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A NEW METHOD FOR REPETITIVELY-PULSED

LASER PROTECTION STANDARDS

BY

Wesley J. Marshall

Presented at the Joint Conference

of the

American Industrial Hygiene Association (AIHA)

and the

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The presentation discussed an alternative approach for establishing laser exposure limits for repetitively-pulsed lasers. The approach was dependent on the calculation of the additivity between pulses in a train for producing retinal injury.

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A NEW METHOD FOR REPETITIVELY-PULSED LASER PROTECTION STANDARDS

By

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INTRODUCTION

The present method for evaluating repetitive pulsed lasers is based primarily on data taken for a fixed exposure time (0.5 s).[1-3] The biological effect from these studies was interpreted to be a function of the pulse repetition frequency when in fact this same effect could just as well have been plotted against the total number of pulses in the pulse train.[4] It is the opinion of this author that the reason several pulses cause retinal injury when a retinal lesion is not observed from a single pulse of the same energy is that microscopic cell changes partially combine together to cause visible injury.[5]

ADDITIVITY METHOD

Since pulses only partially add to produce retinal injury, a quantitative definition had to be developed for additivity (A). The following definition was considered appropriate:

$$A = \left(n - ED_{50}^{RP}/ED_{50}^{single}\right)/(n - 1) \qquad (1)$$

Where ED_{50}^{RP} and ED_{50}^{single} represent the total interocular energy necessary to produce a retinal burn 50 percent of the time for n pulses or for 1 pulse respectively. If a particular experiment showed complete additivity between pulses, ED_{50}^{RP} would equal ED_{50}^{single} and A in the above equation would reduce to 1.0. On the other hand for an experiment which showed no additivity, the above expression would reduce to zero.

In evaluating currently available biologic data with pulse durations less than 10 μs, additivity values were generally found to lie between 90 and 98 percent when several pulses were included in the exposure. A functional relationship between additivity and pulse-repetition-rate (F) is not totally clear. A slight improvement over adopting one particular value for additivity for all conditions is to use the following function:

$$A = \begin{cases} 0.97 - 3.5 \times 10^{-2} \log F & 1 < F < 100 \\ 0.83 + 3.5 \times 10^{-2} \log F & 100 < F < 10{,}000 \end{cases} \qquad (2)$$

The opinions or assertions herein are those of the author and do not necessarily reflect the official position of the U.S. Department of the Army or the U.S. Department of Defense.

Maximum permissible exposure values (MPE), using the additivity method, may be found by substituting the MPE for n pulses (MPE_n) for ED_{50}^{RP} and substituting the MPE for a single pulse (MPE_{single}) for ED_{50}^{single} in equation 1. The MPE for n pulses is then given as a function of the single pulse MPE by the following equation:

$$MPE_n = MPE_{single} [n - (n - 1)A] \tag{3}$$

The MPE for one pulse in a train of n pulses may be found by dividing the above equation by n; therefore:

$$MPE\begin{pmatrix}\text{single pulse}\\ \text{in a train}\end{pmatrix} = MPE_{single} [n - (n - 1)A]/n \tag{4}$$

An effective C_p value is then obtained as a correction to the single pulse MPE; thus:

$$C_p = [n - (n - 1)A]/n \tag{5}$$

This function may be plotted as a function of the total number of pulses as shown in Figures 1, 2, and 3. Note the similarity between these plots and the C_p as defined in ANSI Z136.1.[6] Data points were plotted on these curves for PRF values of 1, 10, 100, 1000, and 10,000 for exposures with the total number of pulses ranging from 2 pulses to 10,000 pulses. The biologic data used to make these plots are tabulated in the table and listed in the references.[7,8,9,10] The C_p values were calculated for these data points by the following formula:

$$C_p = ED_{50}^{RP}/n\ ED_{50}^{single} \tag{6}$$

Since the biologic data generally follow the calculated C_p values, the additivity method therefore maintains the same margin of safety for repetitive pulses as is available for a single pulse from the same laser.

LIMITATIONS

The additivity method does not work as well as the current method described in ANSI Z136.1 for pulse durations in excess of 10 μs because the additivity value drops below 90 percent for long pulses (>10 μs); therefore, the additivity method should not be used for long pulses.

For trains of short pulses (<10 μs) with a high repetition rate, a person may be expected to be exposed to a high number of pulses. For large n, equation 5 reduces to:

$$C_p = 1 - A \tag{7}$$

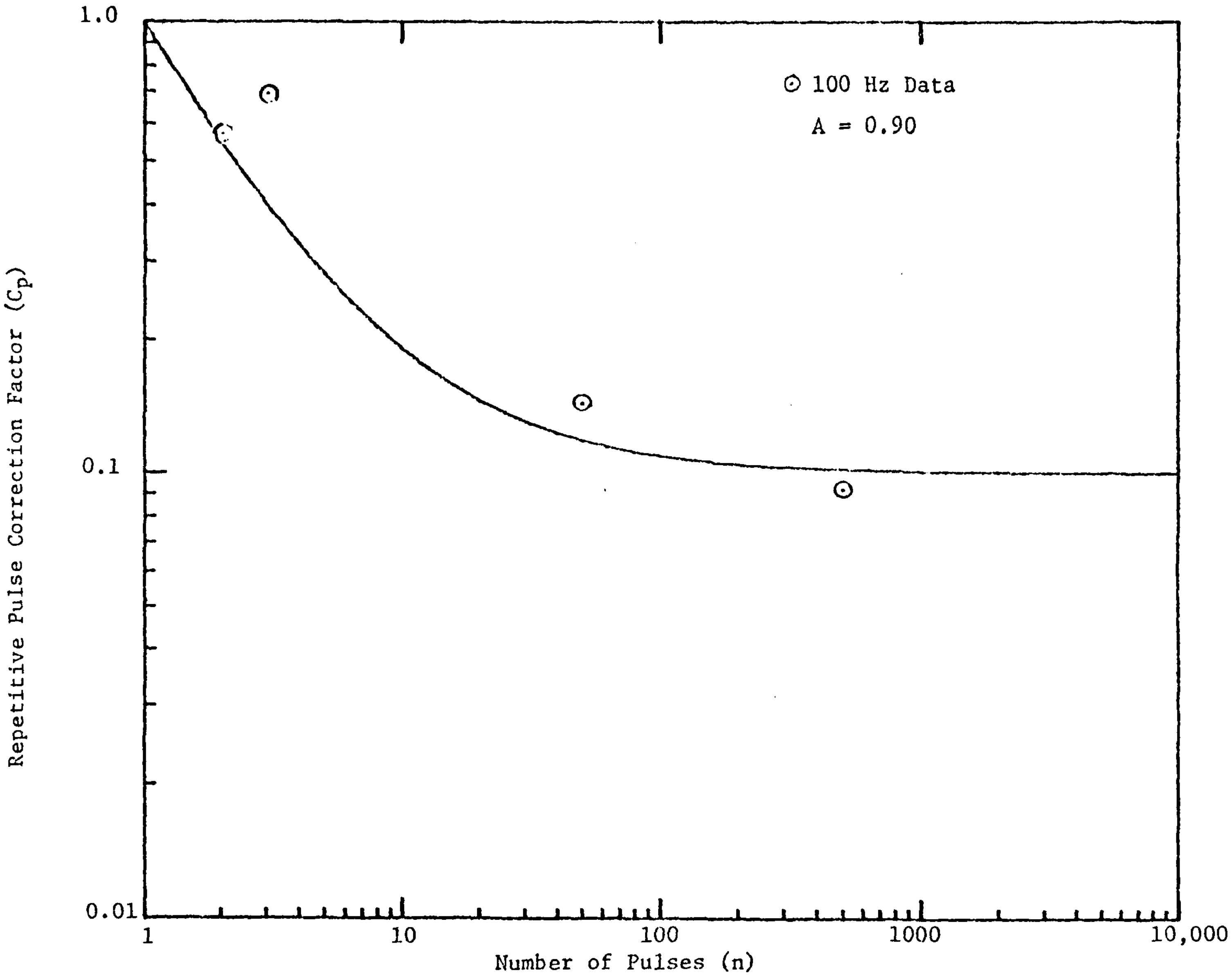

Figure 1. Repetitive-Pulse Data for 100 Hz with a C_p Curve for an Additivity of 0.90

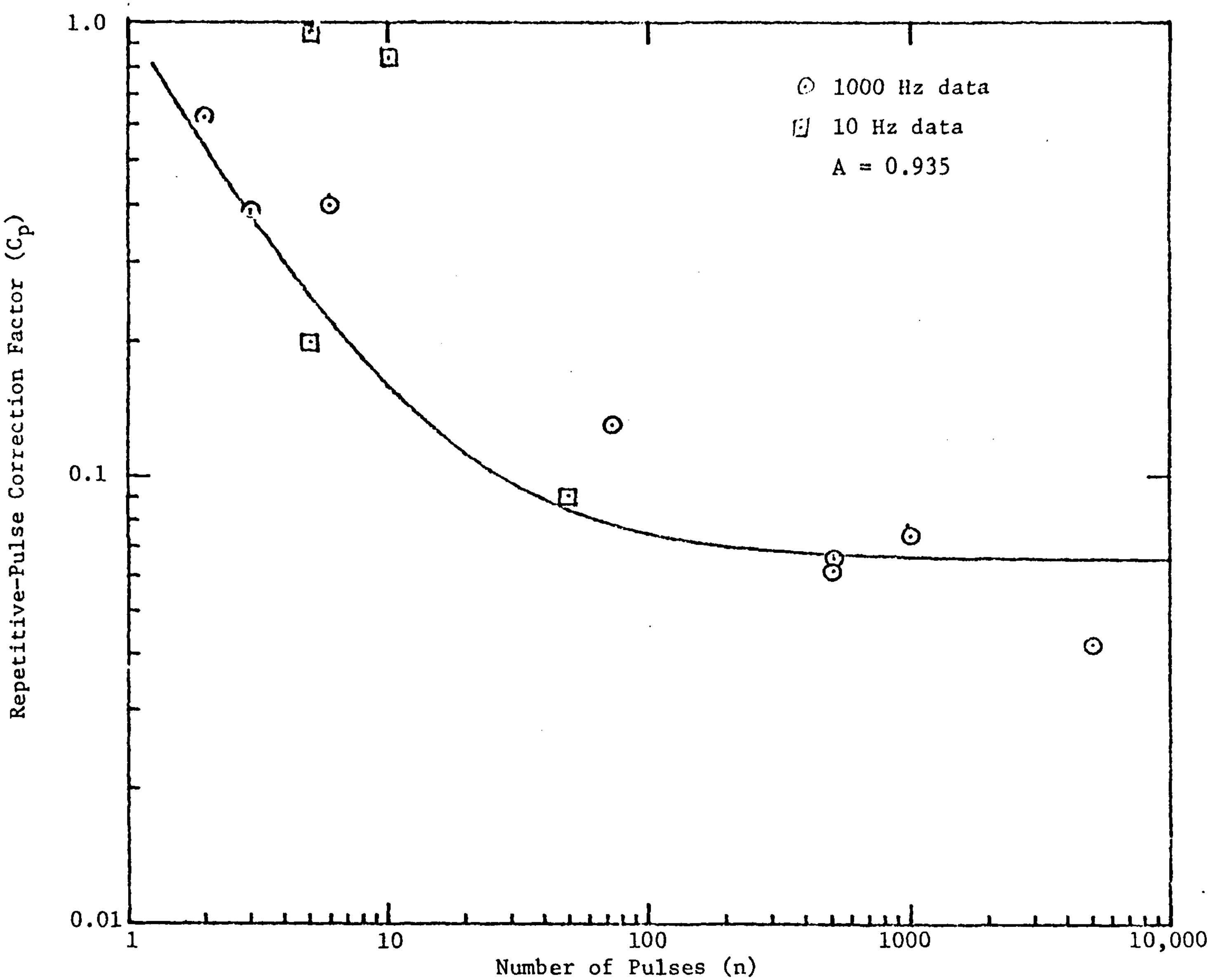

Figure 2. Repetitive-Pulse Data for 10 Hz and 1000 Hz with a C_p Cure for an Additivity of 0.935

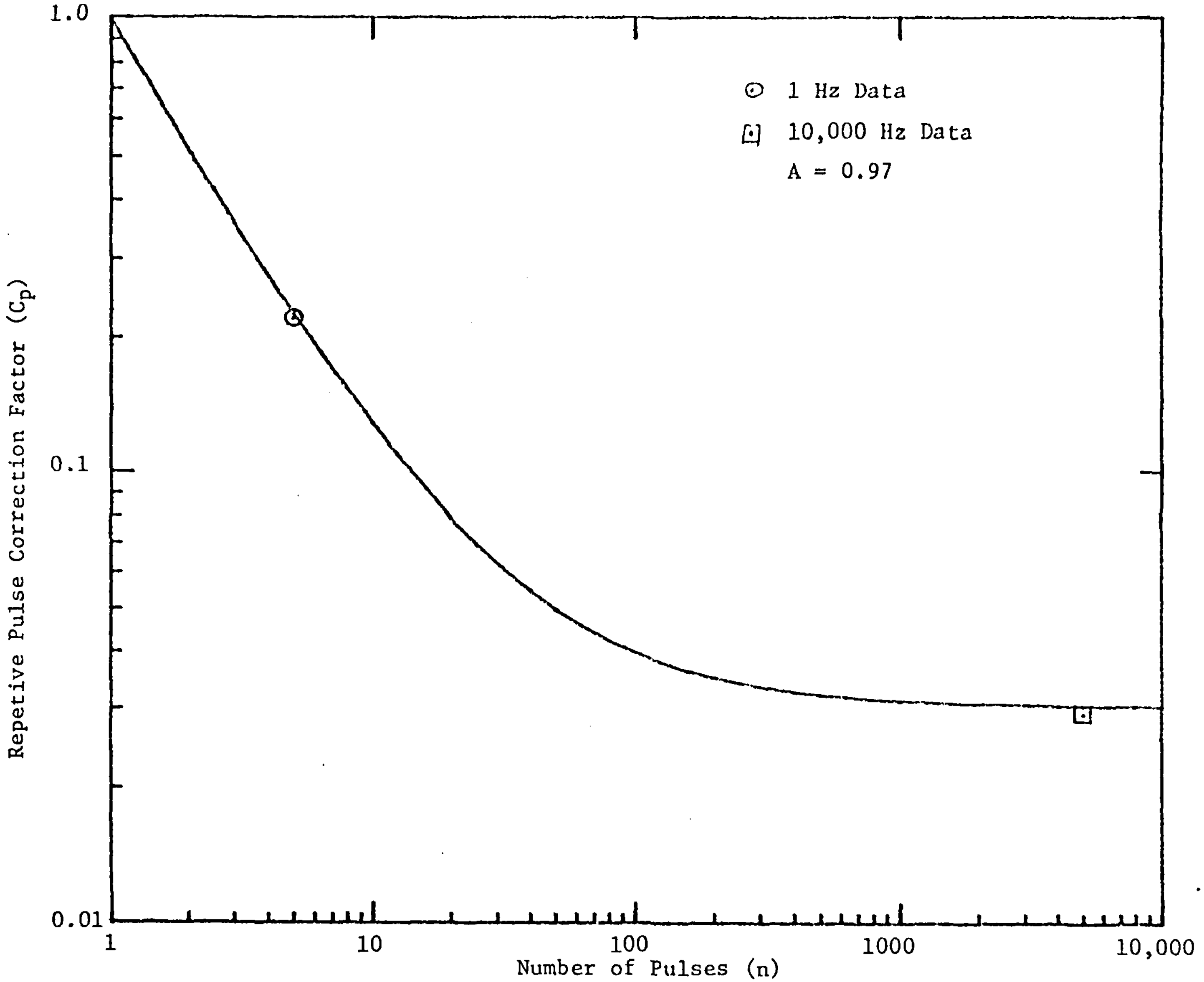

Figure 3. Repetitive-Pulse Data for 1.0 Hz and 10,000 Hz with a C_p Curve for an Additivity of 0.97

TABLE. BIOLOGIC DATA

F (Hz)	n	ED50 (μJ)	t (ns)	Additivity (%) $[n - ED_{50}^{RP}/ED_{50}^{single}]/(n-1)$	C_P $ED_{50}^{RP}/ED_{50}^{single}$	C_P $[n - (n-1)A]/n$	Reference
	1	164					
10	5	785	10	5.34	.95	.25	7
10	10	1370	10	18.3	.835	.16	
20	10	1220	10	28.5	.74	.17	
20	20	2100	10	37.9	.64	.12	
1	1	130	180				
100	2	150	180	84.6	.58	.55	8
100	3	270	180	46.2	.69	.40	
1000	2	160	180	76.9	.62	.53	
1000	3	153	180	91.2	.39	.38	
1000	6	330	180	69.2	.42	.22	
1000	74	1214	180	88.6	.13	.077	
1000	10^3	10100	180	92.3	.078	.066	
3000	2	121	180	106.9	.47	.52	
3000	3	131	180	99.6	.34	.37	
3000	6	182	180	92.0	.23	.21	
	1	28	270				
1	5	31	270	97.3	.22	.22	9
10	5	28.4	270	99.6	.20	.25	
10	50	128	270	92.7	.091	.084	
100	50	202	270	87.3	.14	.12	
100	500	1283	270	91.0	.092	.10	
10^3	500	918	270	93.6	.066	.067	
10^3	5000	5940	270	95.8	.042	.065	
		25	730				
10^4	5K	3650	730	97.1	.029	.030	
10^4	50K	19700	730	98.4	.016	.030	
	1	25	700				3
10	500	770	700	94.0	.062	.067	
	1	3.02	15				10
5	150	76	15	83.8	.17	.060	
5	600	96	15	94.9	.053	.056	

* Continuous Wave Limit

The hazard analysis in this case is then fairly simple. For very high repetition rates, the continuous wave (CW) MPE values would be used when their use yields a more conservative MPE. However, for trains of short pulses having a low repetition rate, an accurate determination must be made of the number of pulses to which an individual would be exposed or alternatively adopt the "worst-case" analysis of equation 7. An alternate solution to assigning a number of pulses would be to assign an exposure time which would be either a reasonable expected exposure time or a limit to the additivity method itself. Based on the limited biologic data for long trains of low repetition rate pulses, 10 seconds would probably be as good of an approximation as any.

EFFECT ON CURRENT STANDARDS

For a 1000 Hz train of short pulses the current C_p value is 0.06.[6] For the additivity method this value is 0.065. These values could be made to correspond without loss of accuracy to biologic thresholds.

For a 10 Hz train of short pulses lasting for 10 s, the C_p value would be 0.074. The present value is 0.32. These values could be made to correspond by limiting the additivity method to 0.4 s. The new C_p value would then be 0.30; however, biological data does not support this assumption.[9] In fact, pulses have been shown to add for exposure durations of 2 minutes![10] Therefore, MPE values for low pulse rate lasers would be lowered if the additivity method were accepted. For an unlimited exposure duration, the C_p would be simply 1 - A. However, for low repetition-rate ND YAG lasers, the present MPE values are probably quite adequate since biologic data indicates that MPE values for single pulses from a Q-switched ND YAG laser are too conservative. This MPE could be raised by a factor of 10 without endangering exposed personnel. However, for repetitive-pulsed lasers, the C_p factor for 10 to 20 Hz should be approximately 0.07 for a few seconds exposure. Therefore, the net result is that the repetitive-pulsed MPE would be more liberal by a factor of 2. A relaxation in the MPE by a factor of 5 would provide a sufficient margin of safety (a factor of 12) between an ED_{50} threshold and MPE values. By using the additivity method, this margin of safety could be maintained for any pulse-repetition frequency. Also, a factor of five increase in the single-pulsed MPE for Q-switched, ND YAG lasers would essentially leave the MPE for 10 to 20 Hz lasers unchanged if the additivity method is adopted.

For laser devices which do not have a large safety margin between MPE values and actual biologic damage for single exposures, such as short pulsed ruby or GaAs lasers, the additivity method would insure that this same safety margin is maintained for repeated exposures even at low repetition rates. The present standards may not be adequate.

SHORT EXPOSURE DURATIONS

Much confusion has arisen when the presently used C_p must be used to evaluate an exposure of 2 or three pulses spaced a few microseconds apart. For those well versed in laser safety, the least conservative of two methods is used:[6]

(1) The entire energy in the pulse train is added and compared to the MPE for 1 pulse.

(2) The C_p correction factor is applied to the single pulse MPE and compared to the radiant exposure for 1 laser pulse.

To the uninitiated, this procedure appears complicated and possibly unreliable; however, the additivity method blends these two procedures smoothly together with one equation.

CODED PULSES

Laser pulses which are coded in order to transmit information are impossible to evaluate by current standards. The repetitively-pulsed correction factor would be assigned based on the minimum interpulse spacing. For many laser systems, this method would be over restrictive. With the additivity method, however, an accurate C_p may be determined. From equation 5, n represents the total number of pulses and n - 1 represents the number of interpulse spacings. The additivity for each interpulse spacing may be determined by equation 2. The additivity values for each pulse separation are added and substituted back into equation 5 in place of (n - 1)A. The resulting equation may be expressed as follows:

$$C_p = \left(n - \sum_{i=1}^{n-1} A \right) / n \qquad (8)$$

Therefore, no matter how involved the coding, a C_p value may be assigned which will provide a uniform margin of safety from a biologic injury threshold.

MECHANISM OF INJURY

The method used for determining whether retinal injury has occurred has been traditionally a human observer who searches for injury at a specific time interval after exposure. This method is probably as good as any. However, just because visible damage does not occur in an exposure does not mean that cell damage has not occurred. This result has been shown by electron microscope observations of exposed retinal tissue.[1 5] Therefore, by no surprise, the additivity between short duration pulses is generally over 90 percent. The additivity generally tends to be better defined as the number of pulses increases.

CONCLUSION

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The additivity method offers a more logical approach for evaluating repeated exposures from short pulsed laser devices. A uniform safety margin may be maintained for multiple pulses and single pulses from the same laser device. Permissible exposures to a very few pulses or to coded pulses may be easily calculated by this method. Most importantly, an adequate margin of safety may be maintained for all repetitively-pulsed lasers. Keywords: Laser damage, Laser [illegible]s, Radiation Protection, Standards, limits. (KW)

REFERENCES

1. Wolbarsht, M.L. and D. H. Sliney: The Formulation of Protection Standards for Lasers, in Laser Applications in Medicine and Biology, Ed. M. L. Wolbarsht, pp. 309-355. Plenum Press, New York (1974).

2. Sheen, C. H., W. R. Bruce, J. H. Tipps, Jr., M. G. Smith, and C. G. Garza: Ocular Effects of Repetitive Laser Pulses. Technology, Inc., San Antonio, Texas Air Force Contract F41609-71-C-0018 (AD746795) (June 30, 1972).

3. Skeen, C. H., W. R. Bruce, J. H. Tipps, Jr., M. G. Smith, and C. G. Garza: Ocular Effects of Near Infrared Laser Radiation for Safety Criteria, U.S. Air Force Contract No. F41609-71-C-0016. Technology, Inc., San Antonio , Texas (AD746793) (June 1972).

4. Stuck, B.E., D. J. Lund, and E. S. Beatrice: Repetitive Pulse Laser Data and Permissible Exposure Limits. Institute Report No. 58, Letterman Army Institute of Research, Presidio of San Francisco, California (May 1978).

5. Bresnick, G. H., G. D. Frisch, J. O. Powell, M. B. Landers, G. C. Holst, and A. G. Dallas: Ocular Effects of Argon Laser Radiation. Invest. Ophthalmol. 9:901 (1970).

6. American National Standard for the Safe Use of Lasers, ANSI Z136.1 (1976).

7. Ebbers, R. W. and I. L. Dunsky: Retinal Damage Threshold for Multiple Pulse Lasers. Aerospace Medicine, 44:317-318 (1973).

8. Lund, D.J. and E. S. Beatrice: Repetitive Pulse Neodymium Data, Documented, Letterman Army Institute of Research, Presidio of San Francisco, California (November 1977).

9. Hemstreet, H. W., W. R. Bruce, K. K. Altobelli, C. C. Stevens, and J. S. Conneolly: Ocular Hazards of Picosecond and Repetitive Pulse Argon Laser Exposures. First Annual Report (February 1973-February 1974), US Air Force Contract, Technology, Inc., San Antonio, Texas (1974).

10. Gibbons, W.D.: Retinal Burn Thresholds for Exposure to a Frequency Doubled Neodymium Laser. USAF Technical Report SAM-TR-73-45, School of Aerospace Medicine, Brooks Air Force Base, Texas (November 1973).