ALTERING POOL UPSLOPE ANGLES TO IMPROVE DEEP END DIVING SAFETY, AND RELATED SAFE WATER ISSUES

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ABSTRACT

The slope of a swimming pool floor from the point of the first slope change at the deep end wall (hereinafter defined as the "upslope") toward the shallow is examined in terms of relative safety to the diver for three different values of upslope. The January 1, 1974, "Suggested Minimum Standards for Residential Swimming Pools" specifies a maximum slope change of one foot in two feet six inches to a water depth of five feet six inches (hereinafter defined as the 2.5:1 slope or the current standard). The "Minimum Recommended Standards for Residential Pools" (not adopted, draft dated September 1985) specifies that the slope should not exceed one foot in three feet (hereinafter defined as the 3.0:1 slope or the proposed standard). The proposed 3.0:1 is a less steep slope than the current standard of 2.5:1. We also examine a hypothetical slope change to 3.5:1.

On the basis of a preliminary review of relevant literature and limited analyses--both analytical and statistical--the authors have not located or formulated sufficient evidence to indicate which upslope is superior with regard to safety. This inability to select a superior upslope angle is based, at least in part, on: (1) the very sparse database involving serious diving injuries in the deep end of a swimming pool; (2) the highly diverse range of diving practices among divers; and (3) the very small difference in speeds of impact with the pool bottom among the three upslope angles examined. Moreover, serious injury and fatalities resulting from diving accidents into the deep end of a swimming pool account for a very small percentage of all water-based (both swimming pool and other aquatic environment) serious injuries, near drownings, drownings, and other fatalities.

Consequently, the authors viewed the issue of safety in a swimming pool from a much broader perspective. In particular, they find that water safety control could best be enhanced through distribution of educational messages to the general population. An information program aimed at the general public, educating them about safe diving and other
safe practices in and around a swimming pool, would have a far greater potential for enhancing water safety than would an upslope angle change.
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I. INTRODUCTION

Residential swimming pools have steadily and vigorously increased in numbers since the end of the World War II. It is now estimated that pools number anywhere from 2-1/2 million to possibly 5 million nationwide. Homes, apartment complexes, condominiums, inns, lodges, and motels are the sites for nearly all of the residential type pools. After an early period of designs of all types with a concomitant wide spectrum of levels of safety and non-safety, recommendations for minimum standards with safety in mind began to appear in 1957. Reference 1, 1974, and Reference 2, 1985, are two such.

The specifications, minimum and desired, in both documents are mostly the same but with one noticeable difference. The slope of the pool floor in the transition region from deep water to shallow water--the upslope--previously recommended as 2.5 ft horizontal to 1 ft vertical (2.5:1) in the 1974 document was proposed as 3.0 horizontal to 1 vertical (3.0:1) in the 1985 draft recommendation.

A specific issue examined in this paper is: Does a change in the upslope ratio from 2.5:1 to 3.0:1 or even to a hypothetical 3.5:1 make any significant contribution to safety in diving into deep water from a springboard, platform, diving block, or edge of pool at the deep end?\(^1\) More specifically, is the potential for quadriplegic trauma resulting from head contact with the upslope at dangerous speeds and angles significantly reduced solely by changing the upslope ratios? We shall see that it is not.

However, in a more general vein, this paper also attempts to place quadriplegia resulting from impact with a pool upslope in the perspective of other pool accidents, other sports accidents, and all

\(^1\)We examined this particular question initially at the request of the National Swimming Pool Institute (NSPI). Later, questions arose concerning the relative frequencies of cervical trauma and quadriplegia in deep end pool diving accidents compared with other trauma and fatalities in general and, consequently, of general pool safety procedures, and these subjects form a considerable part of this paper.
accidents in general. Compared with them, such trauma is rare: swimming pool accidents account for only about 1 in 1000 accidental occurrences of quadriplegia. Such statistics, however, should not induce complacency, and we find it proper and necessary to summarize some recommendations for pool safety cited in the literature.

In Sec. II, we examine the initial issue of whether any upslope change can improve the safety of divers. This section includes mathematical formulation and theory.

In Sec. III, the main body of this paper, we place swimming pool deep end diving accidents in perspective by comparing the incidence of these accidents with broader classes of accidents.

In Sec. IV, we identify a host of alternatives that can maintain or improve the safety of people in a recreational water environment.

We hope that this paper will provide useful information to both the U.S. Consumer Product Safety Commission and the NSPI. The U.S. Consumer Product Safety Commissioner is an independent federal agency charged with reducing unreasonable risks of injury associated with consumer products. The NSPI publishes voluntary, recommended, uniform standards for the design, construction, and equipping of swimming pools, spas, and hot tubs.
II. BIOMECHANICAL CONSIDERATIONS IN POOL SPRINGBOARD DIVES

In this section we present the analysis and conclusions regarding the initial question that motivated this paper. We restrict our consideration to the mechanics of colliding with the upslope of a swimming pool and the potential trauma as a result of a dive by a nonexpert diver using a diving board of a height commonly encountered in a residential swimming pool. We ignore accidents resulting when a diver lands on a swimmer. Such accidents are due to errors in judgment or to inattention and are unrelated to pool upslope design.

Although dives can be made from a springboard, an elevated platform, a small elevated diving block at the edge of a pool, or the edge of the pool (from the deep end) we consider only a "worst case" situation, that of a springboard dive, because such a dive imparts more kinetic energy to the diver on entry into the water than all of the rest put together. Under perfect conditions a diver can leave a springboard with twice the energy that the same diver would have from a rigid platform. Such perfect conditions do not always prevail, but one can use them to achieve upper bounds on the energy. A detailed but simplified analysis of the mechanics and trajectory through the air and later through the water is possible using elementary particle mechanics and elementary drag force analyses. Rotational motion can be neglected in comparison with translational motion. Air resistance is also negligible. Because of the buoyant effects of water shortly after the diver's entry, the effects of gravity on the trajectory in water can also be neglected along with the buoyant force, since they nearly cancel each other. And, to arrive at a "worst case" of maximum speed (or, for the same diver, equivalently maximum kinetic energy) at contact with the bottom, we assume that the diver makes no steering or evasive maneuvers during the underwater segment of his trajectory, i.e., we assume a straight line path from entry into the water to a contact point somewhere on the bottom, the velocity in water being attenuated by drag...
forces. A detailed analysis of this sort appears in Reference 3, and in an earlier 1974 report by the same author, not referenced here because its contents are largely subsumed in his 1980 work.

However, it is not necessary to repeat the entire detailed analysis here. All we need are some assumptions about the pool's dimensions, height of board, water entry speeds and locations, drag coefficient, and mass of diver.

For our considerations we assume a pool with a 1 meter high springboard (see Fig. 1). Residential pools rarely have boards higher than this. Lower boards would impart less mechanical energy of the diver upon entry to the water. Thus, to be conservative in our conclusions, we do not consider that lower boards significantly alter the conditions of safety. Nevertheless, we include results for a 1/2 meter board as well.

Because most individuals suffering accidental quadriplegia after deep end diving are tall athletic males with a median age around 22 years, and because a person's dependent fluid drag forces are essentially inversely proportional to the square of the person's height, we consider in our analyses, again to be conservative, a diver 200 lb in weight, with a cross sectional area of about 0.75 square feet presented to the water in a clean dive. Although fluid drag is a complicated phenomenon involving frontal area drag, skin friction drag, form factors, etc., empirically, from touring tank data and aggregate drag coefficients used with frontal area, Newtonian flow drag coefficients range from a $C_D = 1$ to $1.2$ (Stone, cited in Ref. 4). Conservatively, we assume $C_D = 1$.

As a result of standard particle mechanics analysis, typical parameters (entry distance, entry speed, entry angle, etc.) were obtained as functions of 1 meter springboard takeoff angles in steps of $15^\circ$ from the horizontal and are presented in a table on p. 39 of Ref. 5. For expert divers, the higher takeoff angles of $60^\circ$ and $75^\circ$ are common; the less experienced take off at lower angles. For the takeoff higher angles, entry to the water is closer to the board and at a steeper entry angle from the horizontal so that a straight line path from entry point to the pool bottom would fall short of intersecting the upslope. Thus,
FIGURE 1: GENERIC TRAJECTORY OF DIVER INTO A SWIMMING POOL WITH 1981 RECOMMENDED DIMENSIONS
we need to consider only those springboard takeoff angles that can result in an underwater trajectory that intersects the upslope. Figure 2 shows the underwater trajectory from the elementary geometric analytic point of view, where D represents the horizontal distance in feet from the end of the springboard to entry into the water, a is the slope (in conventional mathematical usage) of the upslope (1:2.5, 1:3.0, 1:3.5), θ is the water entry angle, and S is the length of the underwater straight line trajectory. The origin is set at the start of the upslope as in Fig. 2 and the dimensions are in feet.

Solving the pair of linear equations describing the underwater straight line trajectory and the upslope to obtain their point of intersection (the diver's contact with the upslope), we have:

\[ x_c = \frac{8.5 - (16 - D)\tan\theta}{a + \tan\theta}, \quad y_c = \frac{[8.5 - (16 - D)\tan\theta]a}{a + \tan\theta}. \]

As a consequence, we can estimate the underwater slowdown distance traveled by the diver as:

\[ S = \left[ (x_c + 16 - D)^2 + (8.5 - ax_c)^2 \right]^{1/2} \]

\[ = \frac{[8.5 + (16 - D)a](1 + \tan^2\theta)^{1/2}}{a + \tan\theta} \]

\[ = \frac{8.5 + (16 - D)a}{a \cos\theta + \sin\theta}. \]
FIGURE 2: GEOMETRY OF UNDERWATER TRAJECTORY
The speed of the diver's head at contact with the upslope is in excess of the speed at contact of a point mass concentrated at the diver's center of gravity (the pelvic region) subjected to the same drag forces, simply because the head is forward of the center of gravity in a head-first plunge. We conservatively compute the speed for a center of gravity trajectory. Moreover, it is noted, (Ref. 6) that water drag forces do not attain their full effect until the body is about 2-1/2 feet or so into the water and then a short distance later the speed of the diver is about what it was at entry. A reasonable figure for this distance from entry is about 3 feet and we assume it, i.e., the slowdown distance in the speed attenuation formula is about 3 feet less than the value of s obtained by the above formula.

Under the Newtonian assumption, the drag force on an object with frontal cross area presented to the fluid flow A and speed v relative to the fluid of density \( \rho \) is: \( \frac{1}{2} C_D \rho A v^2 \) where \( C_D \) is the drag coefficient. In our case, we assume a 200 lb diver with a cross-sectional area of .75 square feet. The density of water is about 62 lb/cu ft. Integrating the equation of motion under the decelerating force of fluid drag, we get:

\[
 v_{\text{impact}} = v_{\text{entry}} e^{-C_D \rho A (s-3)/2m} \approx v_{\text{entry}} e^{-1(s-3)} 
\]

Taking the 1 meter and 1/2 meter springboard takeoff angles of 30° and 45° from the horizontal and the corresponding distances, speeds, and angles at entry given on pp. 40 and 41 of Ref. 5, we can construct Table 1, which gives the underwater distance traveled to impact and the speed at impact on the upslope with the three different slopes—2.5:1, 3.0:1, and 3.5:1.

These tabular results for takeoff angles of significance (angles outside these ranges result in lesser speed impacts on the bottom part of the upslope) demonstrate that at upslopes ranging from 2.5:1 to 3.5:1 there is at most a meager 5 percent to 6 percent difference in impact speeds (most are around 2 percent) for divers most at risk for quadriplegia in deep end dives with impacts on the upslope.\(^1\)

\(^1\) The 3.5:1 upslope is less steep than the current 2.5:1 upslope and even less steep than the proposed 3.0:1 standard. When comparing the 2.5:1 upslope with the proposed 3.0:1 upslope, the typical reduction in velocity is less than 2 percent.
<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Underwater Distance (ft)</th>
<th>Entry Angle (deg)</th>
<th>Entry Angle (deg)</th>
<th>Underwater Distance (ft)</th>
<th>Impact Speed (ft/sec)</th>
<th>Normal Component of Speed (ft/sec)</th>
<th>Underwater Distance (ft)</th>
<th>Impact Speed (ft/sec)</th>
<th>Normal Component of Speed (ft/sec)</th>
<th>Underwater Distance (ft)</th>
<th>Impact Speed (ft/sec)</th>
<th>Normal Component of Speed (ft/sec)</th>
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<td>2.5:1</td>
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<td>Distance Entry Speed</td>
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<tr>
<td>45</td>
<td>12.9</td>
<td>20.1</td>
<td>57.9</td>
<td>9.19</td>
<td>10.82</td>
<td>10.64</td>
<td>9.31</td>
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<tr>
<td>30</td>
<td>12.5</td>
<td>17.3</td>
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<tr>
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<td>17.7</td>
<td>52.9</td>
<td>9.68</td>
<td>9.06</td>
<td>8.74</td>
<td>9.81</td>
<td>8.96</td>
<td>8.49</td>
<td>9.91</td>
<td>8.87</td>
<td>8.27</td>
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</table>
Considering the variations in diving styles, the variations in angles of impact of the head with the upslope (top of head straight on, head tucked forward, or head tilted back or rotated to the side) such small differences in impact speeds resulting from differences in upslope ratios are insignificant.

Data obtained by the authors show significant differences in cervical spine trauma as a result of head contact with pool floor. The three principal mechanisms for injury are axial compression of the vertebrae, backward thrust of the head (hyperextension), and forward tuck of the head (hyperflexion) producing fractures and dislocations with resultant severe injury or severance of the spinal cord. Rotational modes are much less frequent. Football and trampoline injuries resulting in quadriplegia are similar to injuries principally occurring between the 3rd and 5th cervical vertebrae inclusively, with the highest occurrence at the 5th (referred to in Refs. 7, 8 and others). Reference 9 considers compression to account for only about 20 percent of quadriplegia cases and a few older references seem to be in agreement, whereas axial loading seems more commonly believed to be the dominant factor (e.g., Refs. 7 and 10). (There is even some difference of reporting on the incidence of contact with the swimming pool upslope. Reference 11 reports that in every injury involving a springboard dive, the victim struck the upslope and none struck the pool bottom at the deepest end; whereas Ref. 6 reports only one case out of 67 involves the upslope.)

However, there appears to be no disagreement that about 700 lb force in axial compression will crush a cervical vertebrae, and about 300 lb force will dislocate a highly flexed spine (Ref. 6). This reference also discusses whether or not the head slips at contact, the latter being much worse for the prospects of injury. Contact speeds cited therein for flexion-caused injuries range around 2 to 4 ft/sec.
One can also determine the kinetic energies per unit mass at pool
bottom impact for all these cases. However, this information is not
particularly useful, since the significant speed is the normal component
of velocity, about 2 to 4 ft/sec being critical, as noted above.

Reference 6 (also reported in Ref. 5) examined in detail 67 cases
of neck injury in swimming accidents, including studies on persons
anthropometrically similar to the victims, who performed the same
maneuvers that the victims did immediately before injury. This study
concluded that speeds for hyperflexion-type injuries (the majority in
their experience) are sometime less than 10.2 ft/sec. (Reference 2
reports that the reverse head motion, hyperextension, is frequent.)
Reference 9 states that neck injuries can occur with head impact
velocities of 8 to 10 ft/sec.

Moreover, Ref. 12, in underwater deceleration data, demonstrates
that a six-foot individual needs about 12 ft of water for safe diving
from typical residential pool board heights.

A remaining question is, What is the result if springboards are
removed and no platforms, jumpboards, or diving blocks are substituted,
so that dives have to be from the edge of the pool? Does the difference
in upslopes matter?

Reference 3 gives an easily derivable formula for the maximum
horizontal range attainable by a diver not using a springboard:

\[ D_{\text{max}} = 0.7L + 2h_j + h_o, \]

where \( L \) is the diver's height, \( h_j \) is the diver's maximum vertical
standing jump height, and \( h_o \) is the height above the water from which
the jump is taken. Let us assume \( L \) to be 6 ft; \( h_j \) usually ranges from
1-1/2 ft to 2 ft for an adult, so we will assume 2 ft; and we will
assume \( h_o \) to be 1 foot.

We shall consider a pool as recommended in Ref. 5 where the
overhang is 2-1/2 ft and the deep water from the edge of the board, now
removed, to the start of the upslope is 16 ft horizontally. Using the
above formula on such a pool (see also Fig. 1) we get a maximum
horizontal distance to entry into the water of 9.2 ft, leaving 9.3 ft horizontally to the start of the upslope (see also Ref. 13). (A "worst case" entry speed would be \( \sqrt{3g} = 13.9 \) ft/sec and the entry angle would be more than 45° below the horizontal.) With a water depth of 8-1/2 ft at the start of the upslope, a straight line trajectory would not intersect the upslope. Consequently, this situation presents no danger.

However, with steering maneuvers on the part of the diver, the situation may vary slightly between the different upslopes. The differences in angles among 2.5:1, 3.0:1, and 3.5:1 upslopes are not great. The angles, respectively, are 21.4°, 18.4°, and 15.9°. The normal components of velocities vary little for these differences in angles. Neither will the extension of underwater trajectory be significant.

Nevertheless, removing the springboard from pools and introducing other takeoff boards or platforms, for pools of the above dimensions, can have a significant safety effect on the arrival speeds at the upslope. A straight line path from the maximum distance water entry point to the start of the upslope is 12.6 ft \( = (9.3^2 + 8.5^2)^{1/2} \).

Using our above convention of 3 ft to return to entry speed, this yields a slowdown distance of 9.6 ft and an impact speed of 5.3 ft/sec \( (= 1.39 \times e^{-0.96}) \) for a "worst case" entry speed. Although this is still a dangerous speed for a cranial impact, for some people, protective actions with the arms and hands ahead of the head may lessen the impact on the skull, "soften the blow," so to speak.

Thus, we see that a change in the upslope ratios, whether a pool of the dimensions assumed above is provided with a springboard of 1/2 meter or one of 1 meter height or none at all, produces not even a marginal reduction in speed of impact with the upslope after a deep end dive by a typical diver of the highest risk class. The variations in diving styles, angles of takeoff, diver weights, and diver heights are much greater than the relative differences in effects resulting from differences in upslope.

Nevertheless, this does not mean that the safety of residential pool diving is hopeless to improve. The issue of safe diving can be considered as a part of the even greater issue of safety in all pool
activities, to say nothing of safety in all sports and recreational activities. Moreover, principles and guidelines for safety in sports and recreational activities, in turn, can apply to all activities where there are risks of accidents, fatalities, or serious trauma.
III. SWIMMING POOL DEEP END DIVING ACCIDENTS IN PERSPECTIVE

Serious injuries and fatalities resulting from diving into the deep ends of swimming pools actually account for a very small fraction of all accidently caused trauma and deaths. Figure 3 illustrates the relation between injuries resulting from diving into the deep ends of pools and other classes of injury.

However, drowning and other water-related deaths place third in frequency in a nationwide annual total of over 100,000 accident-induced fatalities. Drowning accounts for only about 6 to 8 percent of the number of accident-induced fatalities, behind fatalities from automobile accidents and falls, and slightly ahead of fatalities from fires and poisonings (see Table 2). Of the more than five million serious accidental injuries annually, water-related injuries and near drownings account for only a few percent of the total.

Table 3 demonstrates that an individual can face risks in many ways. Some risks are voluntarily accepted, e.g., driving or being driven in a car; others are not voluntarily accepted, e.g., a victim does not choose to be shot. Some risks are perceived to be controllable, e.g., drivers usually believe themselves in control; acrophobes do not climb cliffs. Other risks are not perceived as controllable, e.g., a passenger on a commercial aircraft usually has no control over the risk of airplane disaster.

Table 2

<table>
<thead>
<tr>
<th>MORE THAN 100,000 ACCIDENTAL DEATHS PER YEAR NATIONWIDE</th>
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<tbody>
<tr>
<td>50,000</td>
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<td>12,000</td>
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<td>3,000</td>
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<td>2,000</td>
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<td>16,000+</td>
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</table>
ALL SERIOUS INJURIES

ALL TRAUMATIC SPINAL CORD INJURIES ≈ TEN MILLION

ALL SPORTS RELATED INJURIES ≈ TEN THOUSAND

ALL DIVING INJURIES < TEN THOUSAND

POOL DIVING INJURIES < ONE THOUSAND

DEEP WATER POOL DIVING INJURIES = HUNDREDS

DEEP WATER POOL DIVING INJURIES = A FEW

FIGURE 3. DIVING INTO THE DEEP END OF THE POOL - THE TOTAL RISK (per year - U.S. data)
Table 3

CONTRIBUTORS TO ACCIDENTAL DEATH

Moving vehicles, mainly automobiles

Presence of an individual on high places, e.g., ladders, scaffolds, roofs, stairs, cliffs, mountains, boxes, etc. or obstacles in his or her path, or uncertain footing

Presence of individual in or on water

Presence of flammable solids, liquids, and gases

Ingestion of spoiled or contaminated food, insecticides, other poisons, or of large quantities or combinations of drugs not particularly harmful in small quantities or not in combination

Impeded passage of food from mouth to stomach

Firing guns, particularly small arms

Table 4 further places the issue of deep end pool diving resulting in quadriplegia in proportion to other water-related accidents resulting in quadriplegia.

One usually perceives a benefit of some sort (actual or imagined) that results from placing oneself at risk. When various options exist, e.g., not entering into a risk, entering into a risk, reducing the risk at a cost, or substituting one risk for another, the various benefits and costs, probabilistically weighted, are compared, usually not too analytically, by the risk taker to choose a perceived "best" option. When this process is subjected to a systematic treatment, it is called decision analysis.

We do not intend to embark here on a thorough risk and decision analysis for deep end diving accidents in swimming pools, but would indicate, by the general comments above, that such analyses are possible in this area as well. Ingredients for such an analysis would include frequencies of deaths and para- or quadriplegia for different segments of the population in different modes of diving (springboard, platform,
Table 4

STATISTICAL BREAKDOWN OF ANNUAL DROWNINGS
AND WATER-RELATED ACCIDENTS RESULTING IN QUADRIPLEGIA

OF 7,000 DROWNING/WATER-RELATED DEATHS PER YEAR NATIONWIDE

315 Children under age five drowned in pools/spas
(U.S. data for 1981)

Two out of three were under three years old

Nearly 2,000 near drownings of children (~75 percent were
hospitalized)

97 percent of involved pools were fenced/screened

Drowning essentially uninfluenced by design of pools

OF THE 700 WATER-RELATED QUADRIPLEGIC INJURIES PER YEAR

25 percent happened in domestic swimming pools

<2 percent happened in the deep end of the pool—of these, some
lesser number may be influenced by the upslope angle

rock, pool deck, type of dive) in differently dimensioned pools; costs
of accidental death or quadriplegia (paraplegia is a small fraction of
the nonfatal consequences of a dive-caused injury—2 paraplegics to 129
quadriplegics reported in Ref. 14), which may include litigation and
compensation besides medical expenses; costs of reduction or elimination
of such accidents, e.g., larger, deeper, and better designed pools or
modification of existing ones; restrictions on the use of a pool;
installation of safety measures of various sorts; and education of pool
users.

In Ref. 3, it is reported that approximately 4,000 accidents of all
types to the cervical cord occur annually in the United States, about 500
being associated with diving accidents in lakes, rivers, ponds, oceans,
and swimming pools. Approximately half of these injuries result in
quadriplegia and the rest in lesser injury. Only one-quarter of the
quadriplegia cases result from swimming pool accidents, i.e., about 60
to 65 per year. And, of these, 95 percent occur in the shallow rather than the deep end of the pool. Thus, we see that annually about 3 or 4 diving accidents in the deep end of a swimming pool result in quadriplegia cases—less than 1 in 1,000 annual cases of cervical cord trauma from all accidental causes. These data are, in the main, supported by Refs. 4, 5, and 15 through 20. The vast majority involve males (from 6 to about 20 times the frequency for females), who are tall and athletic, of ages from 15 to 30 years, with the mean around 22 years (Ref. 18).

Very seldom does a severe cervical spine trauma occur in a deep end diving accident to a person under the age of 13 or 14, (Ref. 4). This is in contrast to drowning, where the highest frequency occurs for ages 5 through 14 years (Ref. 19). In fact, of all pool-related injuries, very few are to the neck or spinal column (see Fig. 4). Moreover, according to a German database (Ref. 14), only 8.2 percent of all spinal cord injuries are related to sports or recreation. Figures 5 and 6 depict the distributions of quadriplegia and paraplegia among the sports activities reported in these data.

Even though diving into the deep end of a swimming pool causes annually only a few cases of accidental quadriplegia, this is four too many for the victims; the owners or managers of homes, condominiums, apartment complexes, motels, schools, gymnasiums, recreational sites, or health clubs with swimming pools; and swimming pool design, construction, and sales businesses. By any measure, one must agree that the personal cost to the victim, especially the youthful one, is incalculably high. Successful litigation in such cases can easily exceed a few million dollars.

Consequently, serious efforts to reduce or eliminate this source of accidental paraplegia and quadriplegia at bearable costs, collectively and individually borne, is an option to consider. These facts, when quantified, make the ingredients for a decision analysis. The analysis is not altogether simple. Measures to improve diving safety can also improve safety in other activities in the swimming pool and its immediate environment. Hence, the analysis for one goal is inextricably entwined with options for other specific and general options relating to
Figure 4. Percentages of pool-related injuries to different parts of the body.

- Upper Arm
- Shoulder
- Hip
- Neck
- Back
- Knee
- Ankle
- Arm Passage
- Lower Leg
- Mouth
- Teeth
- Nose
- Chin
- Hand
- Eye
- Face
- Head
- Foot

Percent of Total:
- 25
- 20
- 15
- 10
- 5
FIGURE 5. NUMBER OF DIVING RELATED QUADRIPLEGIC INJURIES RELATIVE TO ALL SPORTS AND RECREATIONAL QUADRIPLEGIC CASES
GERMAN DATABASE - 1967 TO 1978

FIGURE 6. NUMBER OF DIVING RELATED PARAPLEGIC INJURIES RELATIVE TO ALL SPORTS AND RECREATIONAL PARAPLEGIC CASES
pool safety, as well as the utilities and disutilities resulting from these options.

The appropriate allocation of utilities, disutilities, costs and the like among options specifically designed to enhance the safety of diving into the deep end of a pool is a topic that bears a detailed and expert study. The argument that a few dollars insurance per pool, annually assessed, will compensate for the few fatalities and quadriplegic traumas resulting from diving accidents is not well taken, even if there are from 2.5 to 5 million in-ground pools nationwide today (Ref. 20). To actually reduce the number of diving accidents would cost considerably more, even when shared with expenditures for other aspects of pool safety. Thus, to put the issue into a broader social context, nonmonetary costs need to be factored into the analysis before appropriate options can be selected.

However, in this paper we are specifically concerned with the issue of whether changing the swimming pool's upslope ratio from a slope of 2.5 ft horizontal to 1 ft vertical to 3.0 ft or 3.5 ft horizontal to 1 ft vertical would significantly reduce incidents of quadriplegia resulting from diving into the deep end of a swimming pool. We have found that it would not.

However, even though the relative frequency of such accidents is low (Fig. 3) the total costs are high to the victim, the pool owner, and the insurance company; therefore, efforts to reduce these accidents are worthwhile. To this end, we provide in the next section a discussion and "check list" on procedures that can substantially reduce the potential for these accidents.
IV. SAFETY IN THE POOL ENVIRONMENT

In general, one can consider that safety issues in sports or even in more general activities involving an environment and equipment can be categorized as belonging to one element of the following triad:

• Design, manufacture and installation of the environmental equipment;
• Regulation of the design, manufacture and use of the equipment; and
• Training and formation of habits in the use of and behavior in the environment

The driving goals are prevention of accidents, attenuation of their effects, and procedures to limit their consequences post-accident.

We briefly visit these issues relative to the residential pool environment, categorized using the triad above. There is considerable literature on recommendations in all three areas. References 1, 2, 6 (first four chapters), 7 through 30, and many references therein recommended for accident, injury, and death statistics and relevant descriptive matter are part of this literature. The following subsections provide a "check list" of considerations that should be examined by any individual or group contemplating constructing, maintaining, and managing a residential swimming pool, and supervising or being responsible for the pool environment and behavior of the pool users. Advantages and disadvantages, including costs and risks and their attenuation, should be weighed in each case, although in many cases, the decision for an action is manifestly in one direction or another without any doubt.

Figures 7 and 8 indicate where in the pool environment injuries occur and what activities cause them.
FIGURE 7. PERCENTAGES OF ALL INJURIES OCCURRING IN SPECIFIC AREAS OF THE POOL
FIGURE 8: CAUSE OF INJURY IN AND NEAR THE POOL
Of the several thousand quadriplegic injuries per year nationwide, roughly 700 are water related, according to Ref. 25. About 75 percent of these are due to diving accidents in natural aquatic environments; 25 percent are due to diving accidents in pools. Of those accidents resulting from dives into swimming pools, the majority result from dives into the shallow end of the pool. Of course, absolutely no one should dive into the shallow end of a pool. Quadriplegic injuries resulting from dives into the deep end of a swimming pool account for only about 2 percent of all water-related quadriplegic injuries and far less than 1 percent of all quadriplegic injuries.

Of those few quadriplegic injuries per year that result from diving into the deep end of the swimming pool, it is not clear that modifying the upslope angle from 2.5:1 to 3.0:1 or even to 3.5:1 will necessarily reduce the number of those injuries.

The database involving quadriplegic injuries resulting from diving into pools is sparse; from what we observe, most accidents are due to the poor judgment of divers.

Can we say anything else about the safety habits and safety record of people in a swimming pool environment? If we consider all injuries (some serious but primarily less serious), we find that more accidents occur in the pool than on the pool deck; but far more accidents occur outside of the pool (including on the deck, on the accessory equipment, and in adjacent areas) than in the pool (see Fig. 7). Of all serious and less serious injuries both in and around pools, 36 percent occur in the pool, less than 10 percent occur in the deep end and less than 10 percent occur on the diving board. It is fair to say that injuries (both serious and less serious) happen in, near, and adjacent to the pool and that the vast majority of these accidental injuries have little or nothing to do with the specific design of the pool itself, since many are due to slips, falls, and pushes. Some are due to judgmental errors on the part of the injured person or a person who causes the injury. For example, a somewhat common injury involves a diver landing on a swimmer. With the deep end of the pool naturally open to both divers and swimmers, it is safe to say that the injuries that result from a
diver-swimmer encounter are due to poor judgment and poor training and have nothing to do with the design of the pool.

Figure 7 shows that about 50 percent of all accidents in and around pools result from activities other than either diving or swimming.

Again, considering all injuries (some serious, most less serious), less than 7 percent are either back or neck injuries. However, all body parts are subject to injury. Again, it is apparent that pool design influences neither the likelihood nor the probability of the injury.

Nevertheless, all elements of the triad noted above need attention, and details are given in the following subsections.

POOL DESIGN, MANUFACTURE, AND INSTALLATION

Pool Materials, Equipment, and Installation

The materials and construction must be up to standard. Nonslip surfaces should be used above and below the water surface. Is a soft underwater surface effective or feasible? No, or few, jutting protuberances should exist. Guards should be placed over drains to avoid entanglement of hair. Adequate lighting, particularly for night use, is essential. Depths must be marked, perhaps with different colors for different depths.

Diving Board

Only properly designed diving boards should be used. (If inadequate boards are installed, diving from dangerous areas, i.e., from the deck nearer the shallow end, may become frequent.) The board must be nonslip and of the correct flexibility. If a board is not installed, a diving block might attract a diver away from shallow end diving. Should a water slide ever be considered?

Pool Deck

The pool deck should be nonslip and large enough to keep poolside furniture safe distances from the water yet not too large to encourage its use as a game area.
Enclosure
The pool enclosure should be high enough to keep toddlers out; the gate must also be secure.

Pool Cover
Pools should be built far enough away from buildings so that pool users are not tempted to dive from balconies or roofs.

First Aid
First aid supplies must be immediately available. Equipment should include a spineboard for removal of the injured from the water. A better device than a spineboard is used in the Federal Republic of Germany; it would prove a considerable improvement over the "one-size-fits-all" spineboard used in the United States. It is an inflatable, originally flat device not unlike an air mattress. With as many hands as possible to immobilize the victim's body and head, the victim is placed on the device, which is then automatically inflated, conforming itself to the victim's contours. It then solidifies, becoming a rigid cast in which safe transport to the hospital is possible.

REGULATION OF INSTALLATION AND USE
Local residential codes and enforcements should be adequate but even so owners must remain vigilant. There may be times when the pool is used by irresponsible people without supervision. As a safeguard, pool rules must be clear and explicit to any and all users. Readable caution signs on hazards and for safe behavior should be posted. Behavior around pools must be controlled. There should be no drinking, breakable objects, containers, or horseplay. No potentially hazardous objects likely to be thrown into the pool should be allowed. The host or other responsible person must be prepared to escort an inebriate away from the pool and into quarters. (Better broken furniture than a broken neck, rib, limb, or skull, or drowning in the pool.) Furniture should be kept away from pool's edge to allow adequate passage. Divers should be restrained from diving too close behind each other or together, e.g.,
one on another's shoulders. Diving into shallow water and other potentially dangerous behavior must be inhibited, such as diving from table tops, balconies, roofs, heater enclosures, or anything higher than the board. The pool must remain secure when not in use, using locked fence/gates. If one exists, the pool cover should be drawn over pool. Electrical shock or electrocution hazards for the wet bather must be eliminated, including nearby radios, TVs, electrical spit turners, popcorn poppers, other appliances, temporarily strung lights, and extension cords.

**EDUCATION AND TRAINING OF HABITS/BEHAVIOR**

Prevention is the major "name of the game," but educating pool users to proper procedures in the event of an accident should not be slighted. In fact, it is part of prevention. It is clear that this third area of the triad is the most neglected, although it is the one with the greatest potential for action and benefit after the fact of pool installation. It is generally held that, for most people, an explanation of a procedure and the reasons behind it promotes far better behavior than leaving the person to "figure it out" or instinctively to "do the right thing." This is true even when a person wants to be helpful in the event of an accident. The educational questions are not always easy and the answers are even harder.

For example, if a diver were to hit bottom with considerable speed and were rendered unconscious, clearly an informed person would know that the victim might have a broken neck and that considerable care in removing the victim from the pool to medical care is imperative. An uninformed person may, in an effort to help, attempt to force water out of the victim's lungs, to apply CPR, or when the victim is conscious to raise his head to offer a stimulant, such as hot coffee. It is impossible to perform these actions without moving the head relative to the body. It is imperative that a spineboard be used.

Figure 9 shows why the educational process is not an easy one to accomplish. This figure is a flow chart adaptation of a field decisionmaking table for handling an unconscious athlete with head and neck injuries in, say, football. The original appears in Chapter 4 of Ref. 6 (where, incidentally, a spineboard and its use is described).
FIGURE 9. PROCEDURES FOR HANDLING A DIVER WITH A SUSPECTED CERVICAL INJURY
Although this example can seem complicated (and it is), careful training in these procedures seems possible. Just because there are so few cases of this type, safety education should not be dropped as part of general procedures and behavior around pools. At least one person, if not all persons using the pool area, should have first aid training as a means of "damage control" in event of any type of accident. CPR training is also essential.

On the preventive side, no nonswimmers should ever be in the pool unaccompanied. Moreover, even when a nonswimmer is accompanied, it should be by a person capable of handling himself/herself and the nonswimmer simultaneously in case a rescue is called for. Nonswimmers should be taught safe pool behavior as quickly as possible, including proper diving habits. (See Ref. 27 for a detailed article on this subject.)

Safe pool behavior needs to be taught by the host’s example as well--no horseplay, stunts, running, poolside games inappropriate to the environment, drugs, or use of intoxicants; and prompt efforts should be made to remove any intoxicated or drugged person from the pool vicinity. Crowded poolside dances are prescriptions for potential falls into the pool and should be discouraged as a matter of habit. The dangers of potentially hazardous objects near the pool--furniture, toys, objects that some may be tempted to throw--should be explained to young and old alike.

Standing in the pool or on the wet deck and turning switches or controls on radios, TVs, other electrically driven appliances, and toys, or rigging temporary lights and extension cords can be fatal to a wet bather. Similarly dangerous situations exist for spas, hot tubs, and indoor bath tubs and showers. Education on these dangers is a must, as is education on the potential dangers of bathing or being in an outdoor pool, spa, hot tub, or any outdoor body of water during an electrical storm.

More prescriptions and recommendations for pool and poolside safety appear in the references cited above. The concomitant coverage of safety issues relating to residential pool diving in these procedures
can have enormously more potential to reduce accidents than can a small change in the upslope angle of a pool.
V. DISCUSSION AND CONCLUDING REMARKS

The analyses and judgments presented herein are based on information and methodologies derived from various fields--biomedical, biomechanical, engineering, human factor, and risk/benefit analysis. British, Canadian, West German, Australian, and American sources provided information and data. Both analytical and empirical information form the basis for the conclusions.

It is not possible or even reasonable to provide a global, mathematically optimal solution to a complex problem involving human behavior that has no definition in terms of optimization. Nevertheless, one still needs to think in global terms--one of the motivations for providing a triad for consideration and classification of options. In general, one aims at reduction of injuries and deaths within achievable cost limits (not only in monetary terms but also in terms of time, effort, training, behavior modification, and so forth).

Table 5 outlines a procedure for examining pool upslope angle and safety issues. This approach is described in greater detail below.

The methodology we used to form our judgment is quite straightforward (see Table 5). First, we placed the issue of the correct upslope angle into a broader perspective. Serious injuries that occur in the deep end of the pool account for a very small percentage of all serious injuries. To point this out has been the main purpose of Sec. III.

Second, we correlated the upslope angle to accident rate and accident severity. The empirical data here were quite sparse, which is why we resorted to the analytical study of Sec. II. We concluded that the suggested upslope changes would not significantly change impact injury potential.
Table 5

OUTLINE OF A METHODOLOGY FOR EXAMINING POOL SLOPE AND SAFETY ISSUES

PLACE POOL DIVING ACCIDENTS IN THE PROPER CONTEXT

What percentage of all accidents are diving accidents?
Of those that are diving accidents, what percentage are controlled by design

CORRELATE THE UPSLOPE ANGLE TO THE ACCIDENT RATE AND SEVERITY

On a statistical basis
On an analytical basis

IDENTIFY ALTERNATIVES TO MAINTAINING AND ENHANCING POOL SAFETY

Modify the upslope angle
   Disadvantages
      No practicable solution demonstrated, too costly
      May have little or no impact on injuries

Remove diving boards on existing pools
   Advantages
      May reduce some injuries

   Disadvantages
      May actually increase shallow water diving
      Not practicable

Do not add diving boards to future pools
   Advantages
      May reduce some injuries

   Disadvantages
      May actually increase shallow water diving

Add salt water
   Advantages
      Death by drowning is twice as fast in fresh water

   Disadvantages
      Not practicable, corrosive
      Not healthy
Table 5. (Cont'd)

Offer Other Design Changes

Provide training
Advantages
Likely to help many people
Bad habit of diving in shallow end learned young
and
Bad habits most easily broken when young
Reduce reckless diving

Disadvantages
Could take years to be effective
Requires institutional changes

Provide explicit written warning (e.g., Do Not Dive In Shallow Water)
Advantages
May help some people

Disadvantages
Notices in swimming pools and popular beaches
are either not read or widely ignored (Ref. 18)

Provide public awareness campaign
Advantages
Over the long run, likely to help many people
"A vigorous public awareness campaign alone, can
reduce child accidents in pools by one third."
(Ref. 26)

DETERMINE MOST EFFICIENT WAY OF MAINTAINING AND ENHANCING
POOL SAFETY IN GENERAL

Third, we identified eight alternatives for reducing the risk to
divers and swimmers in all aquatic environments (pool and natural). One
such alternative that might influence risk is modifying the upslope
angle. Another alternative is removing the diving boards on existing
pools and/or not adding diving boards to future, yet-to-be-built pools.
Removing diving boards on existing pools would (1) probably pose some
small pool deck modification problems, (2) probably cause resistance,
possibly extreme, from some pool owners, (3) probably cause some
resistance from consumers who want to buy boards for new pools, and (4)
possibly encourage more shallow water diving, a serious potential for injury including quadriplegia.

A fourth alternative is to add salt water to swimming pools. Although regular salt water does not add sufficient buoyancy to prevent drownings, using it would indeed reduce the number of drownings in pools by doubling the time of survivability underwater. Hemalytic and other electrolytic changes occur more slowly in salt water. However, this option is usually impracticable and quite costly.

Further alternatives are to consider other design changes, if any can be imagined; to offer and/or require training of all people who purchase or use pools, lakes, rivers, etc.; to provide additional written warnings; and, to implement a broad public awareness campaign.

The institutional changes appear to have the most promising outcomes. Although warning signs are very often ignored, some people read such signs and would be alerted to risks that they had not previously recognized. Signs placed in the shallow end of the pool tend to be at least noticed, but perhaps not always followed.

Training has been severely neglected. Children should never be taught to dive into the shallow end. Some continue to do this in adulthood, and we have seen the potentially catastrophic consequences of such an unsafe practice.

A vast public awareness campaign could provide the highest payoff in reducing both the likelihood and the severity of injuries. Public awareness campaigns have proved successful in getting people to use seatbelts while driving (Ref. 32). These campaigns must be addressed to all divers--not just those who dive into pools. A 10 percent reduction in all serious diving injuries would reduce the number of all accidental paraplegia by 25 per year. A complete elimination of all serious diving injuries--in the deep end of a pool--would reduce the number of paraplegics by perhaps three to five per year.

The final step, shown in Figure 10, is to display, in a relative, qualitative way, the advantages and disadvantages of the eight alternatives listed above in a cost/benefit framework. The magnitudes of the cross-hatched and checkered rectangles are qualitatively large or small according to whether the advantages or disadvantages are, respectively, large or small. Areas that do not extend below the horizontal neutral axis indicate alternatives without disadvantages.
FIGURE 10. ALTERNATIVES FOR MAINTAINING/ENHANCING POOL SAFETY: ADVANTAGES AND DISADVANTAGES
REFERENCES


