and with both source and detector suspended 7 ft above the ground.

The normalizing channels were standardized before and after each reactor run by means of a PuBe source. Differences between beginning and end of run readings were less than 1% most of the time and in no case exceeded 2.4%.

3.2 MEASUREMENTS

The measurements were made in the three houses singly and in combinations, some of which included wall silhouettes as shown in Figs. 3.2-3.13. In many cases measurements were made at the 1- and 7-ft elevations in addition to those at 3 and 5 ft. In the case of grouped houses, only those points were measured which had previously been found to be affected by neighboring structures.

The raw data were corrected for counter factors and for distance when there was a significant difference between air dose at the distance of the measured point from the source and the standard locations for air measurements (750 or 1000 yds). For gamma measurements, corrections were also made for effects of temperature, since the power normalization was made on the basis of the paraffin (or wood) encased BF_3 counters, which monitored neutron flux reaching them, and the relaxation lengths of gamma and neutron radiation and, consequently, air attenuation varied at different rates with the temperature which is an important factor influencing air density.

The adjusted values for both gamma-ray and neutron doses were plotted in their respective positions on the floor plans of each house, according to the key appearing in Fig. 3.14. These values are presented in Figs. 3.15-3.65. The floor plans also show representations of adjacent structures, where appropriate. A summary of these data also appears in Tables 3.1-3.6.

In most cases, when the same house configuration was used but some other condition was changed, the same layout number was used with a prime ('). For example, 1A' lies in the same configuration as 1A, but the roof has been added, whereas 1A had no roof. An exception is the 11B series, which used the same layout as 9B, but for which the reactor elevation was varied.

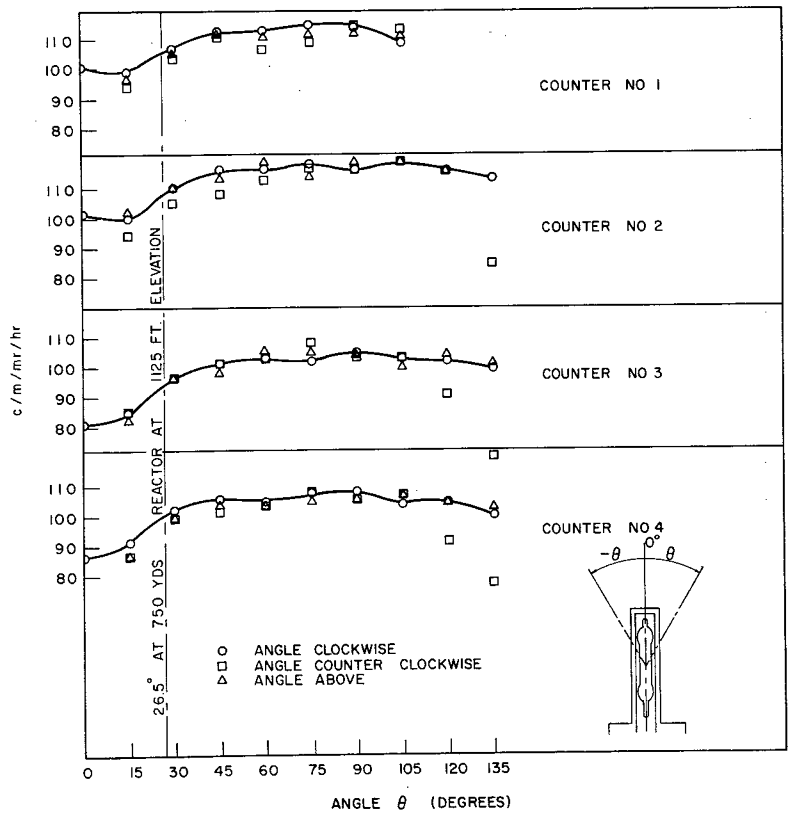


Fig. 3.1--Angular response of Phil detectors (drop at -135° due to shadow of Radsan).

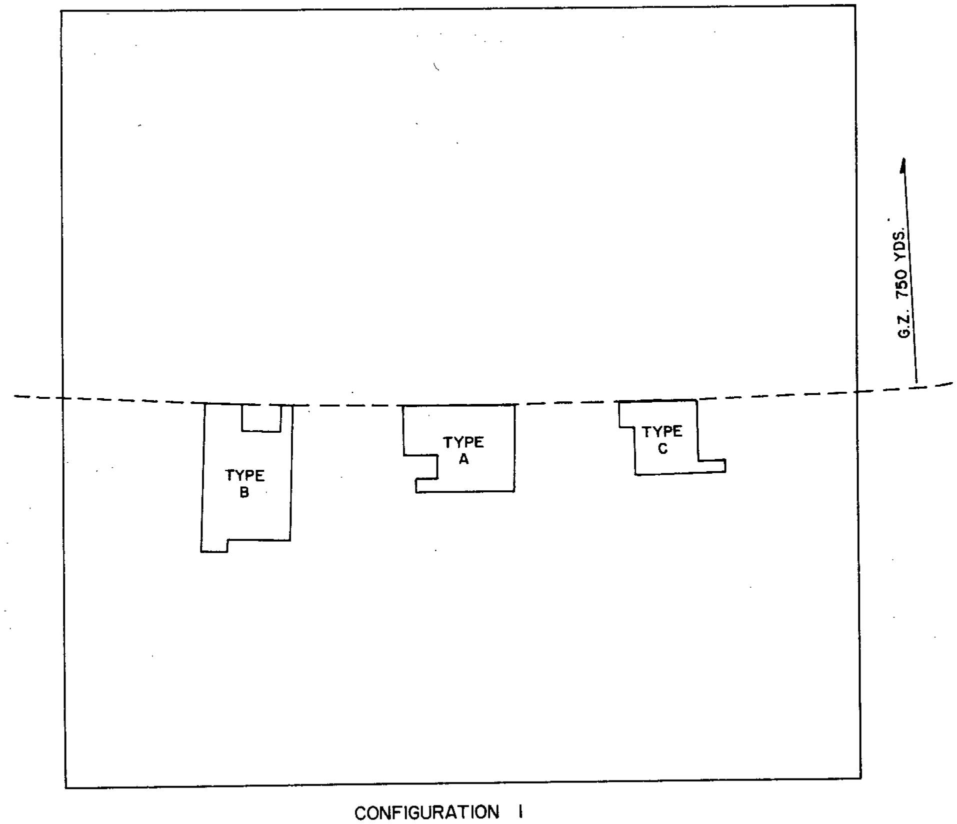
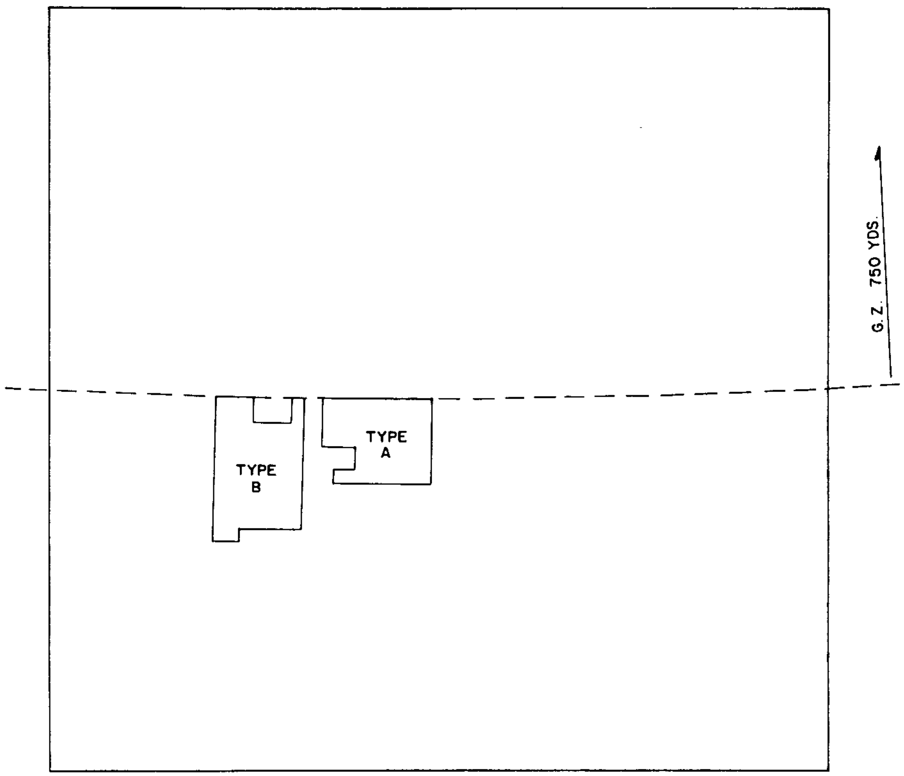
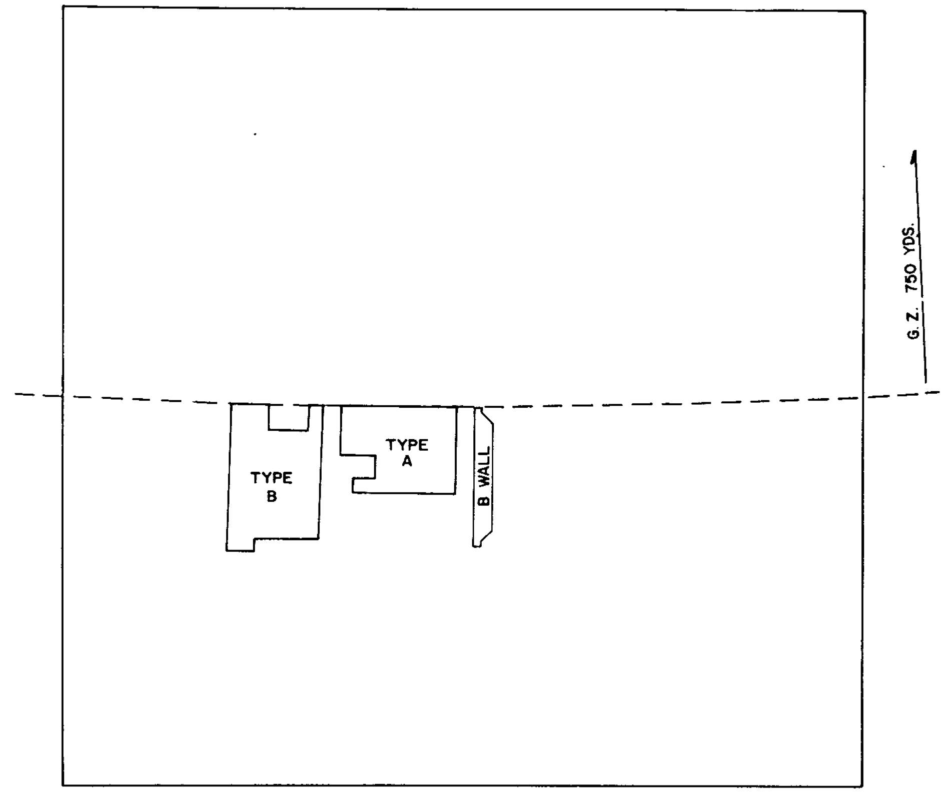


Fig. 3.2--House arrangement in configuration No. 1.



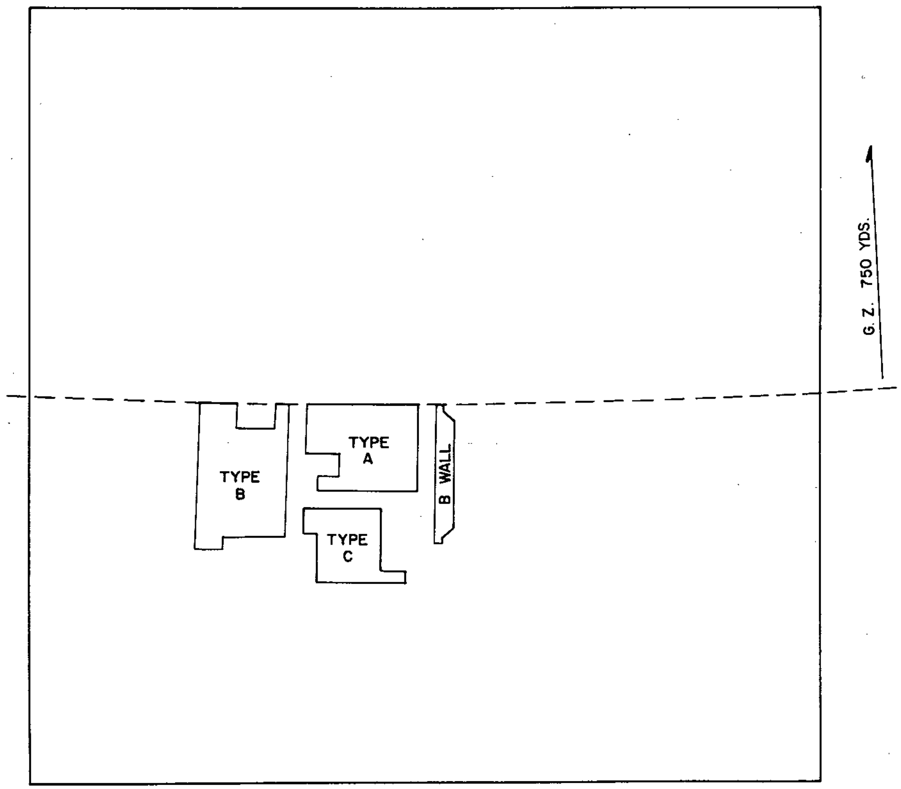
CONFIGURATION 2

Fig. 3.3--House arrangement in configuration No. 2.



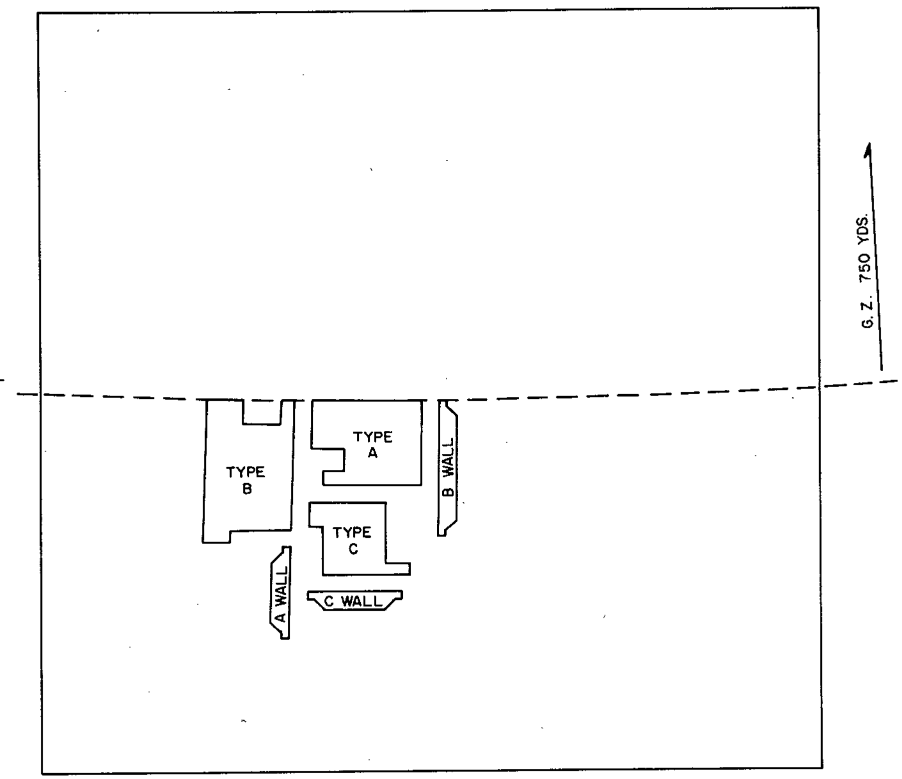
CONFIGURATION 3

Fig. 3.4--House arrangement in configuration No. 3.



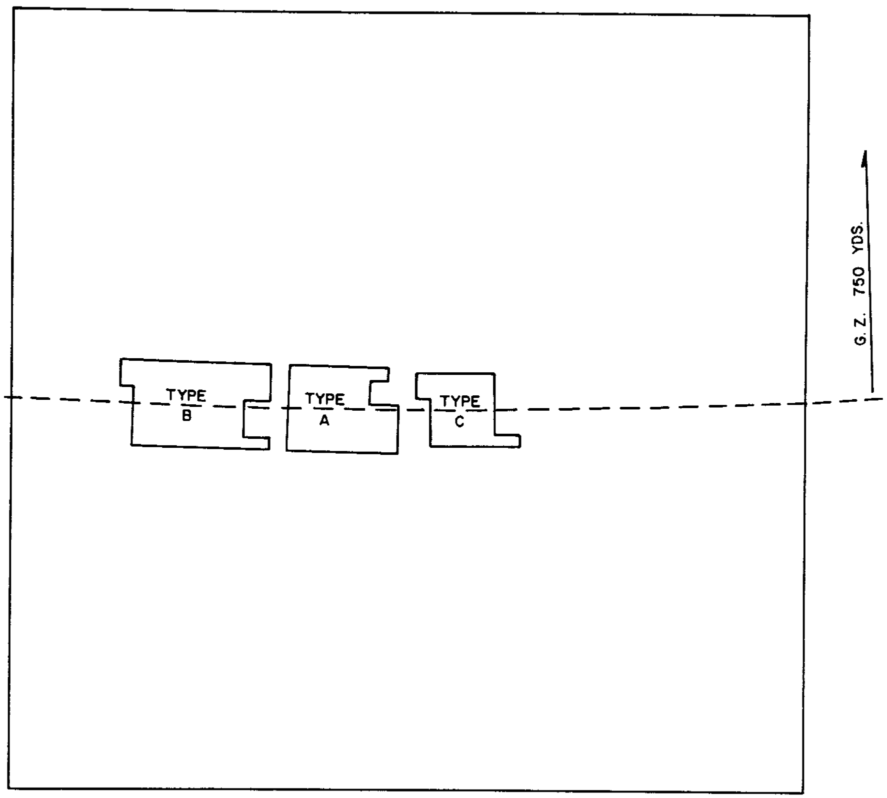
CONFIGURATION 4

Fig. 3.5--House arrangement in configuration No. 4.



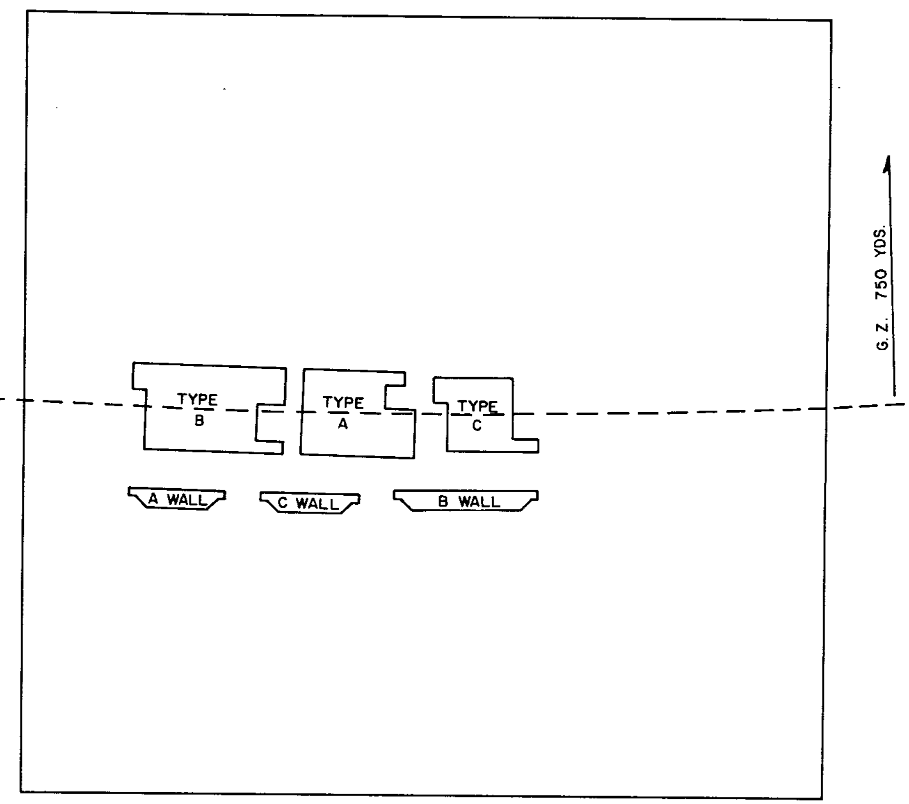
CONFIGURATION 5

Fig. 3.6--House arrangement in configuration No. 5.



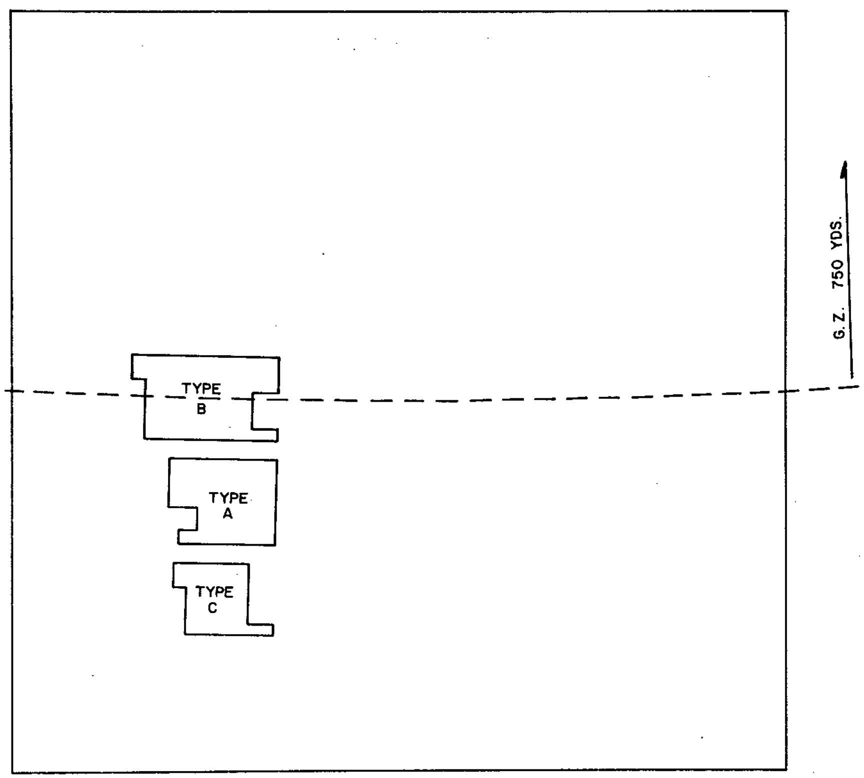
CONFIGURATION 6

Fig. 3.7--House arrangement in configuration No. 6.



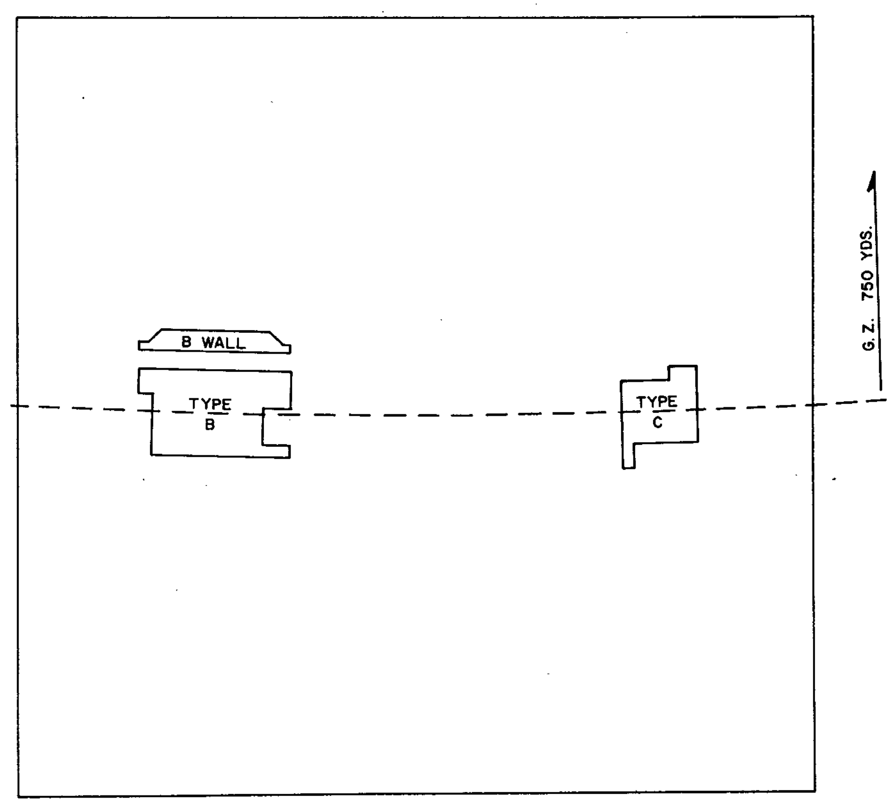
CONFIGURATION 7

Fig. 3.8--House arrangement in configuration No. 7.



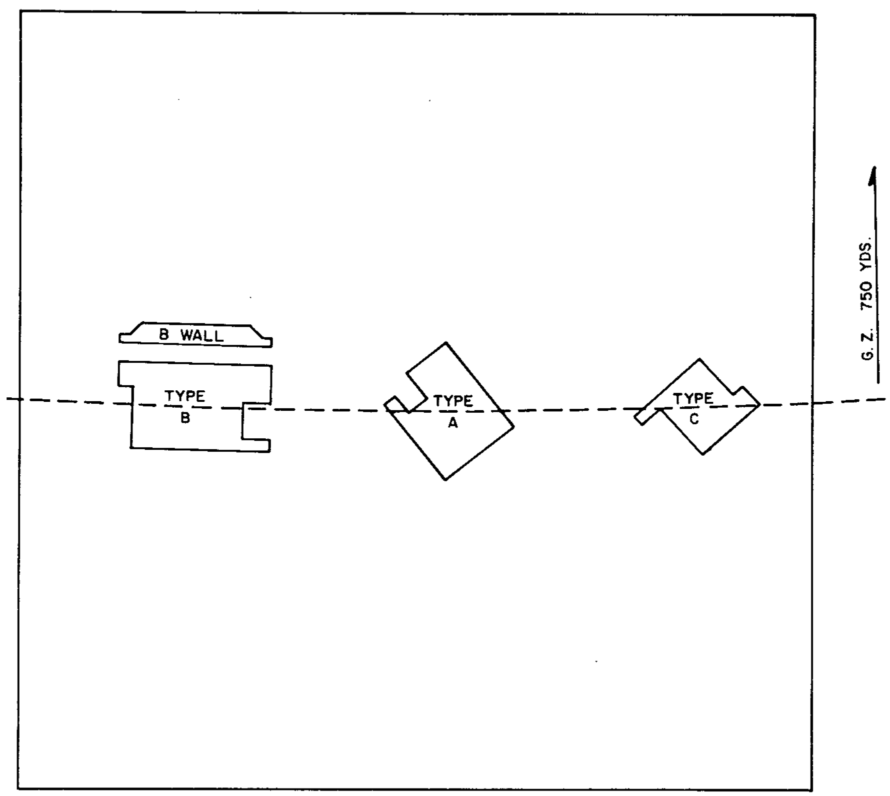
CONFIGURATION 8

Fig. 3.9--House arrangement in configuration No. 8.



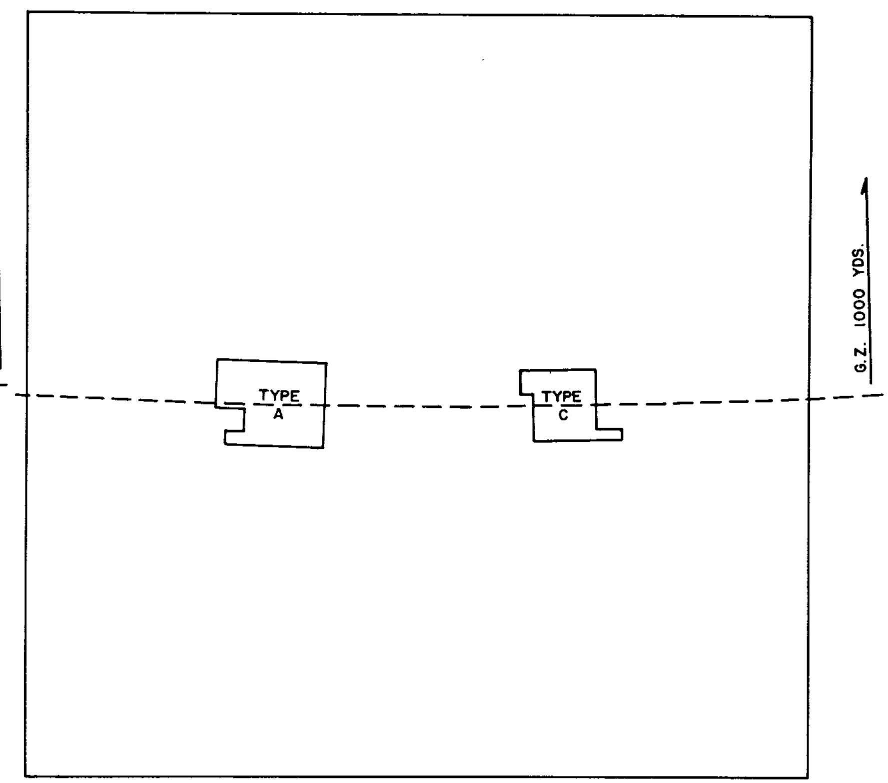
CONFIGURATION 9

Fig. 3.10--House arrangement in configuration No. 9.



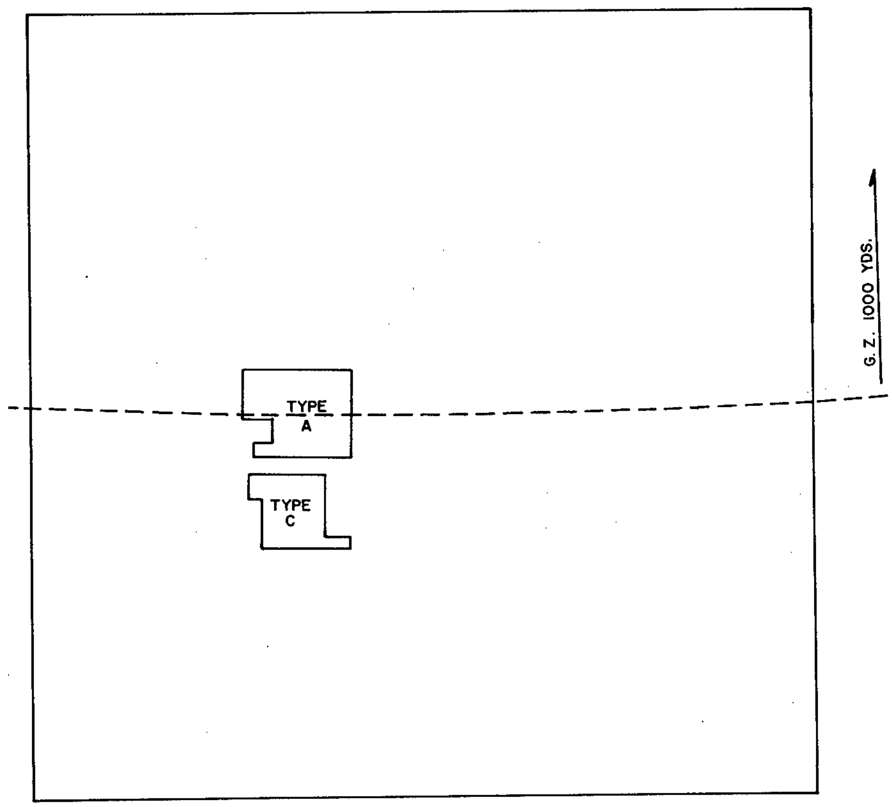
CONFIGURATION 10

Fig. 3.11--House arrangement in configuration No. 10.



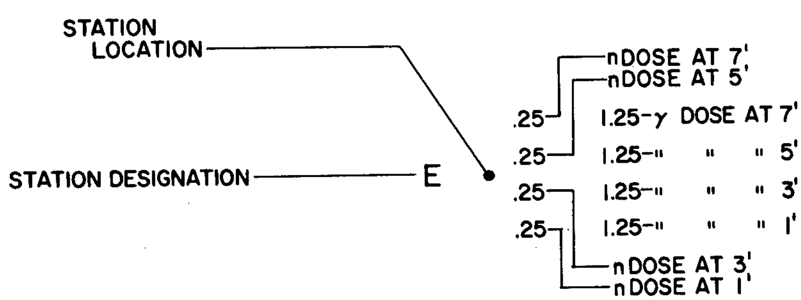
CONFIGURATION 12

Fig. 3.12--House arrangement in configuration No. 12.



CONFIGURATION 13

Fig. 3.13--House arrangement in configuration No. 13.



NOTE:

BLANK SPACE IN ANY POSITION INDICATES NO MEASUREMENT AT THAT LOCATION

Fig. 3.14--Key to presentation of ratios of measured doses to air doses at corresponding distances at indicated locations.

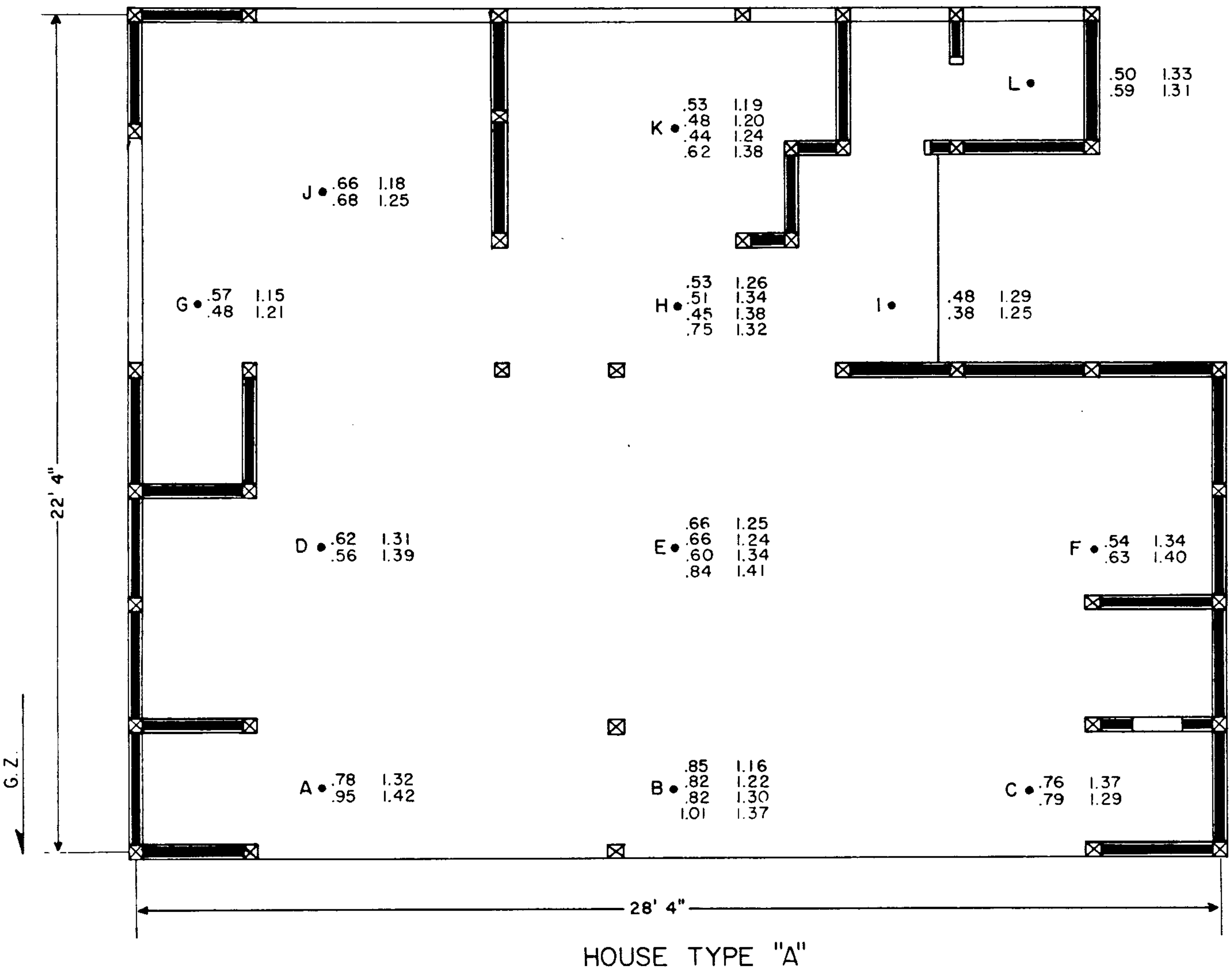


Fig. 3.15--D_m/D_a ($Dose_{measured}/Dose_{air}$), reactor radiation in house type A (no roof) in configuration No. 1.

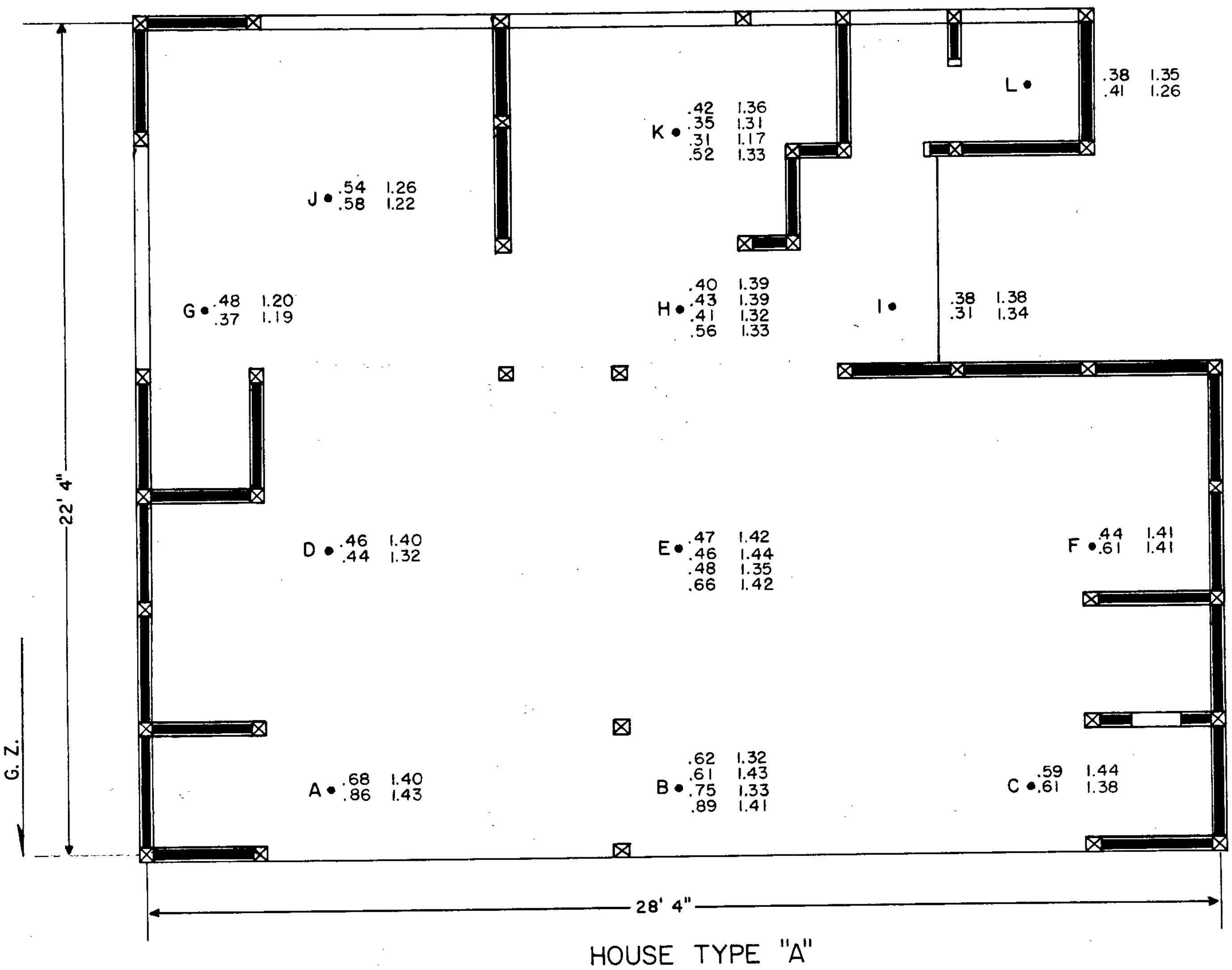


Fig. 3.16--D_m/D_a, reactor radiation in house type A (roof added) in configuration No. 1.

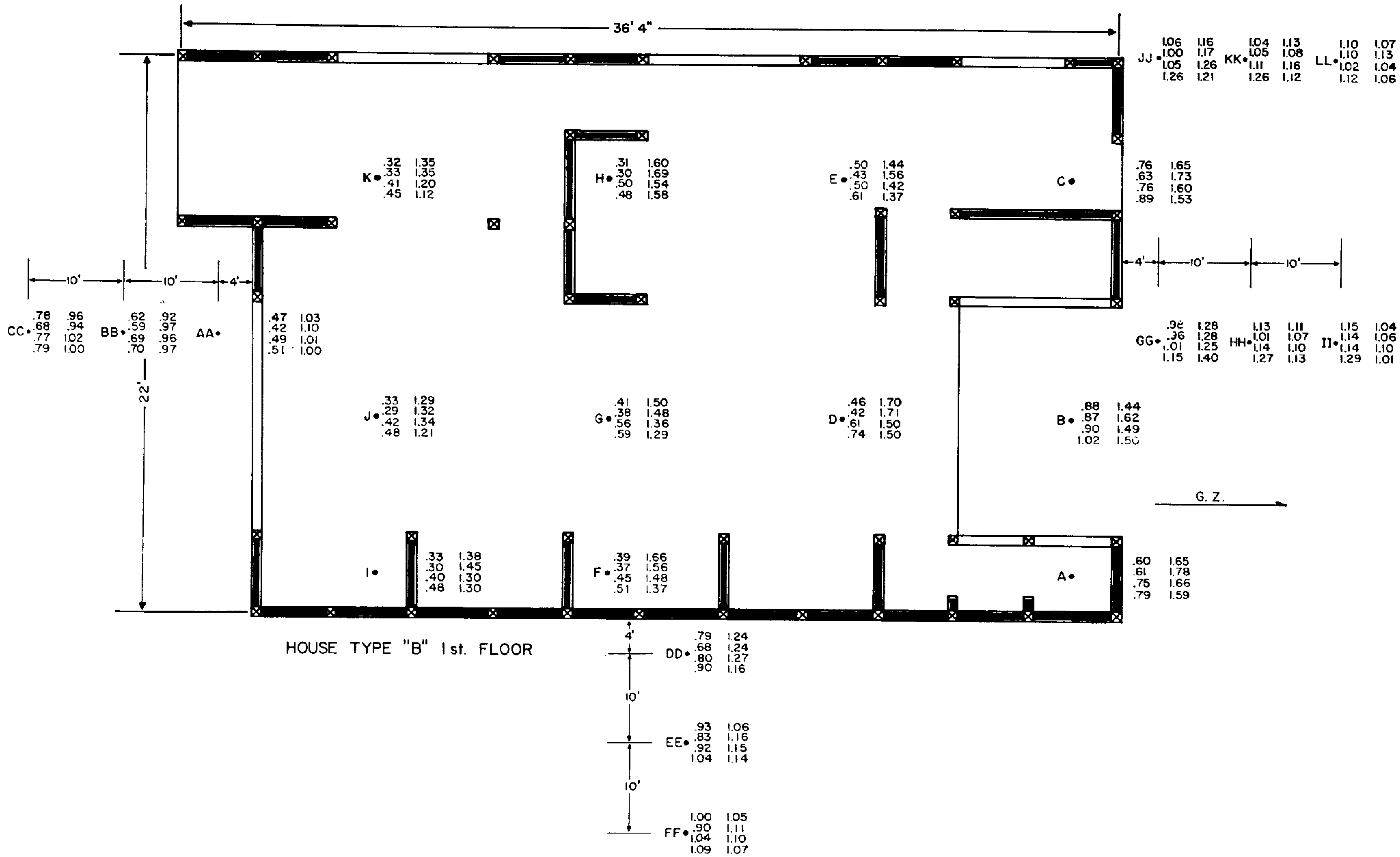


Fig. 3.17--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 1, together with nearby outside locations.

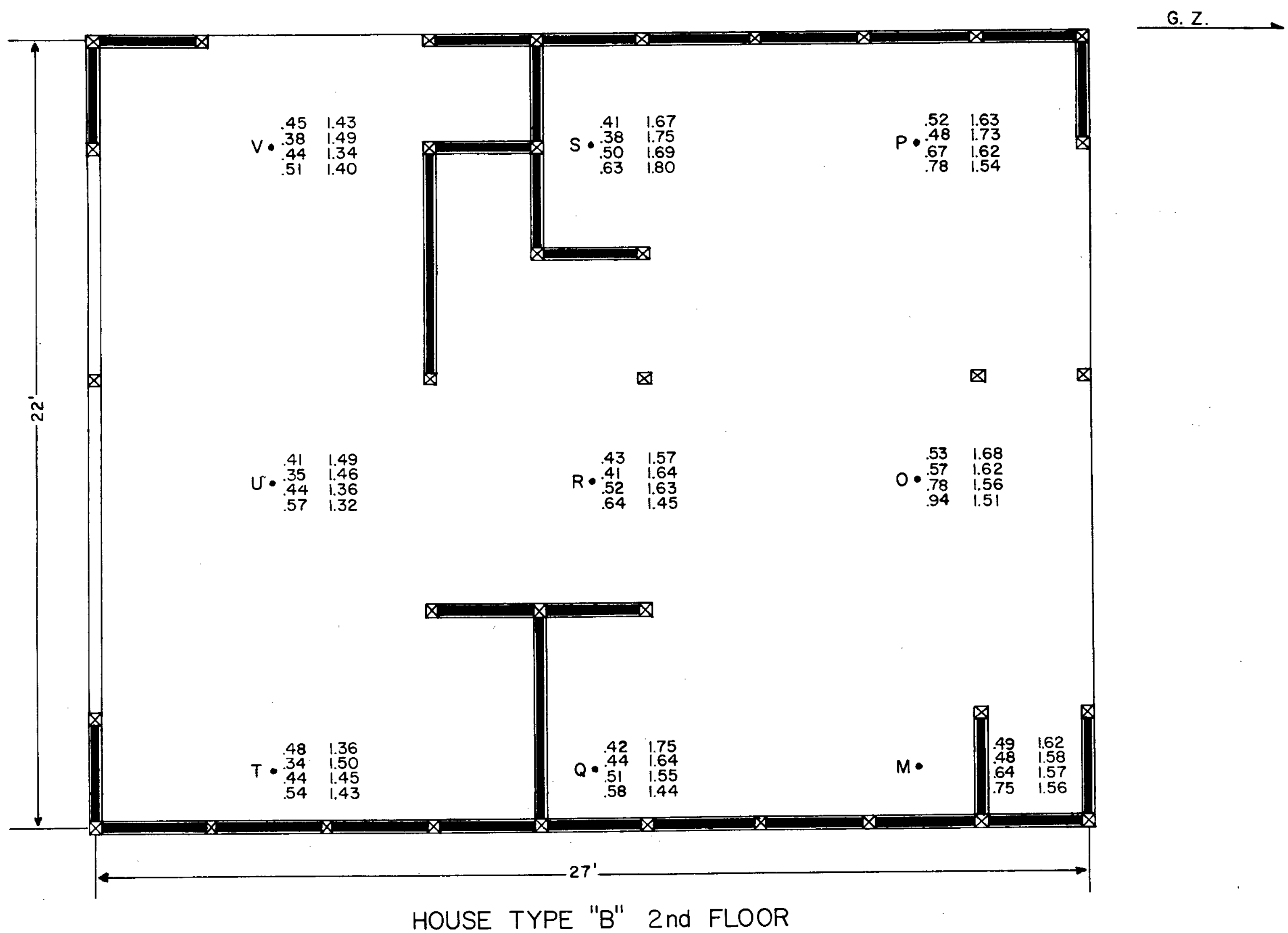


Fig. 3.18--D_m/D_a, reactor radiation on upper floor of house type B in configuration No. 1.

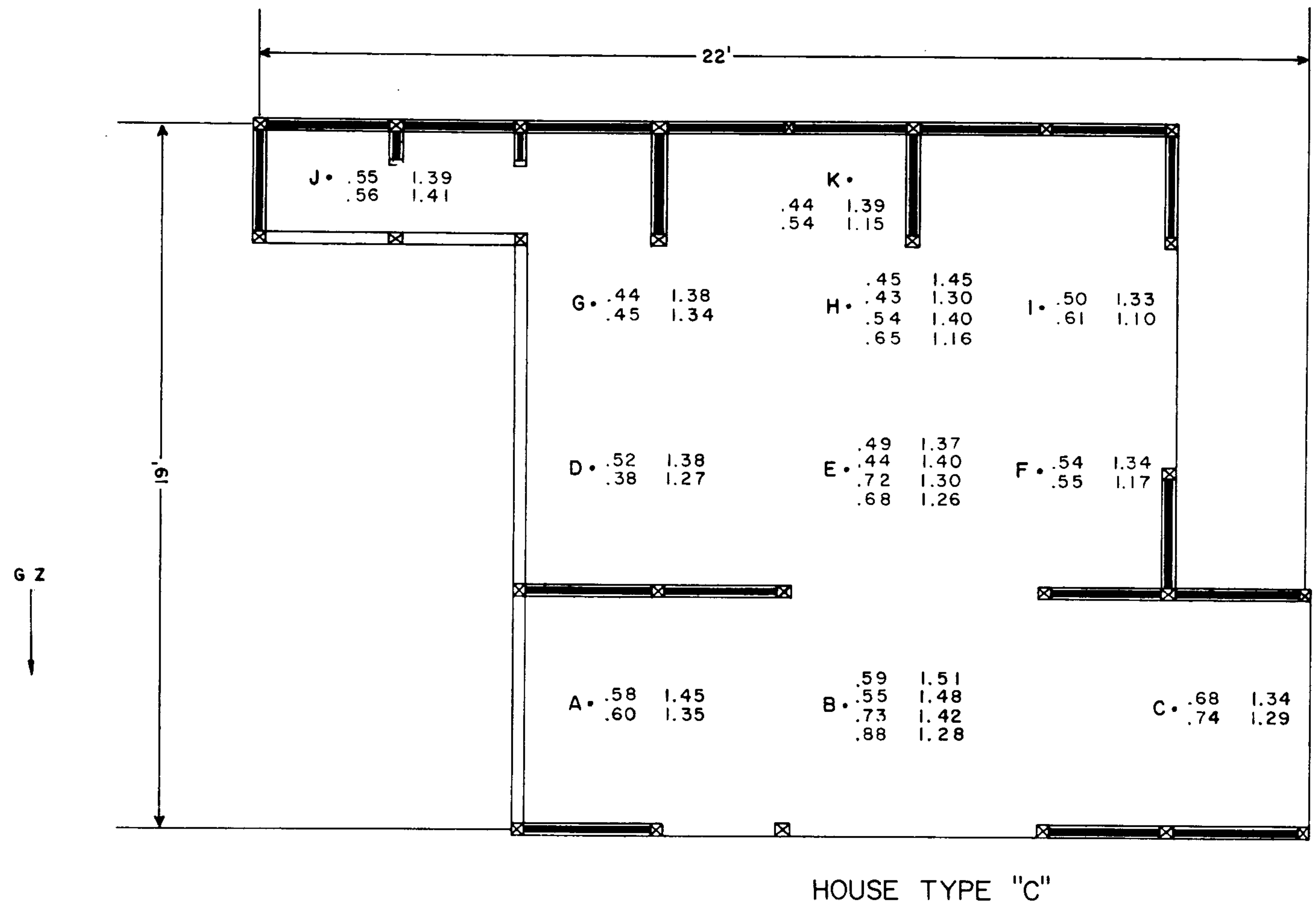


Fig. 3.19--D_m/D_a, reactor radiation in house type C in configuration No. 1.

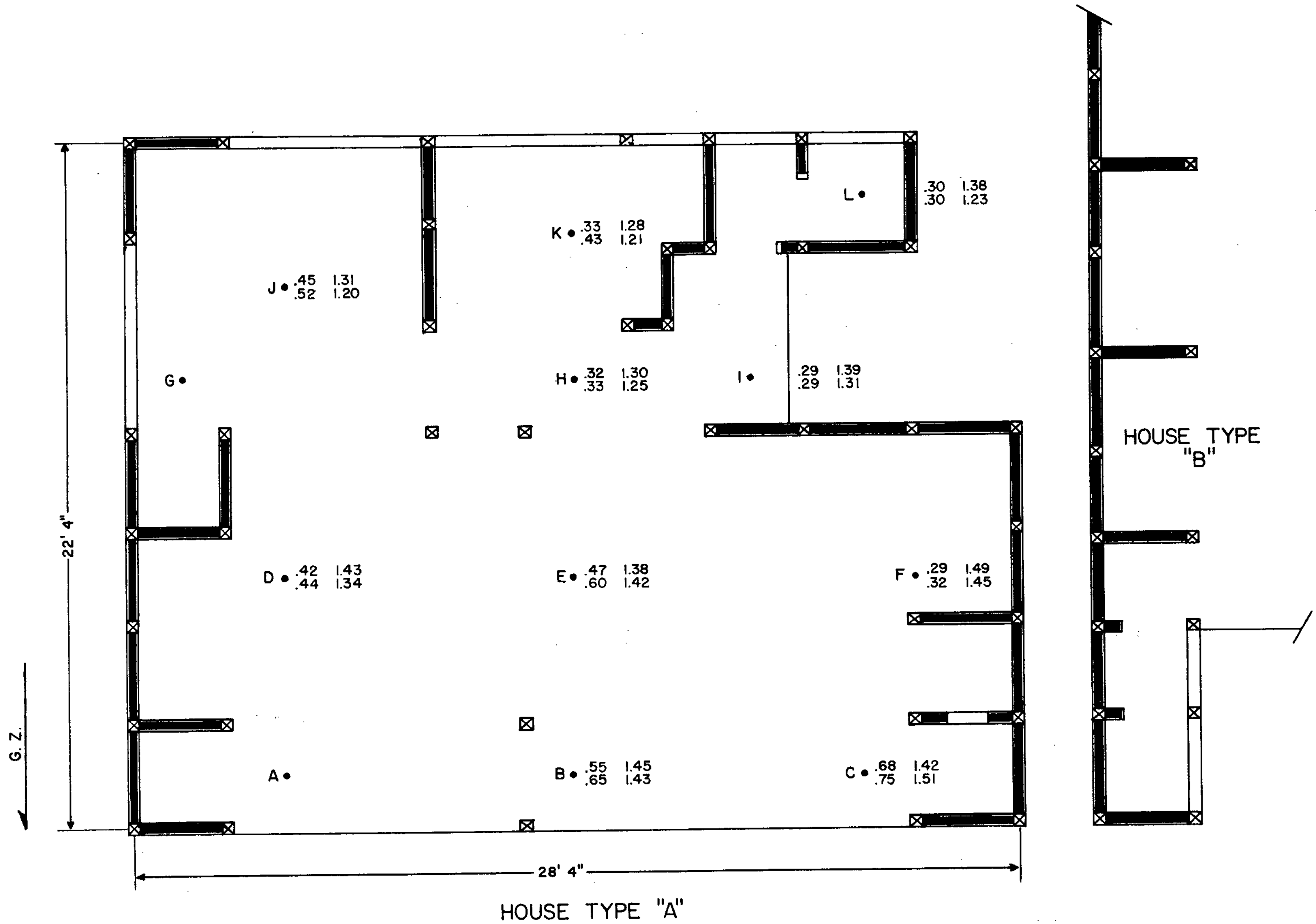


Fig. 3.20--D_m/D_a, reactor radiation in house type A in configuration No. 2.

Fig. 3.21--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 2.

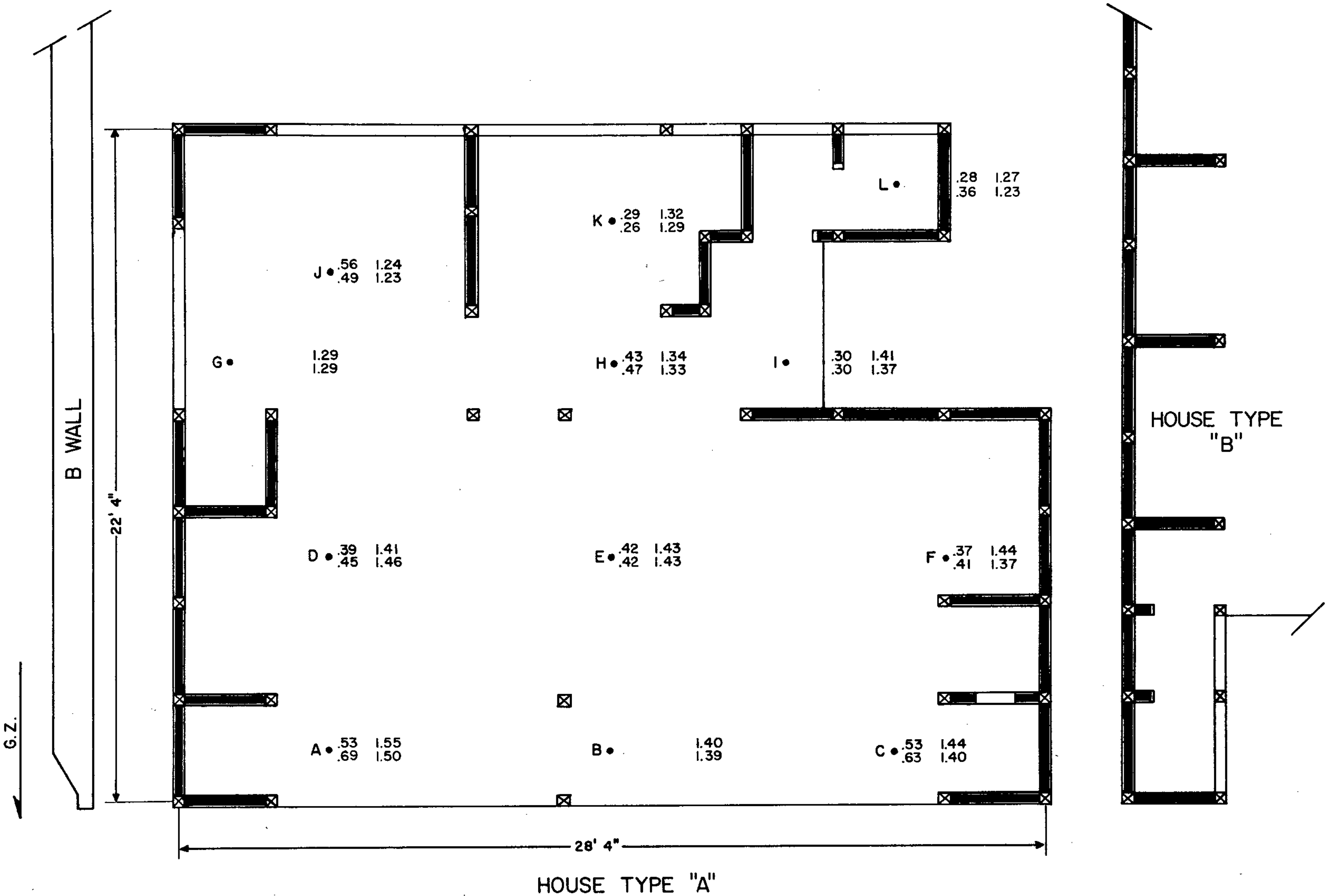


Fig. 3.22--D_m/D_a, reactor radiation in house type A in configuration No. 3.

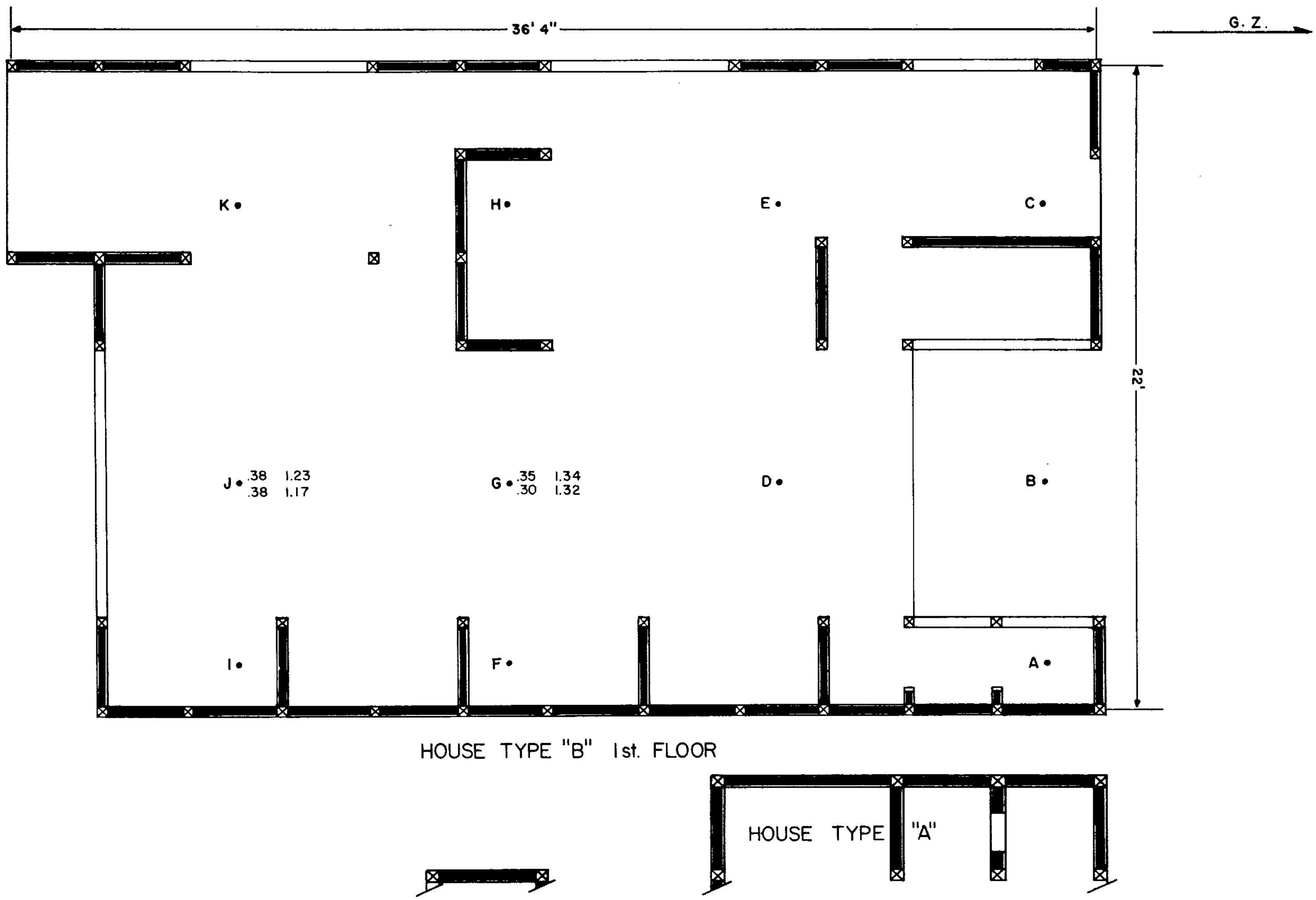


Fig. 3.23--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 3.

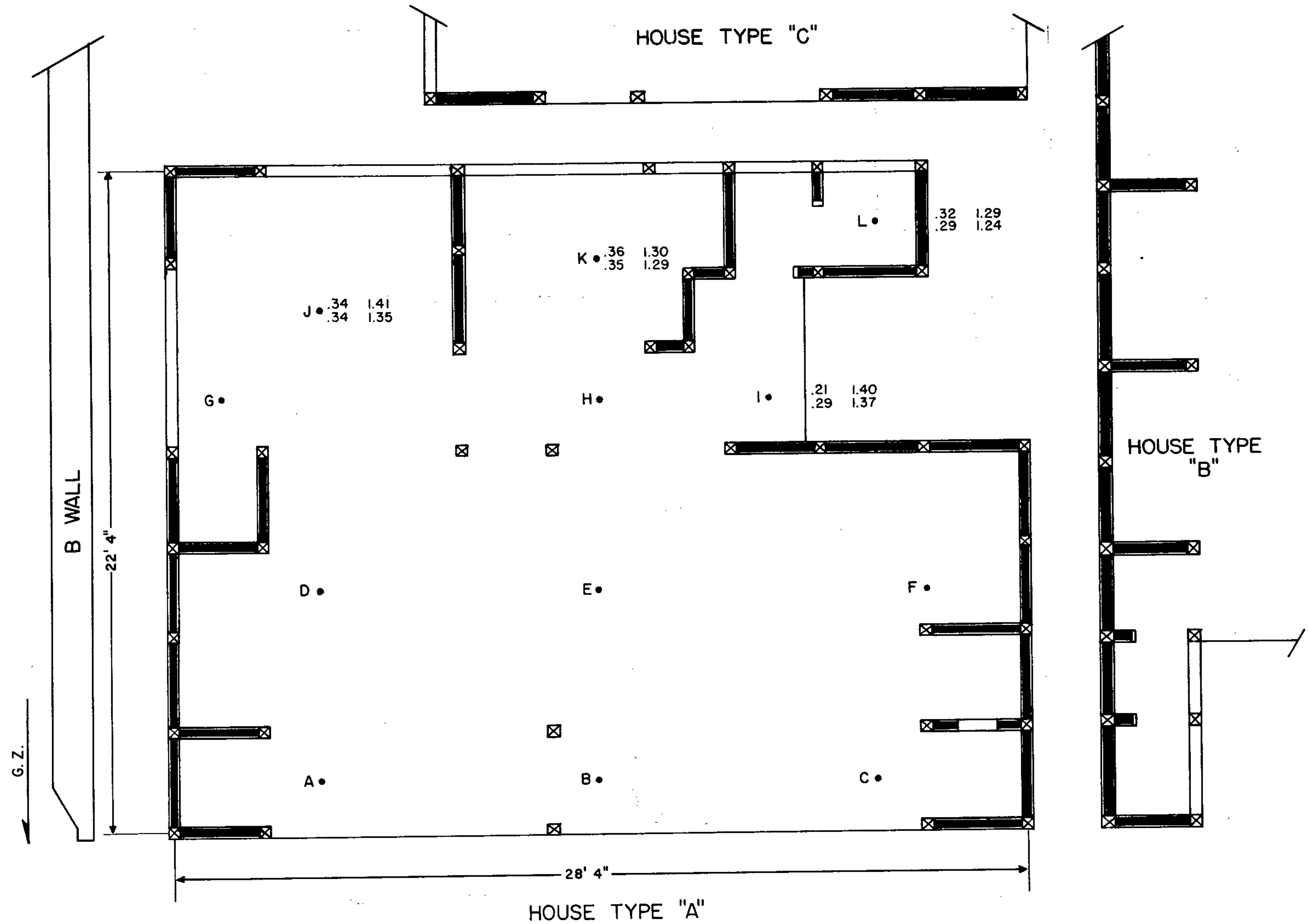


Fig. 3.24--D_m/D_a, reactor radiation in house type A in configuration No. 4.

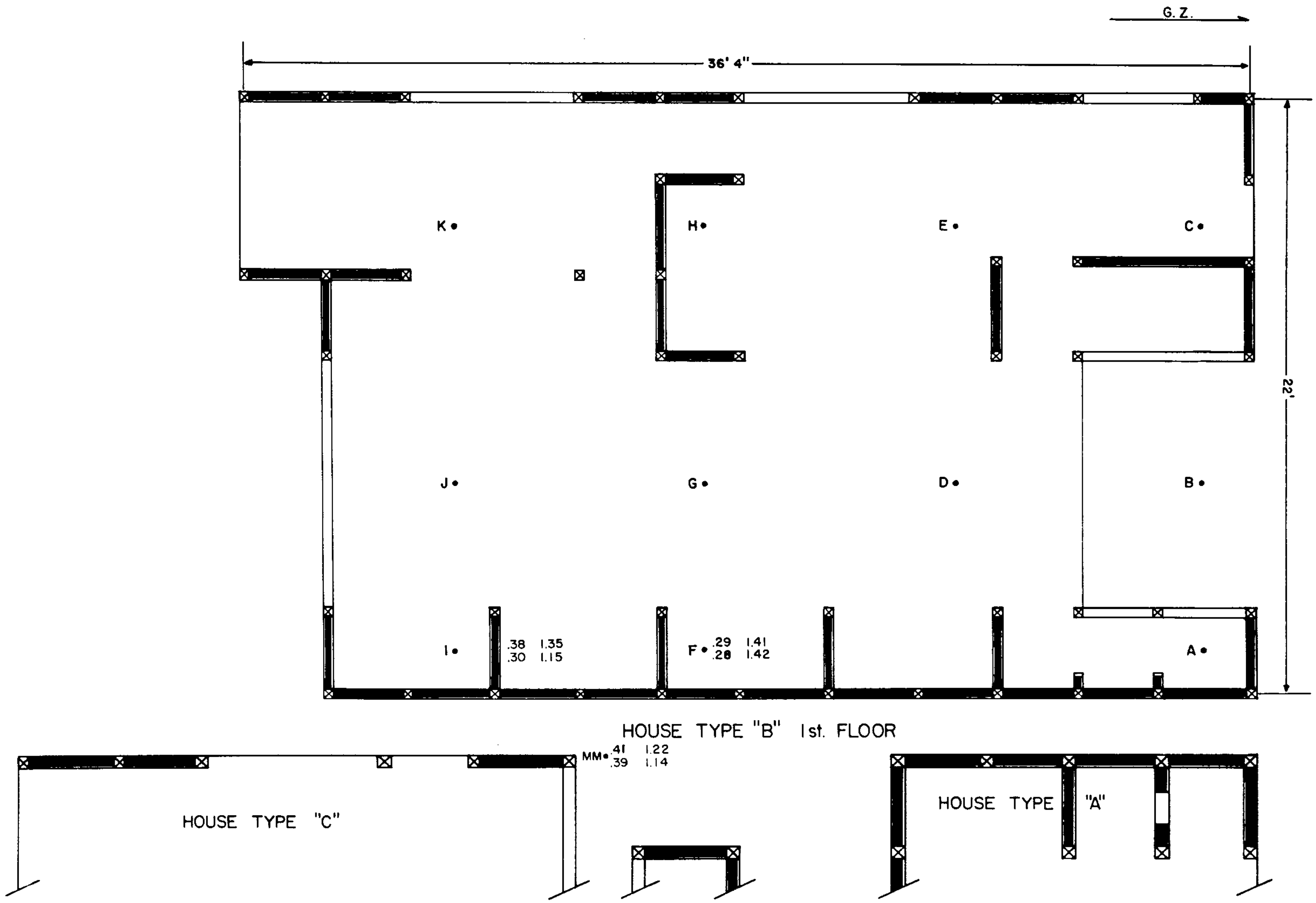


Fig. 3.25--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 4.

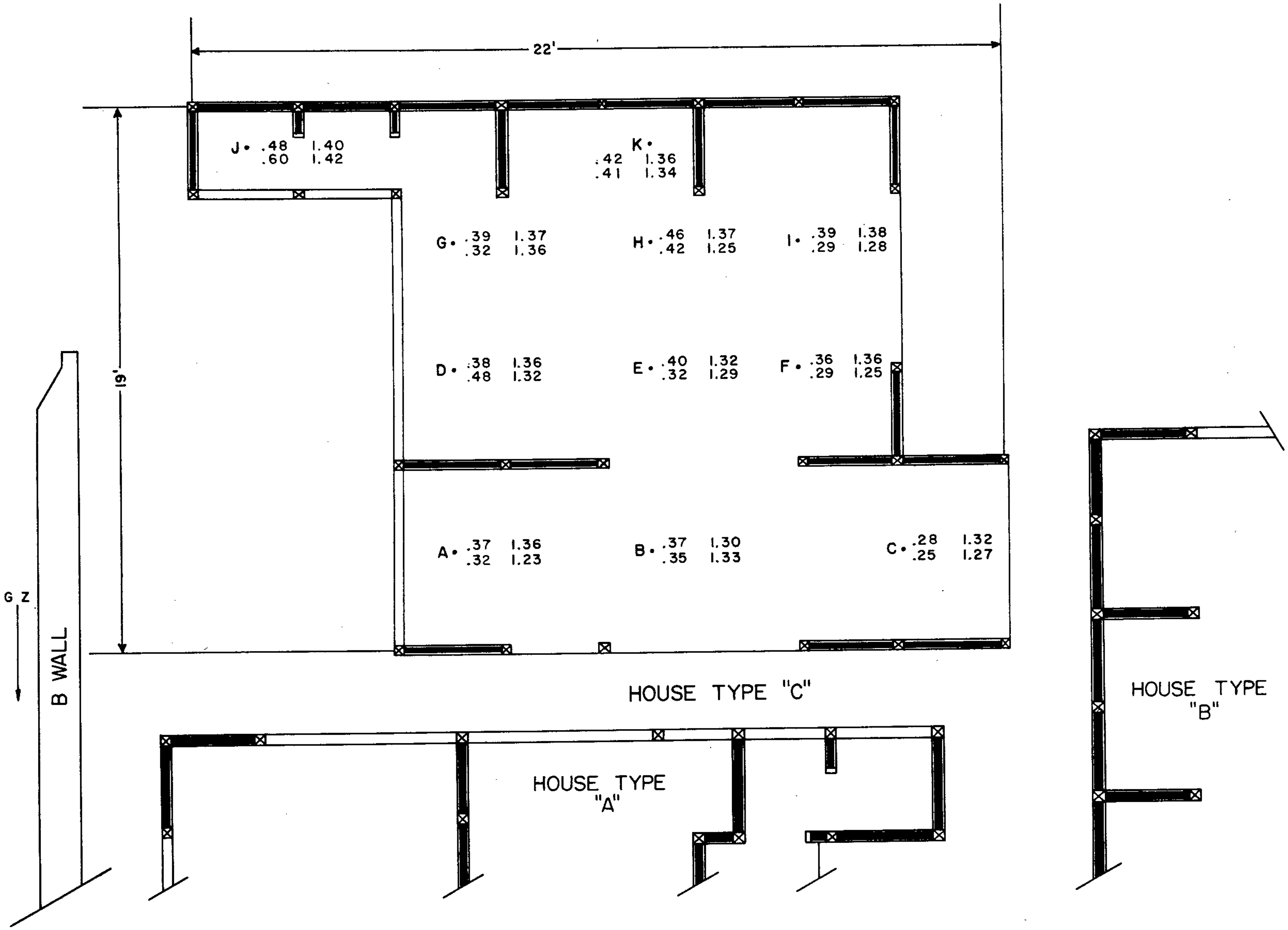


Fig. 3.26--D_m/D_a, reactor radiation in house type C in configuration No. 4.

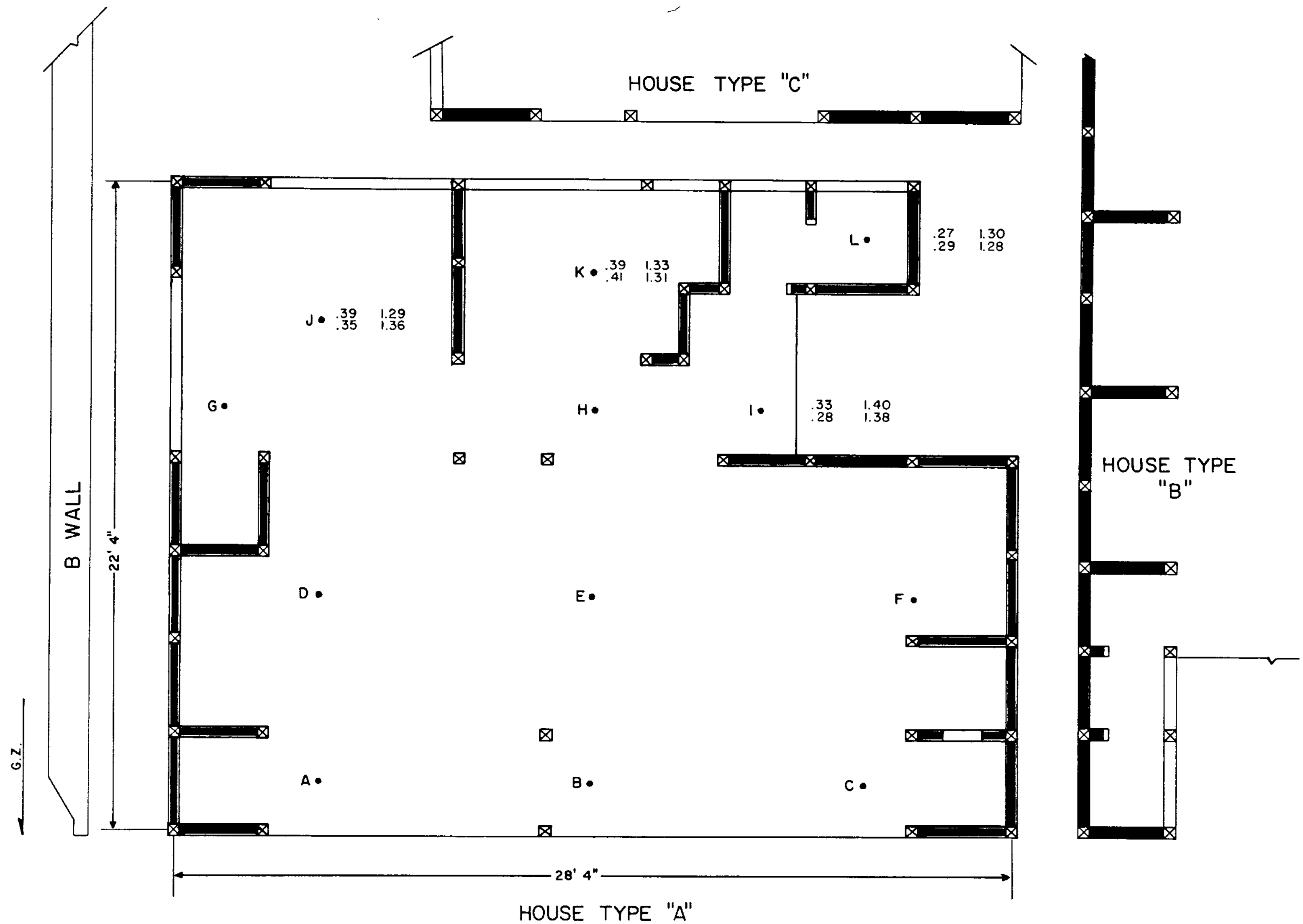


Fig. 3.27--D_m/D_a, reactor radiation in house type A in configuration No. 5.

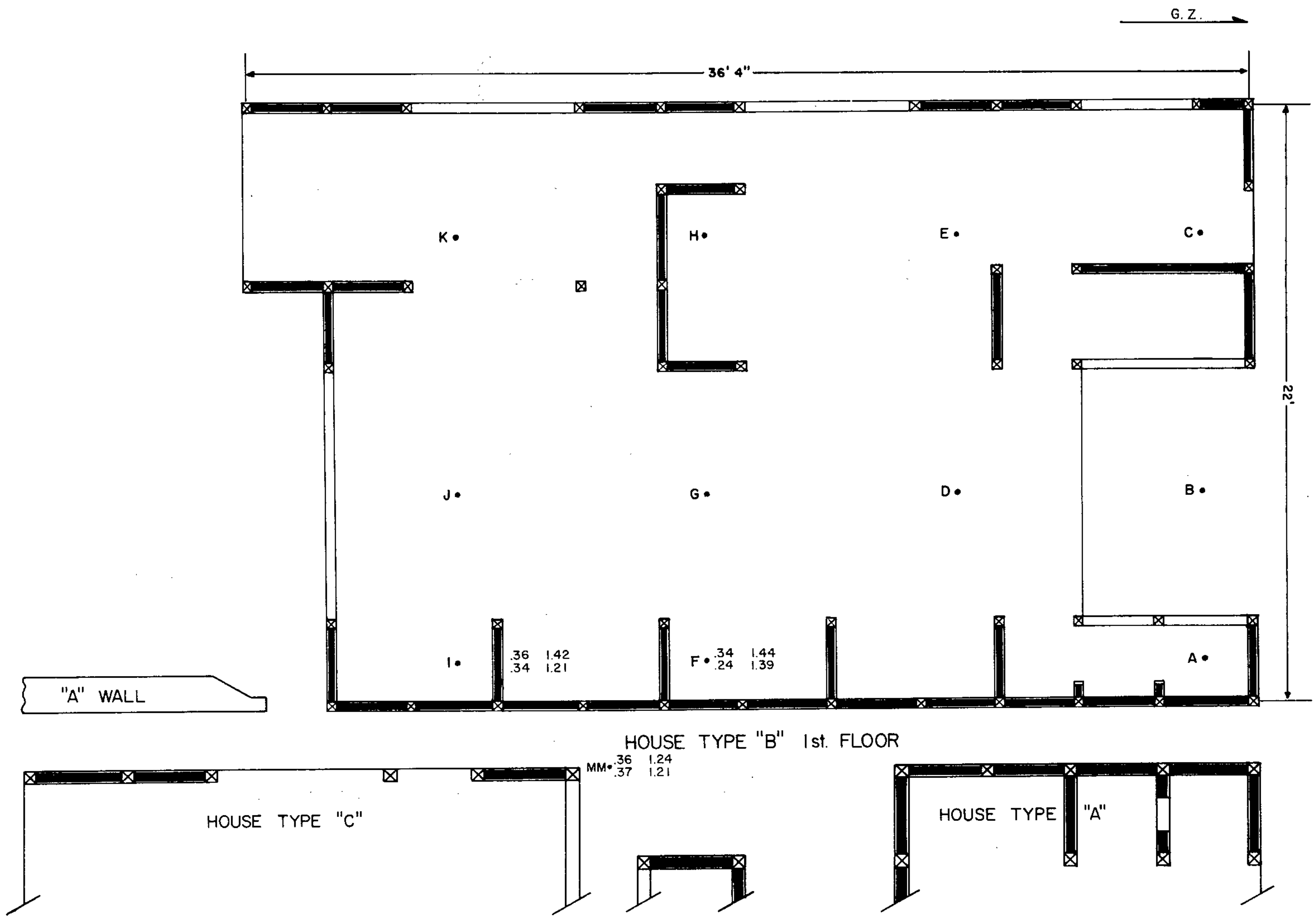


Fig. 3.28--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 5.

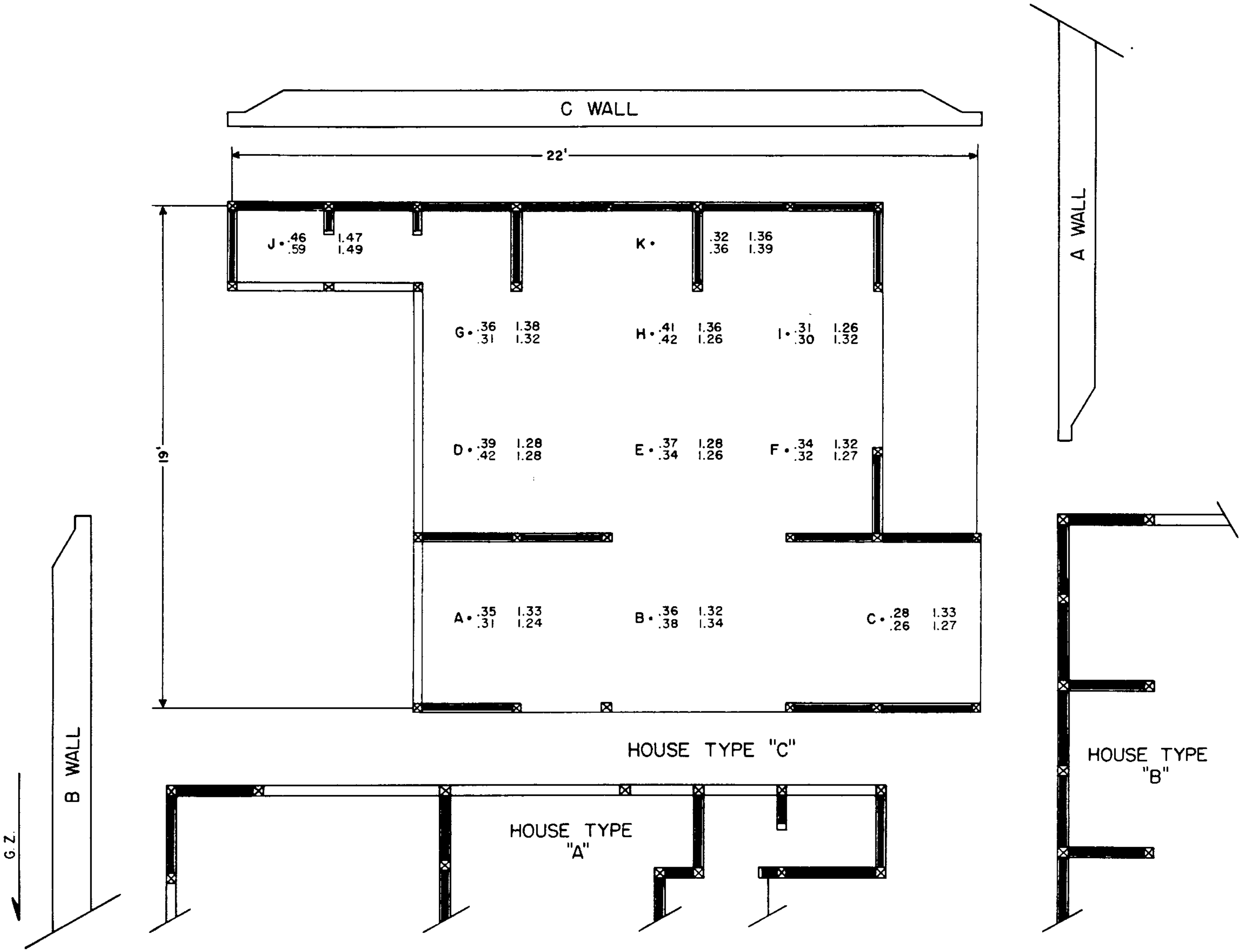


Fig. 3.29--D_m/D_a, reactor radiation in house type C in configuration No. 5.

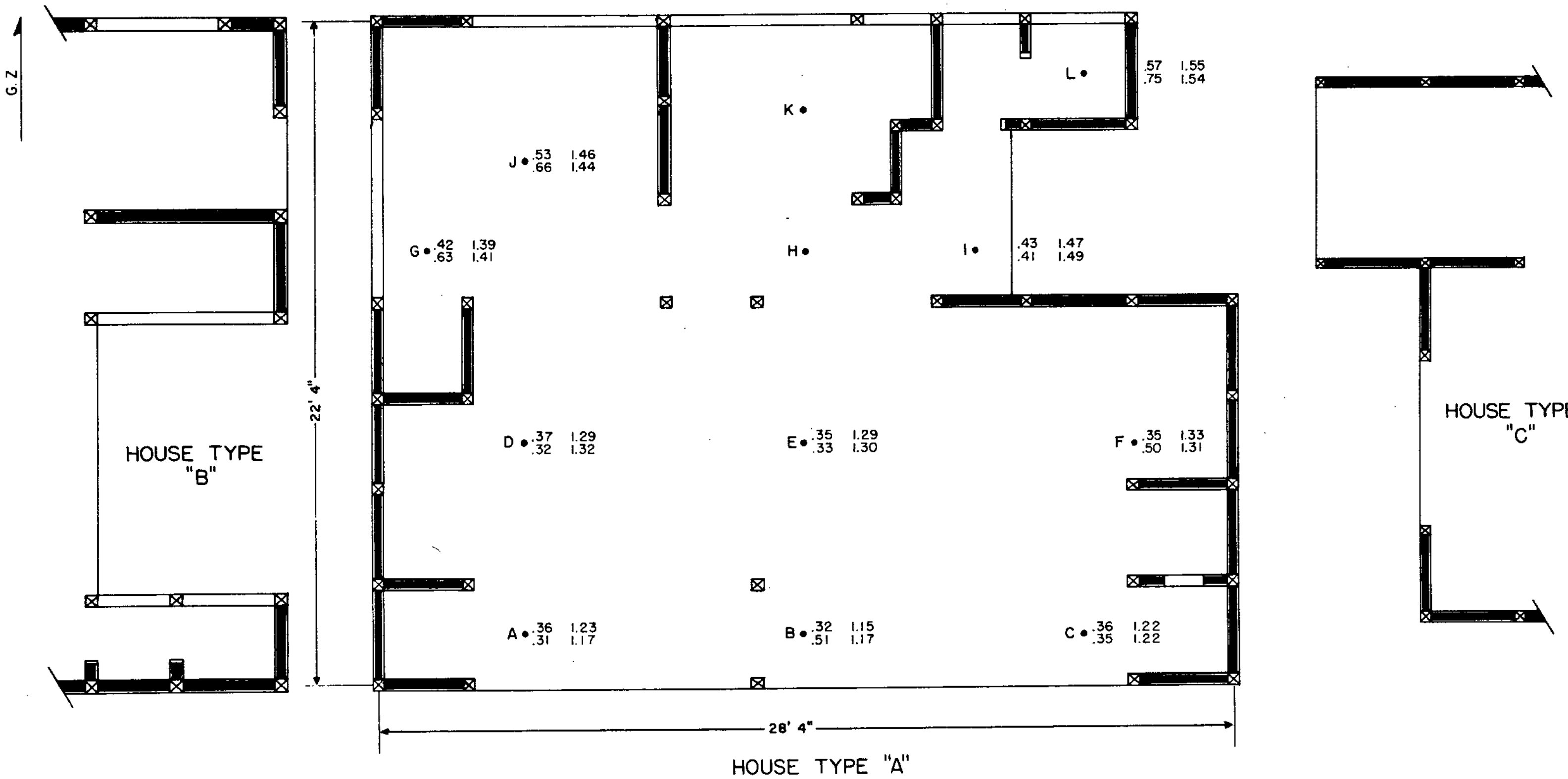


Fig. 3.30--D_m/D_a, reactor radiation in house type A in configuration No. 6.

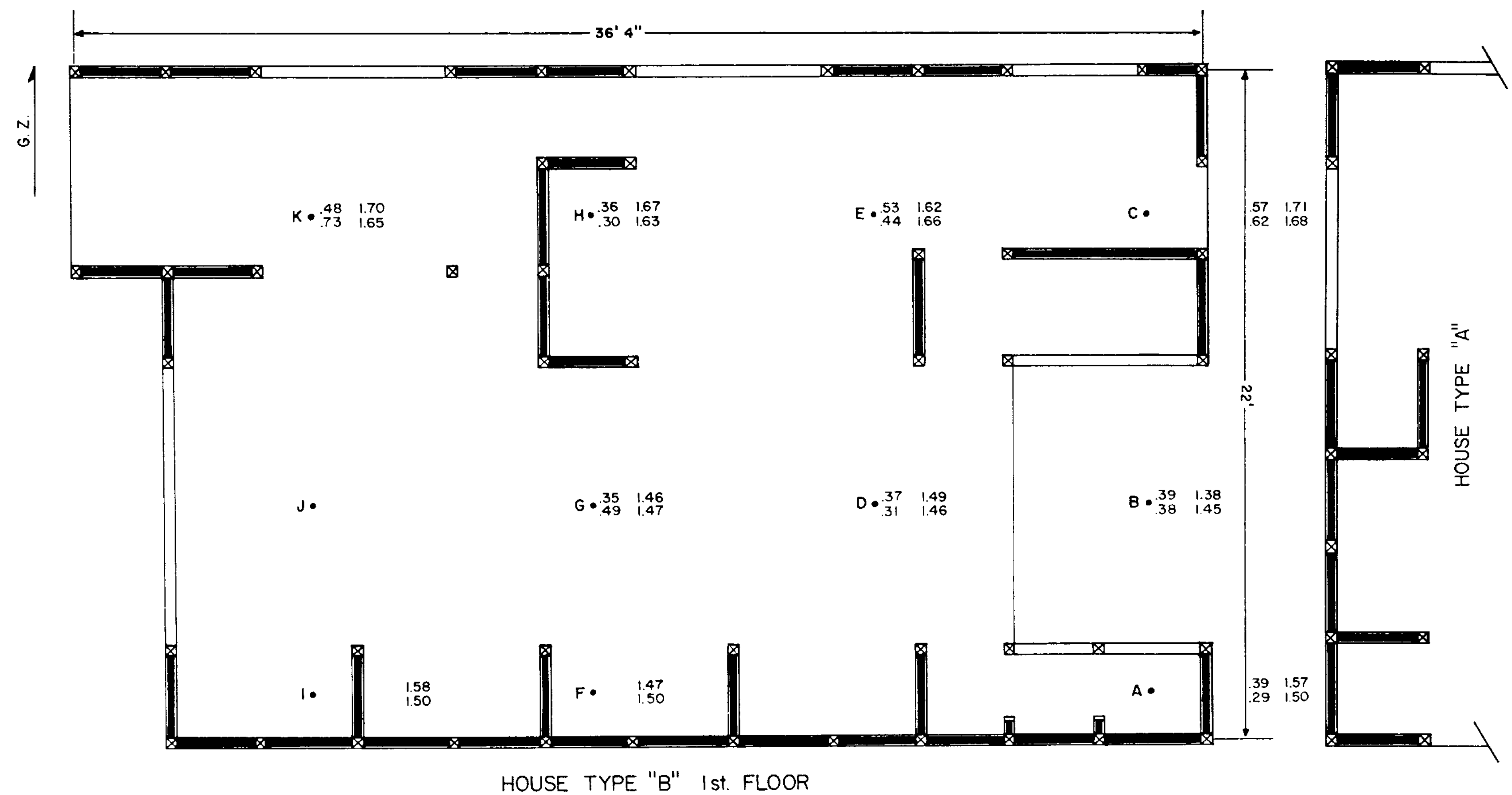
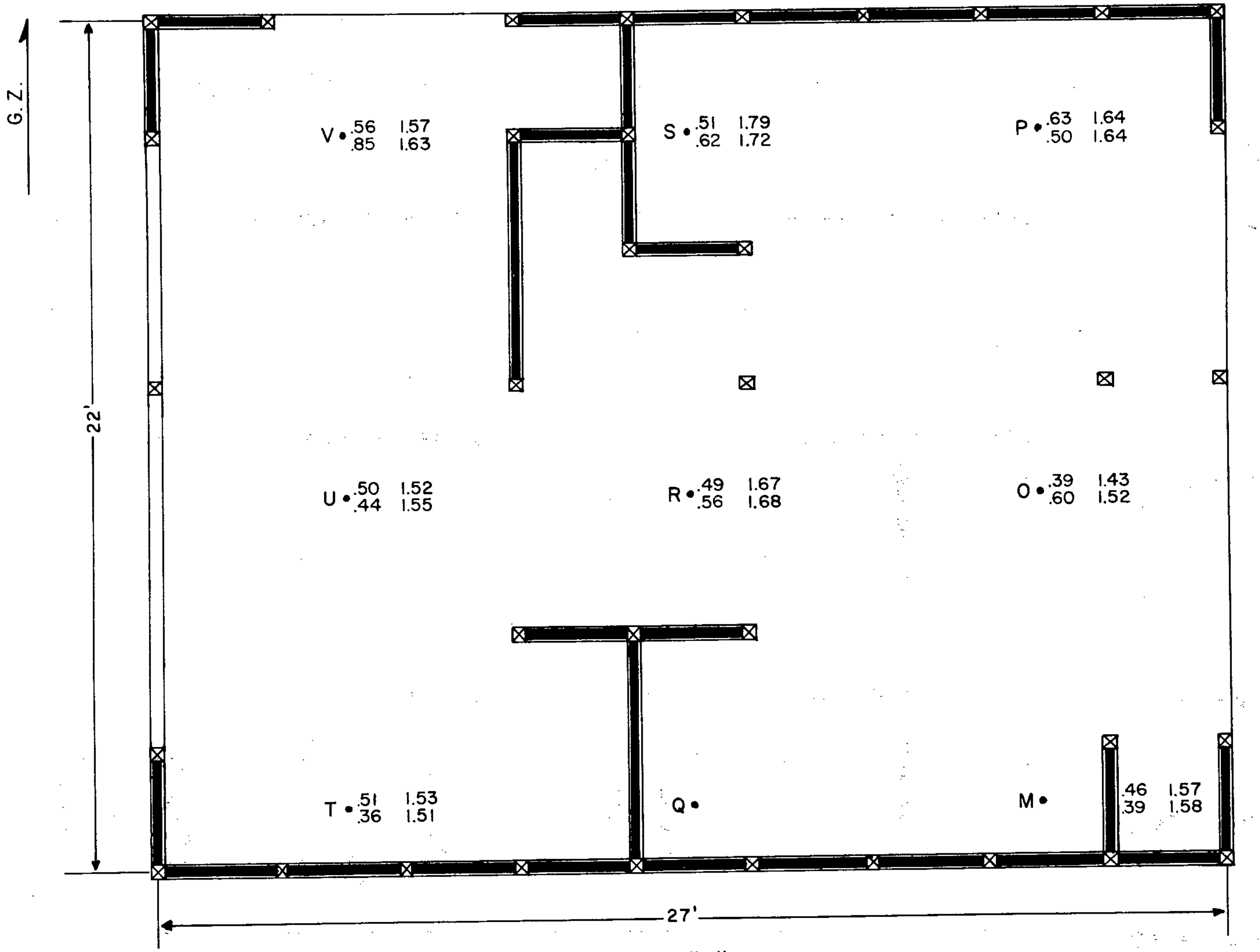


Fig. 3.31--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 6.



HOUSE TYPE "B" 2nd FLOOR

Fig. 3.32--D_m/D_a, reactor radiation on upper floor of house type B in configuration No. 6.

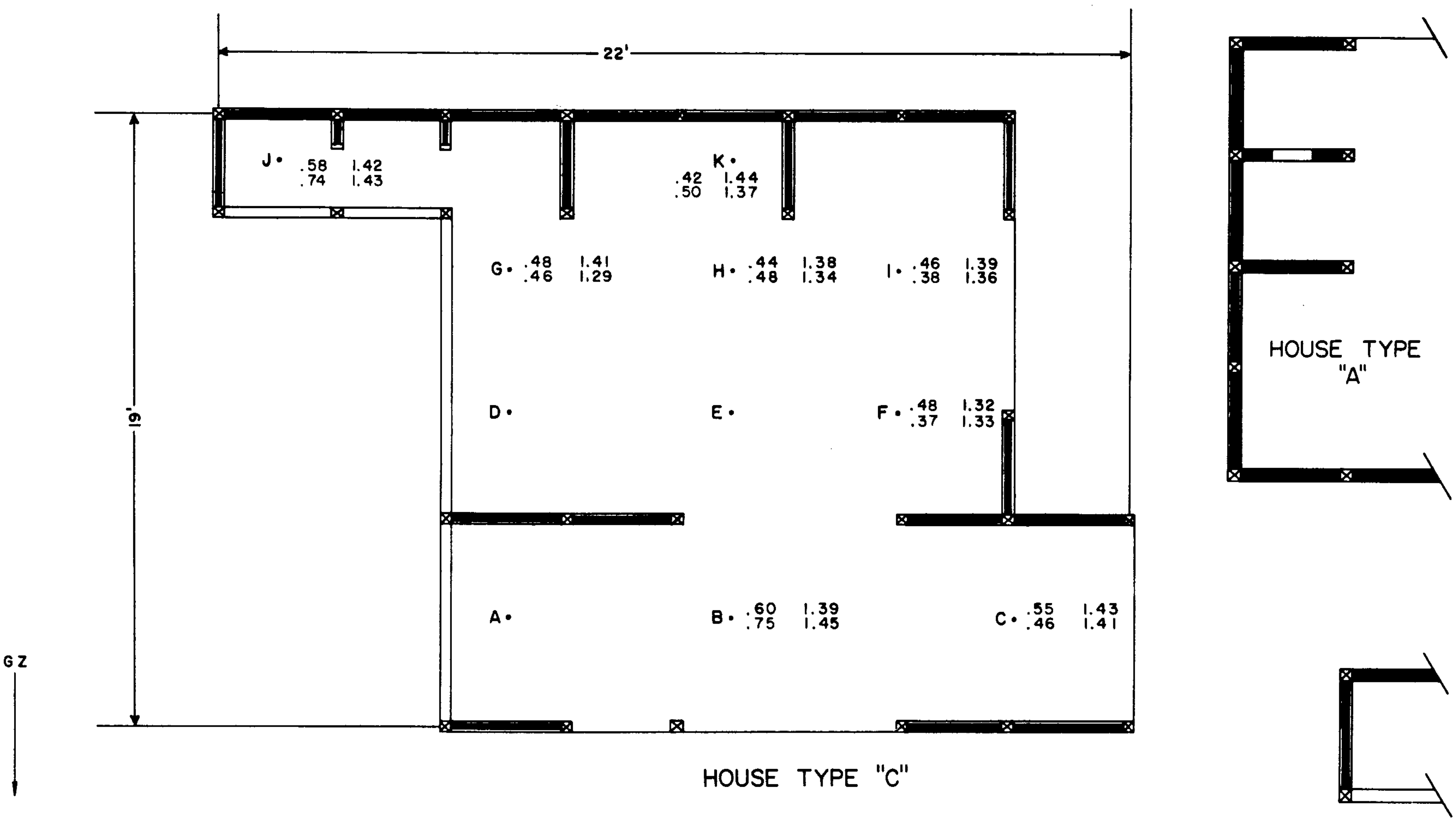


Fig. 3.33--D_m/D_a, reactor radiation in house type C in configuration No. 6.

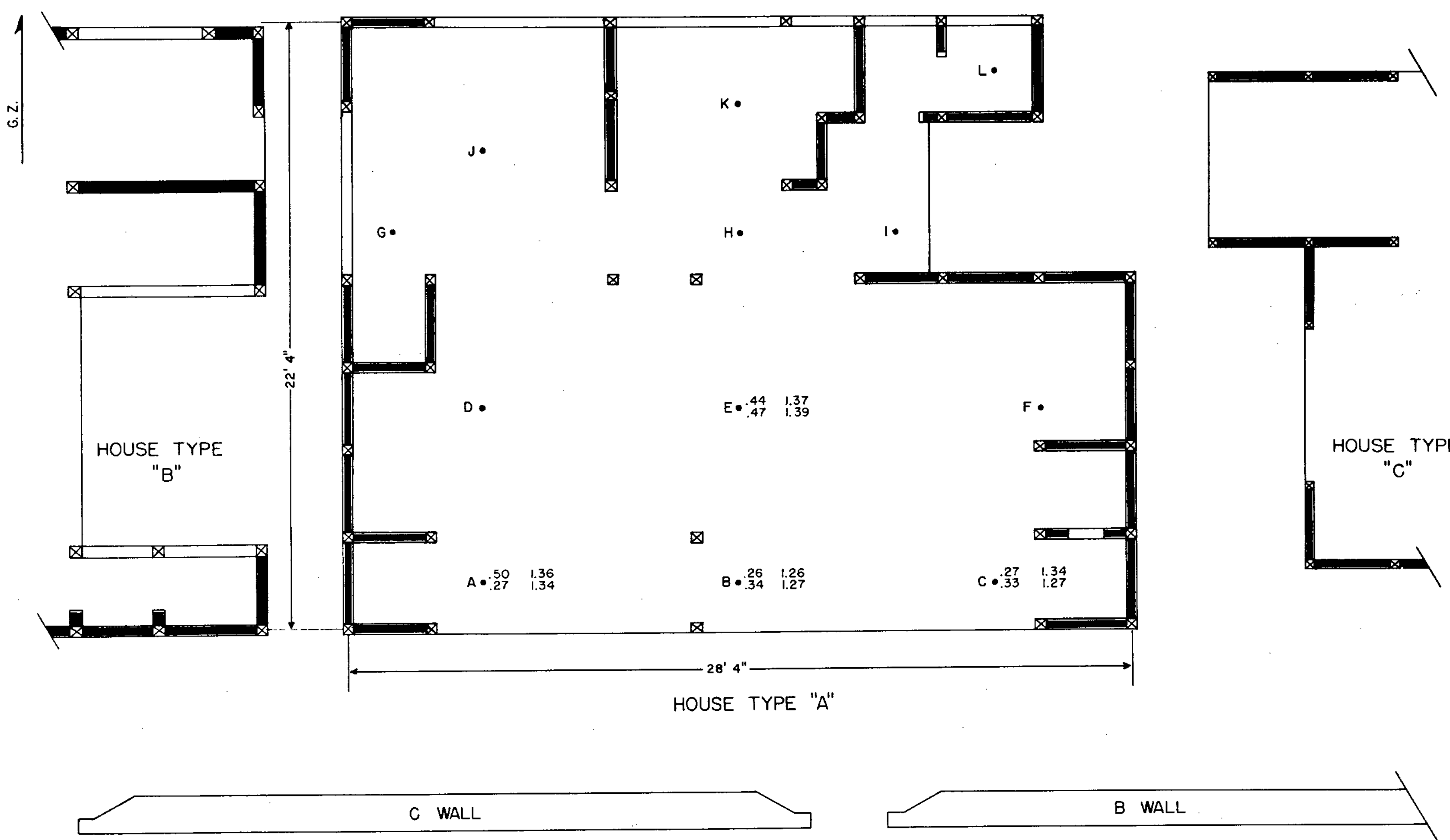


Fig. 3.34--D_m/D_a, reactor radiation in house type A in configuration No. 7.

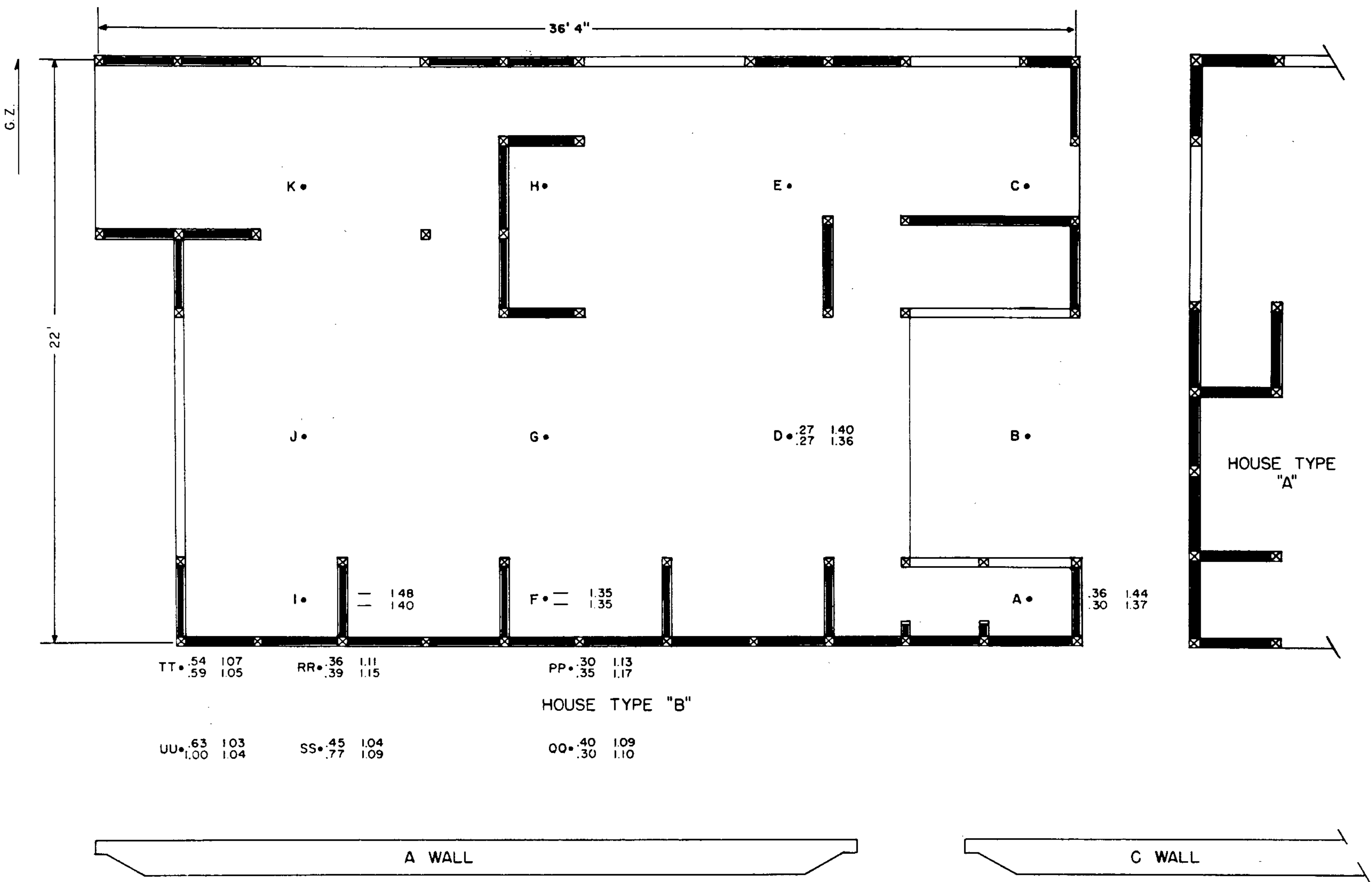


Fig. 3.35--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 7.

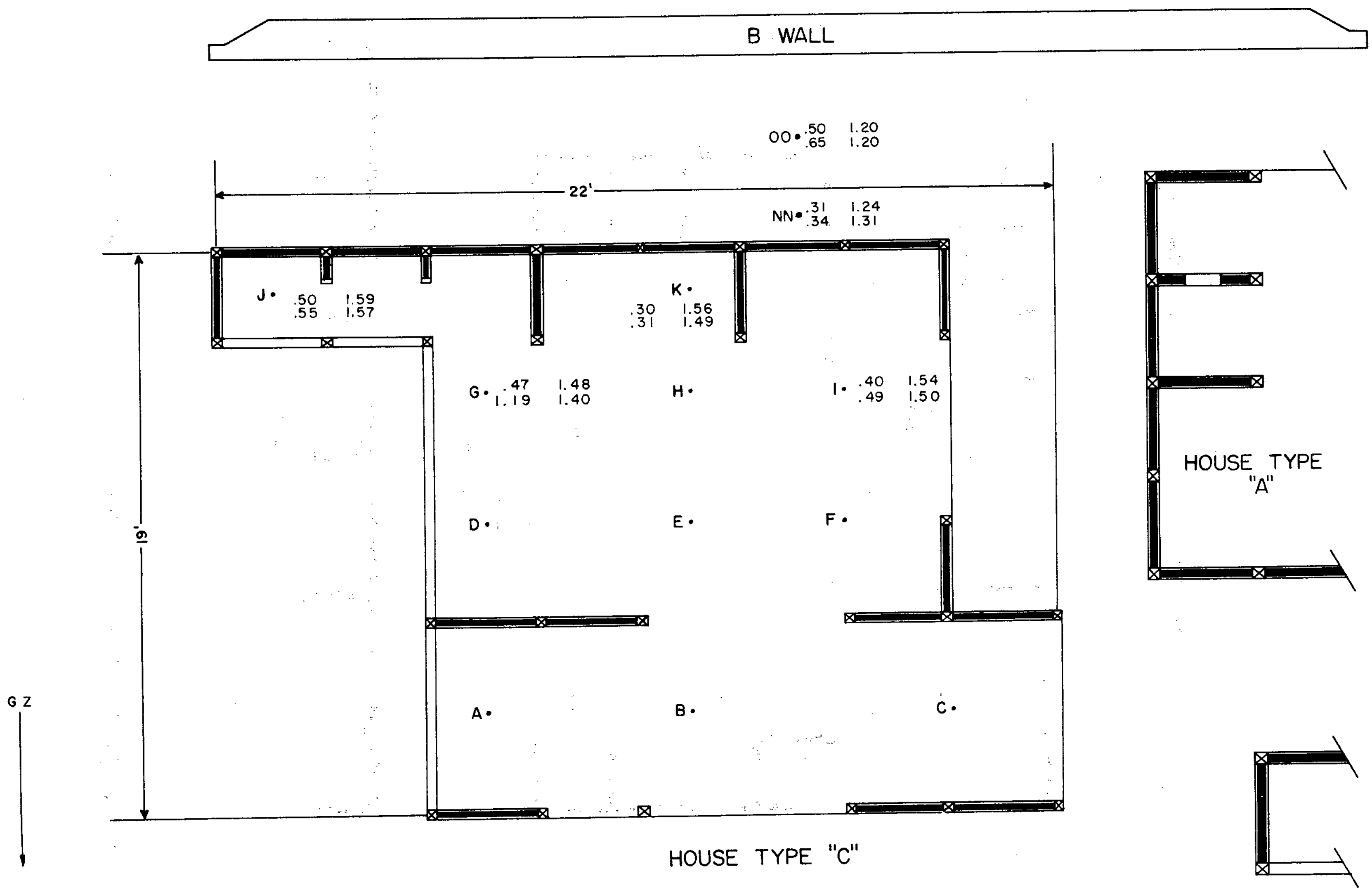


Fig. 3.36--D_m/D_a, reactor radiation in house type C in configuration No. 7.

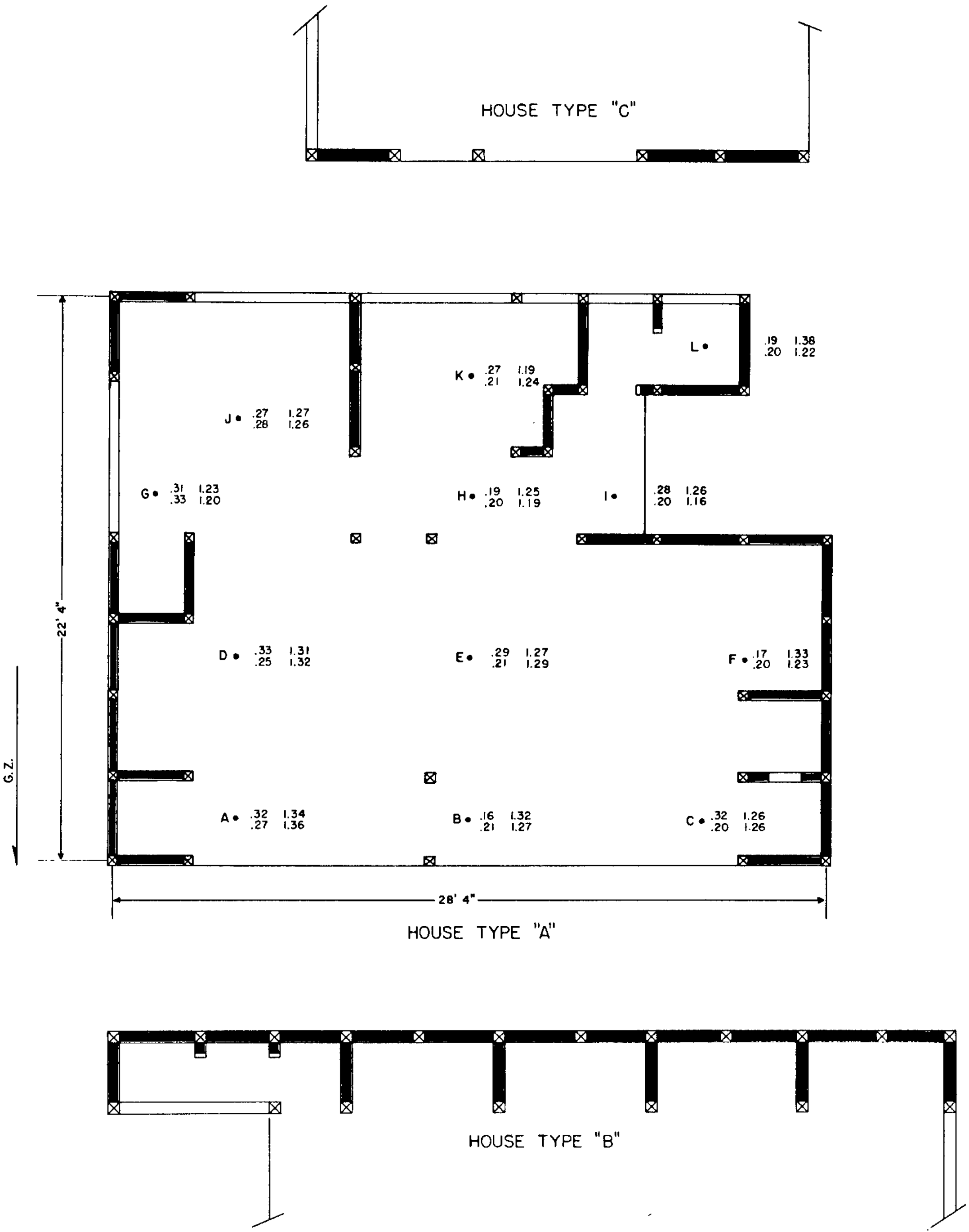


Fig. 3.37--D_m/D_a, reactor radiation in house type A in configuration No. 8.

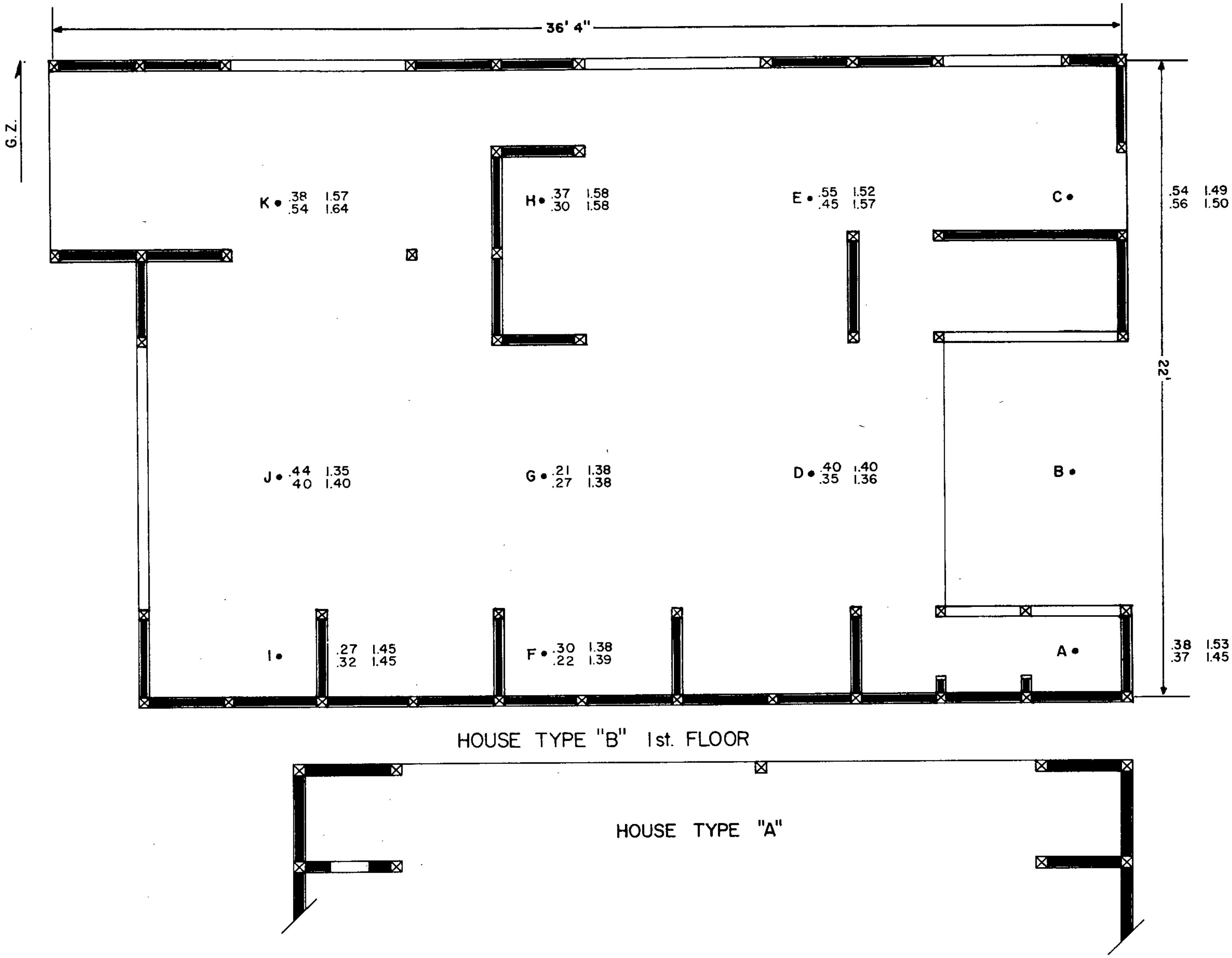


Fig. 3.38--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 8.

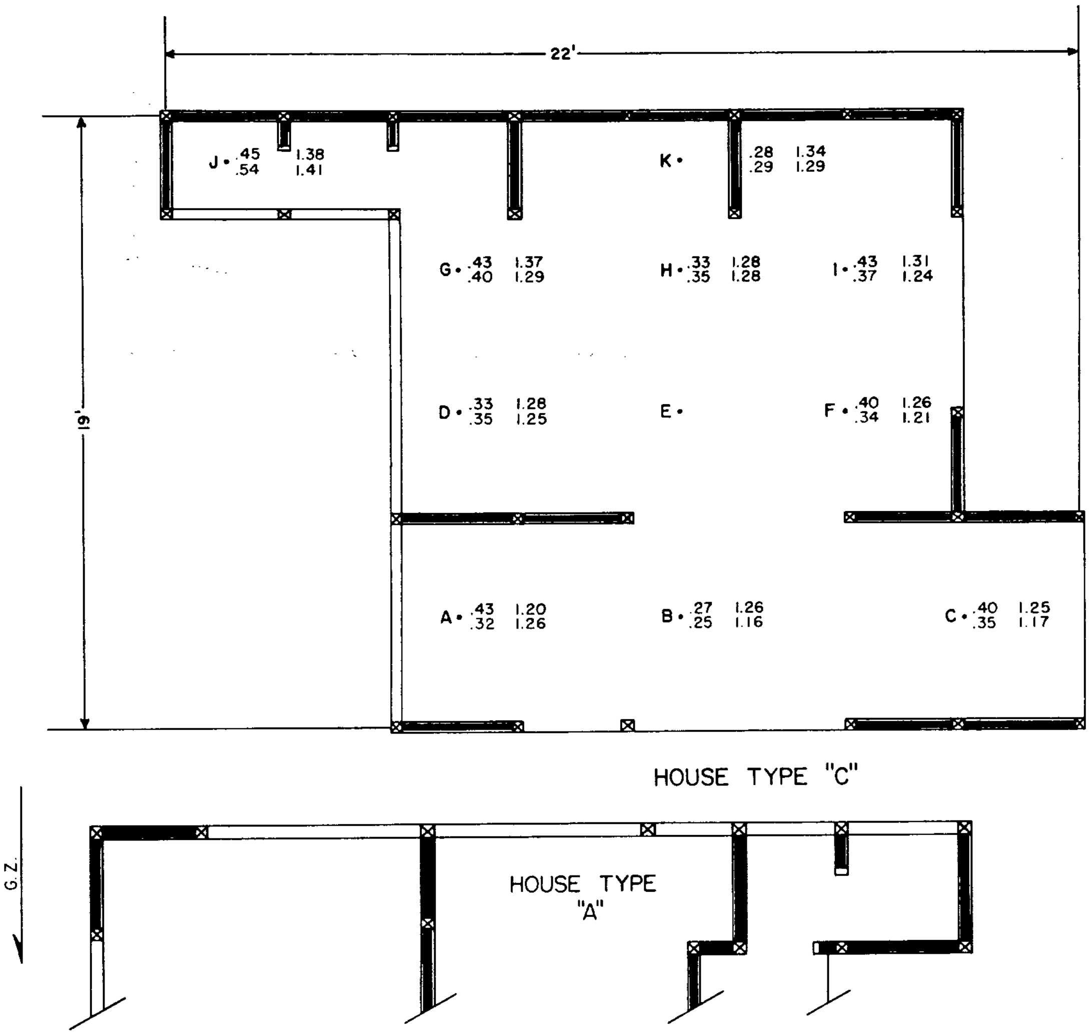


Fig. 3.39--D_m/D_a, reactor radiation in house type C in configuration No. 8.

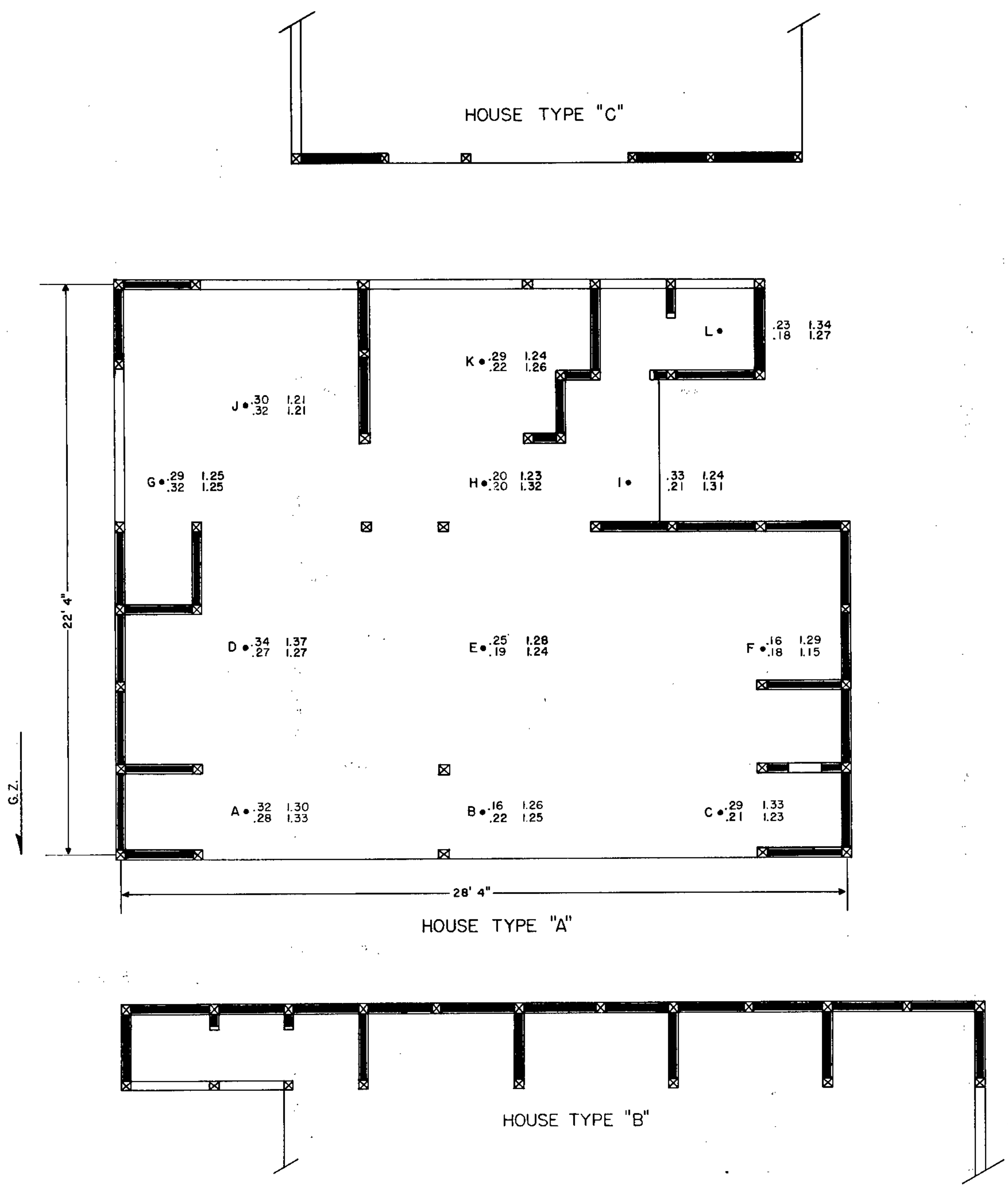


Fig. 3.40--D_m/D_a, reactor radiation in house type A in configuration No. 8'.

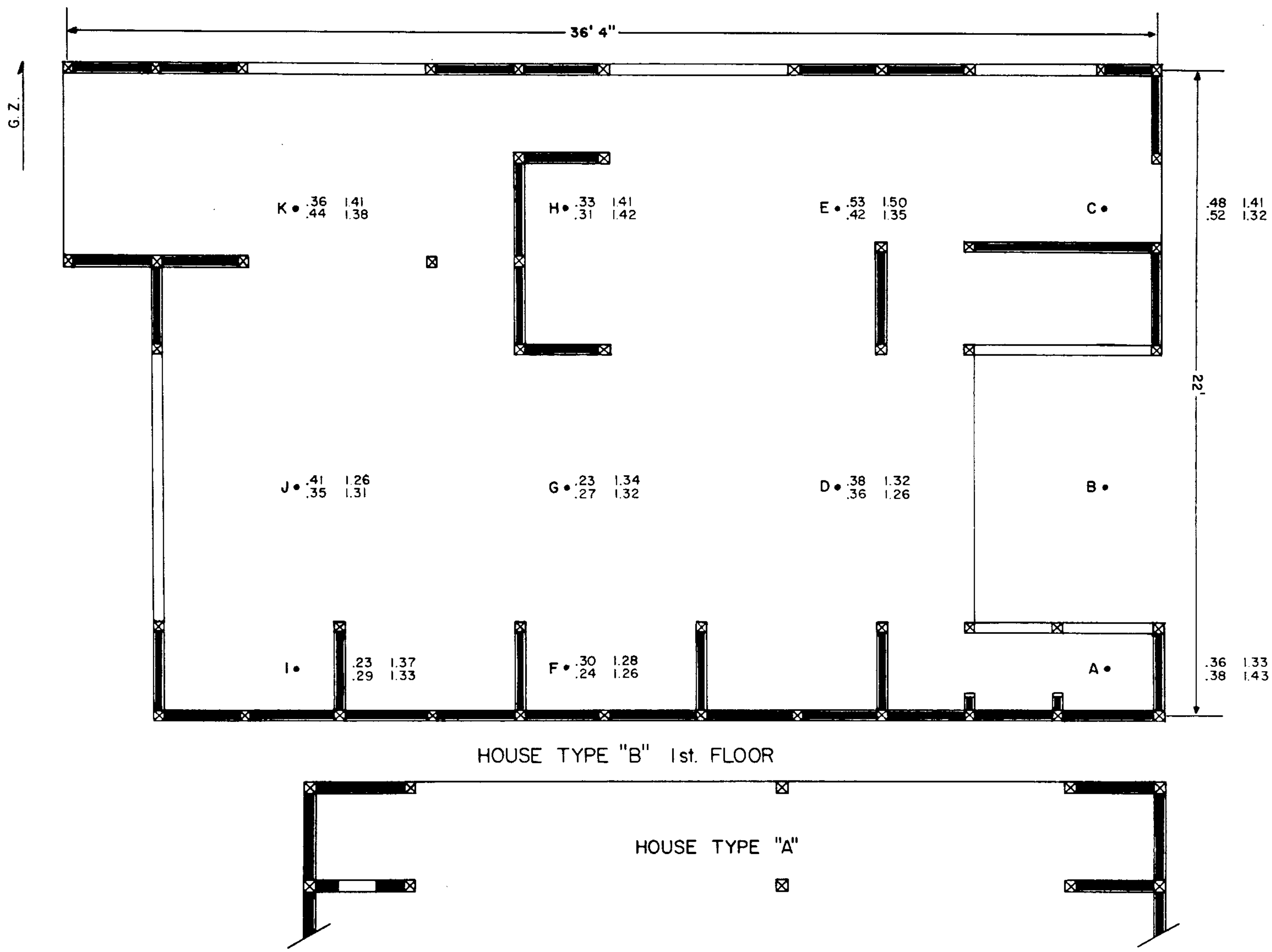


Fig. 3.41--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 8'.

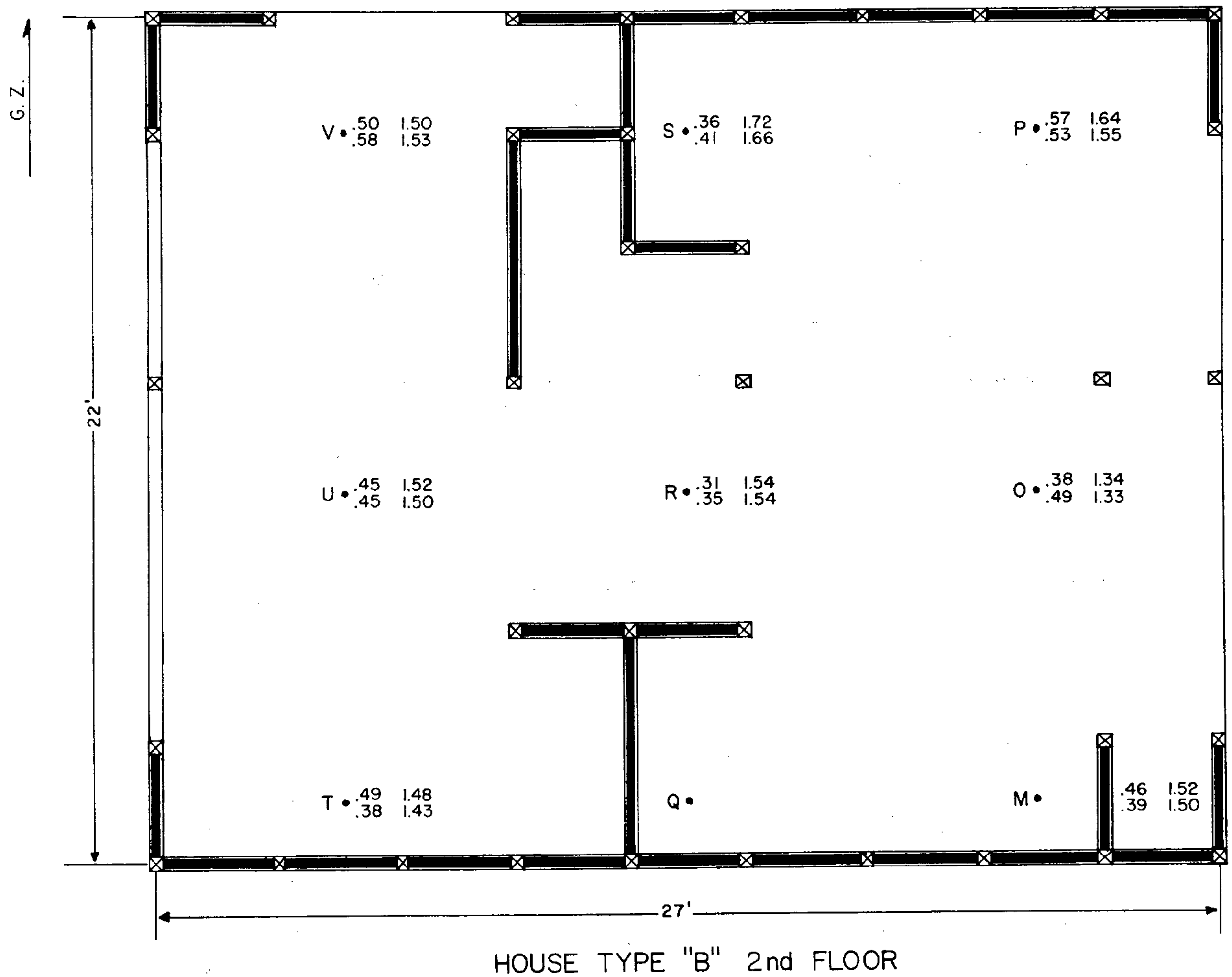


Fig. 3.42--D_m/D_a, reactor radiation on upper floor of house type B in configuration No. 8'.

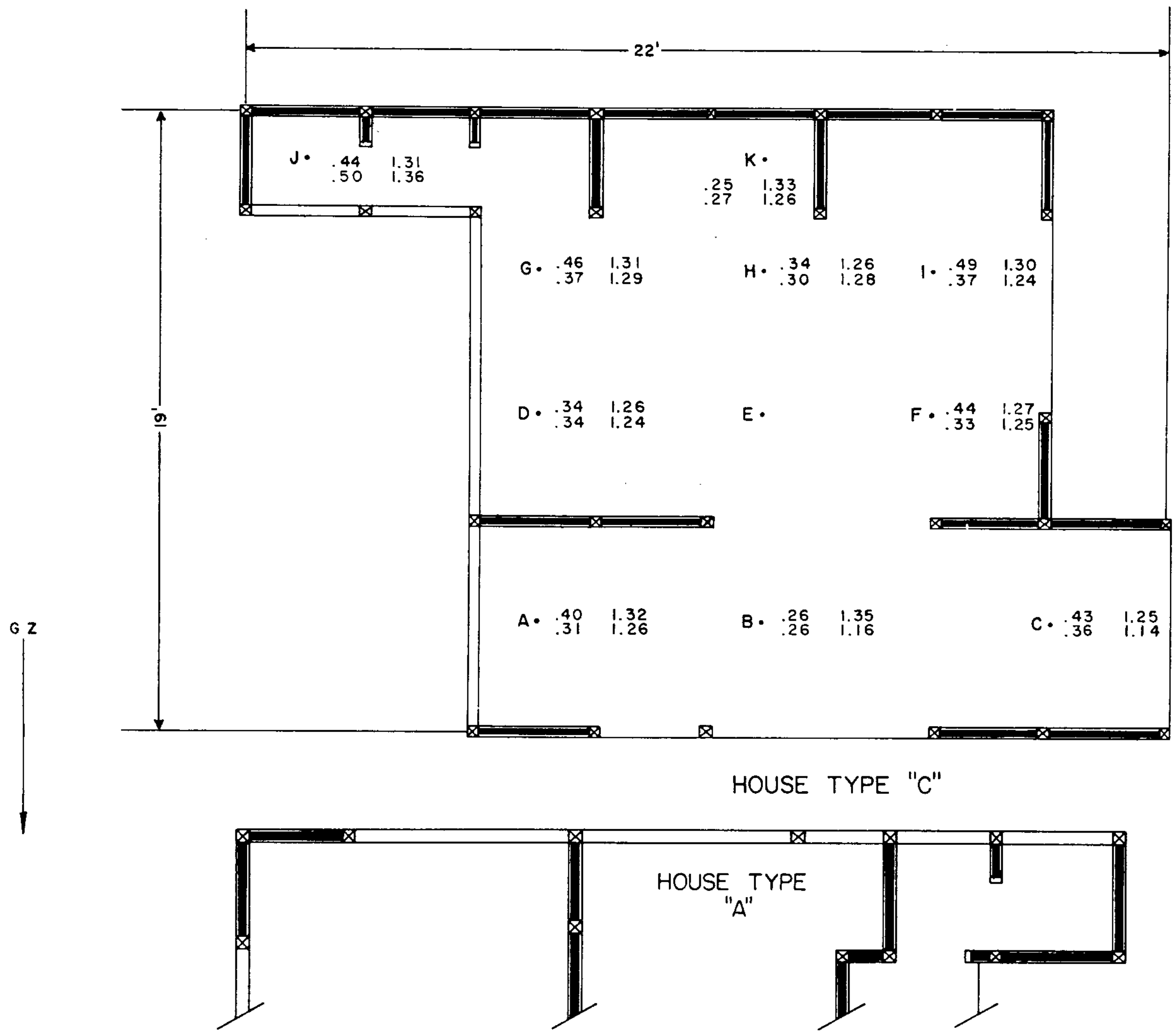


Fig. 3.43--D_m/D_a, reactor radiation in house type C in configuration No. 8'.

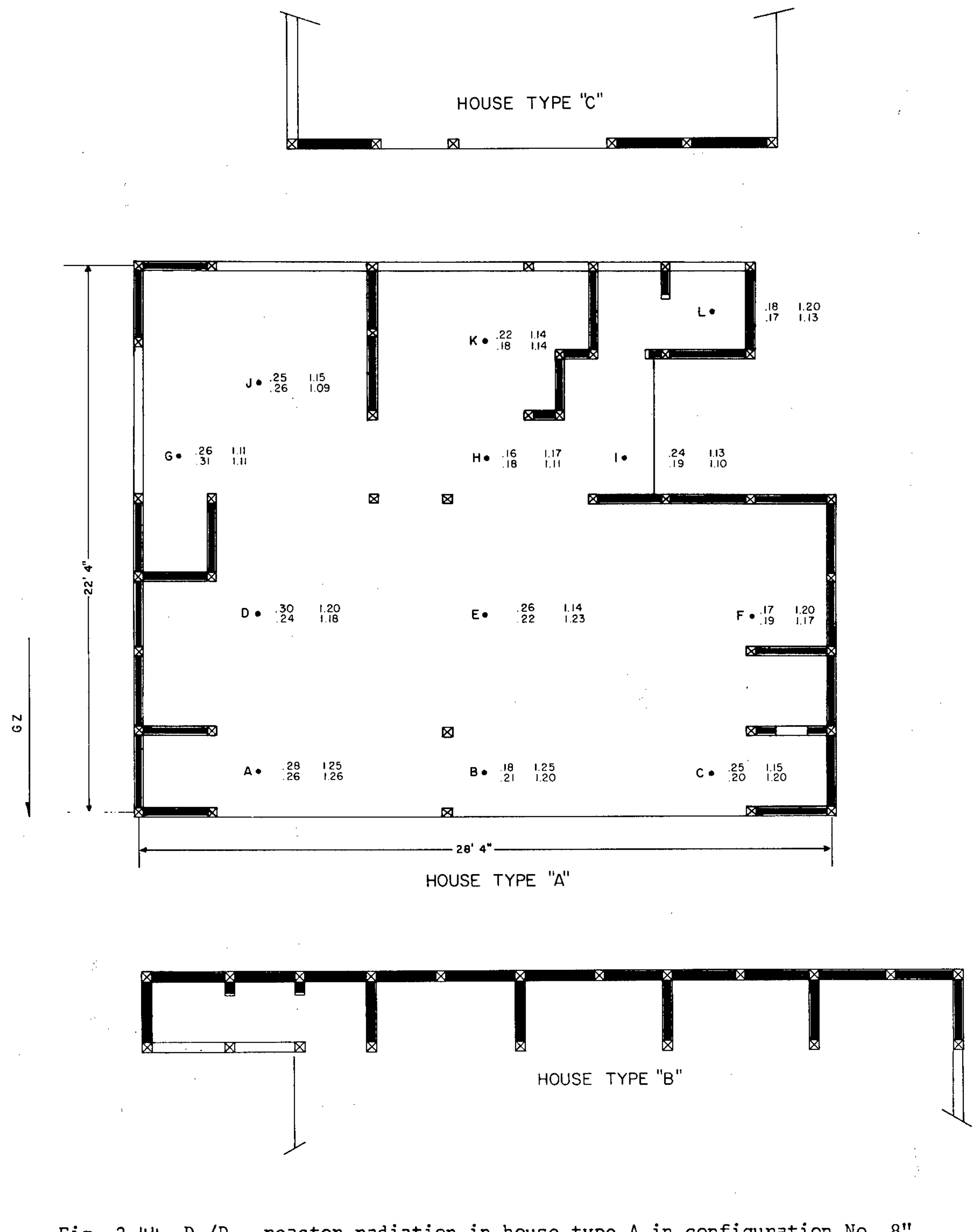


Fig. 3.44--D_m/D_a, reactor radiation in house type A in configuration No. 8".

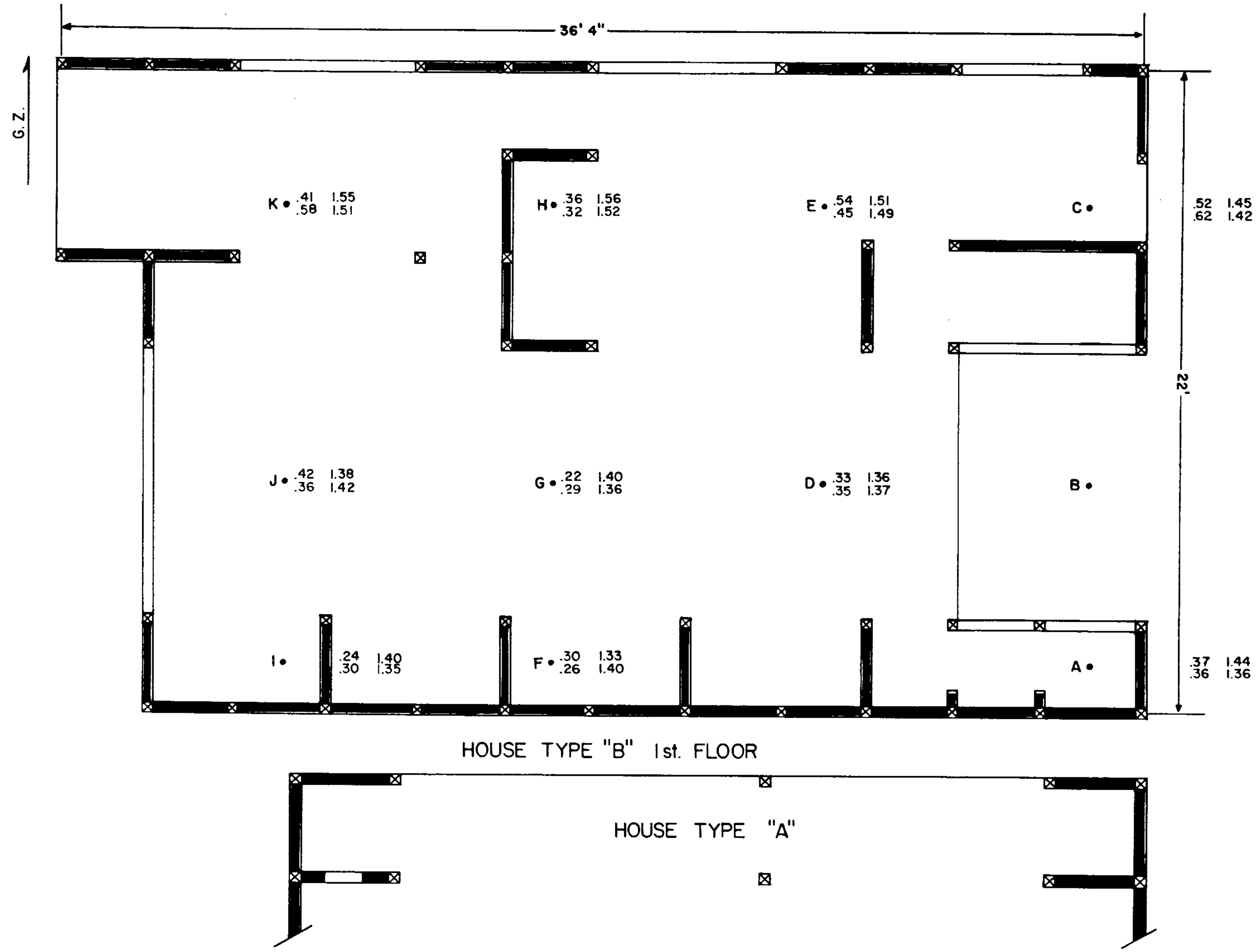
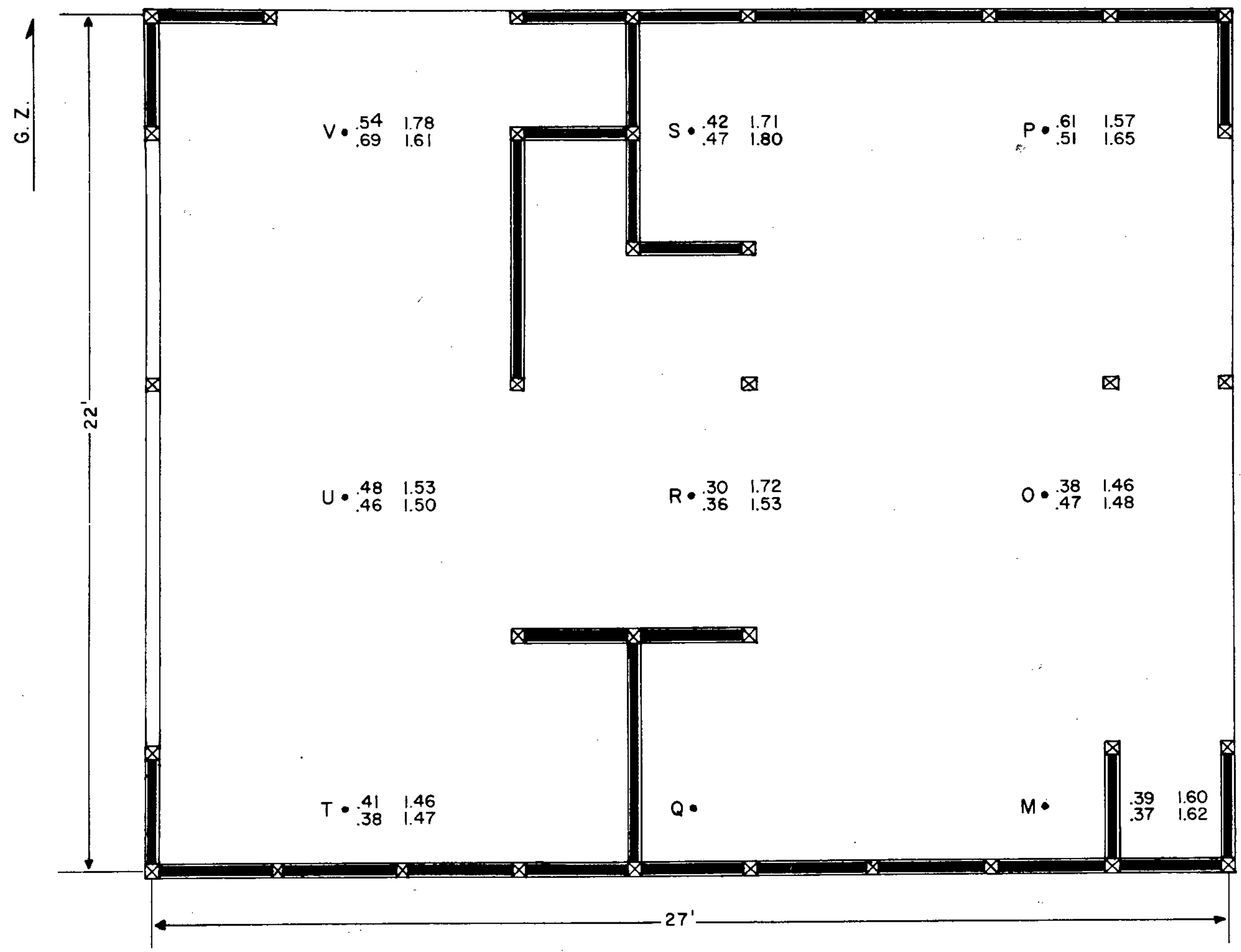


Fig. 3.45--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 8".



HOUSE TYPE "B" 2nd FLOOR

Fig. 3.46--D_m/D_a, reactor radiation on upper floor of house type B in configuration No. 8".

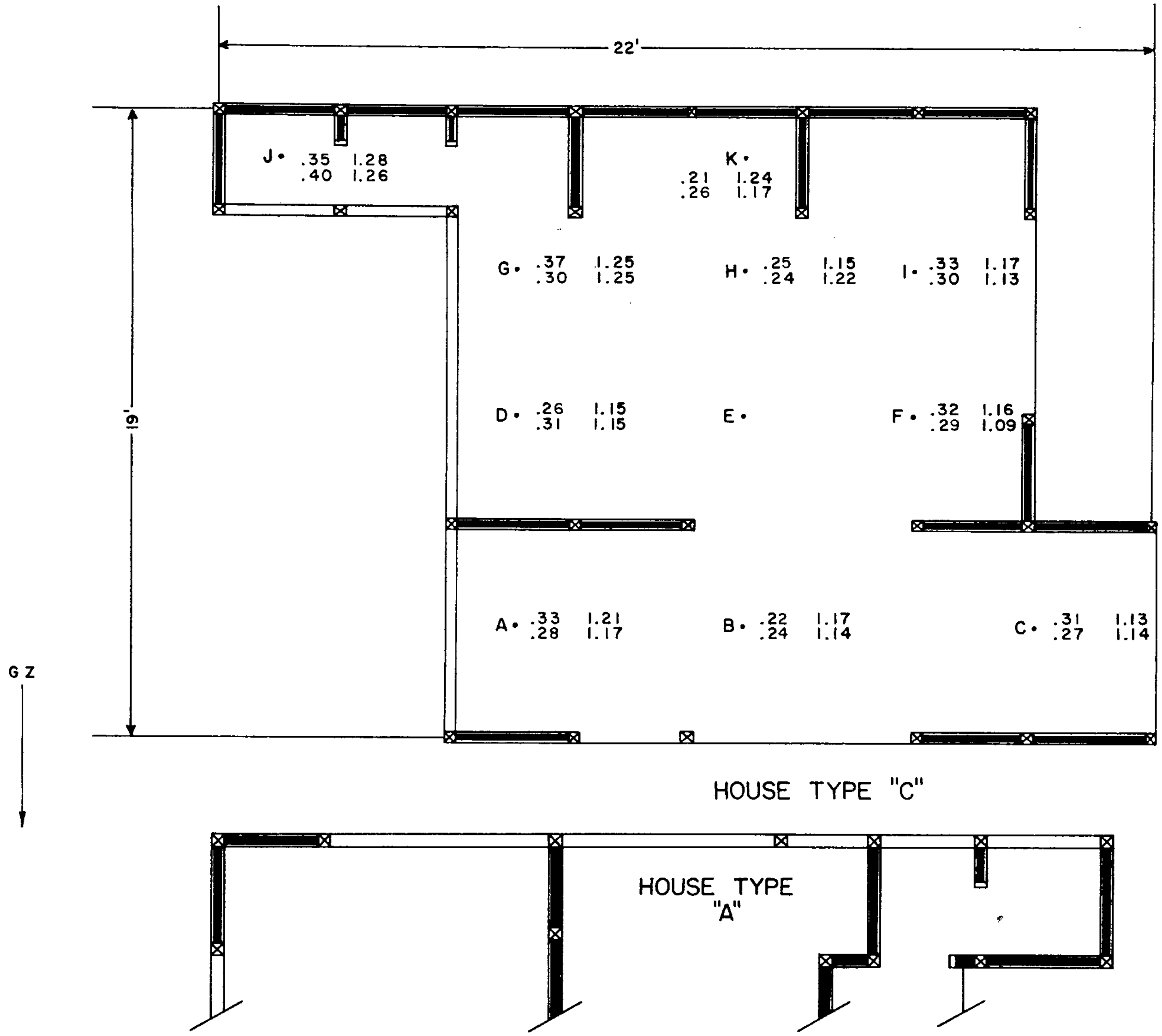


Fig. 3.47--D_m/D_a, reactor radiation in house type C in configuration No. 8".

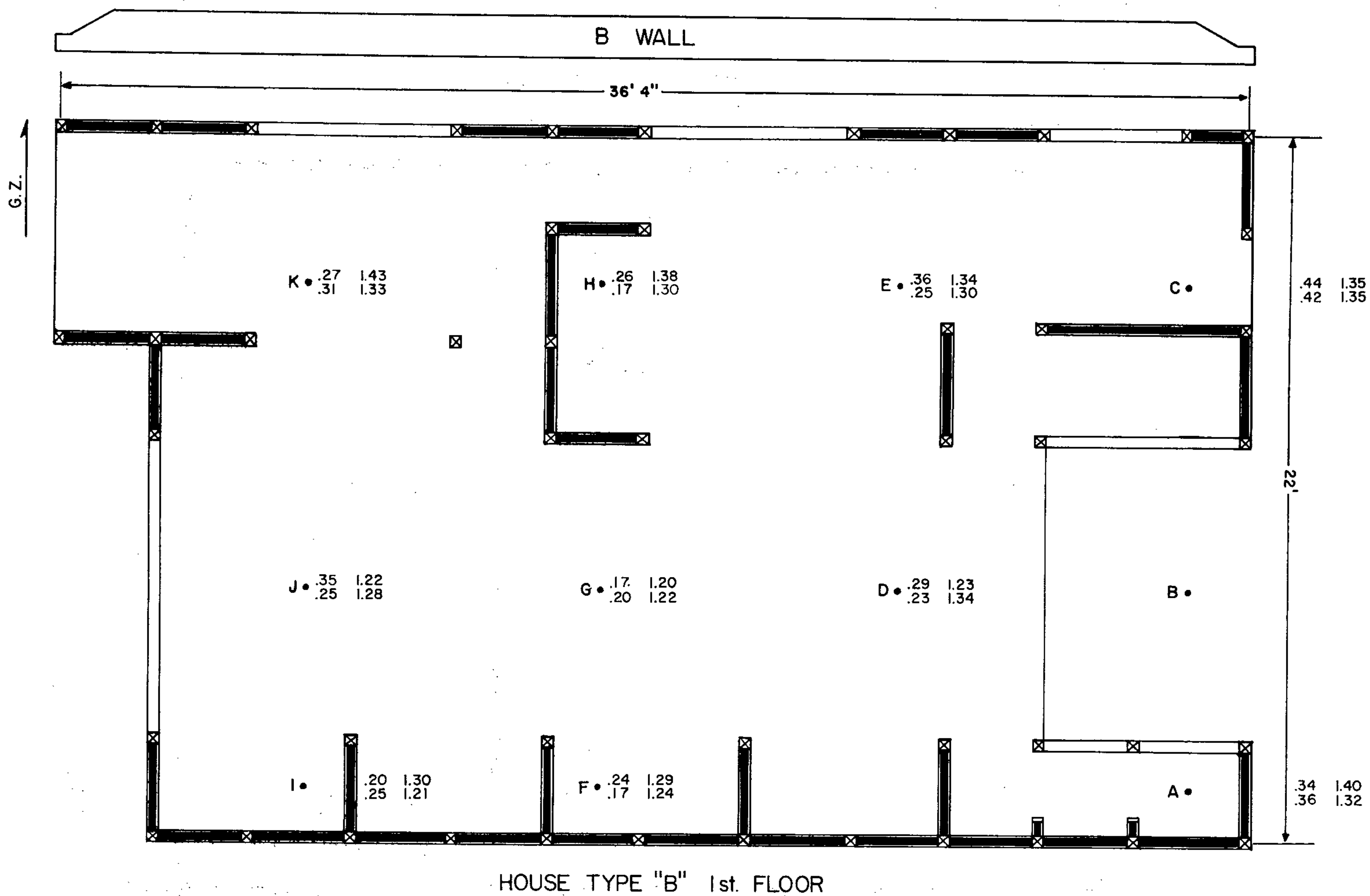


Fig. 3.48--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 9.

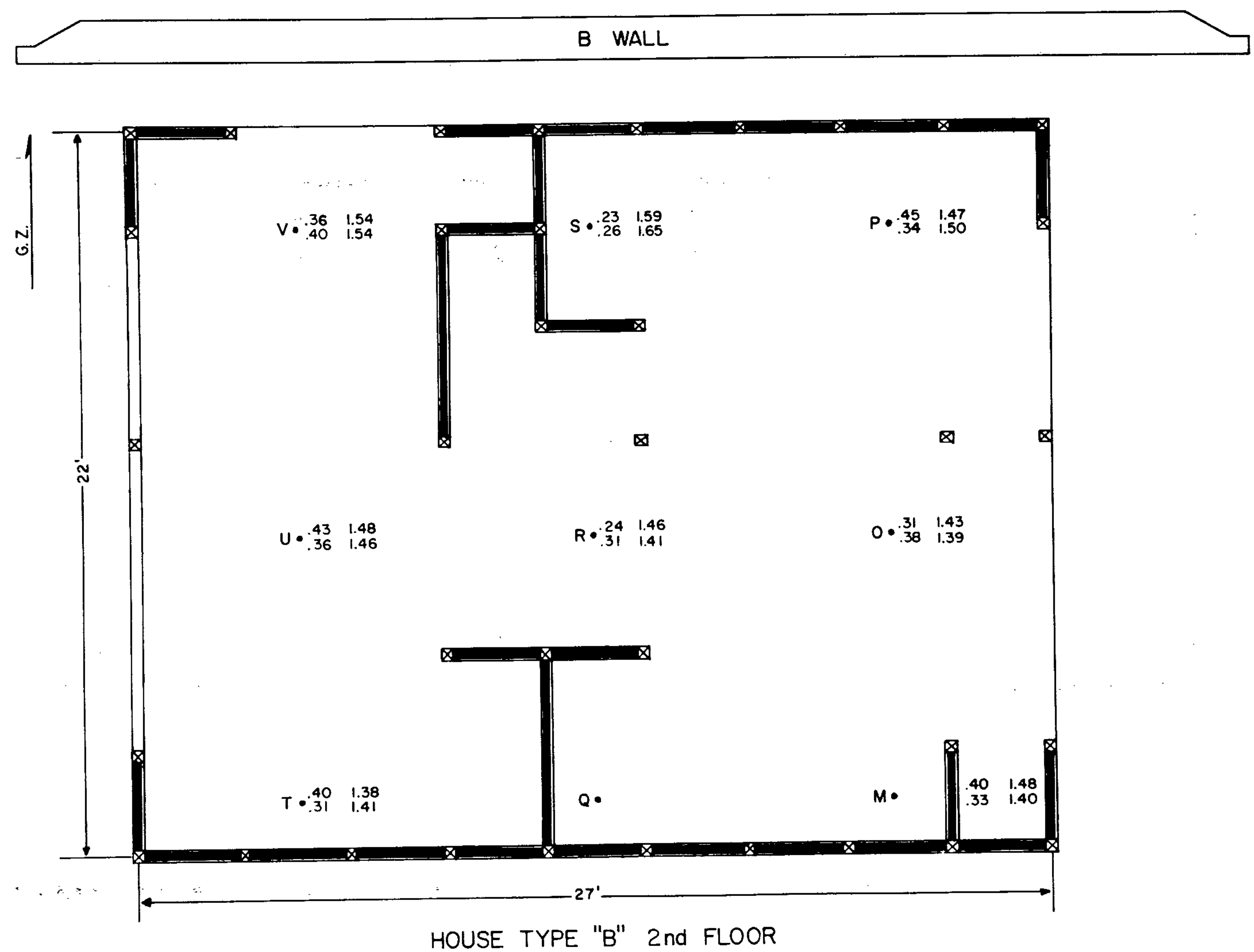


Fig. 3.49--D_m/D_a, reactor radiation on upper floor of house type B in configuration No. 9.

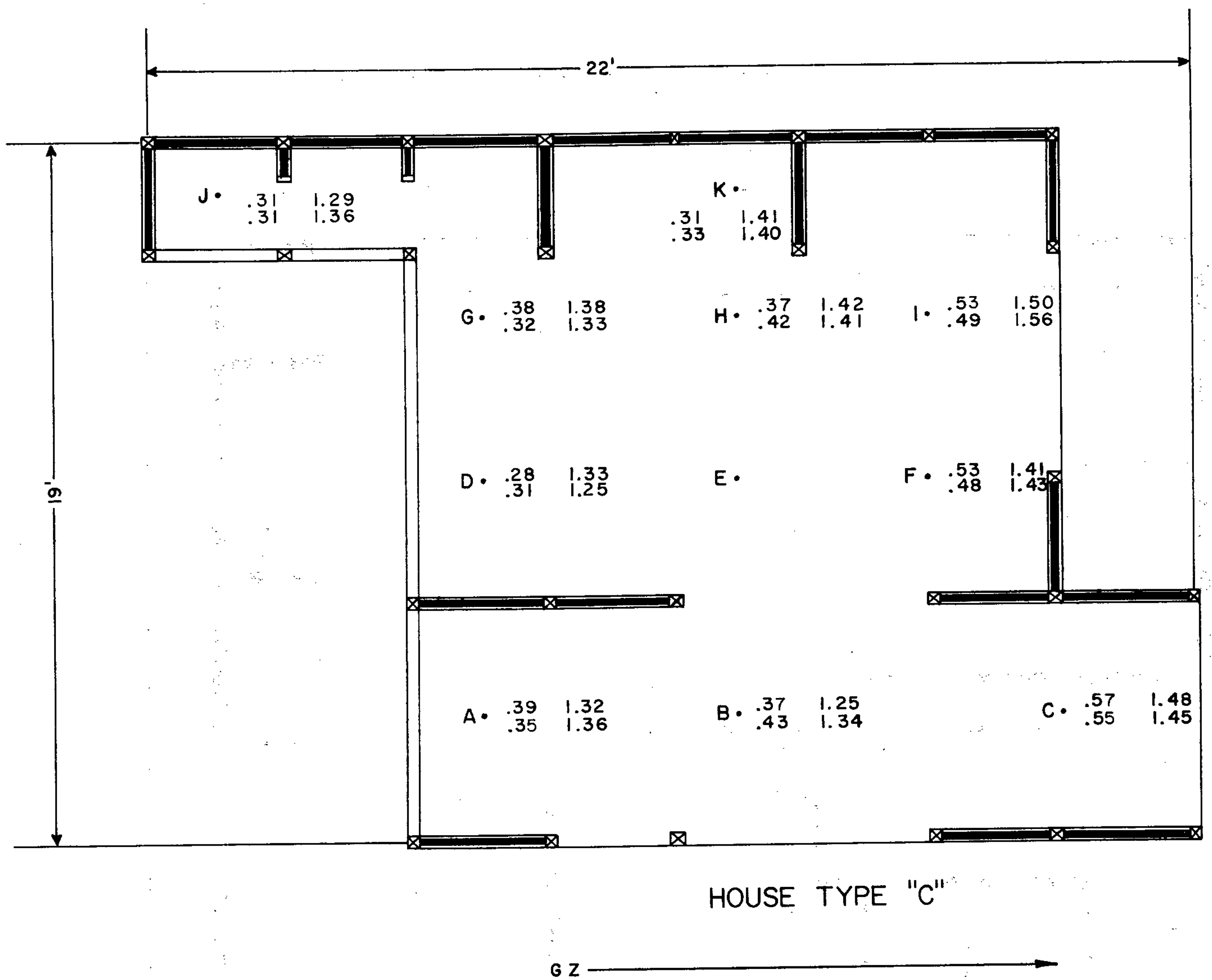


Fig. 3.50--D_m/D_a, reactor radiation in house type C in configuration No. 9.

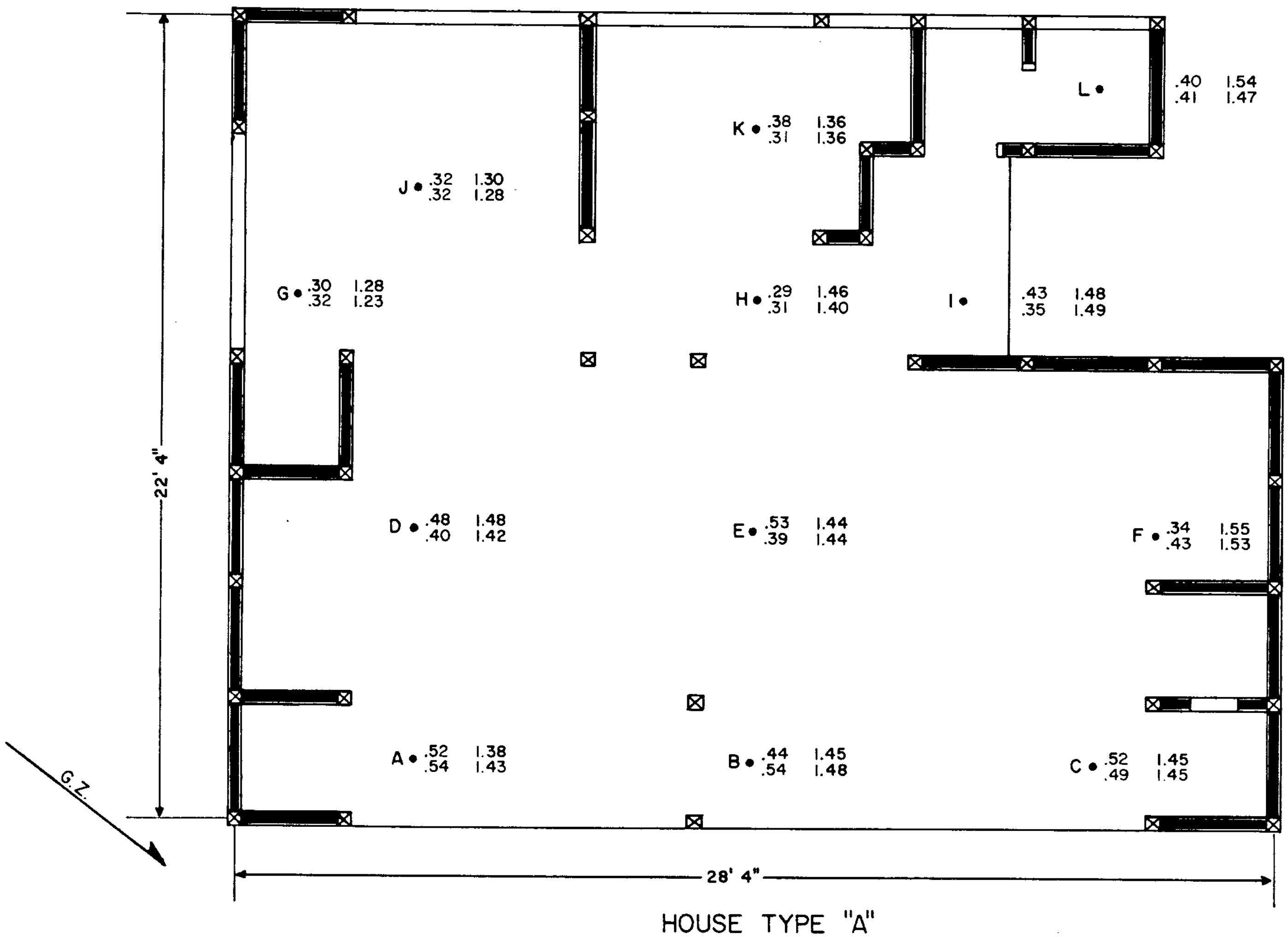


Fig. 3.51--D_m/D_a, reactor radiation in house type A in configuration No. 10.

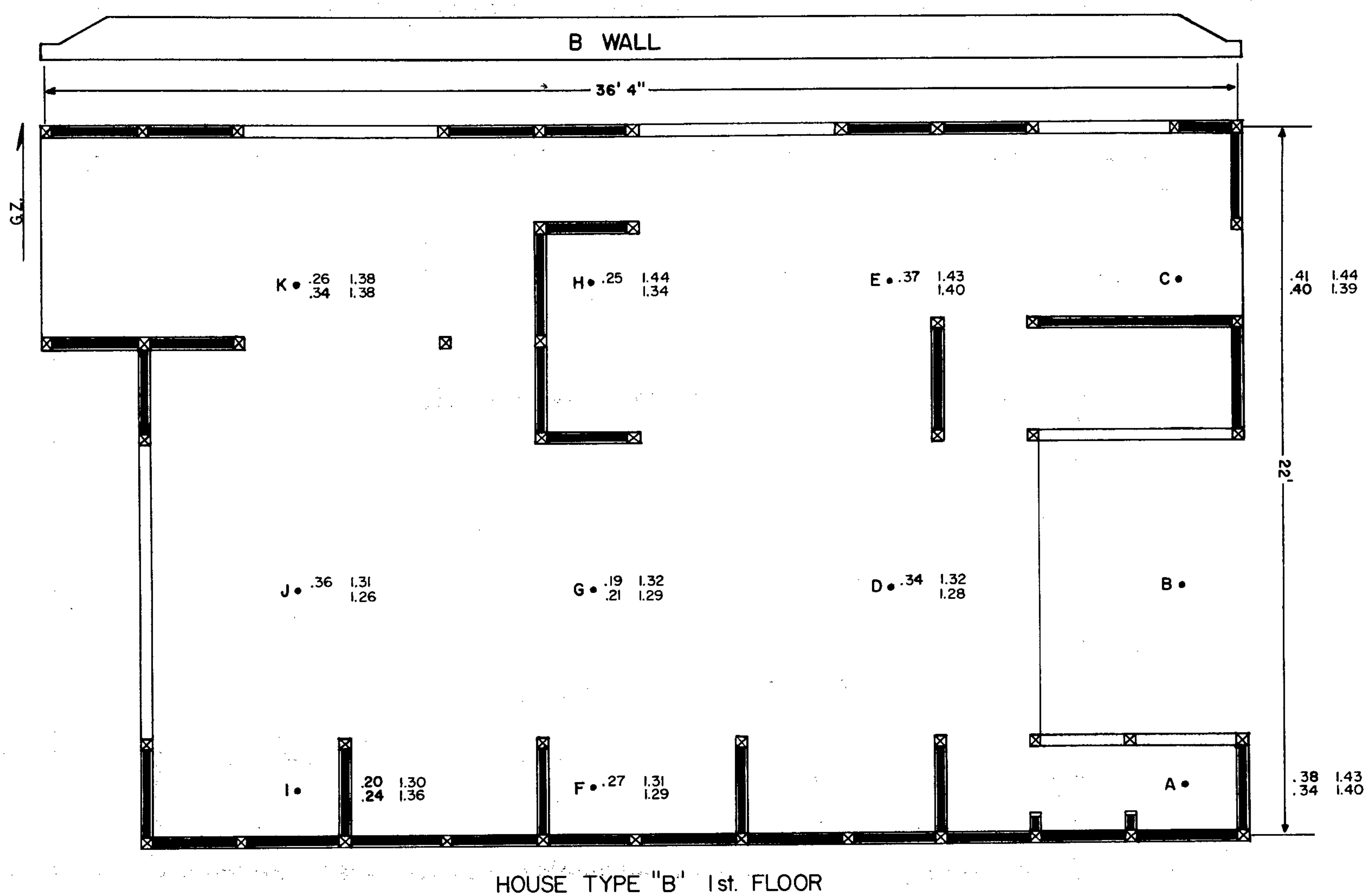


Fig. 3.52--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 10.

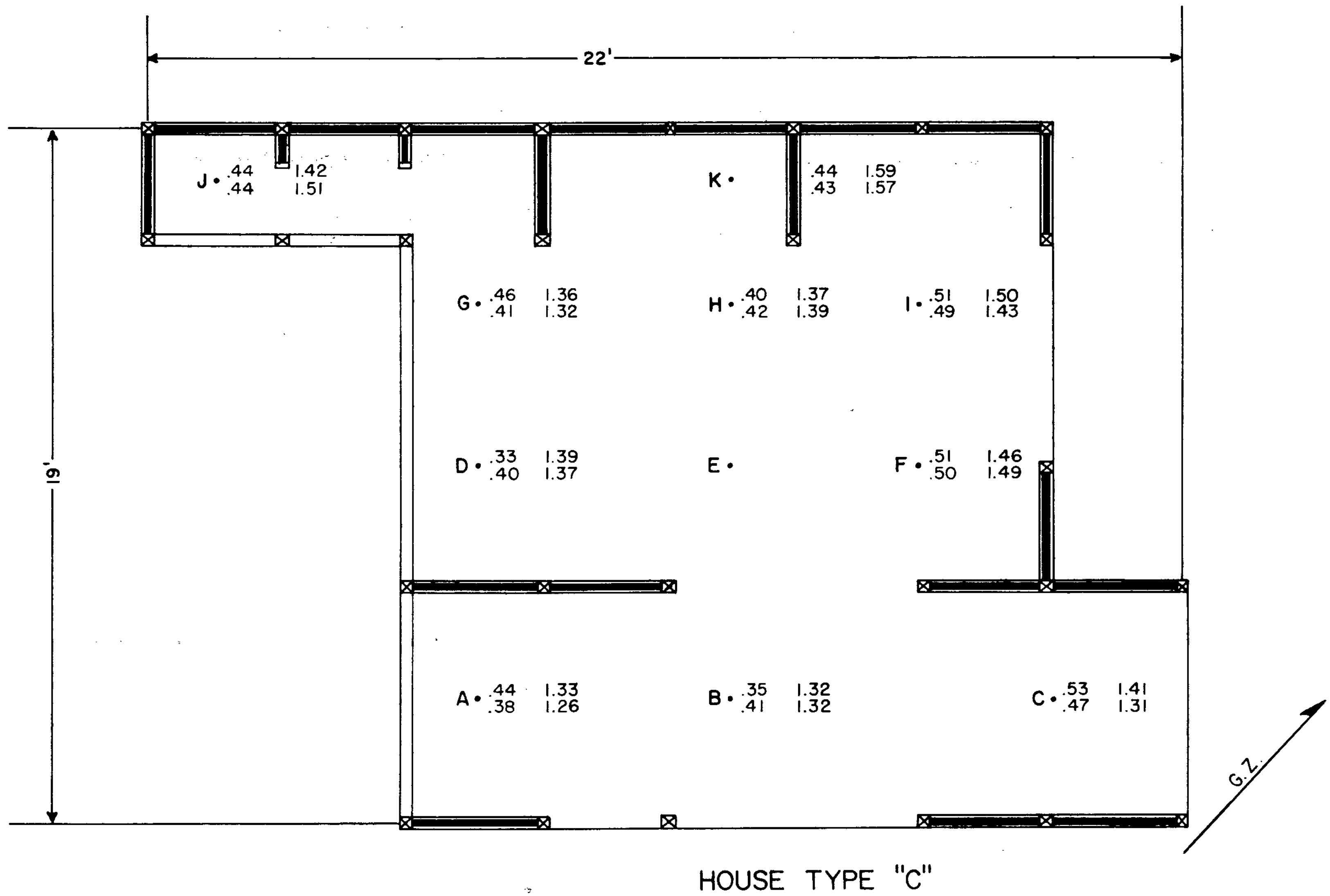


Fig. 3.53--D_m/D_a, reactor radiation in house type C in configuration No. 10.

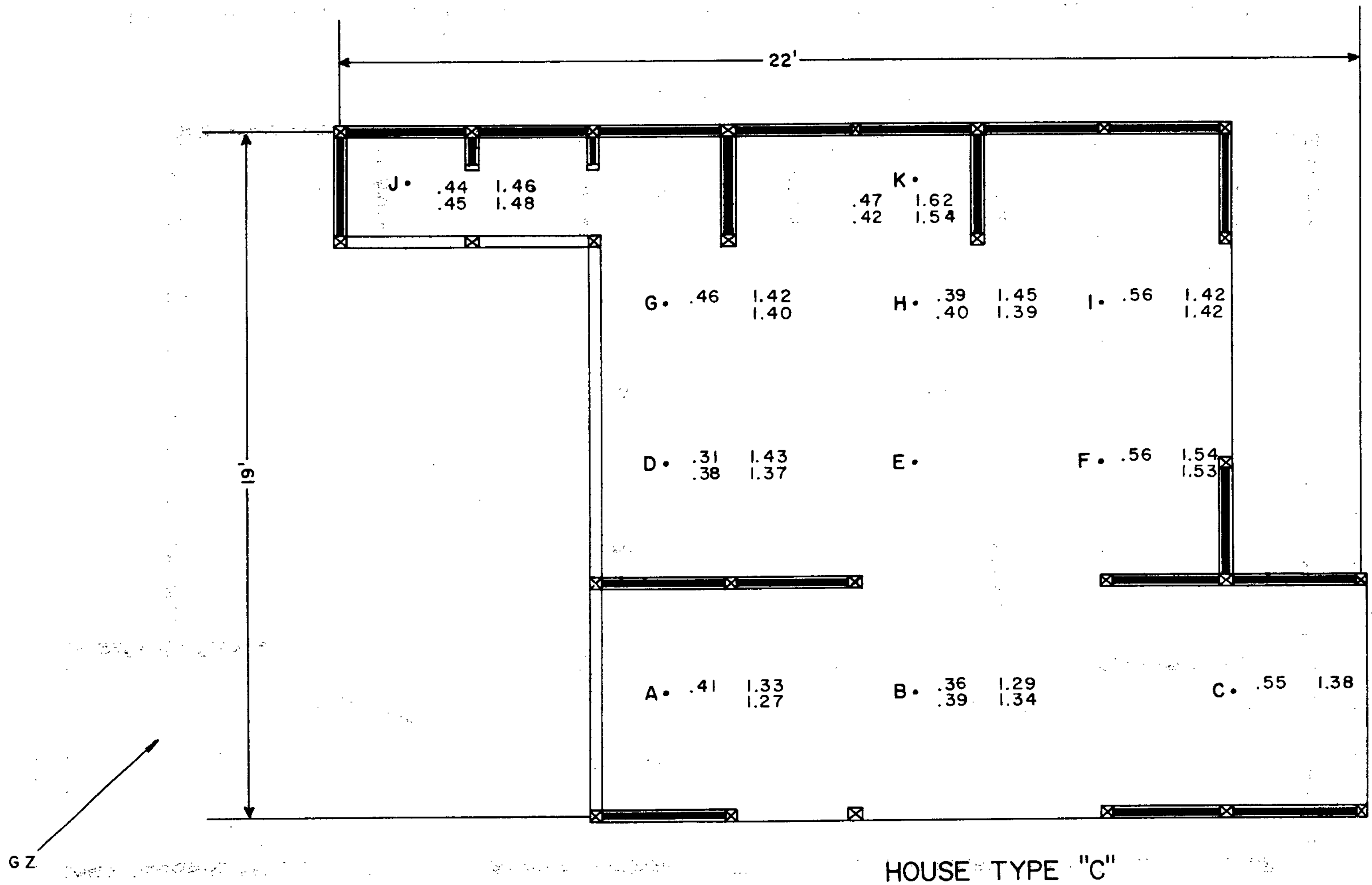


Fig. 3.54--D_m/D_a, reactor radiation in house type C in configuration No. 10'.

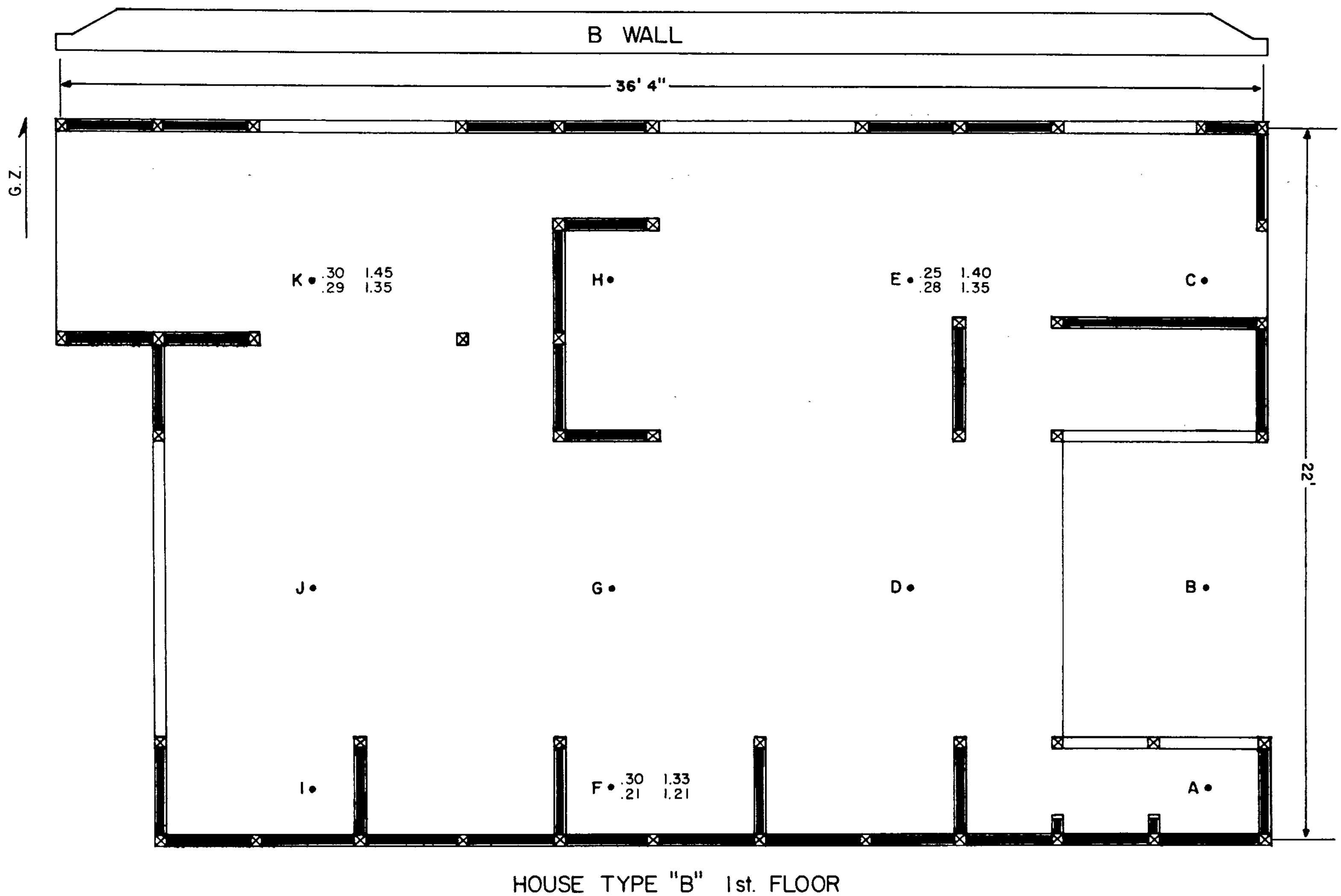


Fig. 3.55--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 11.

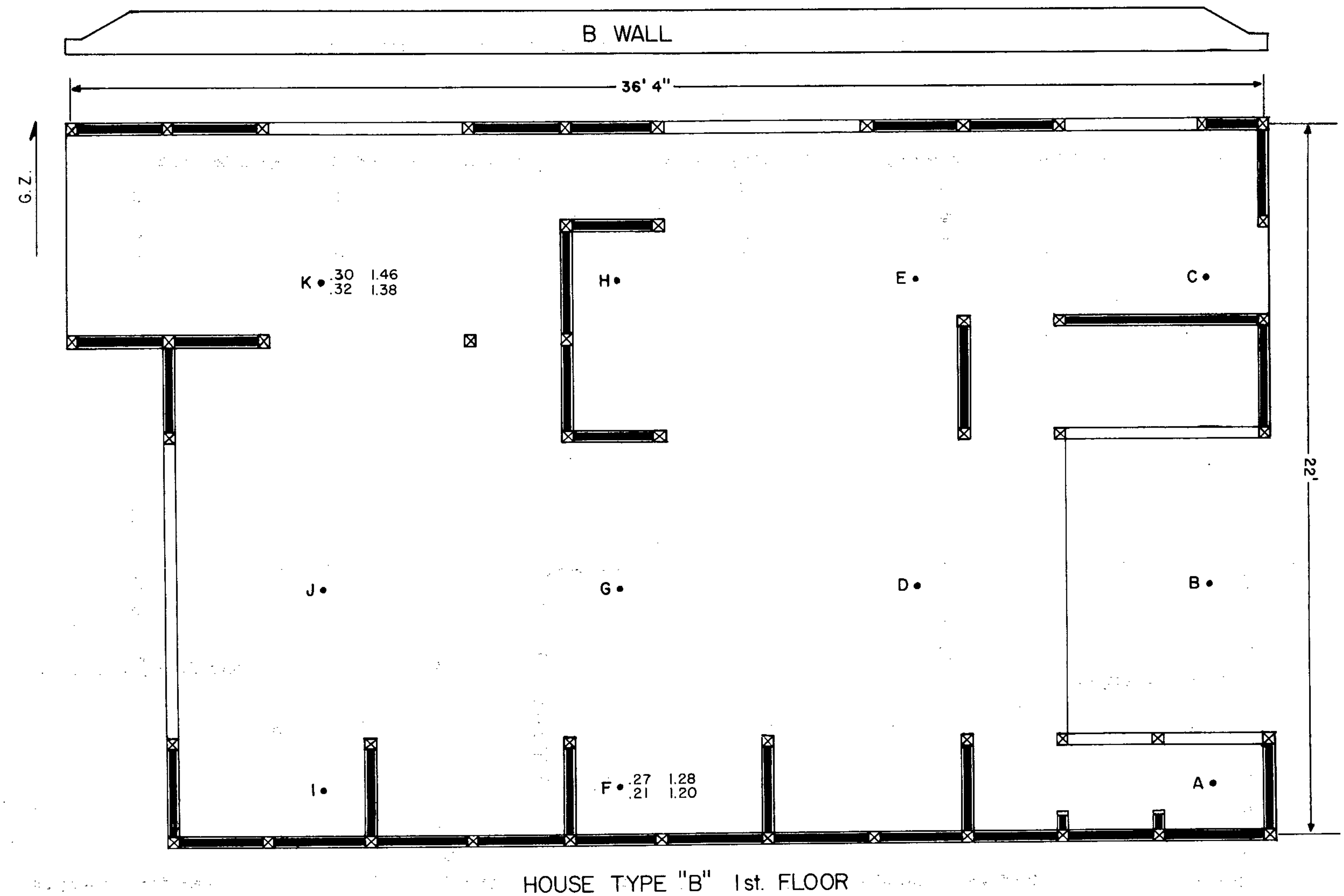


Fig. 3.56--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 11'.

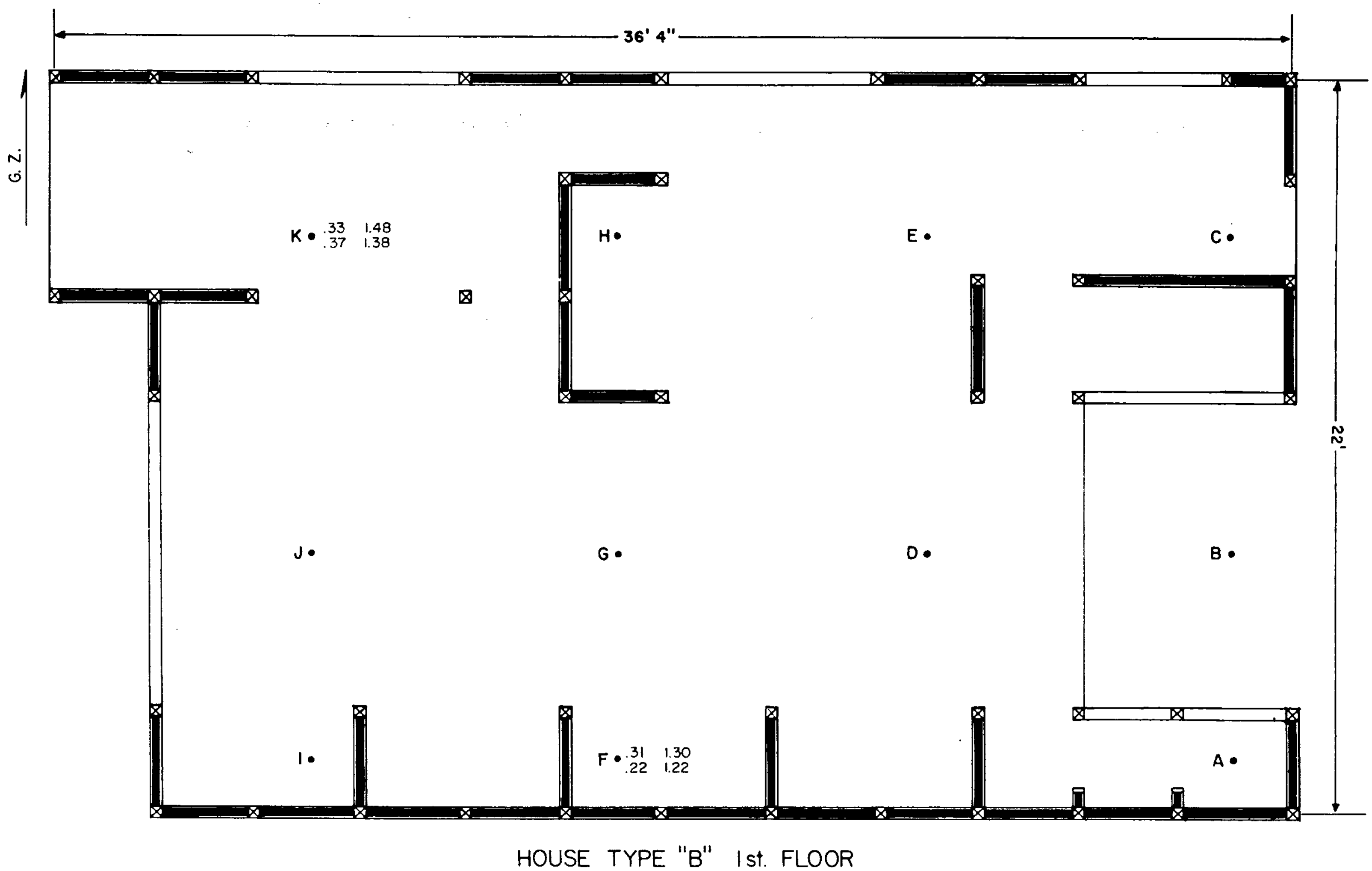


Fig. 3.57--D_m/D_a, reactor radiation on lower floor of house type B in configuration No. 11".

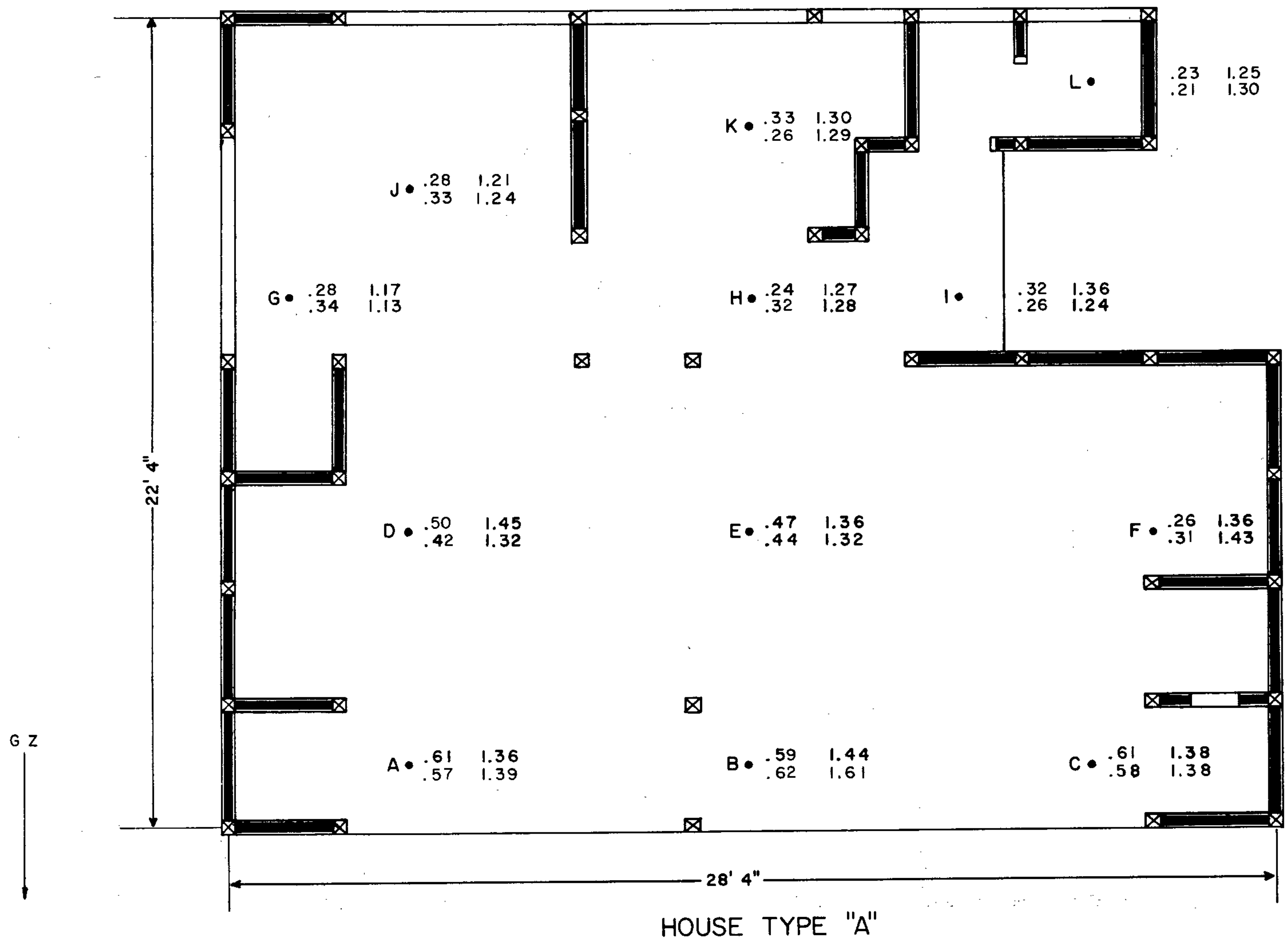


Fig. 3.58--D_m/D_a, reactor radiation in house type A in configuration No. 12 with reactor at 1500 ft.

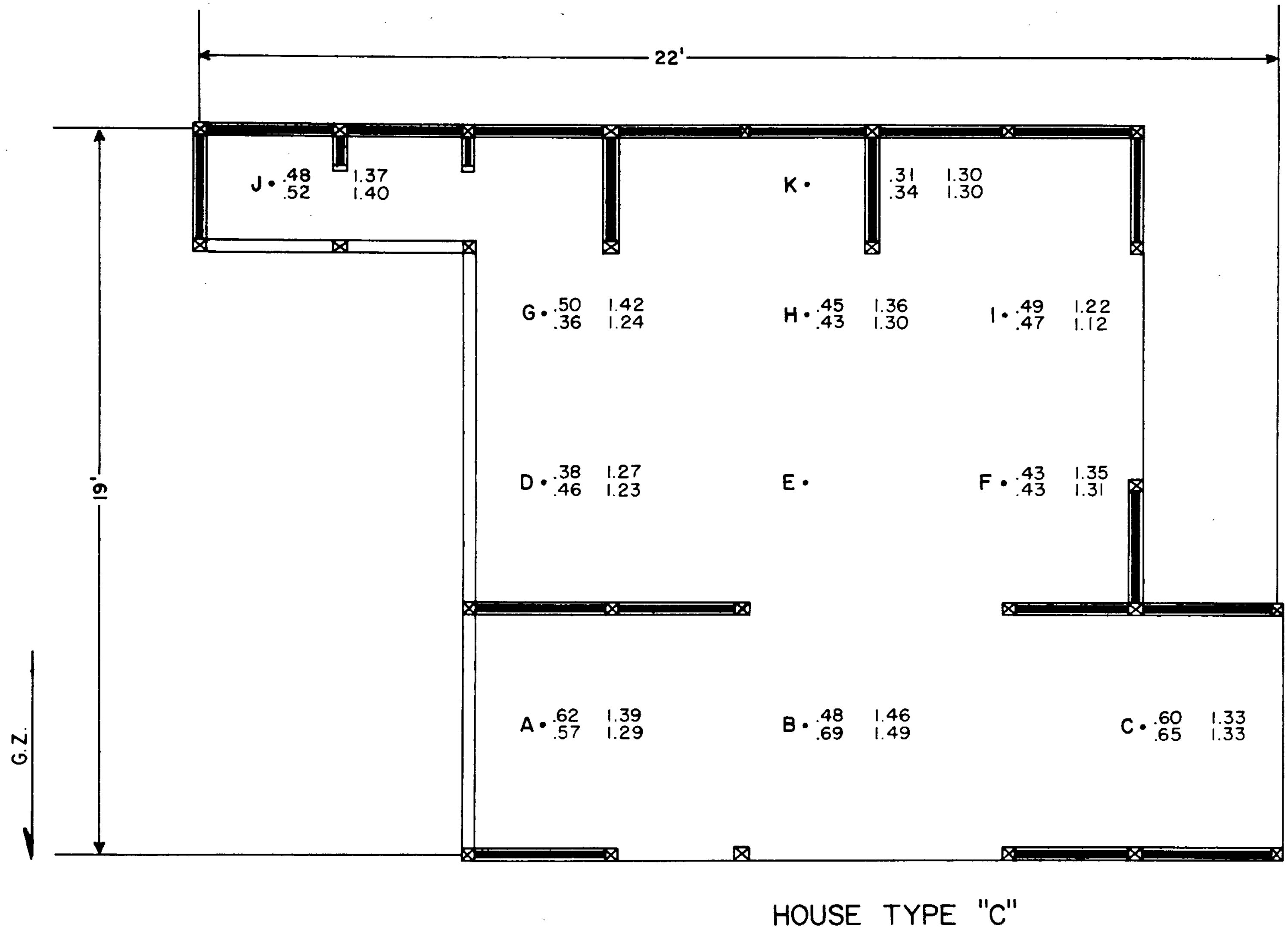


Fig. 3.59--D_m/D_a, reactor radiation in house type C in configuration No. 12 with reactor at 1500 ft.

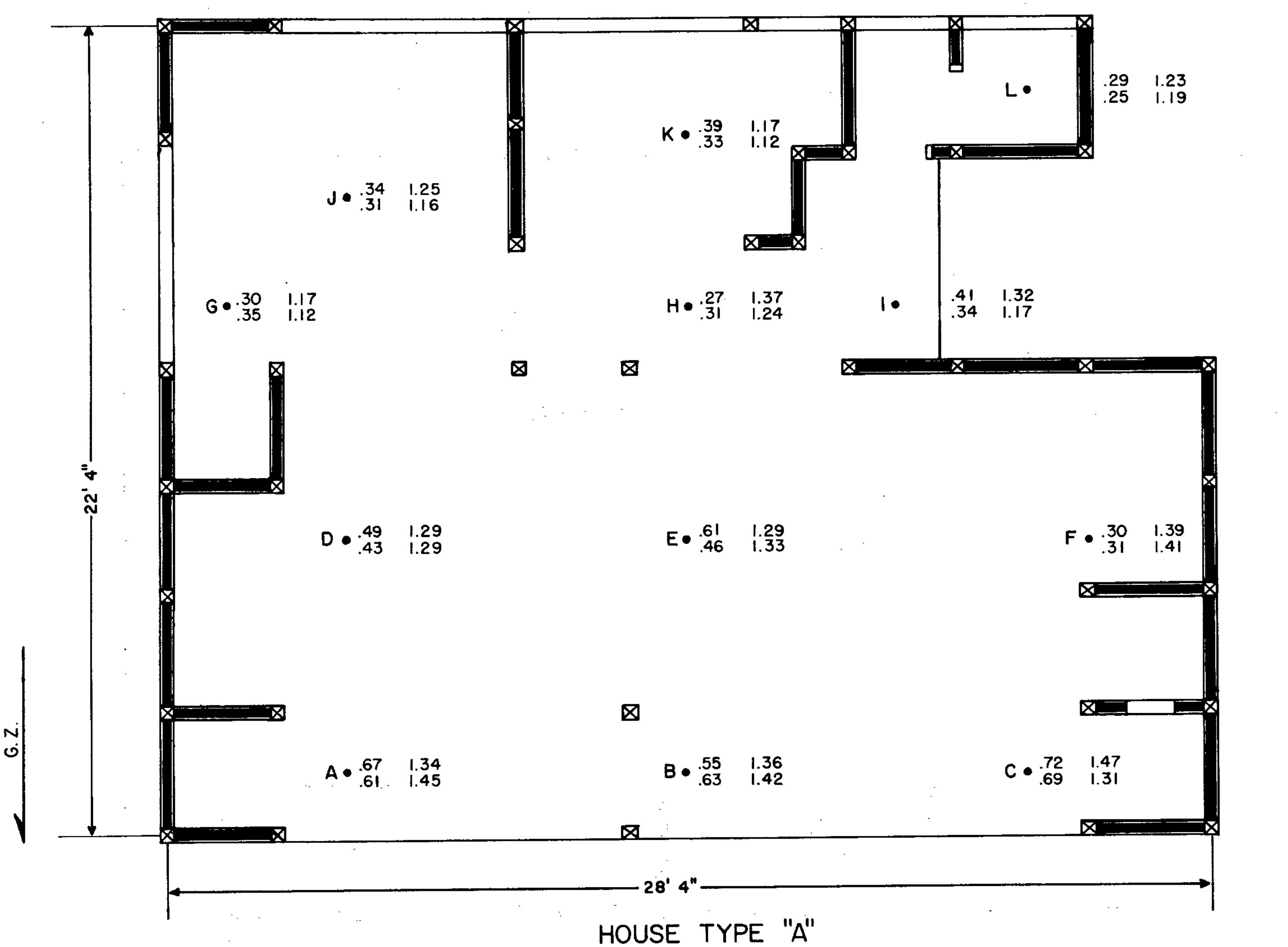


Fig. 3.60--D_m/D_a, reactor radiation in house type A in configuration No. 12' with reactor at 1125 ft.

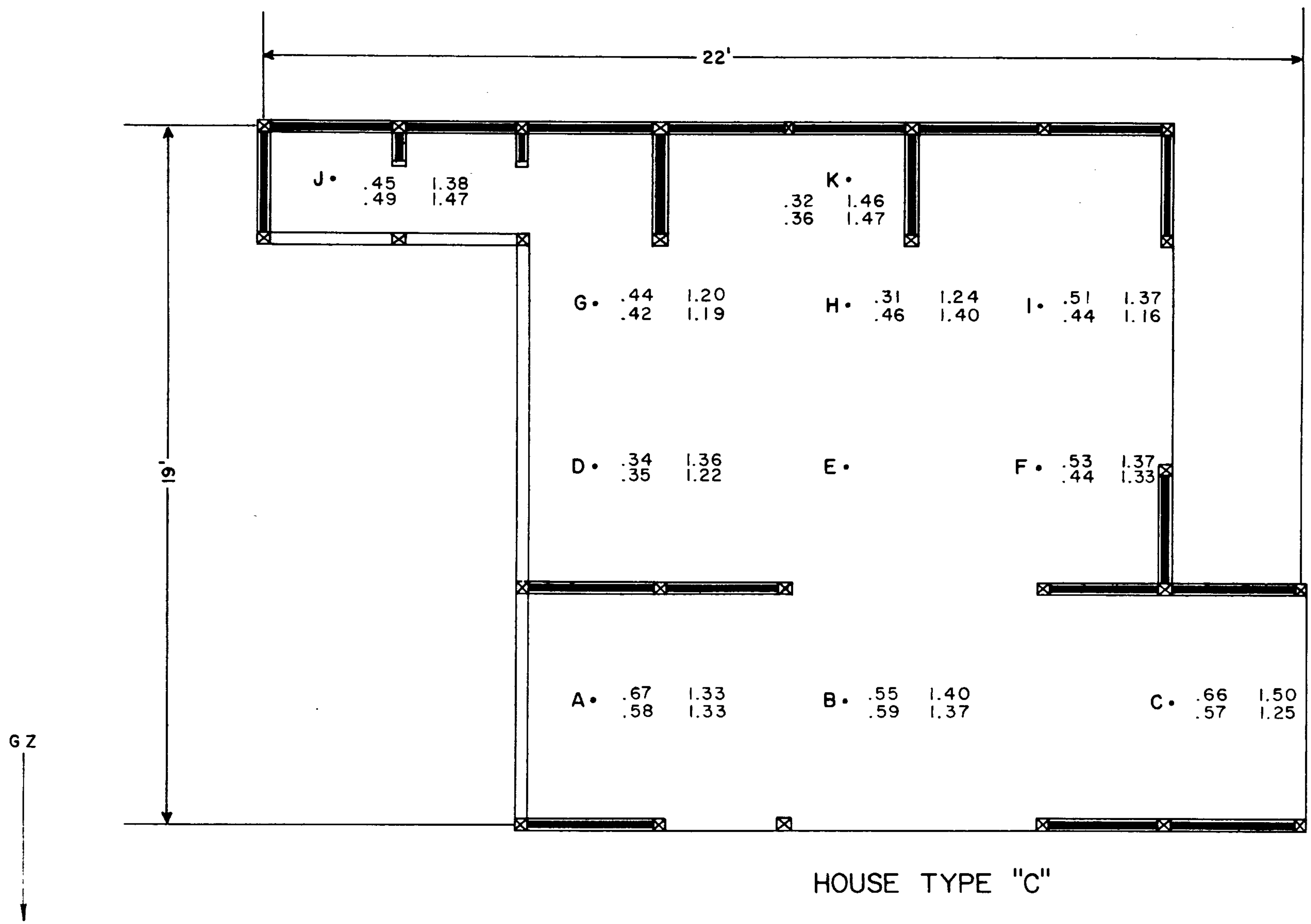


Fig. 3.61--D_m/D_a, reactor radiation in house type C in configuration No. 12' with reactor at 1125 ft.

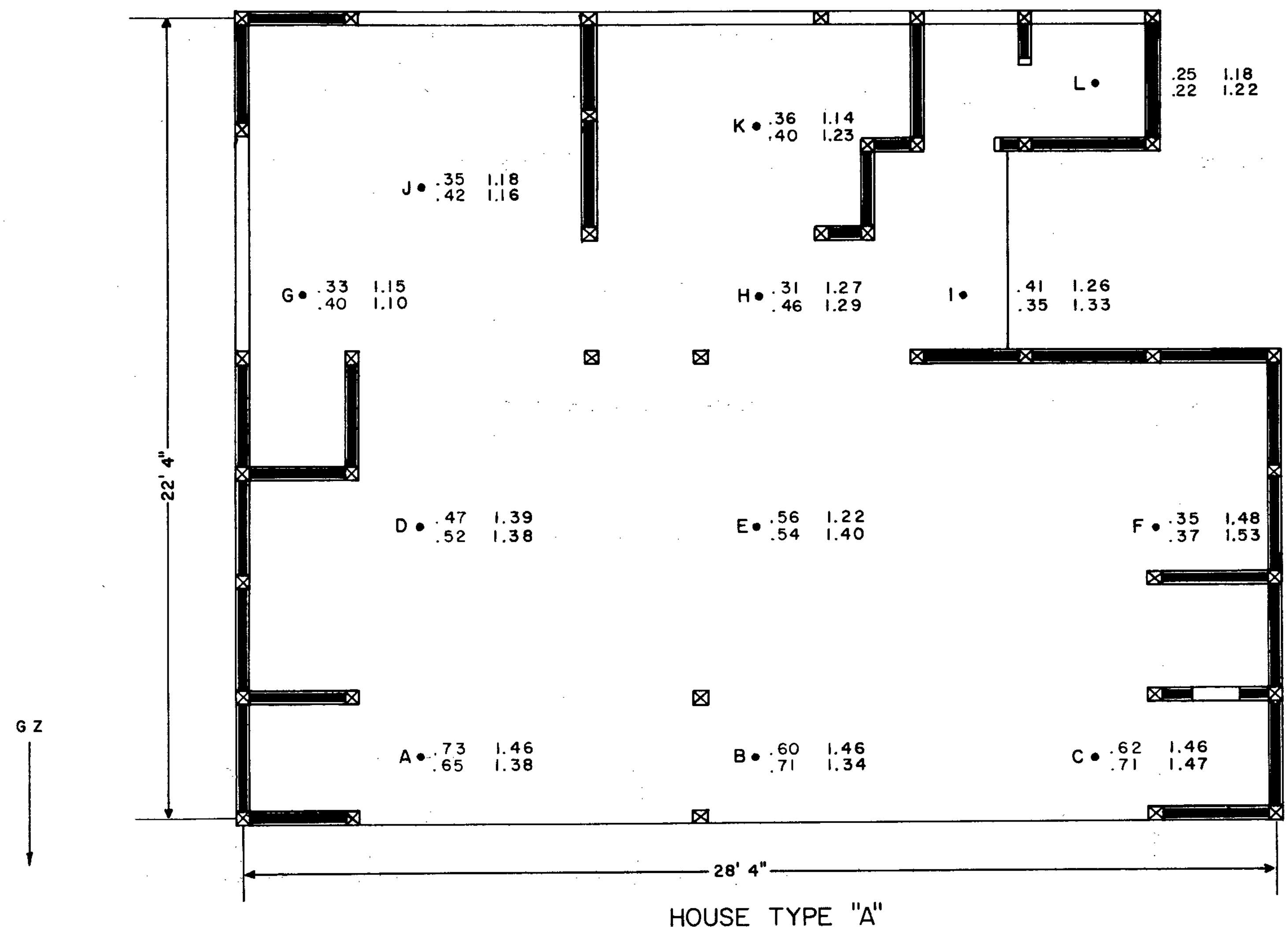


Fig. 3.62--D_m/D_a, reactor radiation in house type A in configuration No. 12" with reactor at 500 ft.

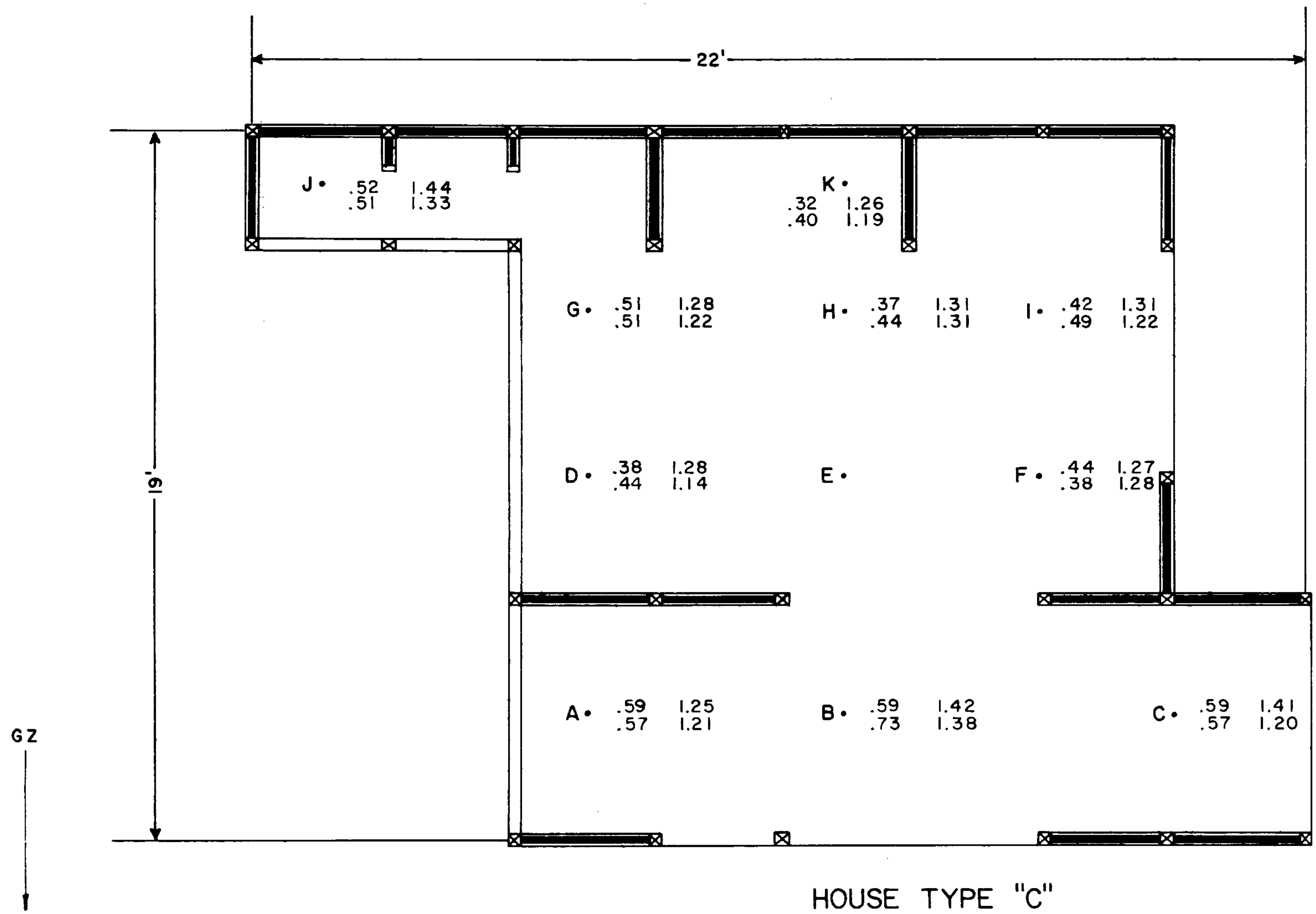


Fig. 3.63--D_m/D_a, reactor radiation in house type C in configuration No. 12" with reactor at 500 ft.

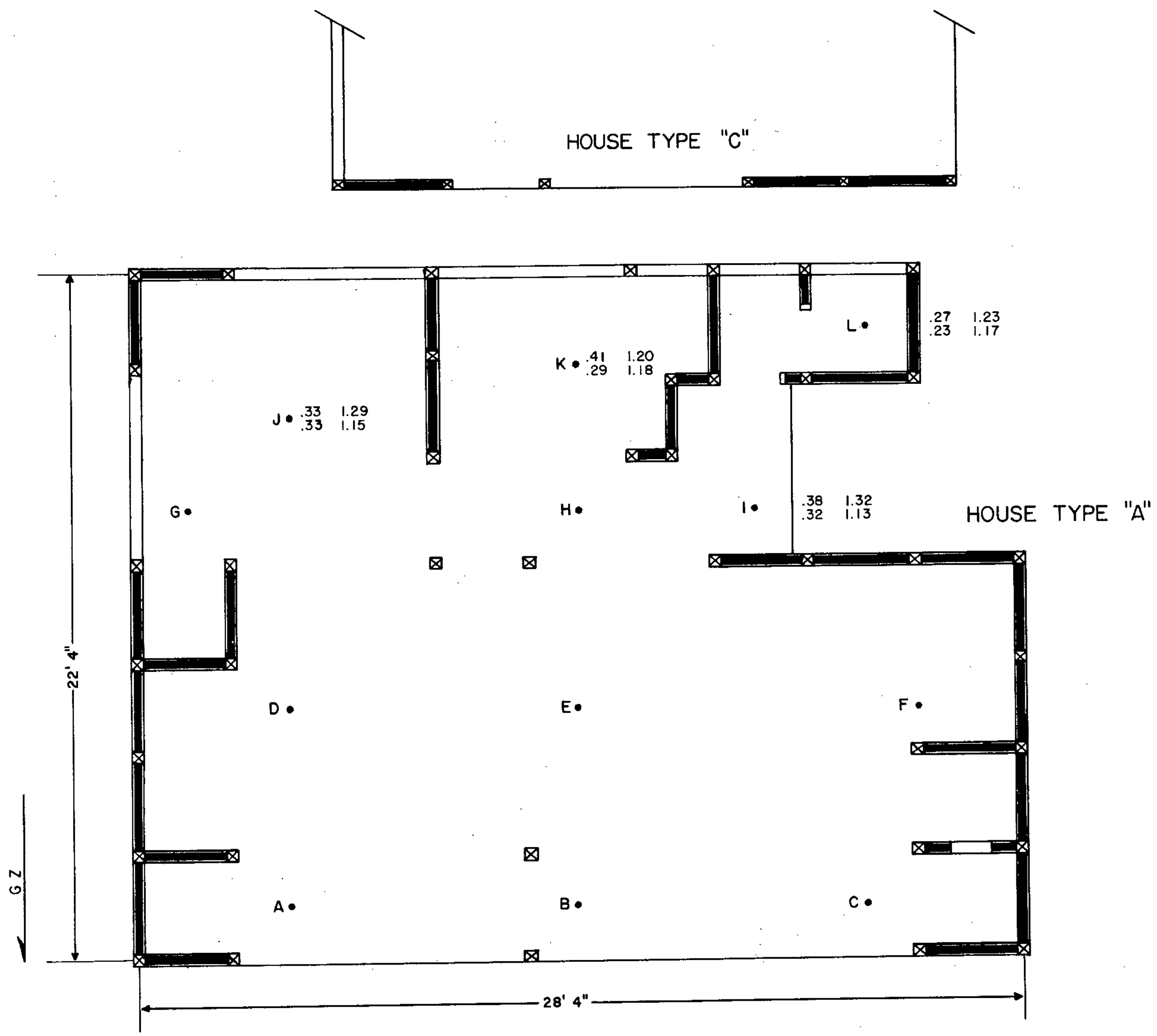


Fig. 3.64--D_m/D_a, reactor radiation in house type A in configuration No. 13.

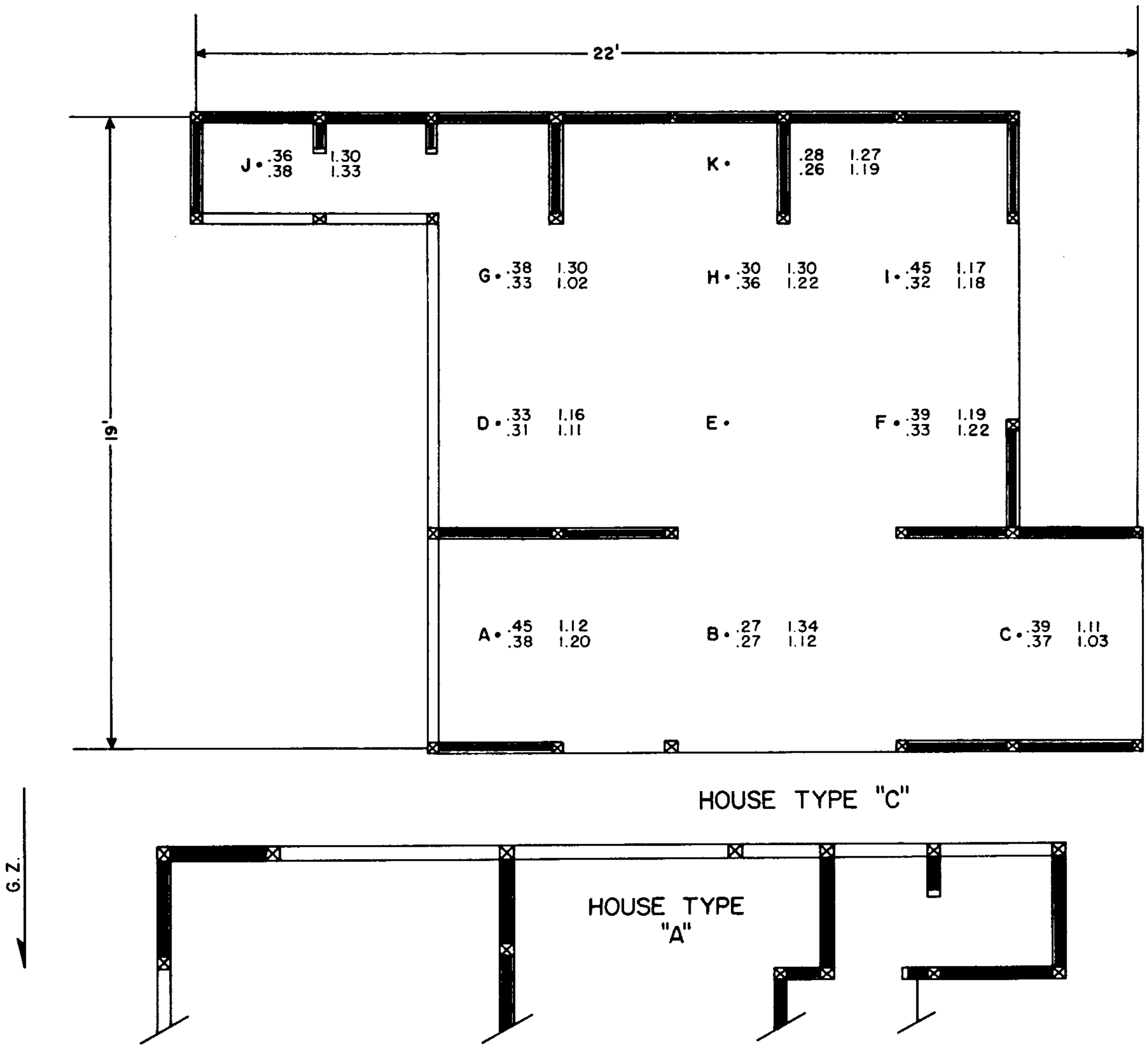


Fig. 3.65--D_m/D_a, reactor radiation in house type C in configuration No. 13.

TABLES

The following items apply to all the tables:

1. The numbers in column headings refer to corresponding configurations as illustrated in Figs. 3.2-3.13 and 4.3-4.6.
2. Except where indicated otherwise, all houses were 750 yds from the foot of the reactor tower.
3. The reactor and the ^{60}Co source were never used together.
4. Notes in column headings indicate changes from preceding configurations; e.g., "No. 3 lateral wall added" implies: configuration 3 (Fig. 3.4) differs from configuration 2 (Fig. 3.3) by the addition of a lateral wall.
5. The station letter symbols refer to locations in the houses as shown in Figs. 2.10-2.13. The number in the station symbol is the number of feet above the floor.

Table 3.1--REACTOR GAMMA DOSE MEASUREMENTS IN HOUSE A, RELATIVE TO "AIR DOSE"

													1000 yards			
Station	No. 1 no roof	No. 1' roof added	No. 2 near B	No. 3 lateral wall added	No. 4 as 3 C to rear	No. 5 as 4 walls around C	No. 6 reversed between B and C	No. 7 as 6 walls 10 ft to rear	No. 8 behind B front of C R at 1125 ft el.	No. 8' as 8 R at 1500 ft el.	No. 8" as 8 R at 500 ft el.	No. 10 set at 45°	No. 12 R at 1500 ft el.	No. 12' R at 1125 ft el.	No. 12" R at 500 ft el.	No. 13 backed by C
A3	1.42	1.43		1.50			1.17	1.34	1.36	1.33	1.26	1.43	1.39	1.45	1.38	
A5	1.32	1.40		1.55			1.23	1.36	1.34	1.30	1.25	1.38	1.36	1.34	1.46	
B1	1.37	1.41														
B3	1.30	1.33	1.43	1.39			1.17	1.27	1.27	1.25	1.20	1.48	1.61	1.42	1.34	
B5	1.22	1.43	1.45	1.40			1.15	1.26	1.32	1.26	1.25	1.45	1.44	1.36	1.46	
B7	1.16	1.32														
C3	1.29	1.38	1.51	1.40			1.22	1.27	1.26	1.23	1.20	1.45	1.38	1.31	1.47	
C5	1.37	1.44	1.42	1.44			1.22	1.34	1.26	1.33	1.15	1.45	1.38	1.47	1.46	
D3	1.39	1.32	1.34	1.46			1.32		1.32	1.27	1.18	1.42	1.32	1.29	1.38	
D5	1.31	1.40	1.43	1.41			1.29		1.31	1.37	1.20	1.48	1.45	1.29	1.39	
E1	1.41	1.42														
E3	1.34	1.35	1.42	1.43			1.30	1.39	1.29	1.24	1.23	1.44	1.32	1.33	1.40	
E5	1.24	1.44	1.38	1.43			1.29	1.37	1.27	1.28	1.14	1.44	1.36	1.29	1.22	
E7	1.25	1.42														
F3	1.40	1.41	1.45	1.37			1.31		1.23	1.15	1.17	1.53	1.43	1.41	1.53	
F5	1.34	1.41	1.49	1.44			1.33		1.33	1.29	1.20	1.55	1.36	1.39	1.48	
G3	1.21	1.19		1.29			1.41		1.20	1.25	1.11	1.23	1.13	1.12	1.10	
G5	1.15	1.20		1.29			1.39		1.23	1.25	1.11	1.28	1.17	1.17	1.15	
H1	1.32	1.33														
H3	1.38	1.32	1.25	1.33					1.19	1.32	1.11	1.40	1.28	1.24	1.29	
H5	1.34	1.39	1.30	1.34					1.25	1.23	1.17	1.46	1.27	1.37	1.27	
H7	1.26	1.39														
I3	1.25	1.34	1.31	1.37	1.37	1.38	1.49		1.16	1.31	1.10	1.49	1.24	1.17	1.33	1.13
I5	1.29	1.38	1.39	1.41	1.40	1.40	1.47		1.26	1.24	1.13	1.48	1.36	1.32	1.26	1.32
J3	1.25	1.22	1.20	1.23	1.35	1.36	1.44		1.26	1.21	1.09	1.28	1.24	1.16	1.16	1.15
J5	1.18	1.26	1.31	1.24	1.41	1.29	1.46		1.27	1.21	1.15	1.30	1.21	1.25	1.18	1.29
K1	1.38	1.33														
K3	1.24	1.17	1.21	1.29	1.29	1.31			1.24	1.26	1.14	1.36	1.29	1.12	1.23	1.18
K5	1.20	1.31	1.28	1.32	1.30	1.33			1.19	1.24	1.14	1.36	1.30	1.17	1.14	1.20
K7	1.19	1.36														
L3	1.31	1.26	1.23	1.23	1.24	1.28	1.54		1.22	1.27	1.13	1.47	1.30	1.19	1.22	1.17
L5	1.33	1.35	1.38	1.27	1.29	1.30	1.55		1.38	1.34	1.20	1.54	1.25	1.23	1.18	1.23

Table 3.2--NEUTRON DOSE MEASUREMENTS IN HOUSE A, RELATIVE TO "AIR DOSE"

													1000 yards			
Station	No. 1 no roof	No. 1' roof added	No. 2 near B	No. 3 lateral wall added	No. 4 as 3 C to rear	No. 5 as 4 walls around C	No. 6 reversed between B and C	No. 7 as 6 walls 10 ft to rear	No. 8 behind B front of C R at 1125 ft el.	No. 8' as 8 R at 1500 ft el.	No. 8" as 8 R at 1500 ft el.	No. 10 set at 45°	No. 12 R at 1500 ft el.	No. 12' R at 1125 ft el.	No. 12" R at 500 ft el.	No. 13 backed by C
A3	.95	.86		.69			.31	.27	.27	.28	.26	.54	.57	.61	.65	
A5	.78	.68		.53			.36	.50	.32	.32	.28	.52	.61	.67	.73	
B1	1.01	.89														
B3	.82	.75	.65				.51	.34	.21	.22	.21	.54	.62	.63	.71	
B5	.82	.61	.55				.32	.26	.16	.16	.18	.44	.59	.55	.60	
B7	.85	.62														
C3	.79	.61	.75	.63			.35	.33	.20	.21	.20	.49	.58	.69	.71	
C5	.76	.59	.68	.53			.36	.27	.32	.29	.25	.52	.61	.72	.62	
D3	.56	.44	.44	.45			.32		.25	.27	.24	.40	.42	.43	.52	
D5	.62	.46	.42	.39			.37		.33	.34	.30	.48	.50	.49	.47	
E1	.84	.66														
E3	.60	.48	.60	.42			.33	.47	.21	.19	.22	.39	.44	.46	.54	
E5	.66	.46	.47	.42			.35	.44	.29	.25	.26	.53	.47	.61	.56	
E7	.66	.47														
F3	.63	.61	.32	.41			.50		.20	.18	.19	.43	.31	.31	.37	
F5	.54	.44	.29	.37			.35		.17	.16	.17	.34	.26	.30	.35	
G3	.48	.37					.63		.33	.32	.31	.32	.34	.35	.40	
G5	.57	.48					.42		.31	.29	.26	.30	.28	.30	.33	
H1	.75	.56														
H3	.45	.41	.33	.47					.20	.20	.18	.31	.32	.31	.46	
H5	.51	.43	.32	.43					.19	.20	.16	.29	.24	.27	.31	
H7	.53	.40														
I3	.38	.31	.29	.30	.29	.28	.41		.20	.21	.19	.35	.26	.34	.35	.32
I5	.48	.38	.29	.30	.21	.33	.43		.28	.33	.24	.43	.32	.41	.41	.38
J3	.68	.58	.52	.49	.34	.35	.66		.28	.32	.26	.32	.33	.31	.42	.33
J5	.66	.54	.45	.56	.34	.39	.53		.27	.30	.25	.32	.28	.34	.35	.33
K1	.62	.52														
K3	.44	.31	.43	.26	.35	.41			.21	.22	.18	.31	.26	.33	.40	.29
K5	.48	.35	.33	.29	.36	.39			.27	.29	.22	.38	.33	.39	.36	.41
K7	.53	.42														
L3	.59	.41	.30	.36	.29	.29	.75		.20	.18	.17	.41	.21	.25	.22	.23
L5	.50	.38	.30	.28	.32	.27	.57		.19	.23	.18	.40	.23	.29	.25	.27

Table 3.3--REACTOR GAMMA DOSE MEASUREMENTS IN HOUSE B, RELATIVE TO "AIR DOSE"

Station	No. 1	No. 2 as 1 flanked by A	No. 3 as 2 wall beyond A	No. 4 as 3 C behind A	No. 5 as 4 walls around C	No. 6 rotated 90° clockwise	No. 7 as 6 walls 10 ft to rear	No. 8 as 6 A to rear R at 1125 ft el.	No. 8' as 8 R at 1500 ft el.	No. 8" as 8 R at 500 ft el.	No. 9 as 8 B wall to front	No. 10 as 9 (reproducibility)	No. 11 as 9 R at 1500 ft el.	No. 11' as 9 R at 1125 ft el.	No. 11" as 9 R at 500 ft el.
A1	1.59														
A3	1.66	1.50				1.50	1.37	1.45	1.43	1.36	1.32	1.40			
A5	1.78	1.64				1.57	1.44	1.53	1.33	1.44	1.40	1.43			
A7	1.65														
B1	1.50														
B3	1.49					1.45									
B5	1.62					1.38									
B7	1.44														
C1	1.53														
C3	1.60					1.68		1.50	1.32	1.42	1.35	1.39			
C5	1.73					1.71		1.49	1.41	1.45	1.35	1.44			
C7	1.65														
D1	1.50	1.47													
D3	1.50	1.42				1.46	1.36	1.36	1.26	1.37	1.34	1.28			
D5	1.71	1.44				1.49	1.40	1.40	1.32	1.36	1.23	1.32			
D7	1.70	1.46													
E1	1.37														
E3	1.42	1.34				1.66		1.57	1.35	1.49	1.30	1.40	1.35		
E5	1.56	1.46				1.62		1.52	1.50	1.51	1.34	1.43	1.40		
E7	1.44														
F1	1.37														
F3	1.48	1.31		1.42	1.39	1.50	1.35	1.39	1.26	1.40	1.24	1.29	1.21	1.20	1.22
F5	1.56	1.37		1.41	1.44	1.47	1.35	1.38	1.28	1.33	1.29	1.31	1.33	1.28	1.30
F7	1.66														
G1	1.29	1.31													
G3	1.36	1.35	1.32			1.47		1.38	1.32	1.36	1.22	1.29			
G5	1.48	1.42	1.34			1.46		1.38	1.34	1.40	1.20	1.32			
G7	1.50	1.39													
H1	1.58														
H3	1.54					1.63		1.58	1.42	1.52	1.30	1.34			
H5	1.69					1.67		1.58	1.41	1.56	1.38	1.44			
H7	1.60														
I1	1.30														
I3	1.30	1.17		1.15	1.21	1.50	1.40	1.45	1.33	1.35	1.21	1.36			
I5	1.45	1.27		1.35	1.42	1.58	1.48	1.45	1.37	1.40	1.30	1.30			
I7	1.38														
J1	1.21														
J3	1.34	1.22	1.17					1.40	1.31	1.42	1.28	1.26			
J5	1.32	1.32	1.23					1.35	1.26	1.38	1.22	1.31			
J7	1.29														
K1	1.12														
K3	1.20					1.65		1.64	1.38	1.51	1.33	1.38	1.35	1.38	1.38
K5	1.35					1.70		1.57	1.41	1.55	1.43	1.38	1.45	1.46	1.48
K7	1.35														
Second floor															
M1	1.56														
M3	1.57					1.58			1.50	1.62	1.40				
M5	1.58					1.57			1.52	1.60	1.48				
M7	1.62														
O1	1.51														
O3	1.56					1.52			1.33	1.48	1.39				
O5	1.62					1.43			1.34	1.46	1.43				
O7	1.68														
P1	1.54														
P3	1.62					1.64			1.55	1.65	1.50				
P5	1.73					1.64			1.64	1.57	1.47				
P7	1.63														
Q1	1.44														
Q3	1.55														
Q5	1.64														
Q7	1.75														
R1	1.45														
R3	1.63					1.68			1.54	1.53	1.41				
R5	1.64					1.67			1.54	1.72	1.46				
R7	1.57														
S1	1.80														
S3	1.69					1.72			1.66	1.80	1.65				
S5	1.75					1.79			1.72	1.71	1.59				
S7	1.67														
T1	1.43														
T3	1.45					1.51			1.43	1.47	1.41				
T5	1.50					1.53			1.48	1.46	1.38				
T7	1.36														
U1	1.32														
U3	1.36					1.55			1.50	1.50	1.46				
U5	1.46					1.52			1.52	1.53	1.48				
U7	1.49														
V1	1.40														
V3	1.34					1.63			1.53	1.61	1.54				
V5	1.49					1.57			1.50	1.78	1.54				
V7	1.43														

Table 3.4--NEUTRON DOSE MEASUREMENTS IN HOUSE B, RELATIVE TO "AIR DOSE"

Station	No. 1	No. 2 as 1 flanked by A	No. 3 as 2 wall beyond A	No. 4 as 3 C behind A	No. 5 as 4 walls around C	No. 6 rotated 90° clockwise	No. 7 as 6 walls 10 ft to rear	No. 8 as 6 A to rear R at 1125 ft el.	No. 8' as 8 R at 1500 ft el.	No. 8" as 8 R at 500 ft el.	No. 9 as 8 B wall to front	No. 10 as 9 (reproducibility)	No. 11 as 9 R at 1500 ft el.	No. 11' as 9 R at 1125 ft el.	No. 11" as 9 R at 500 ft el.
A1	.79														
A3	.75	.48				.29	.30	.37	.38	.36	.36	.34			
A5	.61	.53				.39	.36	.38	.36	.37	.34	.38			
A7	.60														
B1	1.02														
B3	.90					.38									
B5	.87					.39									
B7	.88														
C1	.89														
C3	.76					.62		.56	.52	.62	.42	.40			
C5	.63					.57		.54	.48	.52	.44	.41			
C7	.76														
D1	.74	.61													
D3	.61					.31	.27	.35	.36	.35	.23				
D5	.42					.37	.27	.40	.38	.33	.29	.34			
D7	.46	.42													
E1	.61														
E3	.50	.41				.44		.45	.42	.45	.25		.28		
E5	.43	.38				.53		.55	.53	.54	.36	.37	.25		
E7	.50														
F1	.51														
F3	.45	.38		.28	.24			.22	.24	.26	.17		.21	.21	.22
F5	.37	.33		.29	.34			.30	.30	.30	.24	.27	.30	.27	.31
F7	.39														
G1	.59	.43													
G3	.56	.32	.30			.49		.27	.27	.29	.20	.21			
G5	.38	.34	.35			.35		.21	.23	.22	.17	.19			
G7	.41	.43													
H1	.48														
H3	.50					.30		.30	.31	.32	.17				
H5	.30					.36		.37	.33	.36	.26	.25			
H7	.31														
I1	.48														
I3	.40	.34		.30	.34			.32	.29	.30	.25	.24			
I5	.30	.30		.38	.36			.27	.23	.24	.20	.20			
I7	.33														
J1	.48														
J3	.42	.28	.38					.40	.35	.36	.25				
J5	.29	.28	.38					.44	.41	.42	.35	.36			
J7	.33														
K1	.45														
K3	.41					.73		.54	.44	.58	.31	.34	.29	.32	.37
K5	.33					.48		.38	.36	.41	.27	.26	.30	.30	.33
K7	.32														
Second floor															
M1	.75														
M3	.64					.39			.39	.37	.33				
M5	.48					.46			.46	.39	.40				
M7	.49														
O1	.94														
O3	.78					.60			.49	.47	.38				
O5	.57					.39			.38	.38	.31				
O7	.53														
P1	.78														
P3	.67					.50			.53	.51	.34				
P5	.48					.63			.57	.61	.45				
P7	.52														
Q1	.58														
Q3	.51														
Q5	.44														
Q7	.42														
R1	.64														
R3	.52					.56			.35	.36	.31				
R5	.41					.49			.31	.30	.24				
R7	.43														
S1	.63														
S3	.50					.62			.41	.47	.26				
S5	.38					.51			.36	.42	.23				
S7	.41														
T1	.54														
T3	.44					.36			.38	.38	.31				
T5	.34					.51			.49	.41	.40				
T7	.48														
U1	.57														
U3	.44					.44			.45	.46	.36				
U5	.35					.50			.45	.48	.43				
U7	.41														
V1	.51														
V3	.44					.85			.58	.69	.40				
V5	.38					.56			.50	.54	.36				
V7	.45														

Table 3.5--REACTOR GAMMA DOSE MEASUREMENTS IN HOUSE C, RELATIVE TO "AIR DOSE"

												1000 yards			
Station	No. 1	No. 4 behind A next to B	No. 5 as 4 walls added	No. 6 next to A	No. 7 as 6 B wall 10 ft to rear	No. 8 behind A and B R at 1125 ft el.	No. 8' as 8 R at 1500 ft el.	No. 8" as 8 R at 500 ft el.	No. 9 as 1 rotated 90° clockwise	No. 10 as 9 rotated 90° clockwise	No. 10' as 10 (reproducibility)	No. 12 as 1 R at 1500 ft el.	No. 12' as 12 R at 1125 ft el.	No. 12" as 12 R at 500 ft el.	No. 13 behind A
A3	1.35	1.23	1.24			1.26	1.26	1.17	1.36	1.26	1.27	1.29	1.33	1.21	1.20
A5	1.45	1.36	1.33			1.20	1.32	1.21	1.32	1.33	1.33	1.39	1.33	1.25	1.12
B1	1.28														
B3	1.42	1.33	1.34	1.45		1.16	1.16	1.14	1.34	1.32	1.34	1.49	1.37	1.38	1.12
B5	1.48	1.30	1.32	1.39		1.26	1.35	1.17	1.25	1.32	1.29	1.46	1.40	1.42	1.34
B7	1.51														
C3	1.29	1.27	1.27	1.41		1.17	1.14	1.14	1.45	1.31		1.33	1.25	1.20	1.03
C5	1.34	1.32	1.33	1.43		1.25	1.25	1.13	1.48	1.41	1.38	1.33	1.50	1.41	1.11
D3	1.27	1.32	1.28			1.25	1.24	1.15	1.25	1.37	1.37	1.23	1.22	1.14	1.11
D5	1.38	1.36	1.28			1.28	1.26	1.15	1.33	1.39	1.43	1.27	1.36	1.28	1.16
E1	1.26														
E3	1.30	1.29	1.26												
E5	1.40	1.32	1.28												
E7	1.37														
F3	1.17*	1.25	1.27	1.33		1.21	1.25	1.09	1.43	1.49	1.53	1.31	1.33	1.28	1.22
F5	1.34	1.36	1.32	1.32		1.26	1.27	1.16	1.41	1.46	1.54	1.35	1.37	1.27	1.19
G3	1.34	1.36	1.32	1.29	1.40	1.29	1.29	1.25	1.33	1.32	1.40	1.24	1.19	1.22	1.02
G5	1.38	1.37	1.38	1.41	1.48	1.37	1.31	1.25	1.38	1.36	1.42	1.42	1.20	1.28	1.30
H1	1.16*														
H3	1.40	1.25	1.26	1.34		1.28	1.28	1.22	1.41	1.39	1.39	1.30	1.40	1.31	1.22
H5	1.30	1.37	1.36	1.38		1.28	1.26	1.15	1.42	1.37	1.45	1.36	1.24	1.31	1.30
H7	1.45														
I3	1.10*	1.28	1.32	1.36	1.50	1.24	1.24	1.13	1.56	1.43	1.42	1.12	1.16	1.22	1.18
I5	1.33	1.38	1.26	1.39	1.54	1.31	1.30	1.17	1.50	1.50	1.42	1.22	1.37	1.31	1.17
J3	1.41	1.42	1.49	1.43	1.57	1.41	1.36	1.26	1.36	1.51	1.48	1.40	1.47	1.33	1.33
J5	1.39	1.40	1.47	1.42	1.59	1.38	1.31	1.28	1.29	1.42	1.46	1.37	1.38	1.44	1.30
K3	1.15*	1.34	1.39	1.37	1.49	1.29	1.26	1.17	1.40	1.57	1.54	1.30	1.47	1.19	1.19
K5	1.39	1.36	1.36	1.44	1.56	1.34	1.33	1.24	1.41	1.59	1.62	1.30	1.46	1.26	1.27

*Questionable - scaler trouble

Table 3.6--NEUTRON DOSE MEASUREMENTS IN HOUSE C, RELATIVE TO "AIR DOSE"

												1000 yards			
Station	No. 1	No. 4 behind A next to B	No. 5 as 4 walls added	No. 6 next to A	No. 7 as 6 B wall 10 ft to rear	No. 8 behind A and B R at 1125 ft el.	No. 8' as 8 R at 1500 ft el.	No. 8" as 8 R at 500 ft el.	No. 9 as 1 rotated 90° clockwise	No. 10 as 9 rotated 90° clockwise	No. 10' as 10 (reproducibility)	No. 12 as 1 R at 1500 ft el.	No. 12' as 12 R at 1125 ft el.	No. 12" as 12 R at 500 ft el.	No. 13 behind A
A3	.60	.32	.31			.32	.31	.28	.35	.38		.57	.58	.57	.38
A5	.58	.37	.35			.43	.40	.33	.39	.44	.41	.62	.67	.55	.45
B1	.88														
B3	.73	.35	.38	.75		.25	.26	.24	.43	.41	.39	.69	.59	.73	.27
B5	.55	.37	.36	.60		.27	.26	.22	.37	.35	.36	.48	.55	.59	.27
B7	.59														
C3	.74	.25	.26	.46		.35	.36	.27	.55	.47		.65	.57	.57	.37
C5	.68	.28	.28	.55		.40	.43	.31	.57	.53	.55	.60	.66	.59	.39
D3	.38	.48	.42			.35	.34	.31	.31	.40	.38	.46	.35	.44	.31
D5	.52	.38	.39			.33	.34	.26	.28	.33	.31	.38	.34	.38	.33
E1	.68														
E3	.72	.32	.34												
E5	.44	.40	.37												
E7	.49														
F3	.55	.29	.32	.37		.34	.33	.29	.48	.50		.43	.44	.38	.33
F5	.54	.36	.34	.48		.40	.44	.32	.53	.51	.56	.43	.53	.44	.39
G3	.45	.32	.31	.46	1.19	.40	.37	.30	.32	.41		.36	.42	.51	.33
G5	.44	.39	.36	.48	.47	.43	.46	.37	.38	.46	.46	.50	.44	.51	.38
H1	.65														
H3	.54	.42	.42	.48		.35	.30	.24	.42	.42	.40	.43	.46	.44	.36
H5	.43	.46	.41	.44		.33	.34	.25	.37	.40	.39	.45	.31	.37	.30
H7	.45														
I3	.61	.29	.30	.38	.49	.37	.37	.30	.49	.49		.47	.44	.49	.32
I5	.50	.39	.31	.46	.40	.43	.49	.33	.53	.51	.56	.49	.51	.42	.45
J3	.56	.60	.59	.74	.55	.54	.50	.40	.31	.44	.45	.52	.49	.51	.38
J5	.55	.48	.46	.58	.50	.45	.44	.35	.31	.44	.44	.48	.45	.52	.36
K3	.54	.41	.36	.50	.31	.29	.27	.26	.33	.43	.42	.34	.36	.40	.26
K5	.44	.42	.32	.42	.30	.28	.25	.21	.31	.44	.47	.31	.32	.32	.28

Chapter 4

DISCUSSION

4.1 GAMMA-RAY MEASUREMENTS (REACTOR SOURCE)

The gamma-ray distributions in the houses were found to be similar to those during Operation Hardtack II, and the measurements were consistent and reproducible. A small Japanese "house" and a transite "house" (Figs. 4.1 and 4.2) were found to yield identical distributions. These data, together with those from later laboratory experiments, confirmed the hypothesis that neutron interaction with the major elements of the houses and buildup due to scattering of the high energy gamma rays (from neutron interactions in the air) resulted in the observed gamma-ray distributions; the net "attenuation" of gamma radiation was found to be small and frequently there was a net increase in gamma radiation dose at points inside the houses.

In general, the gamma-ray dose readings increased with elevation of the point of observation above the floor, except that this condition was reversed in the case of the roofless A house.

The large house showed the highest doses, those on the second floor being slightly larger than those downstairs. However, differences were not large in any case.

House orientation made only small differences in average values, although dose distributions in the houses were changed.

The placement of structures in lateral juxtaposition with a house increased the readings of the near stations by only a few percent and had no measurable effect on those more distant. A similar effect was noted when a structure was placed behind a house. In the cases of houses behind some structure, some attenuation appeared, i.e., the apparent buildup had gone beyond maximum. However, even in these cases, readings inside houses were greater than air dose.

4.2 NEUTRON MEASUREMENTS

Interpretation of the variation in relative neutron dose at individual points in the houses (i.e., measured dose divided by air dose) requires further analysis of the data; however, a comparison of the averages of the relative doses at all, or selected, points in the various houses and house configurations yields several general observations. The average relative neutron dose was less than unity in all houses. The highest value obtained was for the small house and the lowest value for the two-story house. The average value for the second floor was higher than that for the first floor.

The largest variation in average relative neutron dose due to change of orientation of a single house was found in the small house. This variation amounted to approximately 35%.

The general effect of the addition of neighboring structures was lowering of the average relative dose. Placing a small house behind a medium size house resulted in a 30% reduction in the average value in the small house. Subsequent placement of both houses behind a two-story house resulted in a reduction of the average value in the small house of 33% as compared to that for the small house alone in the same orientation. The average value in the medium size house was reduced by 50%; the reduction of the average in the large house was much less and was most pronounced on the first floor where it amounted to approximately 9%.

4.3 REPRODUCIBILITY

The reproducibility of measurements was demonstrated by duplicate series of measurements in the large and small houses. In both cases, the reproducibility of the average relative neutron dose rate was within 2% and within 4% for gamma rays.

4.4 OUTSIDE MEASUREMENTS

The value of relative neutron doses in simulated streets or between houses in a cluster can vary from almost one to about 0.35, depending upon position. The relative dose values behind a two-story house were as low as 0.5 within a few feet of the house and as low as 0.9 within a few feet of the house laterally. There was a slight buildup in the dose in front of the large house.

For gamma rays, an increase appeared in dose rate near the house to the front and laterally. It became negligible at 24 ft. Behind the house the shielding balanced the buildup so that there was no essential difference from air dose. Tables 4.1 and 4.2 and Figs. 3.17 and 3.35 show the results of neutron and gamma-ray measurements taken outside of, but near, structures.

4.5 ^{60}CO GAMMA RAY MEASUREMENTS

At the conclusion of exposures using the HPRR, the reactor was replaced by the 1.2-kc ^{60}Co source. With this source, gamma-ray intensity was insufficient at 1000 yds to make house measurements. Measurements were made, however, at the 750-yd experimental area.

The first series of measurements, made with the small Phil used throughout the reactor experiments, was somewhat marginal since good statistics would have required inordinately long counting times. Standard deviations ranged from 10 to 25%. At this time, two larger and more sensitive probes became available, and the experiments were concluded with them. Standard deviations of 5 to 8% were obtained with these probes.

A Geiger-Mueller counter, type CD-700, model No. 6*, with the probe at a fixed height above the ground, was used as a normalizing channel. Consequently, comparison of house measurements with air dose could be made directly without necessity of temperature corrections.

The configurations used appear in Figs. 4.3 through 4.6. The results of this series appear in Tables 4.3, 4.4, and 4.5, and also in Figs. 4.7 through 4.17.

*Made by Anton Electronic Laboratories, Brooklyn, New York

A few points were checked for reproducibility (15A' compared to 15A), and the correspondence was well within the probable errors.

With this source the measurements at the 5-ft elevations were, on the average, slightly lower than those at 3 ft.

There appears a slight diminution of average dose in houses as size increased, in each the average dose being slightly less than half of the air dose.

When the A house was shielded by the large B house, average dose values were about 40% of those obtained in an unshielded A house.

4.6 ANALYSIS

Analysis of these data was begun using the coordinate projector method described in connection with Operation Hardtack II.[1] After considerable effort had been expended on this method, it appeared that, with the large number of parameters involved, definitive values of weight factors were difficult to extract. Besides, the method was not one which would be convenient to use in practical cases (in Japan).

The statistical data analysis process known as "multiple regression and correlation" appeared to lend itself to the solution of this system because of the relative ease and speed with which a digital computer could handle the large amount of data. For example, 774,400 additions and multiplications and 21,300 divisions were required for one derivation of one equation.

Multiple linear regression analysis is used to obtain the best fit of a set of observations of independent and dependent variables by an equation of the form:

$$y = b_0 + b_1X_1 + b_2X_2 + \dots + b_nX_n \tag{1-1}$$

or any equation which can be transformed to this form by substitutions such as $X_i = P_1P_2$, P_1^n, $\cos P_1$, $e^{\pm P_1}$, or $\log P_1$, where P_1 and P_2 are parameters. In equation (1-1) the X's are independent variables and the b's are the coefficients to be determined.

A multiple regression solution gives the least squares "best" value of these coefficients for a particular sample of observations. The solution also gives a measure of the reliability of each of the coefficients so that inferences can be made regarding the parameters of the population from which the sample of observations was taken. The stepwise multiple linear regression used,[2] started by assuming an equation, (1-2), containing only one independent variable

$$y^1 = b_0^1 + b_1^1X_1 \tag{1-2}$$

where X_1 is the parameter contributing most to the accuracy of y^1. Successive equations are obtained by adding one variable at a time so that the following intermediate equations are obtained:

$$y^2 = b_0^2 + b_1^2X_1 + b_2^2X_2 \tag{1-3}$$

$$y^3 = b_0^3 + b_1^3X_1 + b_2^3X_2 + b_3^3X_3 \tag{1-4}$$

...
...
...

$$y^{n-1} = b_0^{n-1} + b_1^{n-1}X_1 + \dots + b_{n-1}^{n-1}X_{n-1} \qquad (1\text{-}[n\text{-}1])$$

The final fitted equation containing all n independent variables is

$$y^n = b_0^n + b_1^nX_1 + b_2^nX_2 + \dots + b_n^nX_n \qquad (1\text{-}n)$$

In each successive equation, the variable added is the one which makes the greatest improvement in "goodness of fit".

In this procedure, (a) a variable may be indicated to be insignificant in any early stage and thus enter the equation, and (b) after several other variables have been added to the regression equation, such a variable may be indicated to be insignificant and will be removed from the equation before an additional variable is added. At a certain stage in the regression (i.e., at the ith intermediate equation), the accuracy of the predictor equation may not be significantly improved by including more variables from the preselected list. The equation

$$y_i = b_0^i + b_1^iX_1 + \dots + b_i^iX_i \qquad (1\text{-}i)$$

will be chosen to be most satisfactory because if $i \ll n$, equation (1-i) will be much easier to evaluate than equation (1-n).

An equation of type (1-1) was assumed, and the first attempt to fit it indicated the method could probably be used successfully by proper refinement and certain transformations of some of the variables.

The following parameters were selected as potentially important in the estimation of neutron dose and gamma exposure.

1. Slant penetration (SP)
2. Height of the dosimeter above the floor (HF)
3. Frontal shielding by a neighboring house (FS)
4. Size of shielding in 3 (FSS)
5. Internal lateral walls (ILW)
6. Internal front walls (IFW)
7. Floor number (FN)
8. Lateral shielding (LS)
9. Distance from an unshielded opening (US)
10. Height of radiation source
11. Distance from the source of radiation
12. Floor area
13. Roof area

14-17. Open surface in each of 4 walls*
18-22. Closed surface in each of 4 walls*
23. Shielding by external sources of back-scattered radiation*

Of these 23 independent variables chosen for the exploratory run, 6 predicted the dose so that half the predictions were in error by less than 45% with the

*In case the house did not have a wall perpendicular to the forward 10 degrees of radiation, the projected values were used.

other 17 adding a total of less than 1.5% to the accuracy of the predictor equations. Plots of the dose against each of the important parameters revealed much about the final form of the equation. It was discovered that some of the parameters must appear as exponential terms; e.g., for the ith variable, in equation (1-1) the transformation $b_i X_i = b_i' \exp(-C_i X_i)$ may be made. In the transformation $b_i' \exp(-C_i X_i)$ replaces $b_i X_i$ in the regression process with exp $(-C_i X_i)$ corresponding to X_i and b_i corresponding to b_i, C_i is a constant determined by iteration. The first approximation to C_i was obtained by a "guess" based on an examination of the data. After using these transformations to obtain an approximation formula, the data and the accuracy of the approximation with respect to individual terms were inspected to determine if the accuracy could be significantly improved by either increasing or decreasing C_i. At each step, the linear coefficients, b_i, were determined by regression and thus are the "best values" in the sense of least squares for a given set of estimates on the non-linear coefficients, C_i.

Multiple regression equations were obtained for neutron dose, the gamma-ray exposure due to the reactor, and the exposure resulting from a ^{60}Co source. This "relaxation" or actually "over-relaxation" technique was used for many of the important parameters. The following equations comprising nine parameters were finally obtained to describe the results of these tests; these equations produce attenuation factors which agree with experimentally determined factors so that 50% of the predictions were in error by less than ±6% and 90% of the predictions were in error by less than ±17%.

Neutrons:

$$D/D_{air} = 0.333 + 0.0118FN + 0.675e^{-SP} - 0.00855IFW + 0.0456e^{-FS} + 1.597e^{-(US + HF)} - 0.0332FSS - 0.0267LS - 0.0116ILW \quad (2)$$

Reactor-produced gamma:

$$D/D_{air} = 1.258 + 0.112FN - 0.00467SP - 0.00630FS \quad (3)$$

^{60}Co gamma used to simulate fission product gamma rays (no front opening influencing readings):

$$D/D_{air} = 0.0382 + 0.625e^{-SP} + 0.242e^{-FS} + 0.111e^{-IFW} \quad (4)$$

^{60}Co gamma (front opening influencing readings):

$$D/D_{air} = 0.214 + 0.367e^{-SP} + 0.0535US + 4.006e^{-(US + HF)} \quad (5)$$

US (unshielded) is distance from front window by 5-ft zones. If zone is fractional, use next integer; if no window, use 100. HF is height above floor in ft. Use decimal fractions. FS is frontal shielding (use 0 if no shield, 1 if a wall in front, 2 if one or more houses in front). SP is slant penetration in ft. FN is floor number (use 1 if single-story house, 2 if lower floor of two-story house, 3 if upper floor of two-story house). FSS is front shield size (use 0 if no shield, 1 if single-story house, 2 if two-story house). LS is lateral shielding (use 0 if side window and no external shield, 1 if no window and no external shield, 2 if lateral shield [house] and in zone 2, [Fig. 4.18], 3 if lateral shield [house] and in zone 3). ILW is number of internal lateral walls which shield the point of measurement. IFW is number of internal front walls which shield the point of measurement.

Except for the hard gamma-ray spectrum, slant penetration, the distance measured along a ray path from the point of entry into the house to the dosimeter, ceased to contribute significantly to the dose at distances beyond 9 ft.

In the case of neutron doses, the regression process implied that lateral walls provided a greater shielding factor than did front walls. Since this radiation passing through the lateral walls is scattered radiation, and therefore softer, one would expect the attenuation to be greater.

This method (a) selected variables relative to their importance, eliminating insignificant ones, (b) predicted dose values such that good agreement was obtained between calculated magnitudes and instrumental observations, (c) yielded equations which were based on measured parameters, and (d) provided a means whereby Japanese technicians can evaluate dose and exposure values speedily and with no computational equipment other than a slide rule.

Equations (2) through (5), having been derived on the basis of BREN data, were then tested on data from Hardtack II. The neutron field data checked within the previous confidence limits. The gamma-ray data, however, required a combination of the formulae for the hard and soft spectra, since with a weapon the fission product gamma radiation is not attenuated as with the core of the reactor. It was found that if these were combined on the assumption of a relative distribution of 45% hard gamma and 55% soft gamma, the calculated or predicted values agreed to within the stated accuracy in the majority of the field measurements. Of those which did not fit this pattern, several differed widely. However, since these were the values which were neither internally consistent nor reproducible during Hardtack II, it was concluded that they were due to malfunctioning of the detectors then used.

It was assumed that this division of the gamma spectrum would be a good approximation to that at Nagasaki. Since the neutron-gamma ratio at Hiroshima was somewhat higher, 55 to 45% hard to soft gamma ratio was assumed to fit that city better.

The combined equations for gamma-ray dose ratio at Nagasaki are as follows: If the point of interest is not behind a window,

$$D/D_{air} = 0.587 + 0.344e^{-SP} + 0.133e^{-FS} + 0.0609e^{-IFW} + 0.0504FN - 0.00210SP - 0.00284FS \quad (6)$$

and, if the point of interest is behind a window,

$$D/D_{air} = 0.684 + 2.203e^{-(US + HF)} + 0.202e^{-SP} + .0294US + 0.0504FN - 0.00210SP - 0.00284FS \quad (7)$$

The corresponding equations for gamma dose at Hiroshima are: If the point of interest is not behind a window,

$$D/D_{air} = 0.708 + 0.281e^{-SP} + 0.109e^{-FS} + 0.0498e^{-IFW} + 0.0616FN - 0.00257SP - 0.00346FS \quad (8)$$

and, if the point of interest is behind a window,

$$D/D_{air} = 0.787 + 1.803e^{-(US + HF)} + 0.165e^{-SP} + 0.0241US + 0.0616FN - 0.00257SP - 0.00346FS \quad (9)$$

Equation (2) is used for neutrons in both cities.

REFERENCES

1. J. A. Auxier, J. S. Cheka, and F. W. Sanders, Projects 39.1 and 39.2, Operation Hardtack (Phase II) Report, WT-1725, March 1961. (Classified)
2. W. J. Dixon (Ed.), "BMD Biomedical Computer Programs", Health Sciences Computing Facility, University of California, Los Angeles, California, 1964.

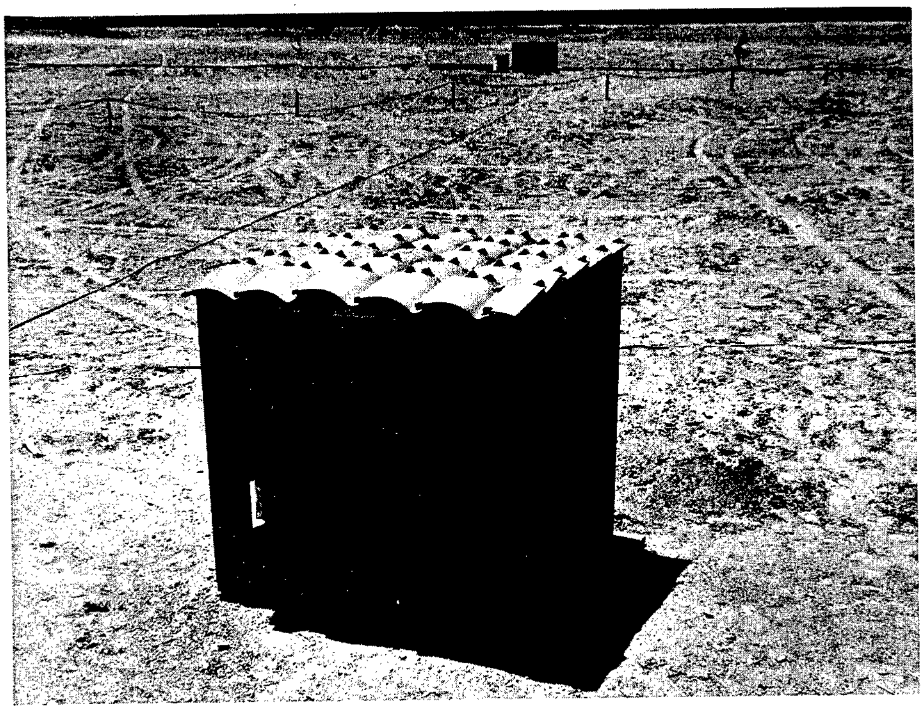


Fig. 4.1--Small "house", 3 ft x 3 ft x 3 ft, made of Japanese materials to Japanese specifications.

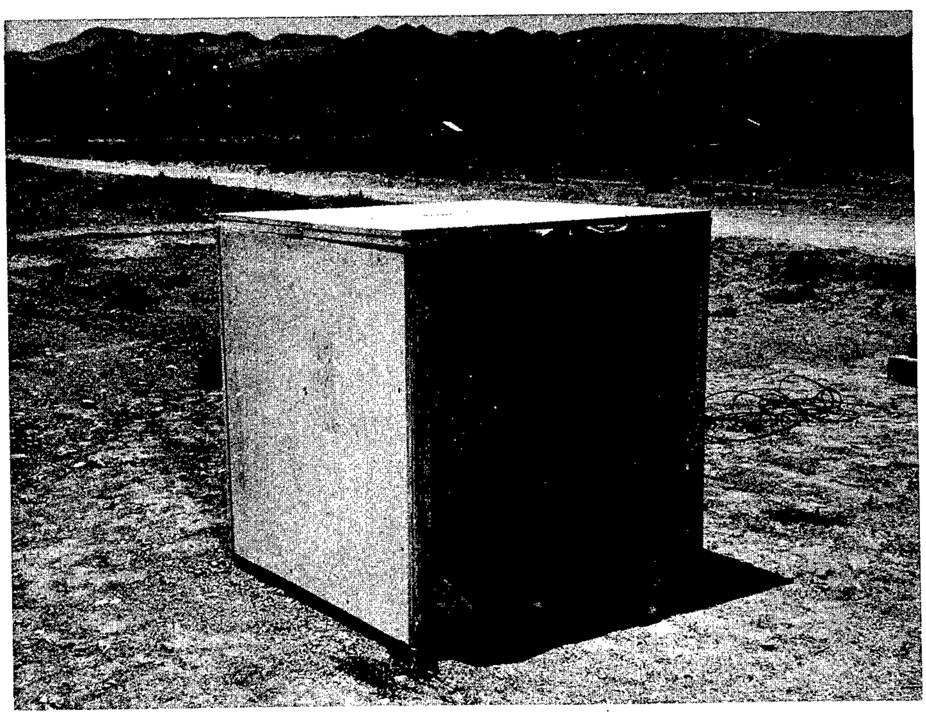
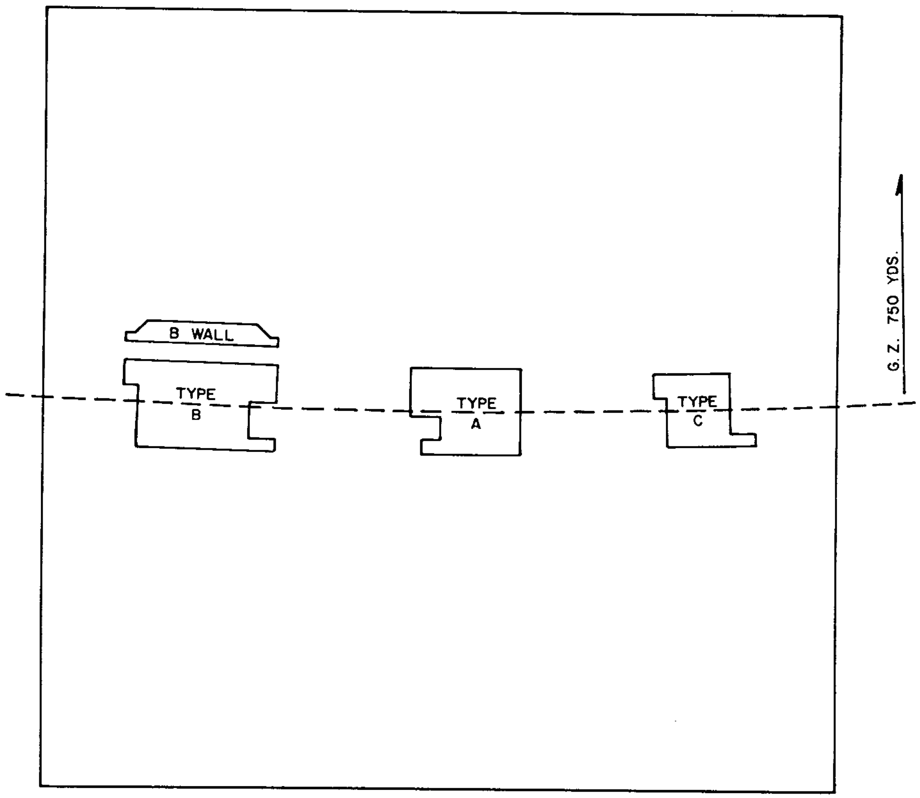
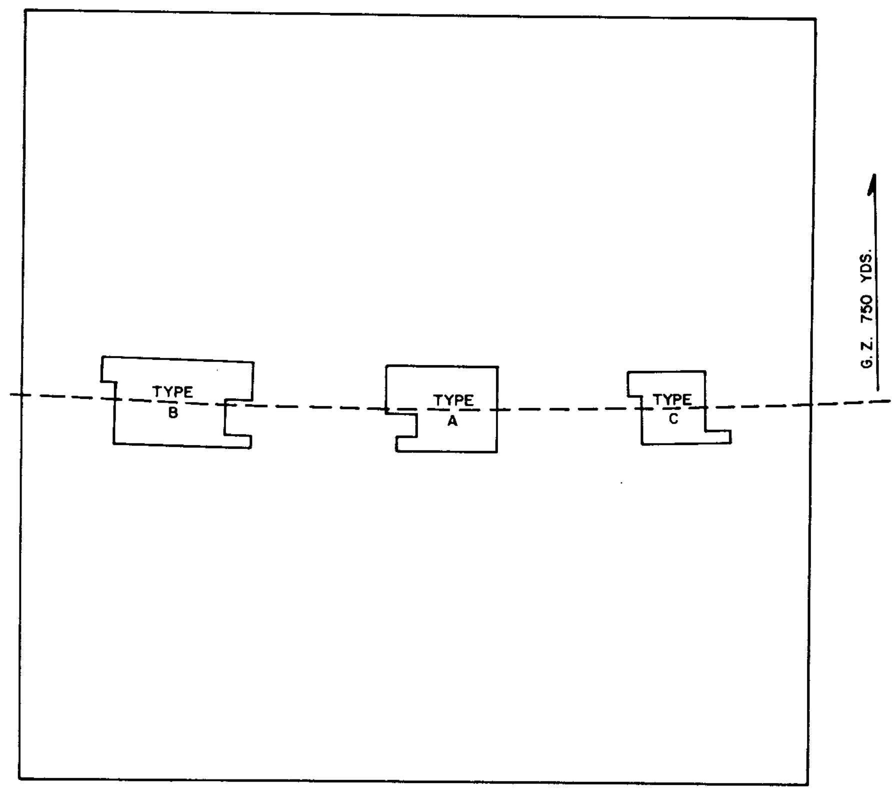


Fig. 4.2--Small transite "house", 3 ft x 3 ft x 3 ft, made of same wall and roof thickness as Japanese house analogs.



CONFIGURATION 15

Fig. 4.3--House arrangement in configuration No. 15.



CONFIGURATION 15′

Fig. 4.4--House arrangement in configuration No. 15'.

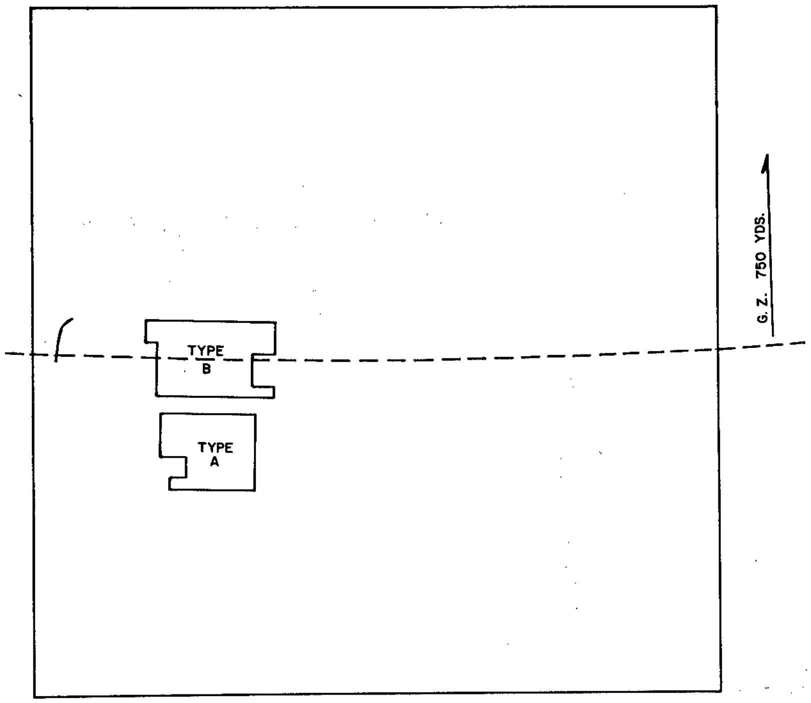


Fig. 4.5--House arrangement in configuration No. 16.

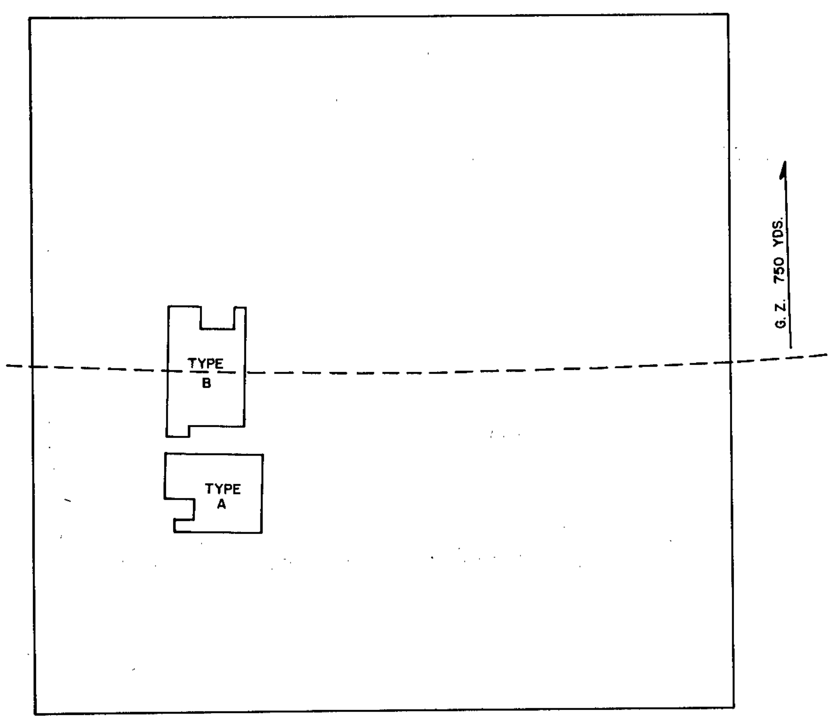


Fig. 4.6--House arrangement in configuration No. 17.

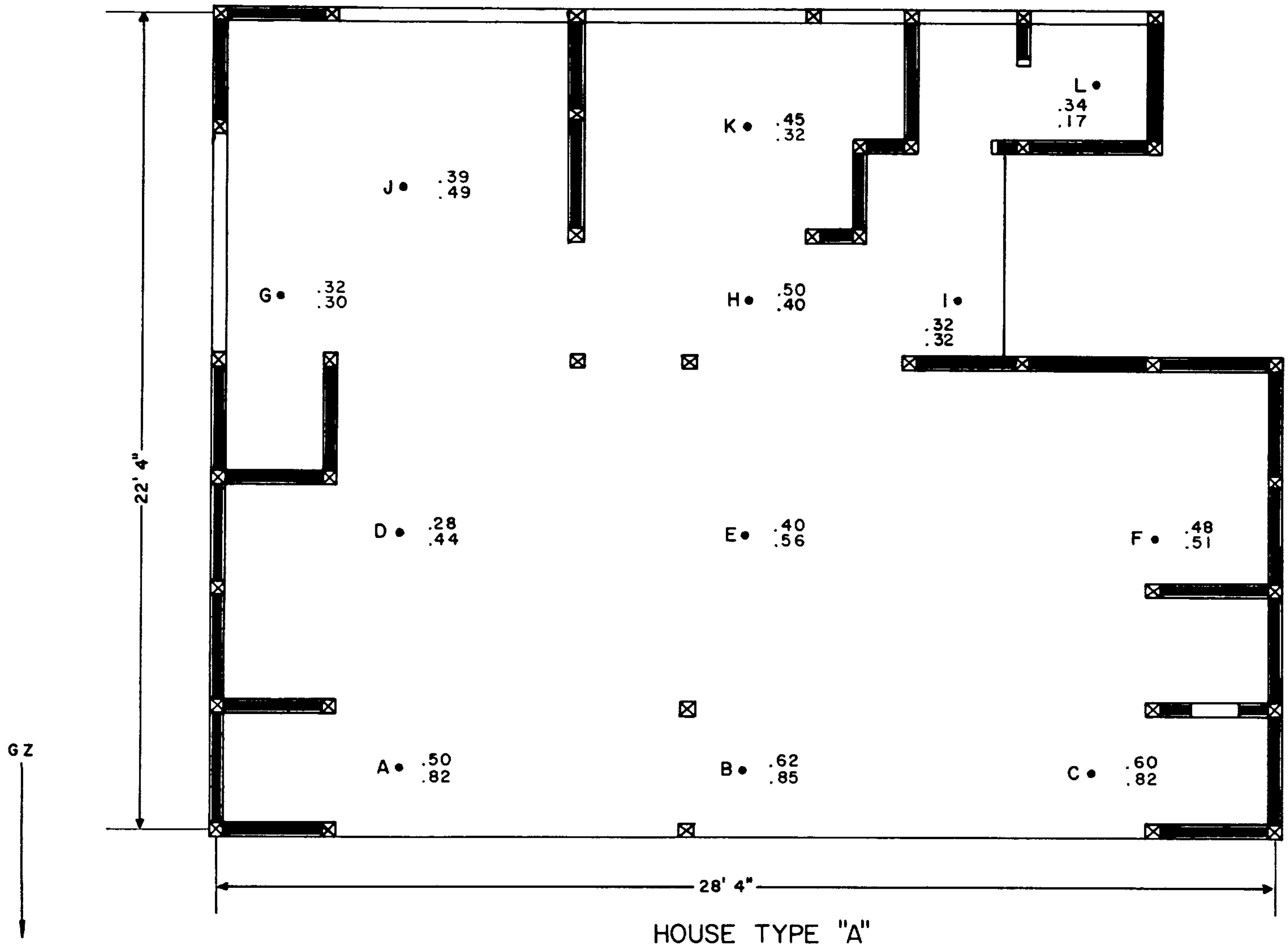


Fig. 4.7--D_m/D_a, ^{60}Co radiation in house type A in configuration No. 15.

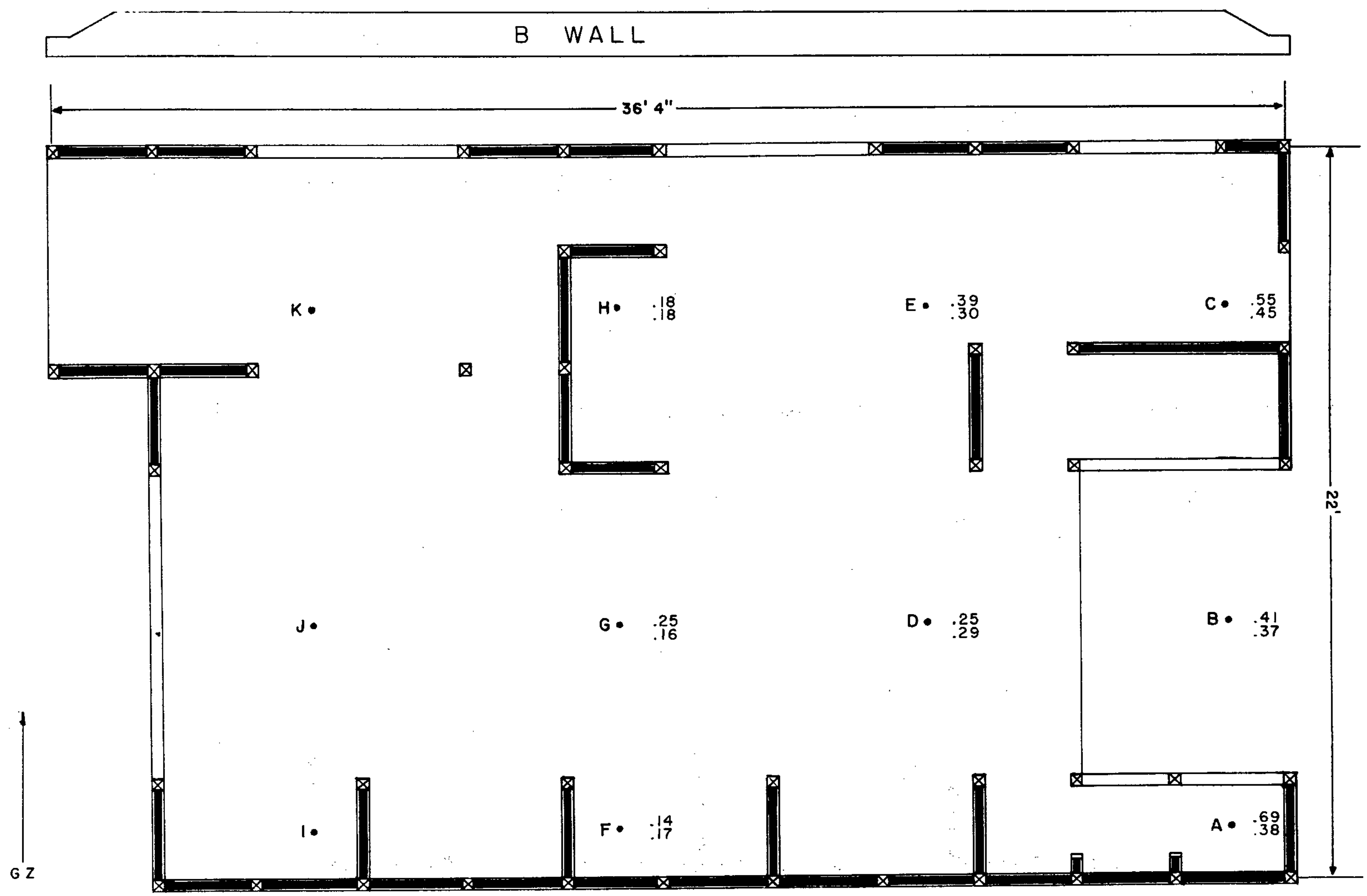


Fig. 4.8--D_m/D_a, ^{60}Co radiation on lower floor of house type B in configuration No. 15.

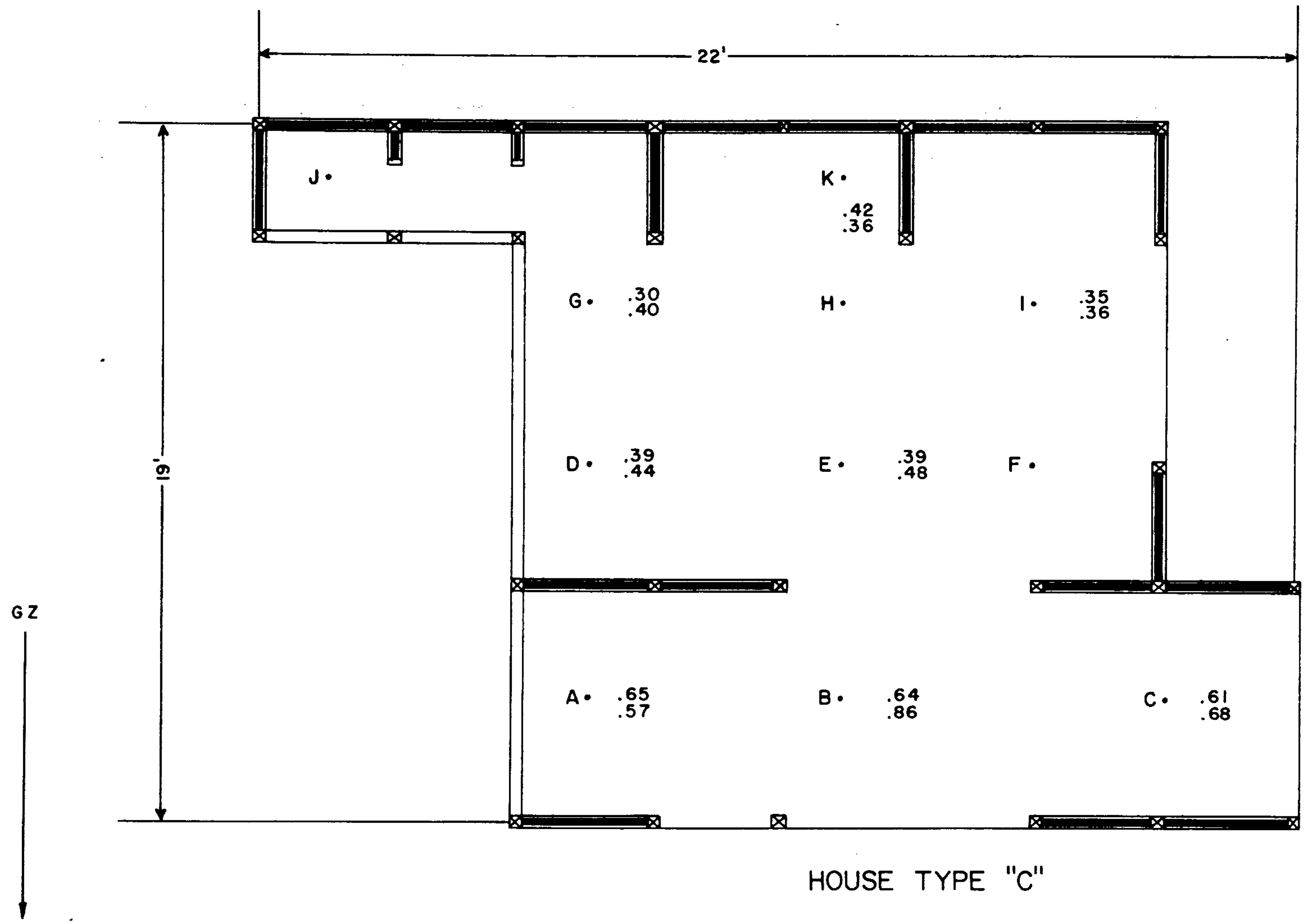


Fig. 4.9--D_m/D_a, ^{60}Co radiation in house type C in configuration No. 15.

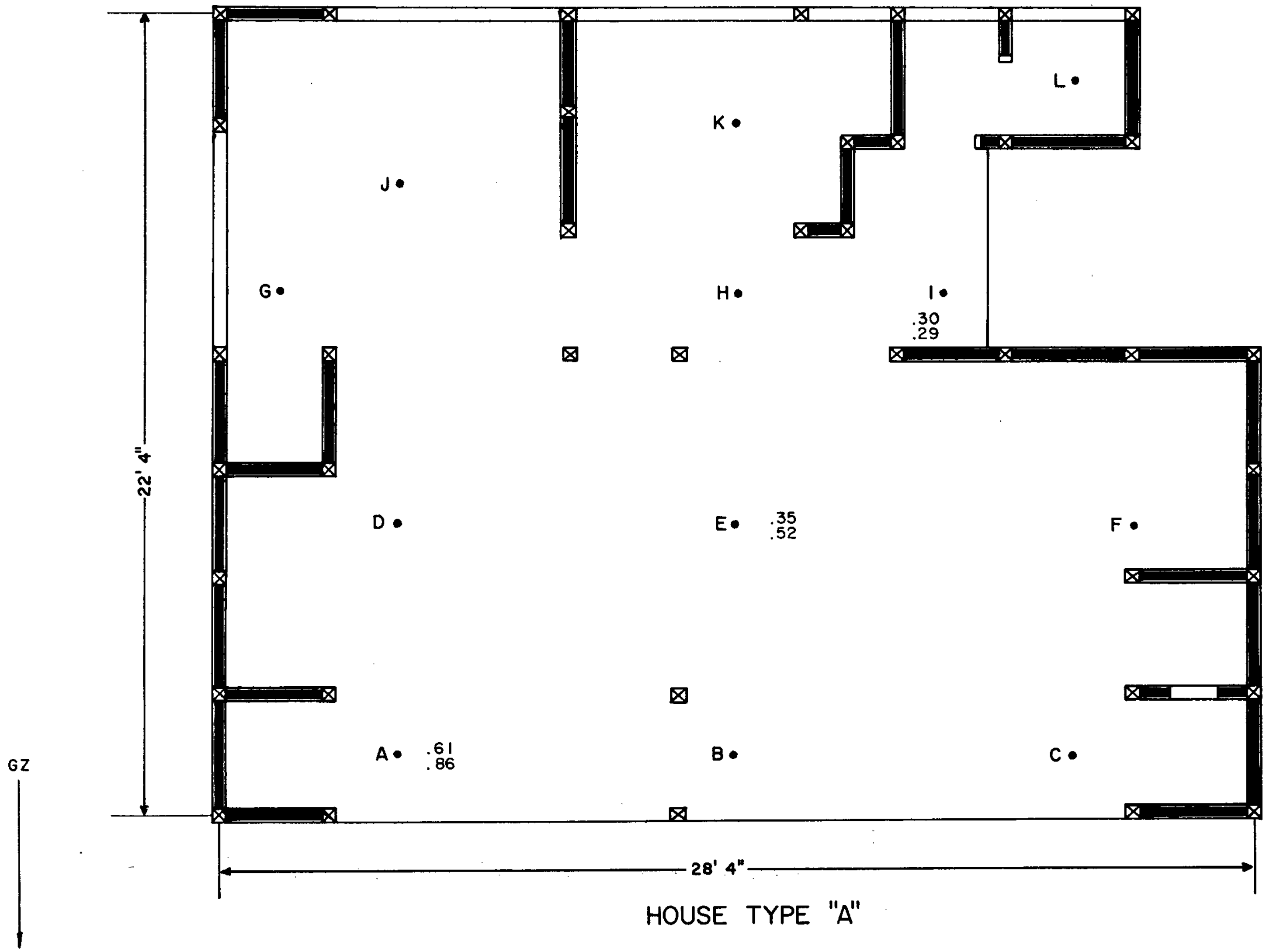


Fig. 4.10--D_m/D_a, ^{60}Co radiation in house type A in configuration No. 15'.

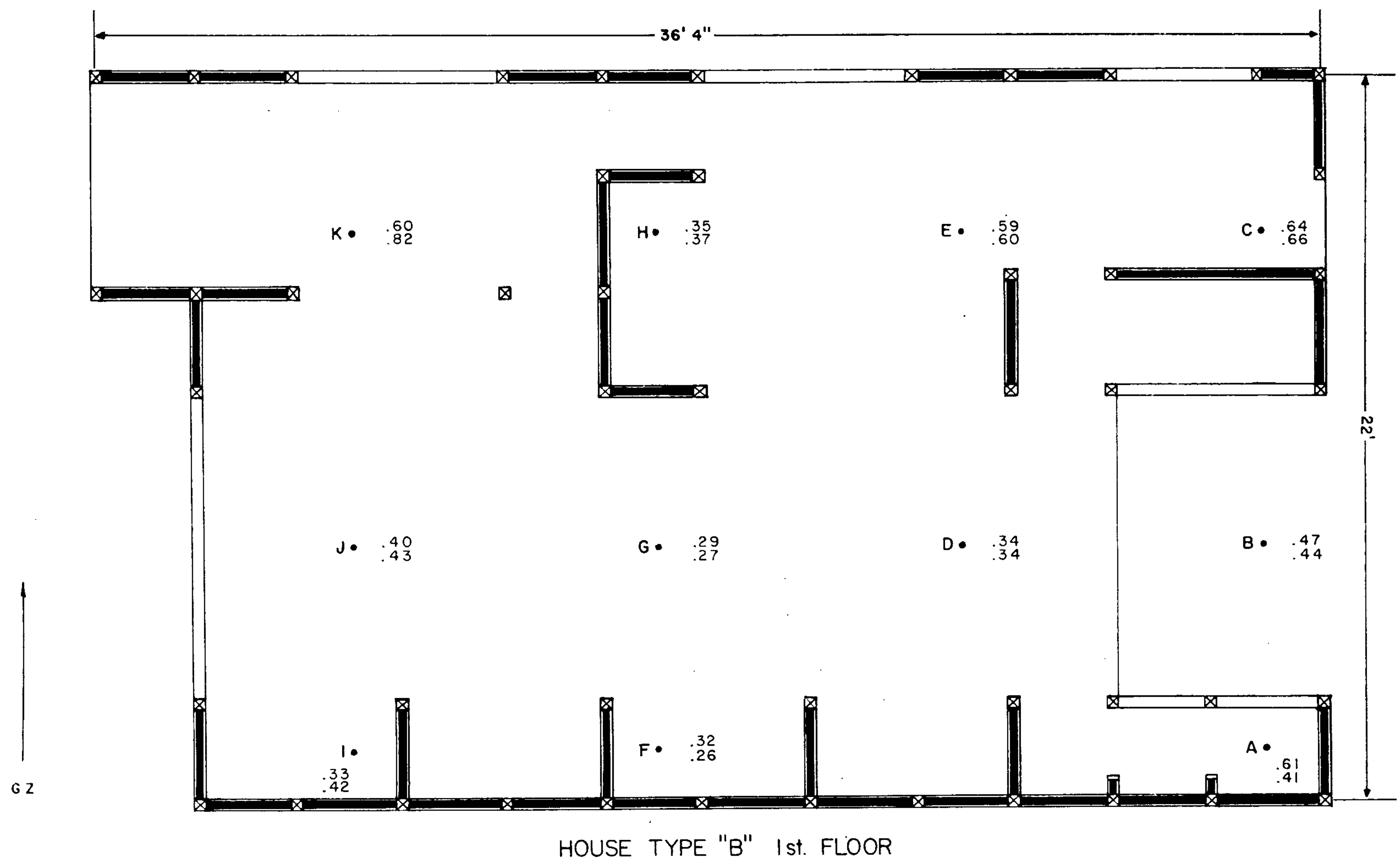
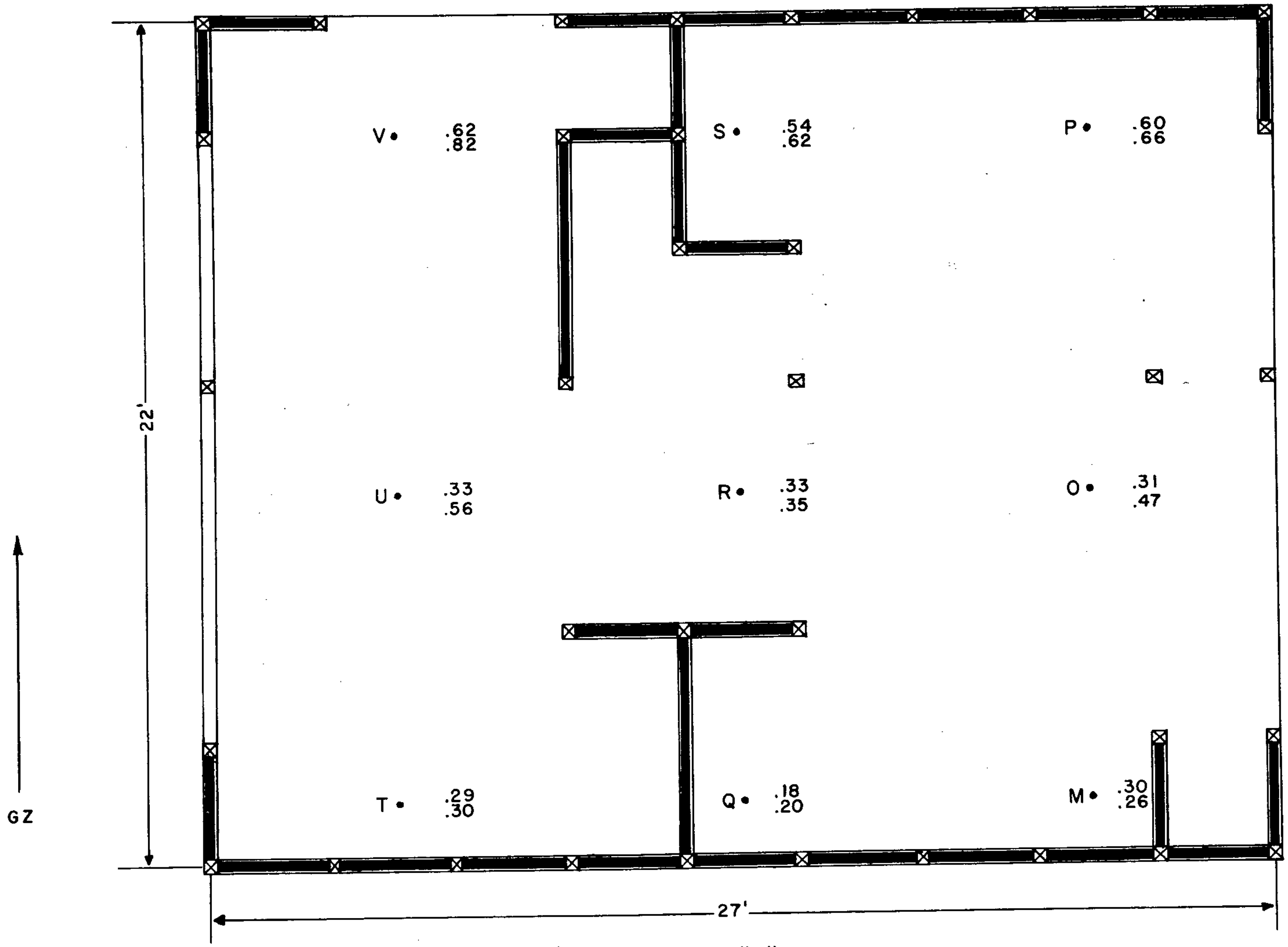


Fig. 4.11--D_m/D_a, ^{60}Co radiation on lower floor of house type B in configuration No. 15'.



HOUSE TYPE "B" 2nd FLOOR

Fig. 4.12--D_m/D_a, ^{60}Co radiation on upper floor of house type B in configuration No. 15'.

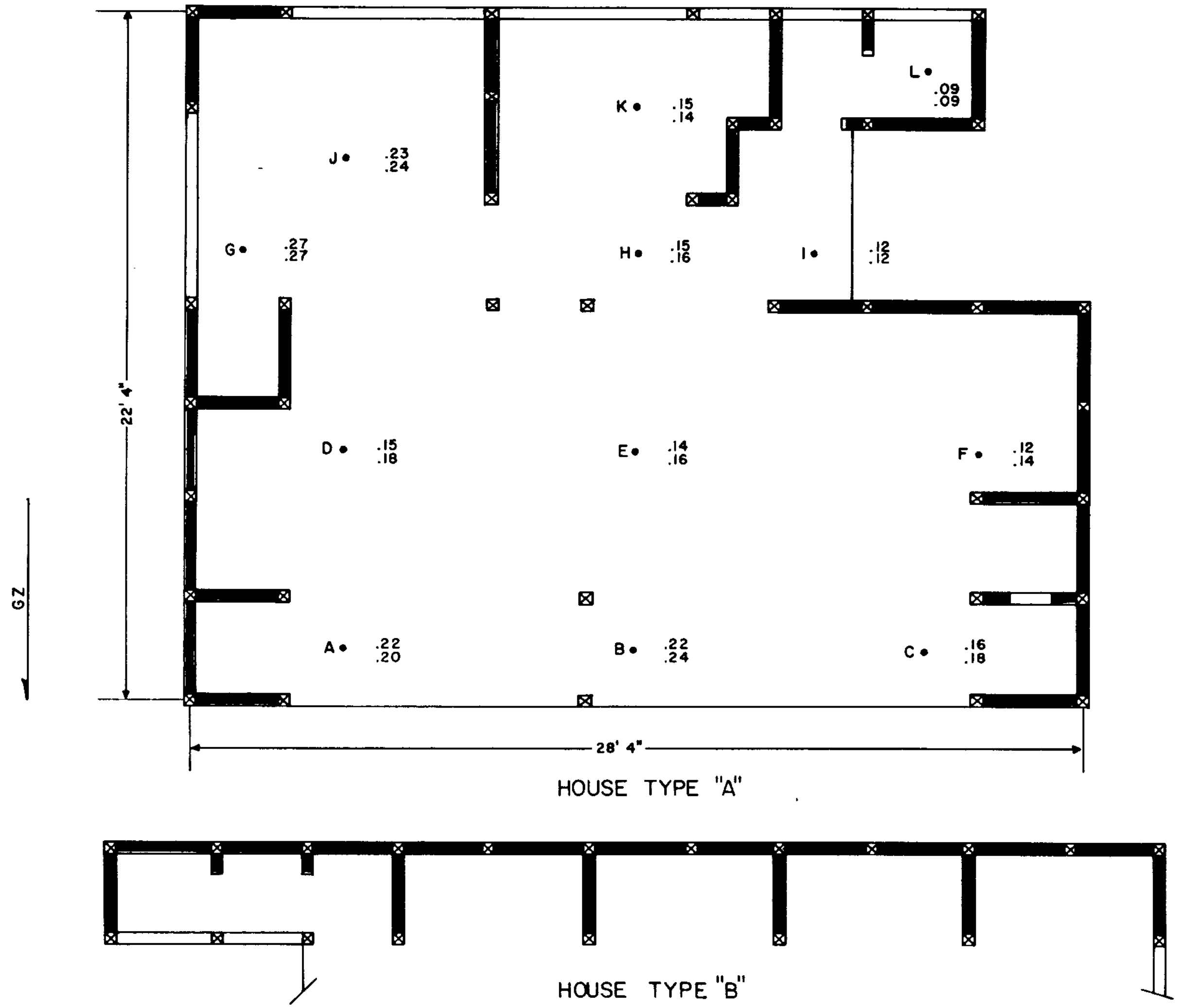


Fig. 4.13--D_m/D_a, ^{60}Co radiation in house type A in configuration No. 16.

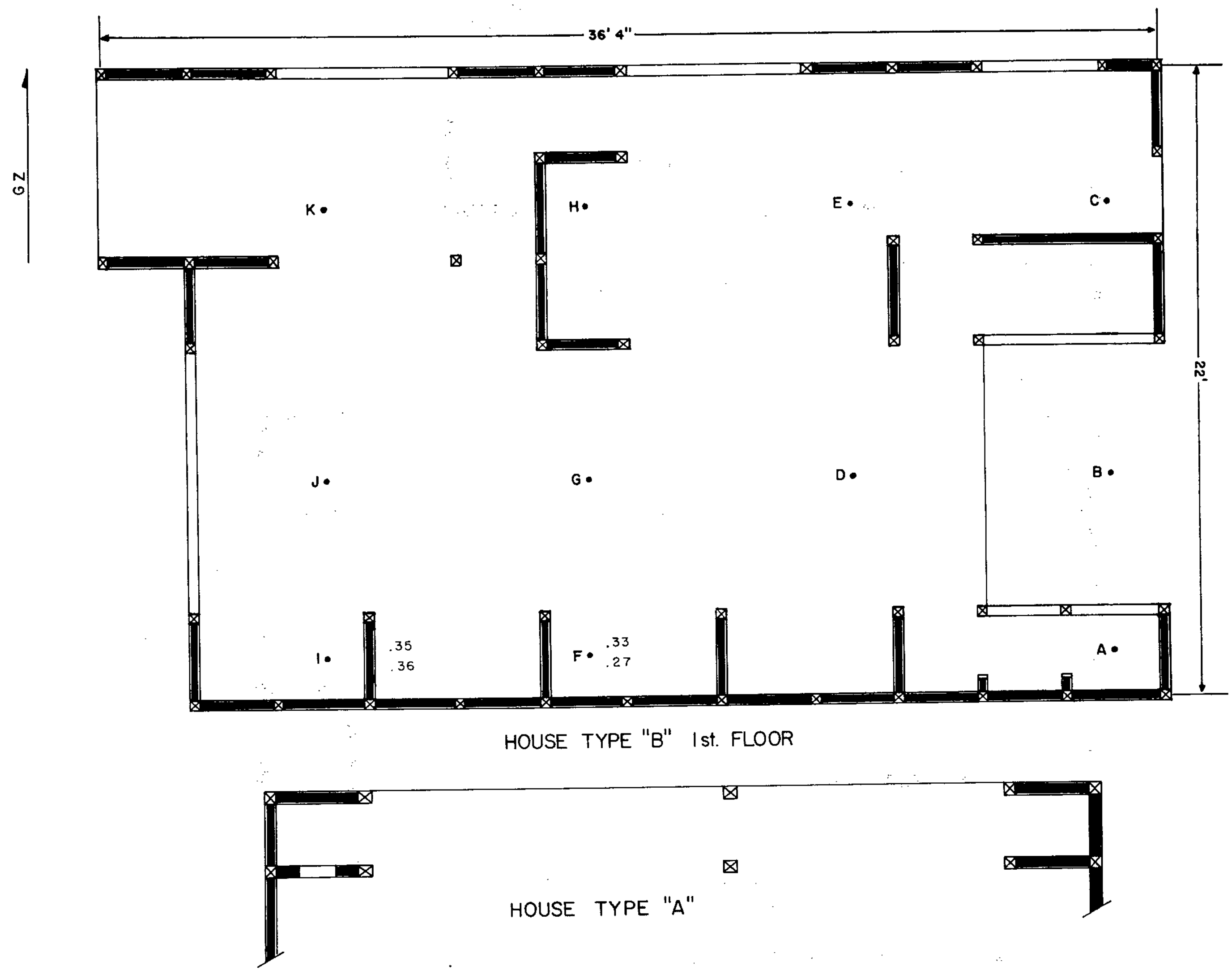


Fig. 4.14--D_m/D_a, ^{60}Co radiation on lower floor of house type B in configuration No. 16.

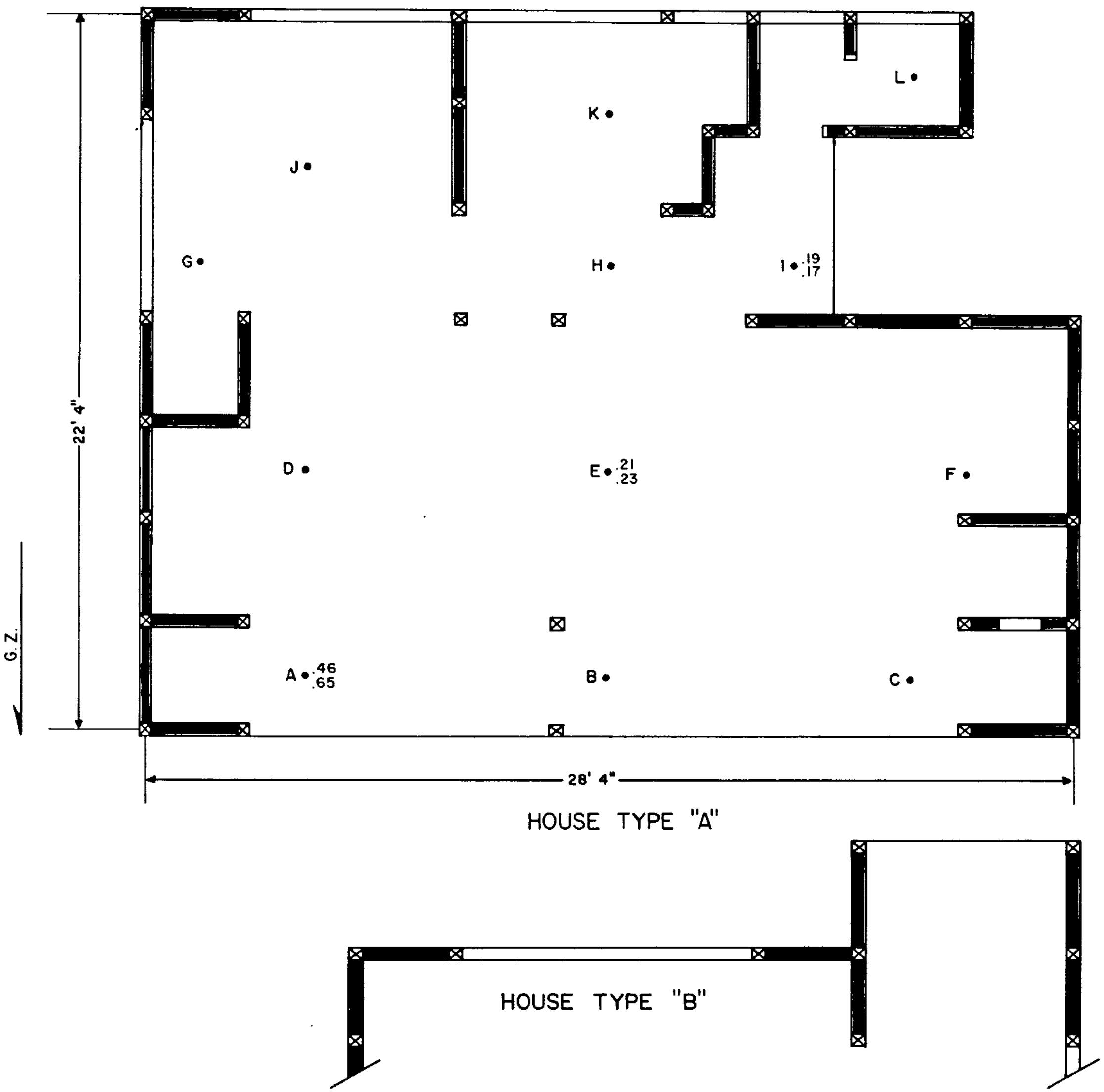


Fig. 4.15--D_m/D_a, ^{60}Co radiation in house type A in configuration No. 17.

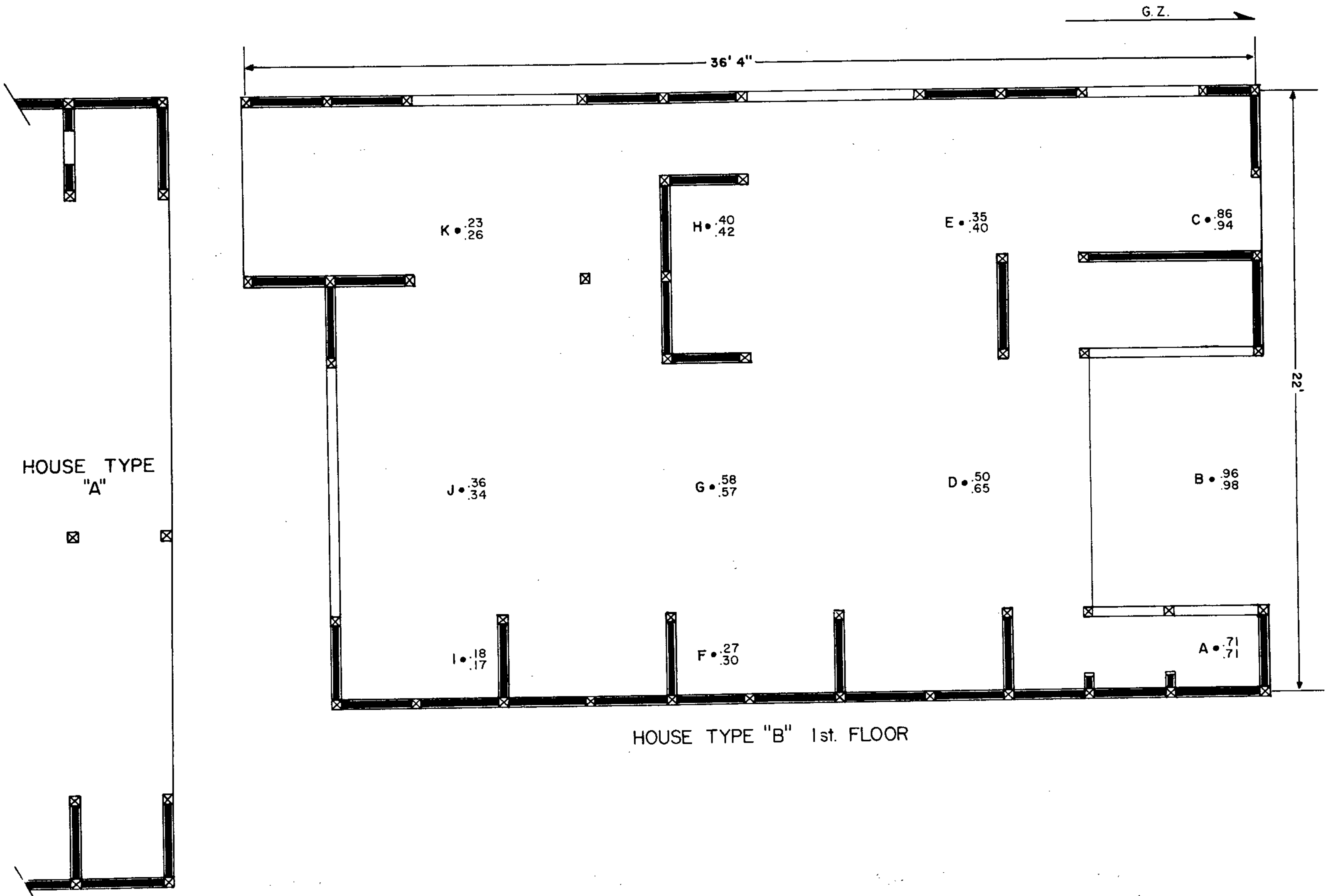
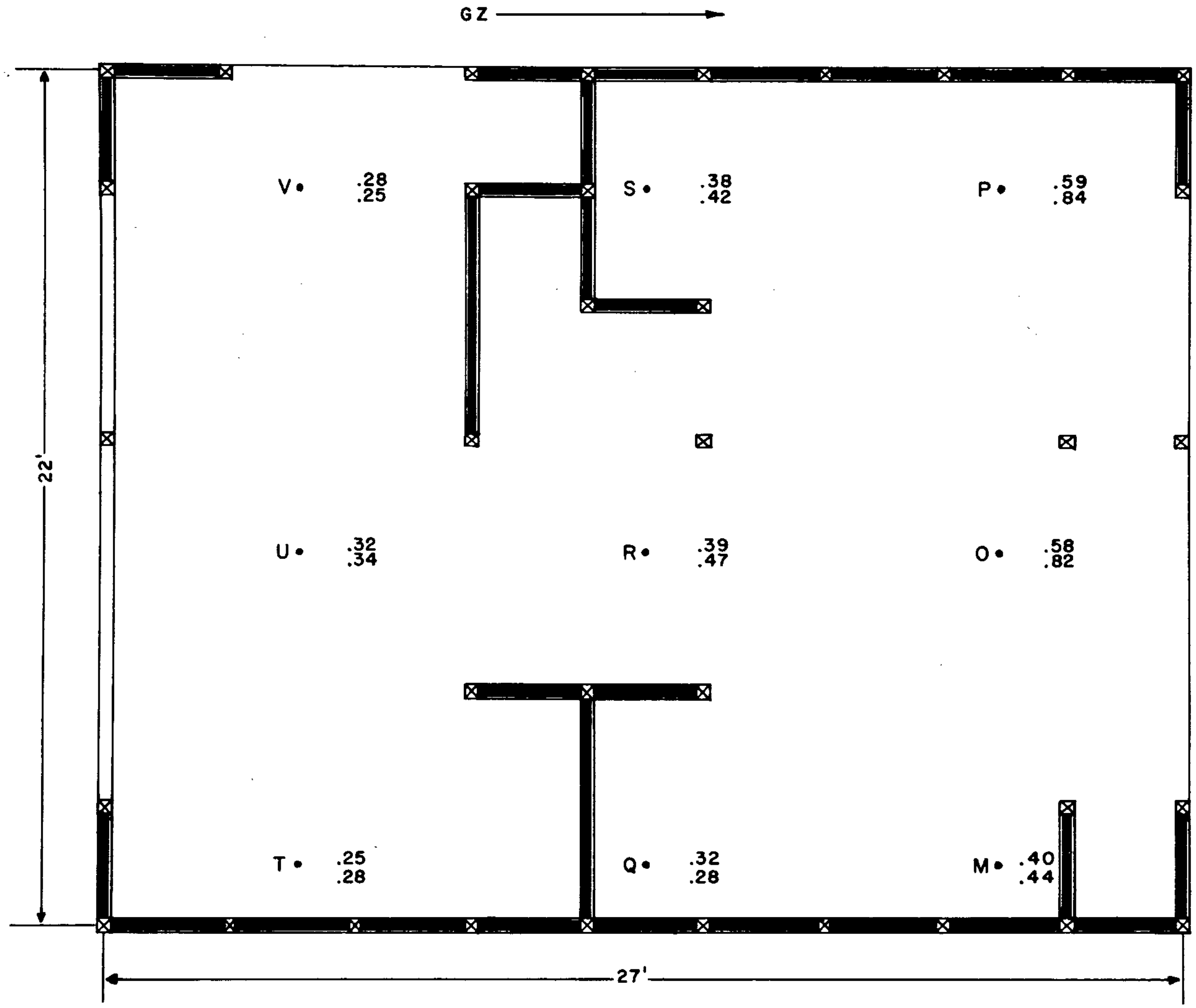


Fig. 4.16--D_m/D_a, ^{60}Co radiation on lower floor of house type B in configuration No. 17.



HOUSE TYPE "B" 2nd FLOOR

Fig. 4.17--D_m/D_a, ^{60}Co radiation on upper floor of house type B in configuration No. 17.

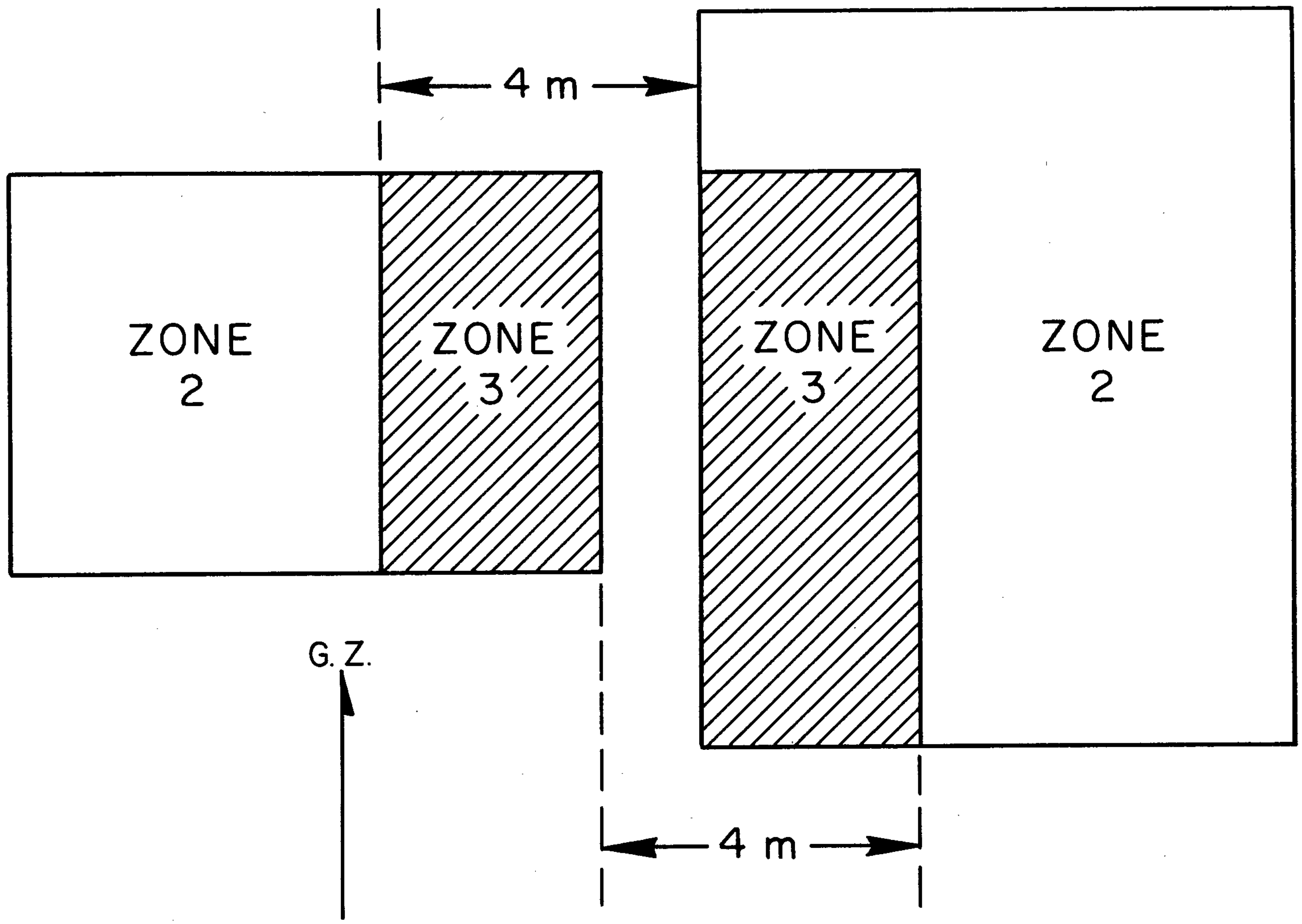


Fig. 4.18--Diagram showing limits of LS zones used in equation No. 2.

TABLES

The following items apply to all the tables:

1. The numbers in column headings refer to corresponding configurations as illustrated in Figs. 3.2-3.13 and 4.3-4.6.
2. Except where indicated otherwise, all houses were 750 yds from the foot of the reactor tower.
3. The reactor and the Co source were never used together.
4. Notes in column headings indicate changes from preceding configurations; e.g., "No. 3 lateral wall added" implies: configuration 3 (Fig. 3.4) differs from configuration 2 (Fig. 3.3) by the addition of a lateral wall.
5. The station letter symbols refer to locations in the houses as shown in Figs. 2.10-3.13. The number in the station symbol is the number of feet above the floor.

Table 4.1--REACTOR GAMMA DOSE MEASUREMENTS OUTSIDE, BUT NEAR, STRUCTURES, RELATIVE TO "AIR DOSE"

Configuration	Station	Station Elevation			
		1 ft.	3 ft.	5 ft.	7 ft.
1	AA	1.00	1.01	1.10	1.03
1	BB	.97	.96	.97	.92
1	CC	1.00	1.02	.94	.96
1	DD	1.16	1.27	1.24	1.24
1	EE	1.14	1.15	1.16	1.06
1	FF	1.07	1.10	1.11	1.05
1	GG	1.40	1.25	1.28	1.28
1	HH	1.13	1.10	1.07	1.11
1	II	1.01	1.10	1.06	1.04
1	JJ	1.21	1.26	1.17	1.16
1	KK	1.12	1.16	1.08	1.13
1	LL	1.06	1.04	1.13	1.07
4	MM		1.14	1.22	
5	MM		1.21	1.24	
7	NN		1.31	1.24	
7	OO		1.20	1.20	
7	PP		1.17	1.13	
7	QQ		1.10	1.09	
7	RR		1.15	1.11	
7	SS		1.09	1.04	
7	TT		1.05	1.07	
7	UU		1.04	1.03	

Table 4.2--NEUTRON DOSE MEASUREMENTS OUTSIDE, BUT NEAR, STRUCTURES, RELATIVE TO "AIR DOSE"

Configuration	Station	Station Elevation			
		1 ft.	3 ft.	5 ft.	7 ft.
1	AA	.51	.49	.42	.47
1	BB	.70	.69	.59	.62
1	CC	.79	.77	.68	.78
1	DD	.90	.80	.68	.79
1	EE	1.04	.92	.83	.93
1	FF	1.09	1.04	.90	1.00
1	GG	1.15	1.01	.96	.98
1	HH	1.27	1.14	1.01	1.13
1	II	1.29	1.14	1.14	1.15
1	JJ	1.26	1.05	1.00	1.06
1	KK	1.26	1.11	1.05	1.04
1	LL	1.12	1.02	1.10	1.11
4	MM		.39	.41	
5	MM		.37	.36	
7	NN		.34	.31	
7	OO		.65	.50	
7	PP		.35	.30	
7	QQ		.30	.40	
7	RR		.39	.36	
7	SS		.77	.45	
7	TT		.59	.54	
7	UU		1.00	.63	

Table 4.3--^{60}CO GAMMA DOSE MEASUREMENTS IN HOUSE A, RELATIVE TO "AIR DOSE"

Station	No. 15	No. 15' as 15 (reproducibility)	No. 16 behind B faced N	No. 17 behind B faced W	Station	No. 15	No. 15' as 15 (reproducibility)	No. 16 behind B faced N	No. 17 behind B faced W
A3	.82	.86	.20	.65	G3	.30		.27	
A5	.50	.61	.22	.46	G5	.32		.27	
B3	.85		.24		H3	.40		.16	
B5	.62		.22		H5	.50		.15	
C3	.82		.18		I3	.32	.29	.12	.17
C5	.60		.16		I5	.32	.30	.12	.19
D3	.44		.18		J3	.49		.24	
D5	.28		.15		J5	.39		.23	
E3	.56	.52	.16	.23	K3	.32		.14	
E5	.40	.35	.14	.21	K5	.45		.15	
F3	.51		.14		L3	.17		.09	
F5	.48		.12		L5	.34		.09	

Table 4.4--^{60}CO GAMMA DOSE MEASUREMENTS IN HOUSE B, RELATIVE TO "AIR DOSE"

Station	No. 15 behind B wall	No. 15' as 15 B wall removed	No. 16 as 15'	No. 17 rotated 90° counterclockwise	Station	No. 15 behind B wall	No. 15' as 15 B wall removed	No. 16 as 15'	No. 17 rotated 90° counterclockwise
A3	.38	.41		.71	K3		.82		.26
A5	.69	.61		.71	K5		.60		.23
B3	.37	.44		.98	M3		.26		.44
B5	.41	.47		.96	M5		.30		.40
C3	.45	.66		.94	O3		.47		.82
C5	.55	.64		.86	O5		.31		.58
D3	.29	.34		.65	P3		.66		.84
D5	.25	.34		.50	P5		.60		.59
E3	.30	.60		.40	Q3		.20		.28
E5	.39	.59		.35	Q5		.18		.32
F3	.17	.26	.27	.30	R3		.35		.47
F5	.14	.32	.33	.27	R5		.33		.39
G3	.16	.27		.57	S3		.62		.42
G5	.25	.29		.58	S5		.54		.38
H3	.18	.37		.42	T3		.30		.28
H5	.18	.35		.40	T5		.29		.25
I3		.42	.36	.17	U3		.56		.34
I5		.33	.35	.18	U5		.33		.32
J3		.43		.34	V3		.82		.25
J5		.40		.36	V5		.62		.28

Table 4.5--^{60}CO GAMMA DOSE MEASUREMENTS IN HOUSE C, RELATIVE TO "AIR DOSE"

Station	No. 15	Station	No. 15
A3	.57	F5	
A5	.65	G3	.40
B3	.86	G5	.30
B5	.64	H3	
C3	.68	H5	
C5	.61	I3	.36
D3	.44	I5	.35
D5	.39	J3	
E3	.48	J5	
E5	.39	K3	.36
F3		K5	.42

Chapter 5

CONCLUSIONS

The bare reactor experiment yielded neutron dose distributions in Japanese-type houses which were in good agreement with those obtained from direct weapons measurements. It also yielded consistent gamma dose distributions which showed that only about 20% of the chemical dosimeter measurements obtained on the weapons test in 1958 were in error by more than about 20%. These data then were analyzed as functions of house parameters, and formulae applicable to the Japanese survivor dosimetry problems were obtained.

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations Office, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. However, the following is a list of all reports available from studies that have been completed. All reports listed are available, at the prices indicated, from the Clearinghouse for Federal Scientific and Technical Information, U. S. Department of Commerce, Springfield, Va.

CEX-57.1, The Radiological Assessment and Recovery of Contaminated Areas, C. F. Miller, 1960, $0.75.

CEX-58.1, Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. O. Buchanan, C. Eisenhauer, and H. E. Menker, 1959, $2.75.

CEX-58.2, The Scattering of Thermal Radiation into Open Underground Shelters, T. P. Davis, N. D. Miller, T. S. Ely, J. A. Basso, and H. E. Pearse, 1959, $0.75.

CEX-58.7, AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc., 1960, $0.50.

CEX-58.8, Comparative Nuclear Effects of Biomedical Interest, C. S. White, I. G. Bowen, D. R. Richmond, and R. L. Corsbie, 1961, $1.00.

CEX-58.9, A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves, I. G. Bowen, R. W. Albright, E. R. Fletcher, and C. S. White, 1961, $1.25.

CEX-59.1, An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, 1960, $0.60.

CEX-59.4, Aerial Radiological Monitoring System. I. Theoretical Analysis, Design, and Operation of a Revised System, R. F. Merian, J. G. Lackey, and J. E. Hand, 1961, $1.25.

CEX-59.4 (Pt.II), Aerial Radiological Monitoring System. Part II. Performance, Calibration, and Operational Check-out of the EG&G Arms-II Revised System, J. E. Hand, R. B. Guillou, and H. M. Borella, 1962, $1.50.

CEX-59.7B (Pt.II), Experimental Radiation Measurements in Conventional Structures. Part II. Comparison of Measurements in Above-ground and Below-ground structures from Simulated and Actual Fallout Radiation, Z. G. Burson, 1964, $1.50.

CEX-59.7C, Methods and Techniques of Fallout Studies Using a Particulate Simulant, W. Lee and H. Borella, 1962, $0.50.

CEX-59.13, Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T. D. Strickler and J. A. Auxier, 1960, $0.50.

CEX-59.14, Determinations of Aerodynamic-drag Parameters of Small Irregular Objects by Means of Drop Tests, E. P. Fletcher, R. W. Albright, V. C. Goldizen, and I. G. Bowen, 1961, $1.75.

CEX-60.1, Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, H. Borella, Z. Burson, and J. Jacovitch, 1961, $1.75.

CEX-60.3, Extended- and Point-source Radiometric Program, F. J. Davis and P. W. Reinhardt, 1962, $1.50.

CEX-60.5, Experimental Evaluation of the Fallout-radiation Protection Afforded by a Southwestern Residence, Z. Burson, D. Parry, and H. Borella, 1962, $0.50.

CEX-60.6, Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter, Z. Burson and H. Borella, 1962, $1.00.

CEX-61.1 (Prelim.), Gamma Radiation at the Air–Ground Interface, K. O'Brien and J. E. McLaughlin, Jr., 1963.

CEX-61.4, Experimental Evaluation of the Fallout-radiation Protection Provided by Selected Structures in the Los Angeles Area, Z. G. Burson, 1963, $2.25.

CEX-62.01, Technical Concept — Operation BREN, J. A. Auxier, F. W. Sanders, F. F. Haywood, J. H. Thorngate, and J. S. Cheka, 1962, $0.50.

CEX-62.02, Operation Plan and Hazards Report — Operation BREN, F. W. Sanders, F. F. Haywood, M. I. Lundin, L. W. Gilley, J. S. Cheka, and D. R. Ward, 1962, $2.25.

CEX-62.03, General Correlative Studies — Operation BREN, J. A. Auxier, F. F. Haywood, and L. W. Gilley, 1963, $1.00.

CEX-62.2, Nuclear Bomb Effects Computer (Including Slide-rule Design and Curve Fits for Weapons Effects), E. R. Fletcher, R. W. Albright, R. F. D. Perret, Mary E. Franklin, I. G. Bowen, and C. S. White, 1963, $1.00.

CEX-62.14, An Experimental Investigation of the Spatial Distribution of Dose in an Air-over-Ground Geometry, F. F. Haywood, J. A. Auxier, and E. T. Loy, 1964, $4.00.

CEX-62.81 (Prelim.), Ground Roughness Effects on the Energy and Angular Distribution of Gamma Radiation from Fallout, C. M. Huddleston, Z. G. Burson, R. M. Kinkaid, and Q. G. Klinger, 1963. $1.25.

CEX-63.3, Barrier Attenuation of Air-scattered Gamma Radiation, Z. G. Burson and R. L. Summers, 1965, $1.00.

CEX-63.7, A Comparative Analysis of Some of the Immediate Environmental Effects at Hiroshima and Nagasaki, C. S. White, I. G. Bowen, and D. R. Richmond, 1964, $2.00.

CEX-63.11, Mobile Radiological Measuring Unit: Description and Operating Information, Z. G. Burson, R. L. Summers, and J. T. Brashears, 1965, $1.00.

CEX-64.3, Ichiban: The Dosimetry Program for Nuclear Bomb Survivors of Hiroshima and Nagasaki — A Status Report as of April 1, 1964, J. A. Auxier, 1964, $0.50.

CEX-65.02, Technical Concept — Operation HENRE, S. F. Haywood and J. A. Auxier, 1965, $1.00.