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Title: ECONOMIC COMPARISON OF STRUCTURAL DESIGN WITH REFERENCE TO RADIATION SHIELDING

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Abstract approved: ______________________
V. J. McClellan

This paper investigates the proposed preliminary designs of two gymnasiums with respect to gamma radiation shielding due to radioactive fallout. For each building a determination is made of the protection offered from radiation fallout. If the degree of protection is below the minimum value set by the Office of Civil Defense for public shelters, structural modifications are suggested that will raise the protection to an acceptable level. Where changes are recommended, comparisons are made showing the differences in cost per square foot of floor space.

Both gymnasiums are part of new high schools being built locally, and in both cases, no initial effort was made by the architects to provide shelter space. Gymnasium-1 is found to contain no shelter area, but by modifying the floor construction, shelter space

can be provided for 400 people. The changes suggested for this gymnasium would decrease the total construction costs by $10,000, or about 28 cents per square foot of total floor space. Gymnasium-2 has an initial potential shelter space for 1052 people and by modifying the exterior walls, the number of spaces can be increased to 1565 spaces with a total increase in cost of $2780, or about 4.6 cents per square foot of total floor space.

Economic Comparison of Structural Design With Reference to Radiation Shielding

by

William Kent Rasmussen

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Head of Department of Civil Engineering

Redacted for Privacy

Dean of Graduate School

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INTRODUCTION

During the last decade, the Office of Civil Defense of the Department of Defense provided engineers and architects with methods of determining the amount of shielding protection afforded by a building from radiation fallout. Designers have been encouraged to incorporate shielding principles in their original plans, a technique called "slanting."

Radiation shielding is an engineering and research specialty consisting of four major subdivisions:

1. reactor shielding,
2. accelerator shielding,
3. space shielding, and
4. weapons shielding.

This study approaches the subject from a Structural Engineering standpoint and will only include shielding of gamma rays from radioactive fallout, a segment of "weapons shielding." Possible locations for shelter areas within the gymnasiums will be identified and the degree of protection determined for those areas. If the shielding is found inadequate for a public shelter, design changes are suggested, and the resulting costs estimated.

This paper investigates the proposed preliminary design of two gymnasiums with respect to radiation shielding. It is not the author's purpose to present exact structural designs of the proposed changes. Rather, the author will find the size of members required and in the case of concrete, approximate the amount of reinforcing steel needed without specifying bar size or location. The purpose of this paper is to develop a comparison of designs structurally, economically and from a shielding aspect.

REVIEW OF TERMINOLOGY

It is impossible to determine the degree of radioactive contamination a given area might be subjected to in the event of a nuclear attack. Therefore, the amount of protection offered by a structure is not measured by the quantity of radiation reaching some interior point. Rather, it is a relative measure of the dosage that would be experienced without a shelter at some standard reference location as compared to that experienced within a shelter. The standard reference location used in shielding analysis is a detector which measures the amount of radiation received from all directions at a point three feet above a smooth, infinite, uniformly contaminated plane. This quantity is normalized to unity and is related to the lesser quantity of radiation received at a protected location. This lesser quantity is often called the reduction factor, R_f, and the ratio of the two is called the protection factor, PF, and may be expressed by the equation

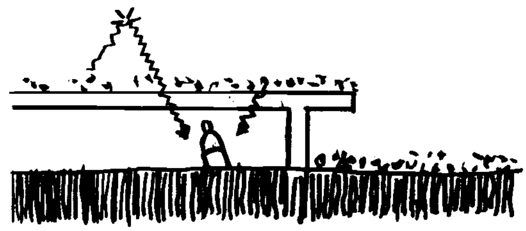
$$PF = \frac{1}{R_f}$$

Studies conducted by the Department of Defense of the lifesaving potential of fallout shelters indicate that "shelters with a protection factor of at least 40 could save over 90% of those people who would otherwise perish if they were unprotected against lethal radiation levels" (5, p. 8.2). This has led to the current policy of the

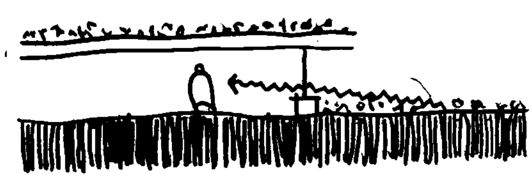
Office of Civil Defense requiring a protection factor of at least 40 for all public shelters that are so marked. This means that an unprotected person would receive 40 times more radiation than a person inside a shelter with a PF of 40.

Gamma radiation reaches an individual from two main sources, overhead and ground. The overhead contribution refers to radiation initiating from radioactive particles (dust and debris) which may accumulate on an overhead source plane such as a roof. The ground contribution comes from the surrounding ground and is further subdivided into ground direct, wall scatter, skyshine and ceiling shine. (See Fig. 1.)

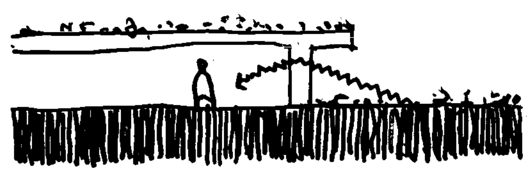
High protection factors in buildings are achieved by geometric and barrier relationships between the radioactive source and sheltered enclosure. Geometric shielding places people out of the direct path of radiation (Fig. 2) or at some distance from it. The latter is explained in Fig. 3 where two wall segments of equal length are chosen so that one is directly opposite the detector and one far removed. There would be a greater radiation contribution from the near segment. As an analogy, if the wall segments were windows, a light meter in the position of the detector would register substantially more response from the close source than from the far source. The same holds true for radiation. Thus, an interior core room would



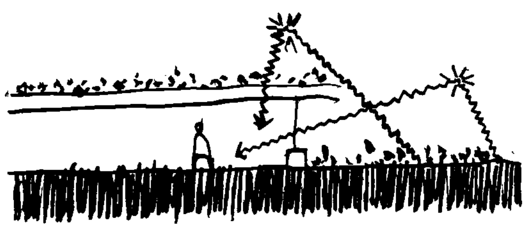
ROOF CONTRIBUTION
Some Radiation Comes Directly from the Roof Surface.



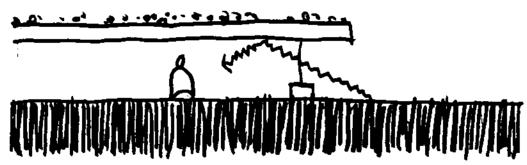
GROUND CONTRIBUTION - DIRECT
Some Radiation Comes Directly from the Ground Surface.



GROUND CONTRIBUTION - WALL SCATTER
Some Radiation Is Deflected by the Wall.



GROUND CONTRIBUTION - SKYSHINE
Some Radiation is Reflected from Particles in the Air.



GROUND CONTRIBUTION - CEILING SHINE
Some Radiation Is Reflected by the Ceiling or Other Horizontal Plane.

Fig. 1. Radiation Sources

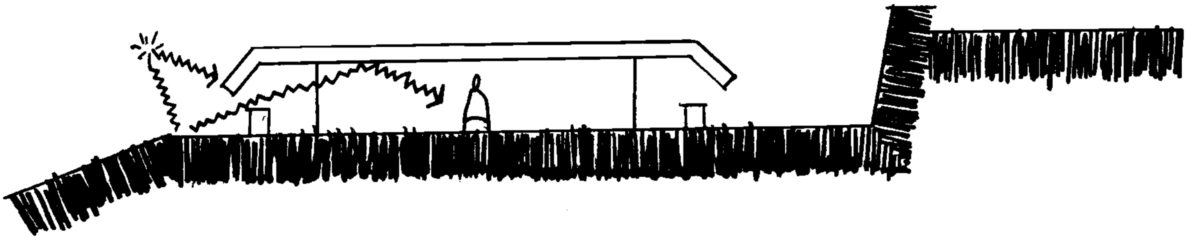


Fig. 2. Geometric Relation. Exposure is reduced when the source area is limited.

receive less radiation than a room with one or more exterior walls exposed to a contaminated plane.

The second general shielding relationship used is that of barrier shielding. This technique simply involves placing mass between the shelter occupant and the radioactive source. A barrier attenuates the radiation in several ways (Fig. 4) causing the direct, scatter, and skyshine contributions mentioned previously.

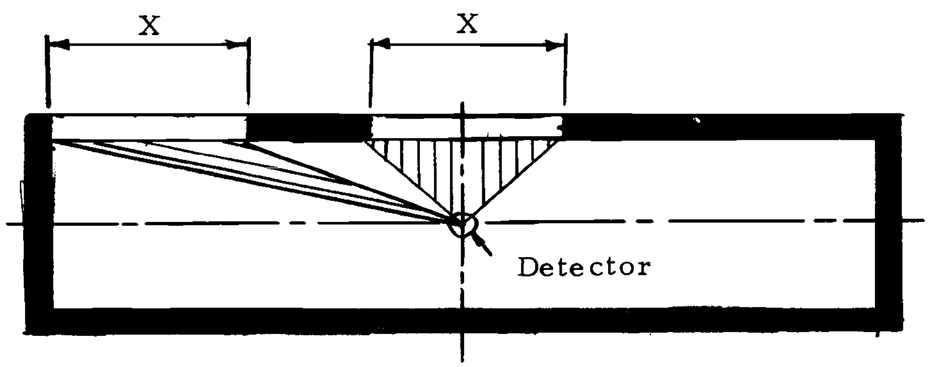


Fig. 3. Distance Factor. Exposure is reduced as distance from source increases.

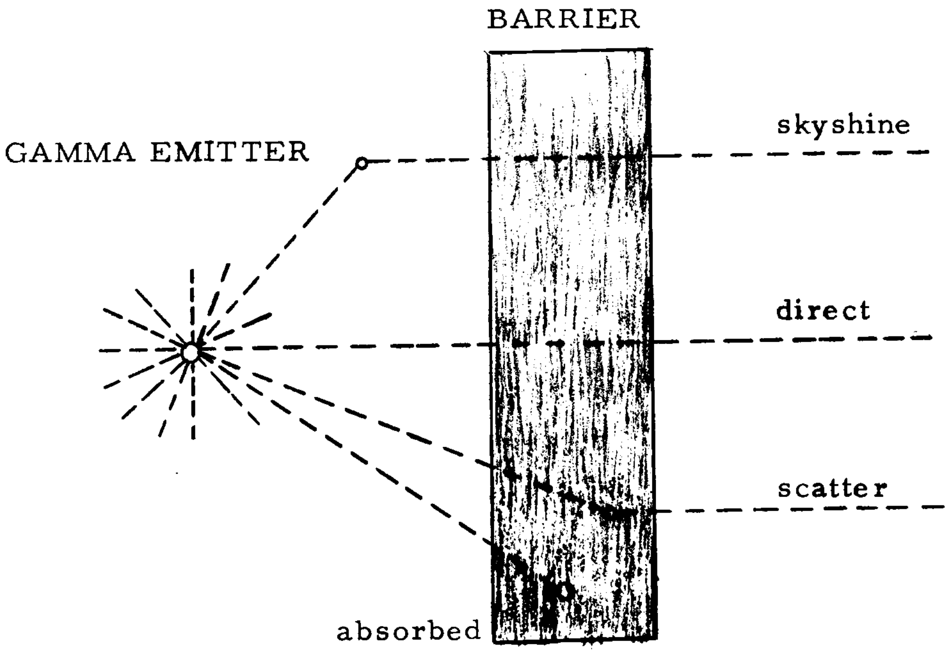


Fig. 4. Radiation attenuating through a barrier

Gamma radiation consists of continuous streams of photons that travel in a straight line until they interact with electrons of obstructing atoms. Photons that first interact with an atom in the atmosphere and then pass through the barrier are termed skyshine radiation. Those that are deflected by the barrier itself are called scatter radiation. Some photons are completely absorbed by a barrier atom while others, called direct radiation, pass through without any interaction.

PROTECTION FACTOR CALCULATIONS

In this study, two methods are used to determine the protection factors. One method employs the techniques furnished in Shelter Design and Analysis (5). This is a manual for engineers and architects in which much of the highly theoretical material has been reduced to simplified equations and charts. The PF at the center of each potential gymnasium shelter area was found using this method. The equations consist mainly of reduction factors that reduce the radiation contribution as it passes through the various barriers such as walls and roof. The reduction factors are generally functions of the barrier mass density, expressed in pounds per square foot, and building geometry. A set of sample calculations are included in the Appendices.

For a complex building with many wall densities and irregular geometrical shapes, the manual calculations are laborious and tedious. Therefore, O.C.D. has developed a computer program based on the methods of the Engineering Manual (3). The input data is sent to a protection factor computation service called Shelter Analysis for New Designs (SAND). The methods used in the SAND Program are similar to those used for the manual calculations and therefore serve as a check for the PF calculations the author made at the center of the shelter areas. In addition to the center calculation, the SAND

Program calculates the PF at other locations as will be shown later.

Input data for the SAND Program is submitted on special forms and requires basically the same information as the manual calculations. For more information, the reader is referred to the manual listed in the Bibliography (4).

GYMNASIUM-1

<u>Preliminary Design</u>

The new high school plant will be basically a "campus-plan" type. The gymnasium building is located in one corner of the building complex, leaving two walls exposed to large flat planes. The gymnasium is a two-story structure with the main playing floor occupying the entire northern half of the building and the locker rooms and a smaller second floor playing court occupying the southern half. The first floor elevation is at grade in both cases.

Structural Description . . .

Floor System:

Lower Level --Four inch concrete slab with finished floor

Upper Level - Three and one half inch slab on open-web bar joists; one and one fourth inch finished floor

Roof Construction:

Built up roof over two inches of Tectum and two inches insulation; roof supported by exposed Glue Lam beams, wood purlins and Bulb Tees

Exterior Walls:

Eight inch precast walls

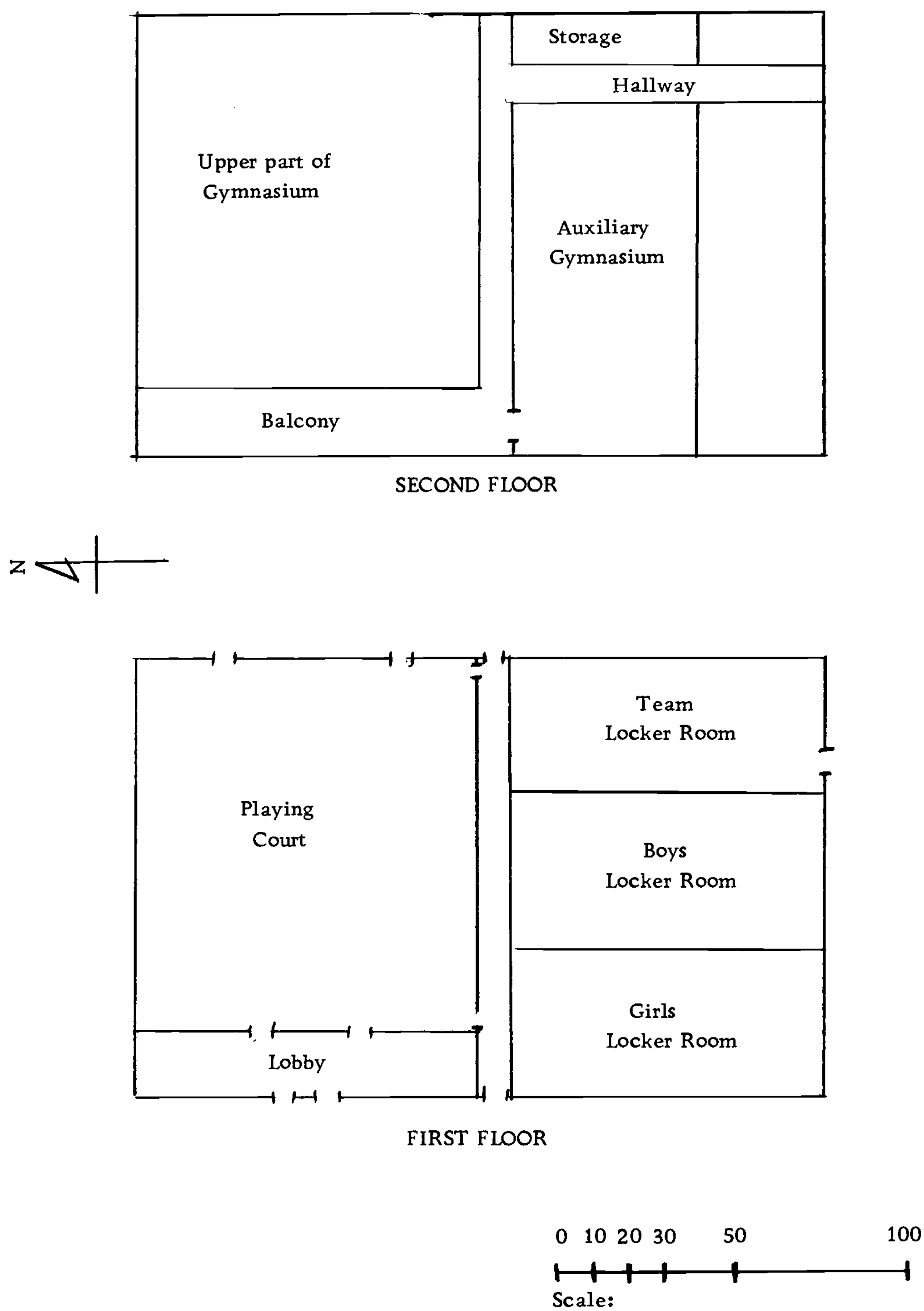


Figure 5. Floor plans of Gymnasium-1 showing the idealized or simplified partition arrangement used in determining the protection factor.

Interior Walls:

Six inch poured in place concrete; two by four stud; four or six inch wall tile

Existing PF

It is apparent that the most protected area of Gymnasium-1 is the Boys' Locker Room since it has only one exterior wall. The resulting PF determinations verify this, indicating that the overhead contribution is 0.026, the ground contribution 0.012, for a total reduction factor, R_f, of 0.038. This gives a PF equal to 1/0.038 which equals 26, a figure well below the minimal value of 40. For a PF of 40, the reduction factor, R_f, cannot be greater than

$$R_f = \frac{1}{PF}$$

which gives

$$R_f = \frac{1}{40} = 0.025$$

In Fig. 6, the PF is given for various points throughout the building. The decimal numbers are the contributions from overhead and ground respectively. The partition arrangement shown is the idealized structure that was used in both the manual calculations and the SAND Program. To include all the small partition lengths and variances is neither practical nor possible. This is, therefore, the

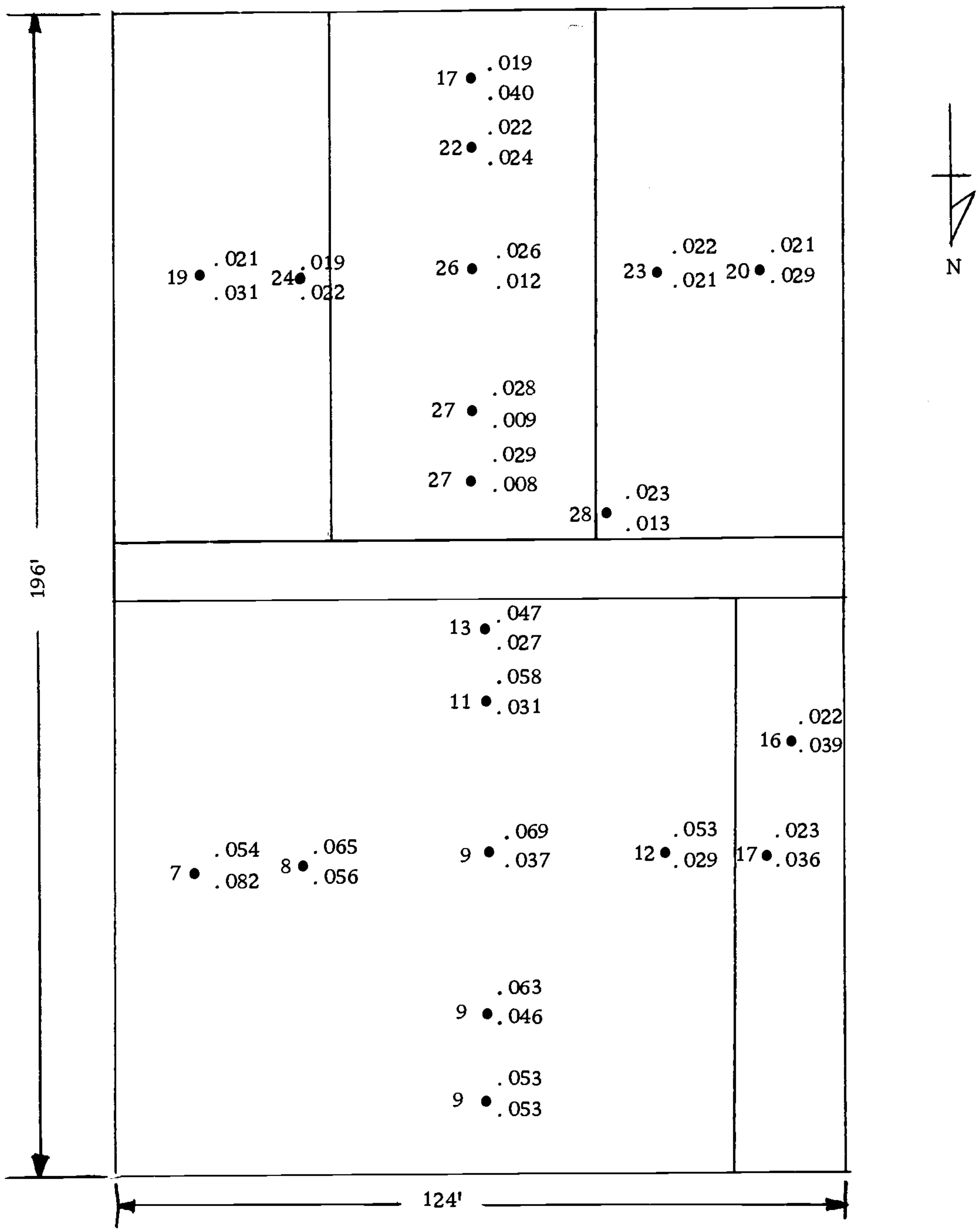


Figure 6. Gymnasium-1 first floor showing PF, overhead contribution (above) and ground contribution (lower).

author's approximation of an equivalent and determinate floor plan with respect to radiation shielding calculations.

Recommended Changes

As stated above, the overhead radiation contribution alone is greater than 0.025 so it is apparent that the major modifications need to be with the second floor or roof to reduce this contribution.

The preliminary roof design is a typical lightweight, long span construction. Increasing the mass of this type of roof is impractical and therefore, the required changes must be with the second floor slab and steel joist construction. As with the roof, the second floor is of lightweight construction (50 psf) but the spans are at the most only 33 feet long so a heavier structural system could be used.

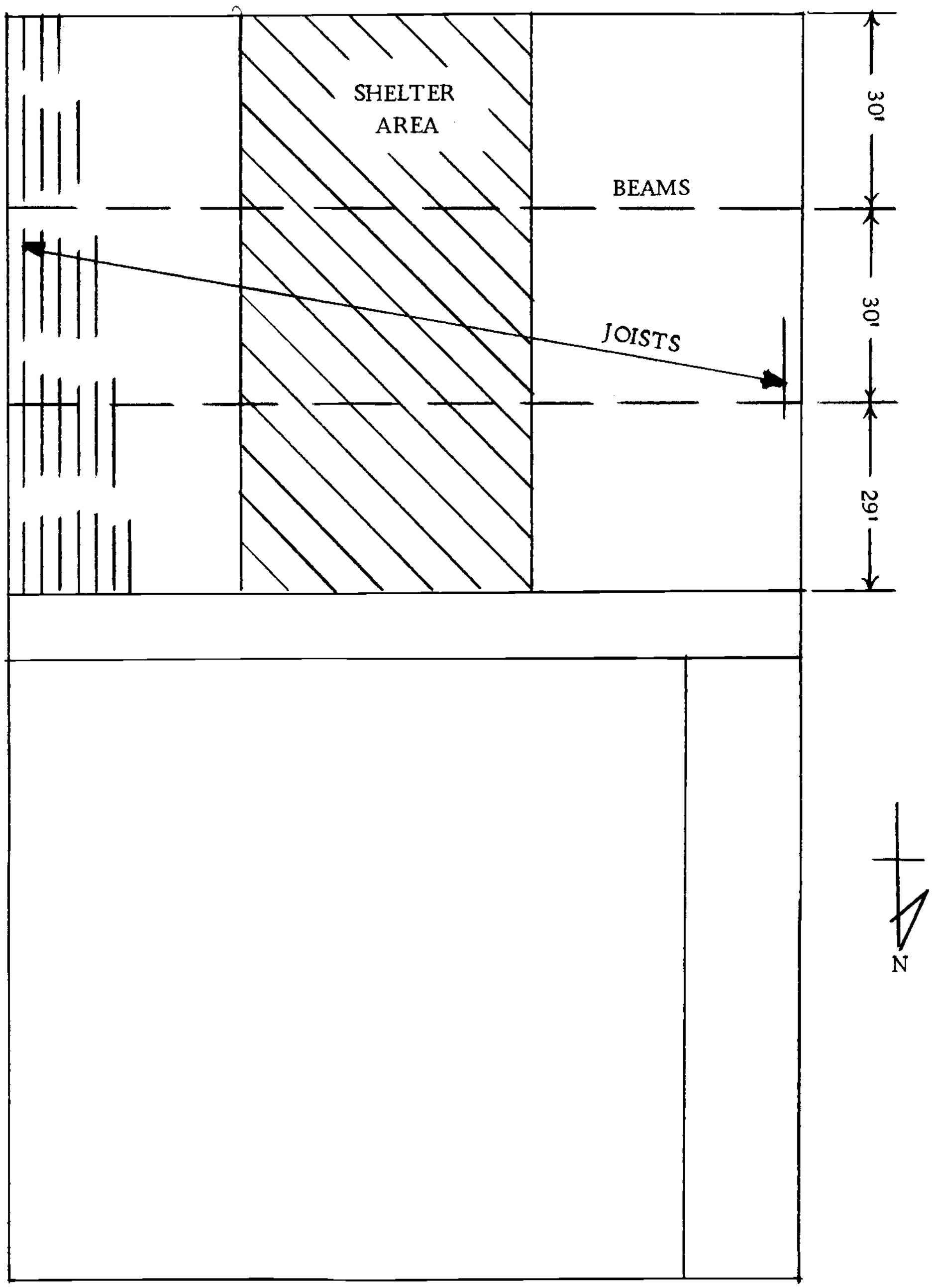
By working backward with the manual calculation, it was found that a PF of 40 can be achieved by increasing the second floor mass from the proposed 50 psf to 80 psf. This would make the Boys' Locker Room and part of the adjacent Girls' Locker Room and Team Locker Rooms adequately protected from fallout radiation. One possibility of increasing the floor mass would simply be to thicken the slab three inches but this would also necessitate increasing the size of the open web steel joist. However, this modification was not eliminated at this point and a cost estimate was made to compare with other possible alternatives.

Other modifications that were considered involve a complete redesign of the second floor structural system. A design of a Waffle Flat Slab, or Two-Way Pan Joist as it is sometimes called, was considered, using 30 inch wide pan forms. Since a total floor area of 11,000 square feet is involved, the pans could probably be used several times. The tables in the CRSI Design Handbook (1) are used for this design and therefore, some changes in span length are required. The tables are based on the assumption that the larger of two adjacent spans does not exceed the shorter by more than 20 percent. In the original design, the joists span lengths of 22 feet, 33 feet and 33 feet. It was found that spans of around 30 feet in each direction would place the columns in acceptable locations. However, if the architect wishes to leave the columns as originally located, more accurate methods of analysis would be needed.

Using span lengths of 30 feet, and designing for a superimposed load of 150 pounds, it was found that a three inch slab with 14 inch deep pans would satisfy the structural requirements. However, this design weighs 114 psf, 34 psf heavier than required to give a PF of 40. Therefore, a One-Way Pan Joist design was attempted. Using the 30 foot spans, it was found that a three inch slab over 30 inch pans, with joists 16 inches deep and seven inches wide, met the structural requirements and had a dead load of only 83 psf, just above the 80 psf needed. As before, if the original lengths of 22, 33 and 33 feet are used with this design, a more exact analysis will be needed. It is assumed that this will only entail more engineering and not more concrete, steel or labor. This paper is not concerned with exact or final designs. The preceeding designs will be adequate for cost estimates.

The selection was made to use reinforced concrete beams to support the joists and slab in place of the wide flange beams specified by the architect. To keep the depth of the concrete beams from exceeding that used in the original design, a maximum span spacing of 16 feet was required. With this criteria, beams 24 inches deep and 14 inches wide satisfy the structural requirements. Concrete columns 12 inches square will carry the total dead and live load and allow for two inches eccentricity. The location of the columns due to the beam span lengths entail relocating some of the interior apertures, but this will not cause a substantial change. No consideration has been given to the footing design since information concerning the soil conditions is not furnished with the preliminary plans. Although the total dead load of the concrete joist construction is 60 percent higher than that of the steel joist construction, shorter beam spans are proposed so that the total load at each column is only 30 percent higher than the original. This will probably not cause much change from the original footing design.

An approximate estimate of the construction costs of the



3 inch slab over 16x7 inch concrete joists, 37 inch O. C. Beams are 24x14 inch reinforced concrete

Figure 7. Suggested design for the upper level floor. The resulting shelter area is indicated by diagonal hatching.

author's suggested designs indicate that the One-Way Pan Joist construction will cost the least. Therefore, it is the only design that is compared with the architect's preliminary design in the next section.

Cost Comparisons

In the author's proposed design of One-Way Pan Joist construction, the primary structural changes are with the

1. columns,
2. beams,
3. joists, and
4. slab.

The finished floor, suspended ceiling and fixtures will remain the same. Cost comparisons are made only for those segments of the design that are changed. The costs given are for materials and installation includinglabor. These prices are the author's best estimate of the in place costs for the local area, based on recommendations from other engineers and a building construction cost book (2). The prices from the construction cost book have been adjusted five to ten percent to reflect 1969 costs in Portland, Oregon.

Cost of preliminary design (without protection).

Columns - 10, 8 inch square, 3/8 inch tube columns, 12 feet long $ 715

Beams - 15,130 pounds of wide flange beams plus welding, splices and bolts	$ 4,781
Joists - open web steel joists and channels	10,038
Slab - 3-1/4 inch concrete over standard corruform deck, wire mesh	18,221
Total:	$33,755

Cost of proposed design (with protection):

Columns - 16, 12x12 inch reinforced concrete columns	$ 1,030
Beams, joists, slab - including reinforcement, four uses for metal pans	23,000
Total:	$24,030

In this particular case, the floor design with radiation protection is lowest in total cost. Although there is a cost difference of $9725 between the two designs, it amounts to only 28 cents per square foot of total floor space. The total cost of the building will probably be in the $15 per square foot range so the change in cost is only around two percent.

The change in construction will give the centrally located Boys' Locker Room a PF greater than 40 making it available as a shelter. This area has a floor space of about 4000 square feet which will provide shelter for 400 people, allowing 10 square feet per person.

Actually, with slight changes in the wall construction, the complete North end of the building could be used for shelter space, giving an additional 7000 square feet or 700 additional spaces. This could be accomplished by placing large planters outside this portion of the building. If properly done, they would not only eliminate much of the direct ground contribution, but also enhance the appearance of the building.

GYMNASIUM-2

Preliminary Design

The gymnasium is one of four main buildings to be built in a campus-plan arrangement. In the lower floor of the gymnasium are the showers and locker rooms while the upper floor has space for four basketball courts, a lobby and a gymnastics room. The upper level is larger than the lower, overhanging by as much as 31 feet. A ramp connects the second floor lobby to the surrounding landscaped ground. Although the ground slopes up around the building, the lower floor is at grade. The effects from the irregular sloping ground and the overhanging second floor are included in the protection factor calculations.

Structural Description . . .

Floor System:

Lower Level - Concrete slab and finished floor

Upper Level - Five inch concrete slab with two feet deep concrete beams; three and one half inch wood floor overlays the slab

Roof Construction:

Built up roof over two inches of rigid insulation and steel decking; roof supported by steel truss and steel purlins

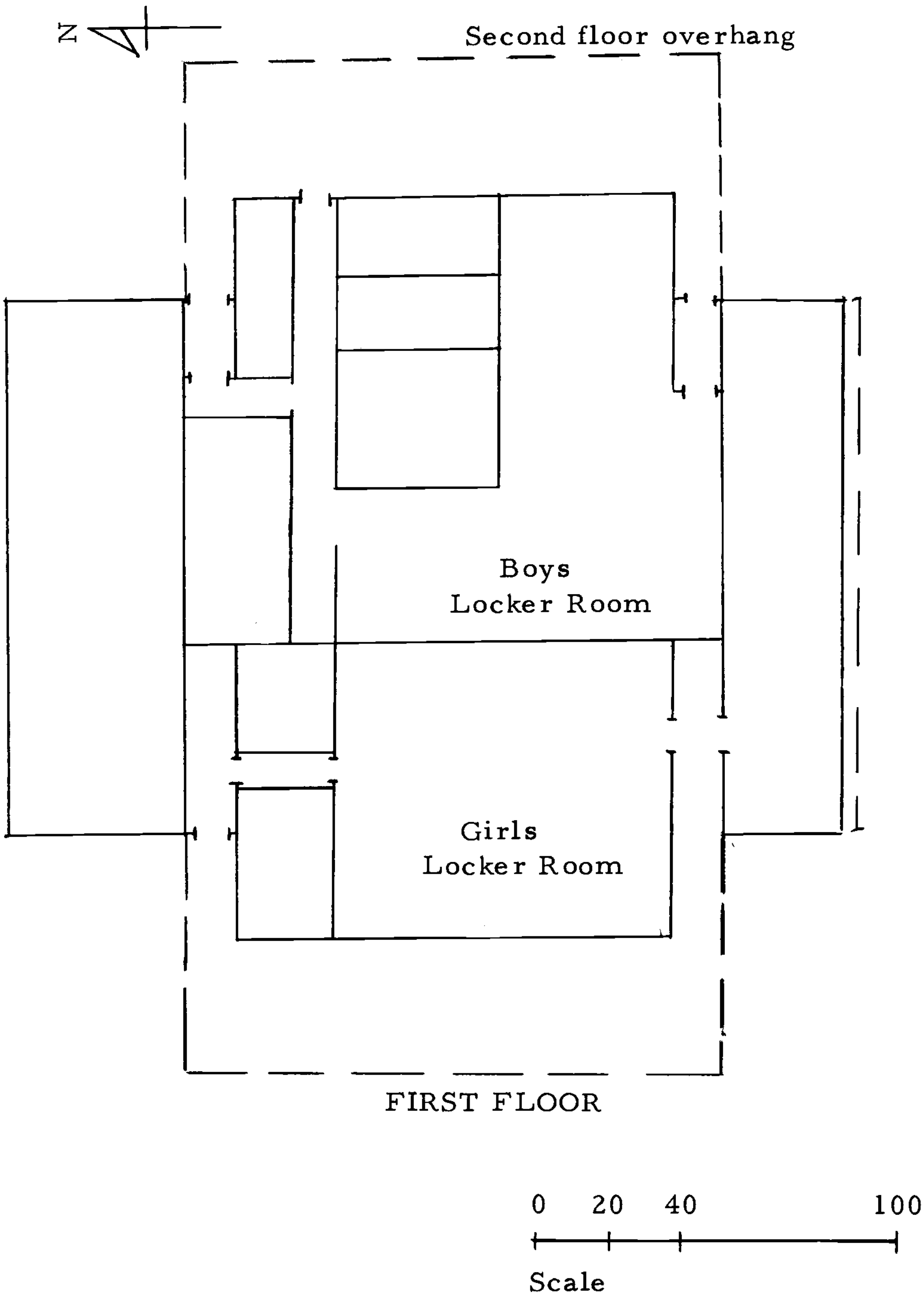


Figure 8. Floor plans of Gymnasium-2.

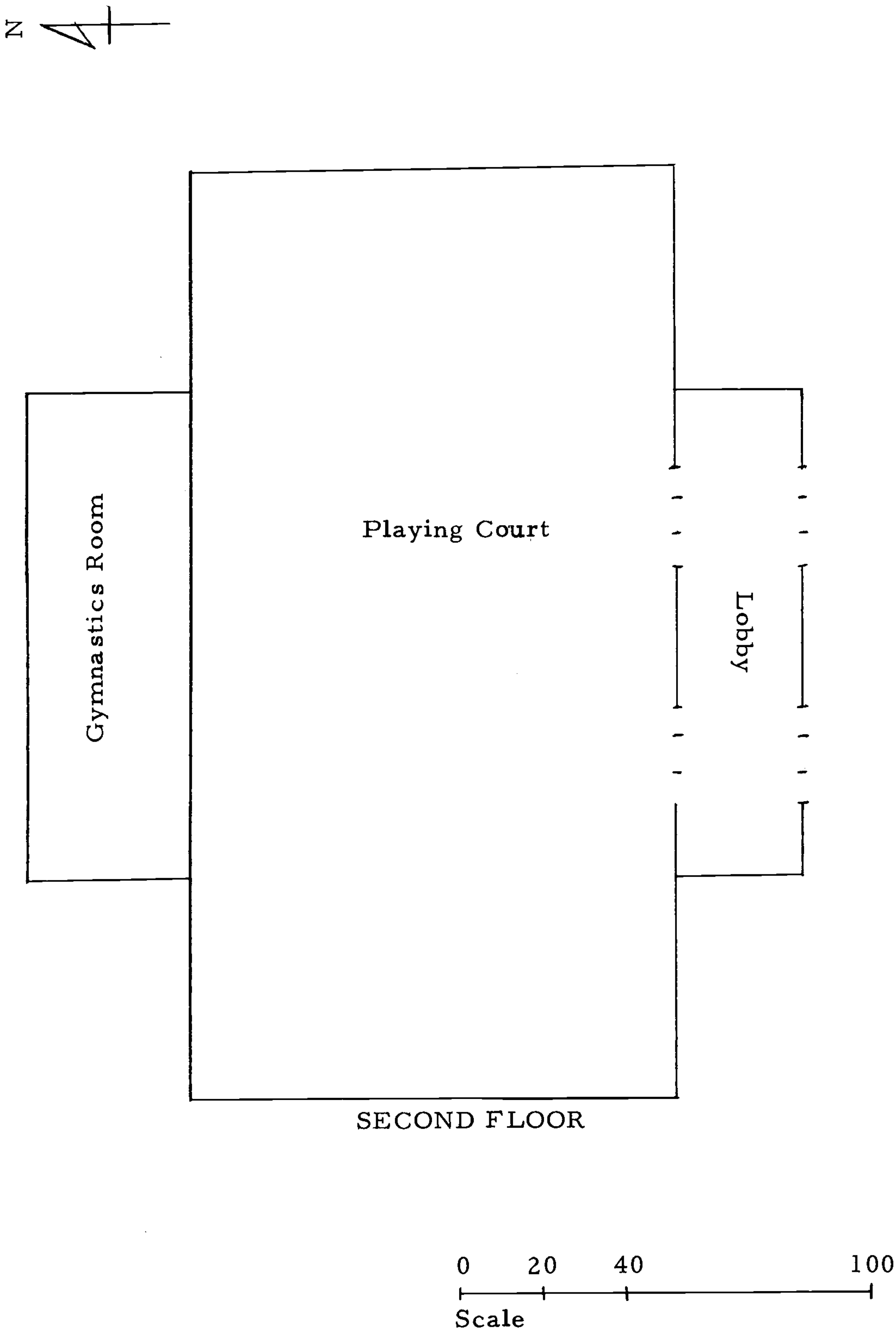


Figure 8. (continued)

Exterior Walls:

Six inch wall title; two by four stud and plaster; six and ten inch concrete walls

Existing PF

The heavy slab and beam construction of the upper floor virtually eliminate any overhead contribution at the lower level. This, coupled with the overhang of the upper level on three sides, result in a protection factor of 70 at the center of the lower level. The overhang not only provides a contamination free plane next to the walls but reduces some of the scatter radiation and much of the skyshine radiation that would normally come through the wall.

As can be seen in Fig. 9, much of the lower level already has a PF above 40. Across the center of the Boys' Locker Room, the PF ranges in the 70's and low 80's. However, near the exterior walls it falls below the required 40. At the corner, where the PF is shown equal to 14, the combined radiation contribution through the wall is 0.066 as compared to the overhead contribution of 0.005, a ratio of about 13 to one. This location will probably have the highest ratio since it is exposed on two sides to an exterior wall and has less overhead area as a more central location.

The PF at the upper level varies between five and seven with the overhead contribution accounting for 80 to 90 percent of the total

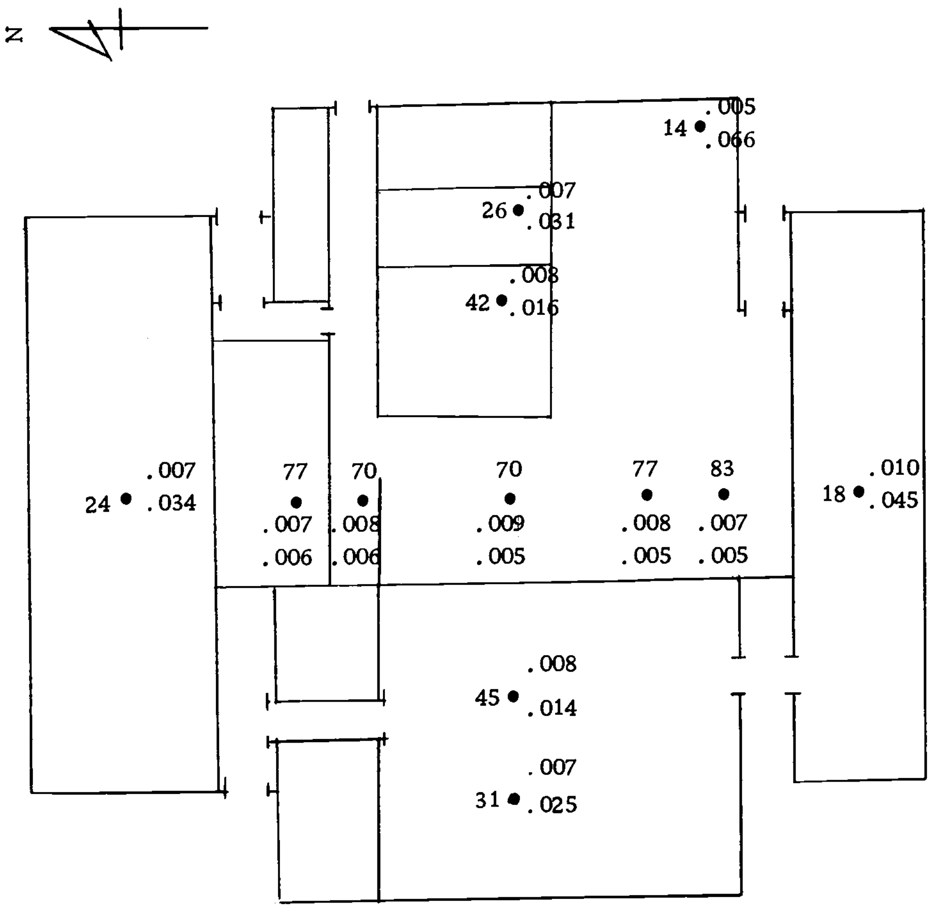


Figure 9. Gymnasium-2 lower level showing PF, along with the overhead contribution (above) and the ground contribution (lower).

contribution. This is due to the lightweight long span roof construction and the large potentially contaminated plane it supports.

Recommended Changes

Extensive structural changes are needed to make any of the upper level available for shelter space. However, much of the area in the lower level already has the minimum required PF of 40, allowing space for 1052 people. The Boys' Locker Room provides most of the shelter space with the Girls' Shower area providing the remainder. Although a large number of spaces are already inherent in the design, much of the lower level is not adequately protected and in the case of the two locker rooms, there are no walls or obvious divisions between the greater than 40 and less than 40 areas. In a distance of 80 feet, the PF varies from 83 to 14. Without proper supervision, a person could easily wander from a well protected spot to one with a low degree of protection. Therefore, the changes suggested are directed toward this problem, making entire rooms acceptable for shelter space.

As was seen in Fig. 9, the PF falls below 40 near the exterior walls at the East and West ends of the locker rooms. To rectify this, the wall mass at these locations can be increased with a four inch concrete wall poured against the inside of the eight inch S.C.R. brick wall that is currently planned. This would reduce the ground contribution so that both locker rooms could be completely used for shelter space, making a total shelter capacity of 1545 people.

Fig. 10 shows the resultant shelter area and where the wall needs thickening.

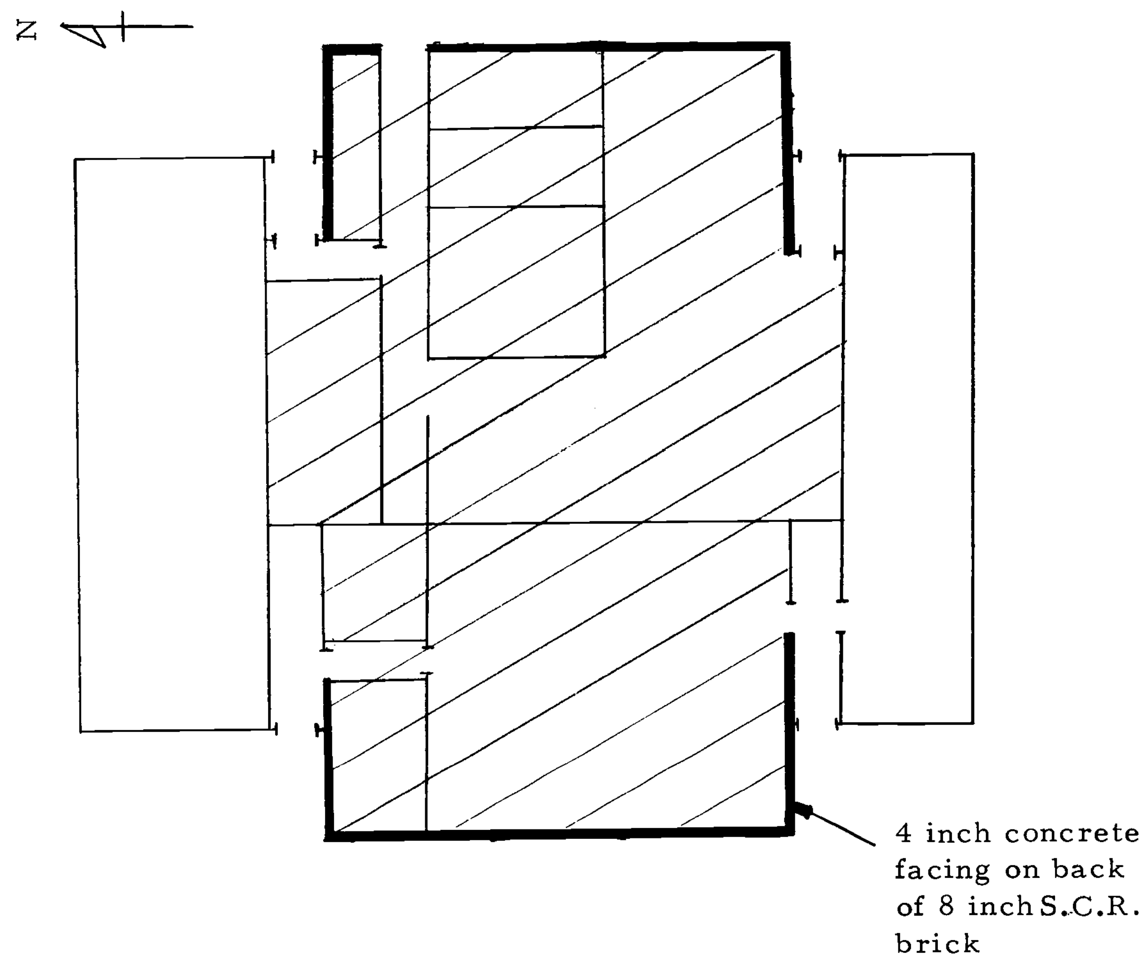


Fig. 10. Suggested wall modifications and the resulting shelter area

Cost Comparisons

As was noted earlier, no changes are required for the first 1052 shelter spaces. However, with a relatively small change in the East and West walls of the lower level, the total central locker room area can be made usable. In this particular case, no structural changes are needed. The four inch concrete wall can be poured directly against the S.C.R. brick wall so that forms will only be needed on one side. The cost of this modification would be around $66 per cubic yard of concrete in place, including materials, labor and reinforcement. Converting this to a cost per unit area of wall gives a figure of 82 cents per square foot.

The modification will affect a wall area of 284 feet by 12 feet, requiring 42.2 cubic yards of concrete. The total cost of the addition will be $2780 or 4.6 cents per square foot of building floor space. The cost for each additional shelter space over the initial 1052 spaces will be $5.42 per person with 513 spaces created by the changes. This gives a total of 1565 spaces which is slightly below the anticipated enrollment in this high school.

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APPENDICES

TERMINOLOGY

W - the lesser horizontal dimensions of a rectangular structure, in feet

L - the greater horizontal dimension of a rectangular structure, in feet

H - the distance in feet measured perpendicularly or vertically from the horizontal detector plane to the contaminated ground plane

Z - the vertical or perpendicular distance in feet from the detector plane to the contaminated overhead plane

X_e - the mass thickness of an exterior wall in pounds per square foot of wall surface

X_o - overhead mass thickness, the total weight in pounds per square foot of all horizontal barriers lying between the detector and the contaminated overhead plane

X_i - average mass thickness of interior partitions in pounds per square foot of partition surface

C_o - the contribution to the detector from radiation sources on the overhead contaminated plane, the roof contribution

C_g - the total contribution to the detector of radiation originating from the contaminated ground plane and reaching the detector through the walls of the structure, the wall contribution

e - eccentricity ratio, W/L

n - normality ratio, $2Z/L$

ω - solid angle fraction, a function of the parameters e and n. At each detector location, there are at least two solid angle fractions, an upper and a lower, ω_u, ω_L, $\omega(e, n)$

B_e - exterior wall barrier factor, a function of mass thickness and height, $B_e(X_e, H)$

B_i - barrier factor for interior partitions applied as a multiplier to C_g or C_o; a function of X_i, $B_i(X_i)$

G_d - directional response for direct radiation through that portion of a wall of a structure lying below the detector plane, a function of lower solid angle fraction and the height of the detector above the contaminated ground plane, $G_d(H, \omega)$

G_a - directional response for skyshine radiation through that portion of a wall of a structure lying above the detector plane, a function of upper solid angle fractions, $G_a(\omega)$

G_s - directional response for wall-scattered radiation through both those portions of a wall lying above and below the plane of the detector, a function of the solid angle fraction defining the portion of the wall of interest, $G_s(\omega)$

E - a shape factor always applied as a multiplier to G_s (and G_s only) to correct for the shape of the building, a function of the eccentricity ratio, $E(e)$

S_w - scatter fraction, that portion of the total radiation reaching the detector that has been scattered in the walls, a function of exterior wall mass thickness, $S_w(X_e)$

R_f - reduction factor, the total contribution from all sources, $C_o + C_g$

PF - protection factor, the degree of protection offered by a structure as compared to a case with no protection, the inverse of R_f

SAMPLE PF CALCULATION

The following example is presented with the assumption that the reader has had some exposure to radiation shielding calculations. The O.C.D. Manual (5) uses around 300 pages to bring the engineer to the stage where he can do a calculation of this magnitude. Therefore, only brief explanations will be included and if more explanation is needed, the reader is referred to the previous reference.

Gymnasium-2 Overhead Contribution (Detector located at center of first floor)

The roof area is divided into five areas due to the various interior partitions the rays must pass through to reach the detector (Fig. 11). The radiation from areas D and E must pass through 92 psf walls on the second floor. The radiation from the eastern part of area C passes through a first floor partition of 18 psf while the western part must go through an 82 psf wall. Areas A and B do not have a partition between the radiation and detector, but as with all of the roof contribution, it must pass through the 17 psf roof and 112 psf floor. All the roof areas are 41 feet above the detector (44 feet above the first floor), except area D which is 25 feet above the detector.

The following calculations are made for the total contributions from each area including the inner areas. For instance, the

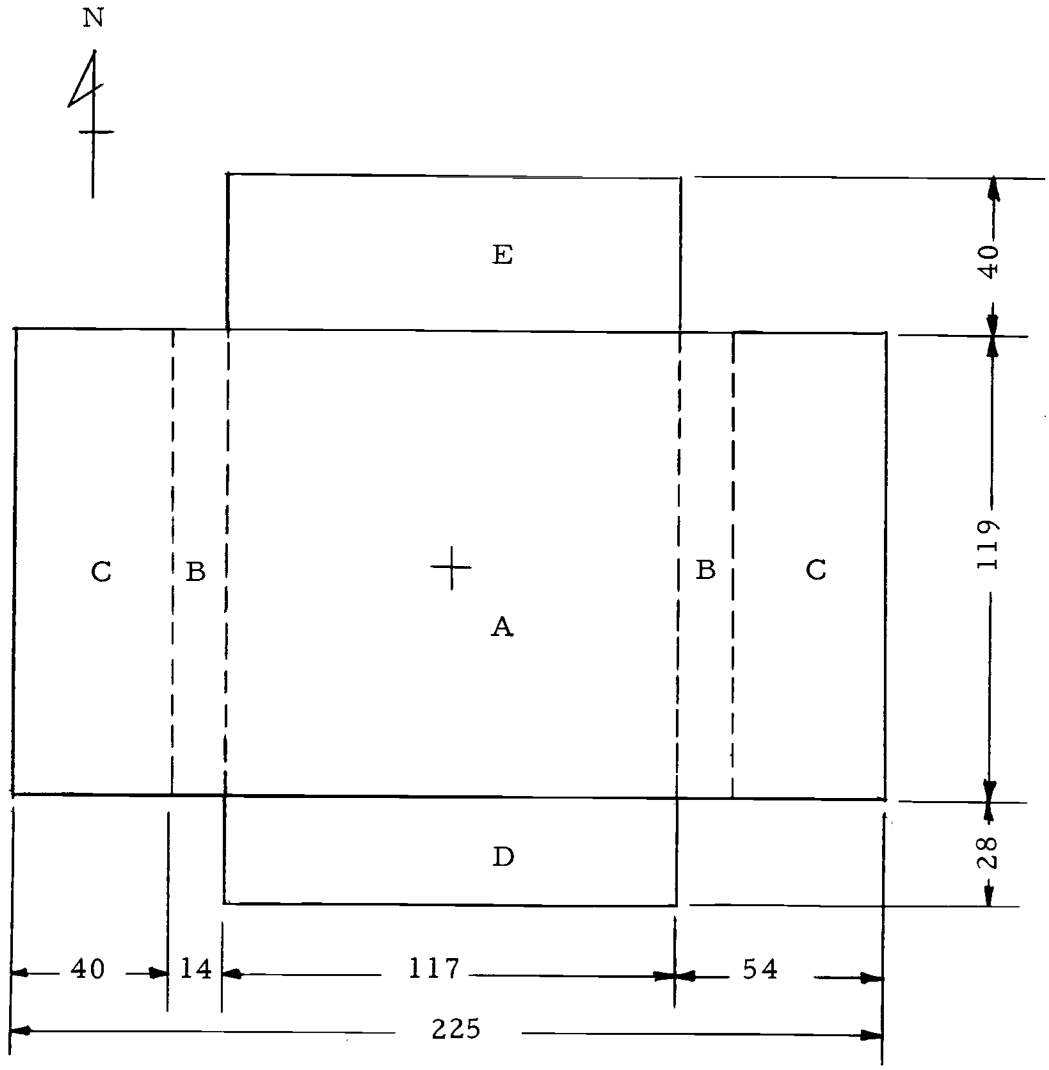

Fig. 11. Roof divisions for the overhead contributions

contribution for area C will also include that of areas A and B. In the final step, the redundant areas will be eliminated. The solid angle fraction, ω, and the contributions, C_o', are taken from graphs found in the manual (5). The rest of the parameters are from the basic dimensions of the building.

Area	W	L	Z	e	n	ω	C_o'
A	117	119	41	.98	.69	.48	0.0084
B	119	145	41	.82	.57	.51	0.0085
C	119	225	41	.53	.36	.56	0.0089
D	117	175	25	.67	.29	.68	0.0093
E	117	199	41	.59	.41	.55	0.0089

$B_i(X_i) = B_i(89) = 0.085$

$B_i(X_i) = B_i(92) = 0.066$

$B_i(X_i) = B(18) = 0.52$

$B_i(0) = 1.0$

$C_o = (C_o')(B_i)$

$C_{oB} = (0.0085)(1.0) = 0.0085$

$C_{oC} = (0.0089 - 0.0085)(1/2)(0.85 + 0.52) = 0.000121$

$C_{oD} = (0.0093 - 0.0084)(1/2)(0.066) = 0.000029$

$C_{oE} = (0.0089 - 0.0084)(1/2)(0.066) = \underline{0.0000165}$

0.0086665

Total overhead contribution = 0.00867

Gymnasium-2 Ground Contribution

The greatest portion of the ground contribution will come through the first floor walls, although theoretically, skyshine and scatter radiation can come through the second floor walls. The first floor contribution will be found first.

As is the case with the overhead contribution, the equations are only good for rectangular buildings with a centrally located detector. Therefore, the first floor plan must be divided into two idealized structures. Structure-R will be 96 feet wide and 163 feet long running East-West. Structure-S will be 116 feet wide and 186 feet long running North-South. The building is then divided into azimuthal sectors so that the barrier reductions from the various partitions can be multiplied by the contributions of the two idealized structures R and S. The azimuthal sectors are shown in Fig. 12.

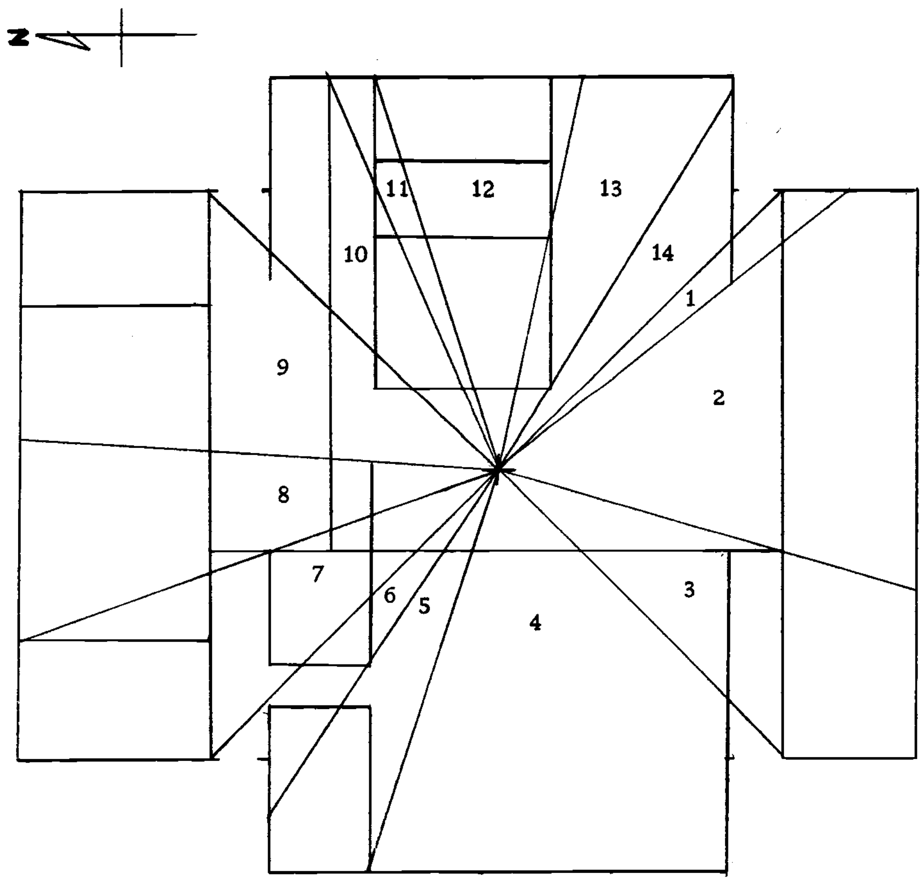

Fig. 12. Floor plan for Gymnasium-2 showing azimuthal sectors

In the calculations for the ground contributions from the idealized structures, the solid angle fraction, ω, is found from charts in the O.C.D. manual (5) as are the directional responses for skyshine, scatter and direct radiation, G_a, G_s and G_d respectively.

Ground contributions from the idealized structures R, S:

		W	L	Z	e	n	ω	G_d	G_s	G_a
R	W_u	96	163	9	.59	.103	.84	--	0.177	0.047
	W_L	96	163	3	.59	.0368	.954	0.235	0.0545	
S	W_u	116	186	9	.62	.0978	.88		0.136	0.037
	W_L	116	186	3	.62	.0322	.962	0.205	0.045	

$B_e(H, X_e) = B_e(3.89) = 0.124$

$S_w(X_e) = S_w(89) = 0.76$

$E(e) = E(.59) = 1.367$

$E(e) = E(.62) = 1.374$

Structure R:

direct radiation

$$C_g = G_d(H, W_L) \; [1 - S_w(X_e)] \; B_e(H, X_e)$$

$$= (0.235)(0.24)(0.124) = 0.00700$$

skyshine radiation

$$C_g = G_a(W_u)[1 - S_w(X_e)] \, B_e(H, X_e)$$

$$= (0.047)(0.24)(0.124) = 0.00140$$

scatter radiation

$$G_g = [G_s(W_u) + G_s(W_L)] \, S_W(X_e) \, E(e) \, B_e(H, X_e)$$

$$= (0.177 + 0.0545)(0.76)(1.367)(0.124) = 0.0298$$

Total contribution from structure R:

$$C_g = 0.03820$$

Structure S:

direct radiation

$$C_g = (0.205)(0.24)(0.124) = 0.00611$$

skyshine radiation

$$C_g = (0.037)(0.24)(0.124) = 0.00110$$

scatter radiation

$$C_g = (0.136 + 0.045)(0.76)(1.374)(0.124) = 0.0234$$

Total contribution from structure S:

$$C_g = 0.03061$$

Summation of azimuthal segments

$$A_z = (\text{Angle})(B_i)(C_g)$$

Segment	Angle	Part. mass, X_i	$B_i(X_i)$	C_g	A_z
1	6	242	0.0044	0.03061	0.000807
2	54	153	0.029	0.03061	0.0540
3	30	224	0.0064	0.03061	0.00588
4	63	82	0.140	0.0382	0.337
5	16	100	0.094	0.0382	0.0575
6	11	159	0.026	0.0382	0.0109
7	26	370	0.0005	0.03061	0.00398
8	34	212	0.0084	0.03061	0.00874
9	31	220	0.0069	0.03061	0.00654
10	21	54	0.260	0.0382	0.209
11	4	0	1.0	0.0382	0.153
12	30	54	0.260	0.0382	0.298
13	20	36	0.42	0.0382	0.321
14	14	0	1.0	0.382	0.535
				ΣA_z =	2.001

$\Sigma A_z/360$ = total ground contribution from first floor = 0.00556

Calculations for the scatter and skyshine contributions from the second floor give a value of only 0.00011. This is primarily due to the 112 psf floor the rays must pass through to reach the detector. This gives a total reduction factor of

$$R_f = C_o + C_g$$

$$= 0.00867 + 0.00556 + 0.00011$$

$$R_f = 0.01434$$

which gives a protection factor of

$$PF = \frac{1}{R_f} = \frac{1}{0.01434}$$

$$PF = 70$$

This corresponds exactly to the values determined in the SAND Program (See Fig. 9).

Although the protection at the center of the building is quite high, one must remember that it will vary at other points. As was found in the SAND determination, the PF is as low as 14 next to an exterior wall of the same room.

SUMMARY OF GYMNASIUM MODIFICATIONS

Gymnasium-1

Shelter spaces before modification	0
Shelter spaces after modification	400
Cost of change	$9725.00 (decrease)
Cost per square foot of total floor space	$0.28 (decrease)

Modification--replace open web steel joist and slab second floor construction with one-way concrete joist and slab.

Gymnasium-2

Shelter spaces before modification	1052
Shelter spaces after modification	1565
Net change	513
Cost of change	$2780.00
Cost per square foot of total floor space	$0.05

Modification--increase thickness of East and West walls with 4 inch concrete.