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THE SELECTION OF PULSE CHARACTERISTICS FOR ELECTRICAL FISHING EXPERIMENTS FROM MEASUREMENTS ON DIRECT MUSCLE STIMULATION

by

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Summary

Due to the high conductivity of sea water marine electrical fishing requires high power levels. Systems in use at present generate pulses with a fast rise time and exponentiall decay by discharging large capacitors into sea water resistances. It is considered that these pulses directly stimulate fish muscle. Measurements were made on plaice and cod muscle with rectangular and exponential pulses. The muscular tensions developed by pulses with a range of amplitudes and durations were determined and the pulse energy evaluated. Rectangular pulses were found to require lower electric field intensities and energy levels than exponential pulses to produce the same effects. Plaice muscle responded to lower field strengths than cod muscle. Examination of the pulse parameters used in recent electrical fishing experiments showed them to be relatively weak stimuli.

Résumé

A cavse de la conductivité de l'eau de mer, la pêche électrique dans la mer reqviert de hauts niveaux de puissance. Les systèmes employés achellement prodvisent des vibrations à une période de hausse rapide et à une désintegration exponentielle rapide en déchargeant de grands condensateurs dans des résistances d'eau de mer. On considère que ces vibrations stimulent les muscles des poissons d'une facon directe. On a meouré les muscles de carrelet et de morve avec des vibrations rectangulaires et exponentielles. On a déterminé les tensions musculaires développées par des vibrations à une variété d'amplitudes et du divées et on a évalué l'énergie des vibrations. On a trouvé que les vibrations rectangulaires requierent des intensités moins élevées de champs électrique et des niveaux plus bas d'énergie que les vibrations exponentielles, pour produire un même effet. Les muscles de carrelet out réagi aux forces de champs basses que les muscles de morve. Une examination des paramètres des vibrations employées dans des expériences récentes de la pêche électrique a mortré qu'ils étaient des stimuli relativement faibles.

Introduction

Observation of the reactions of fish to pulsed electrical stimulation suggested that the muscles of the fish were stimulated directly, each pulse producing a muscular twitch (Stewart, 1977). Experiments were performed in the Marine Laboratory to investigate this possibility on samples of muscle from freshly killed fish. It was established that electric current pulses in sea water act directly on muscle fibres and induce contraction (Stewart and Wardle, 1979). This paper describes the experiments, and measurements are presented showing the degree of muscular tension produced by rectangular and exponential pulses in cod and plaice muscle over a range of values of pulse amplitude and duration.

The objective of this investigation was to define the parameters which would give effective muscular stimulation with minimum energy consumption. Sea water is highly conducting and to minimise power consumption in electrical fishing experiments pulsed stimulation is used (Sternin et al, 1972). In all recent experiments the pulses were generated by discharging a large capacitor into a sea water resistance, giving pulses with a sharp rise and exponential decay (Boonstra, 1975; Seidel, 1969). The energy E_p, contained in a single exponential pulse, with time constant τ and initial voltage V_o, developed across a resistance R, is given by

$$Ep = \int_0^{\infty} (V_o^2 \, e^{-2t/\tau} / R) \, dt = V_o^2 \, \tau / 2R$$

To minimise the power requirements of an electrical fishing system V_o and τ should be as small as possible. The power consumption is also directly proportional to the pulse frequency. Ideally, the frequency of stimulation should be as low as possible and in experiments conducted during the last decade this parameter has been determined by behavioural observations (Boonstra, 1975; Stewart, 1977).

Experimental Procedure

Samples of muscle, about 5cm x 2cm x 1cm, were taken from freshly killed cod or plaice, about 30cm in length and mounted in a framework designed for isometric tension measurements. A small initial tension of 2-3g was applied to each muscle sample to ensure firm mounting. The framework and sample wereimmersed in a 0.2N saline solution between parallel plate electrodes 13.2cm apart, the electric field being at right angles to the muscle fibres. Test pulses were applied to the plates causing the muscle to develop tension. This tension was detected by a strain gauge the output of which was taken to a chart recorder. Tensions up to 50g were produced.

For each selected pulse width (or time constant in the case of exponential pulses) the tensions produced by single pulses of different amplitudes were recorded. Pulse amplitudes were measured in terms of electric field strength at the muscle. For exponential pulses the amplitude was defined as the peak pulse height. The measured tensions were expressed as percentages of the maximum tension developed in the muscle by a pulse of the same width. The maximum tension declined with activity and had to be remeasured at intervals. The measured tensions were thus compared with a progressively declining maximum value. Measurements were made with pulses varying in width from 20 µs to 30ms and with electric field strengths up to $550Vm^{-1}$.

Results

The measured values of muscle tension produced by pulsed electrical stimulation are shown in Figures 1 and 2 for plaice muscle and cod muscle respectively. Pulse amplitude (in Vm^{-1}) is plotted as a function of pulse width T, or time constant τ (in ms) for 0% (threshold), 25%, 50%, 75% and 100% (maximum) values of muscle tension. These graphs are produced by combining measurements made on several samples of muscle taken from more than one fish. There is some scatter in the results and the curves are drawn to give the best fit. In Figure 3 the data for exponential pulses for cod muscle and plaice muscle are combined to simplify comparison. On the same figure the parameters of the pulsed stimulation used in recent electrical fishing experiments on flatfish are shown (Boonstra, 1976; Neve, 1978; Stewart, 1977 and 1978). The electrical field distributions around practical electrode systems are highly non-uniform containing regions of high and low field strength. The electrical field values shown for the fishing experiments are the approximate mean field strengths in the plane of the electrodes. This factor was selected as suitable for assessing the effect of bottom-contact electrode arrays on flatfish.

Pulse energy was calculated for several of the cases in Figures 1 and 2. The quantities $T.E^2$ and $\frac{1}{2}\tau.E^2$ are plotted in Figure 4 for rectangular and exponential pulses for cod muscle and plaice muscle. The ordinate is scaled in units of (Electric Field Strength $)^2$ x Time. To convert this to the pulse energy in Joules delivered to the saline bath and the muscle the multiplication factors are $6.5.10^{-4}$ and 3.10^{-7} respectively. These factors are calculated from the known dimensions and resistances of the system.

Table 1 presents data on the sample-to-sample variability of muscle tension and on the accuracy of the measurements. In Table 1a the variation of the initial maximum tension in the experimental samples is recorded and in Table 1b the tensions produced by repeated use of the same stimulus in 2 samples are given, corrected to allow for the decline in maximum tension.

Discussion

The measurements presented in Figures 1 and 2 show an inverse relationship between the pulse height and duration (or time constant). As the pulse duration is increased smaller pulses can produce a given level of tension. When the pulse length reaches the region of 3-20 ms (approximately) the curves tend to become parallel to the abscissa. This effect has been recorded in classical experiments on muscle reaction. For both species of fish there is a distinct difference between the results obtained using rectangular and exponential pulses. At short time constants exponential pulses require significantly higher pulse heights to produce the same values of tension. At longer pulse durations the curves for the two pulse shapes tend to converge. Minimum pulse energy should occur around the knee of each curve and in Figure 4 several of the pulse energy curves have minima. There is too much scatter in the data for specific conclusions to be drawn concerning the optimum pulse characteristics for minimum energy consumption. The data in Figure 4 suggest that for the measurements on cod the rectangular pulses were more efficient than the exponential pulses in energy terms.

The data in Figure 3 suggests that plaice muscle is stimulated by lower field strengths than cod muscle. The experimental points from the electrical fishing experiments fit well into the data for plaice muscle. The same stimulation patterns would probably be ineffective if used on cod.

a.

Species	No of Samples	Tension	
		Mean	Standard Deviation
Cod	7	41.42g	5.26g
Plaice	10	27.59g	8.74

b.

Specimen	Field Strength	No of Tests	Tension	
			Mean	Standard Deviation
1	300 Vm^{-1}	9	39.06g	2.14g
1	150 Vm^{-1}	8	23.26g	1.21g
2	75 Vm^{-1}	9	12.74g	0.49g
2	38 Vm^{-1}	5	5.94g	0.12g

Table 1 a) Initial Maximum Tension measured in muscle samples.

b) Tension measured in two samples of plaice muscle when stimulated repeatedly by 30 ms rectangular pulses.

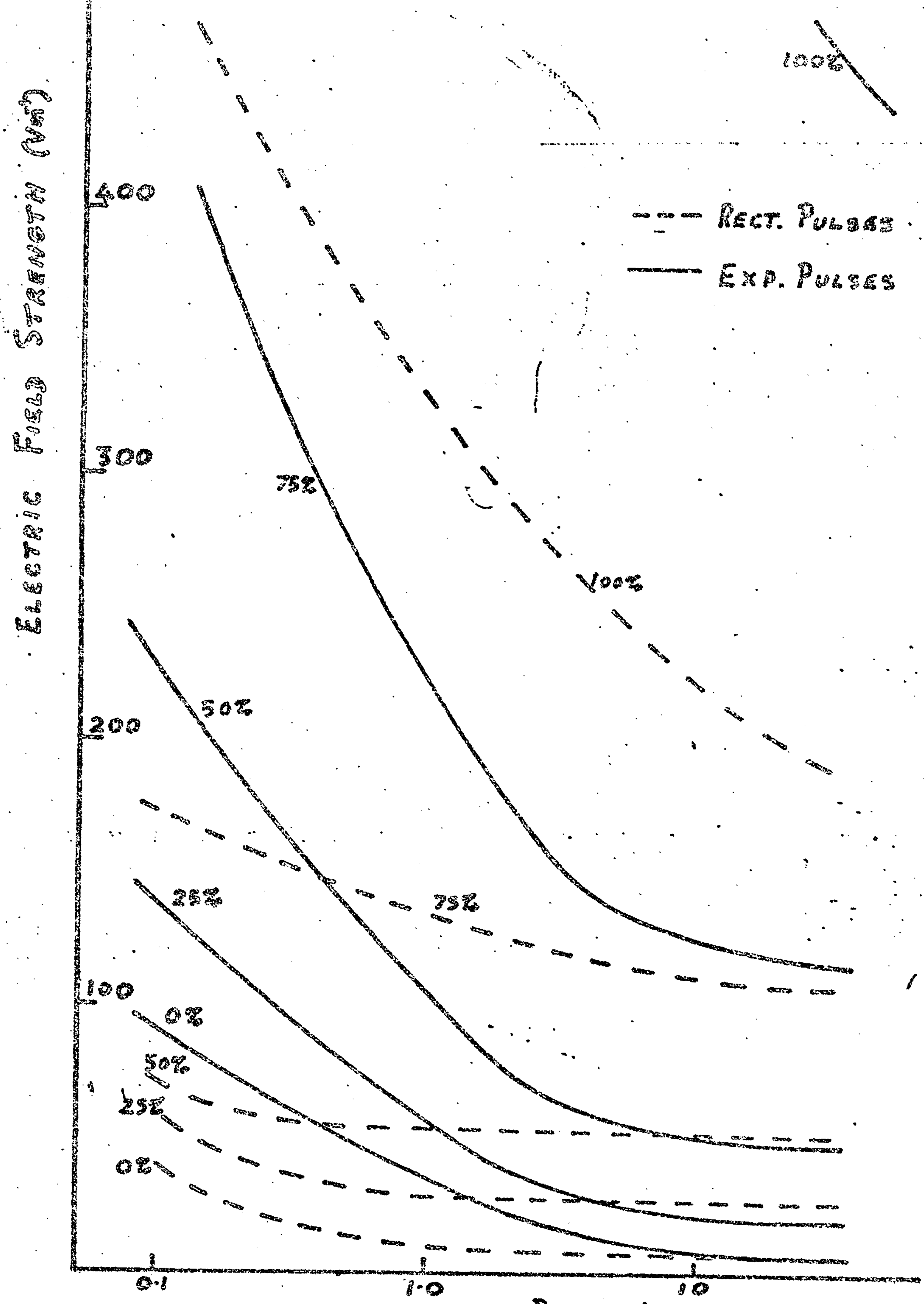

Figure 1 Electrical field strength as a function of pulse length required to produce various degrees of tension in plaice muscle.

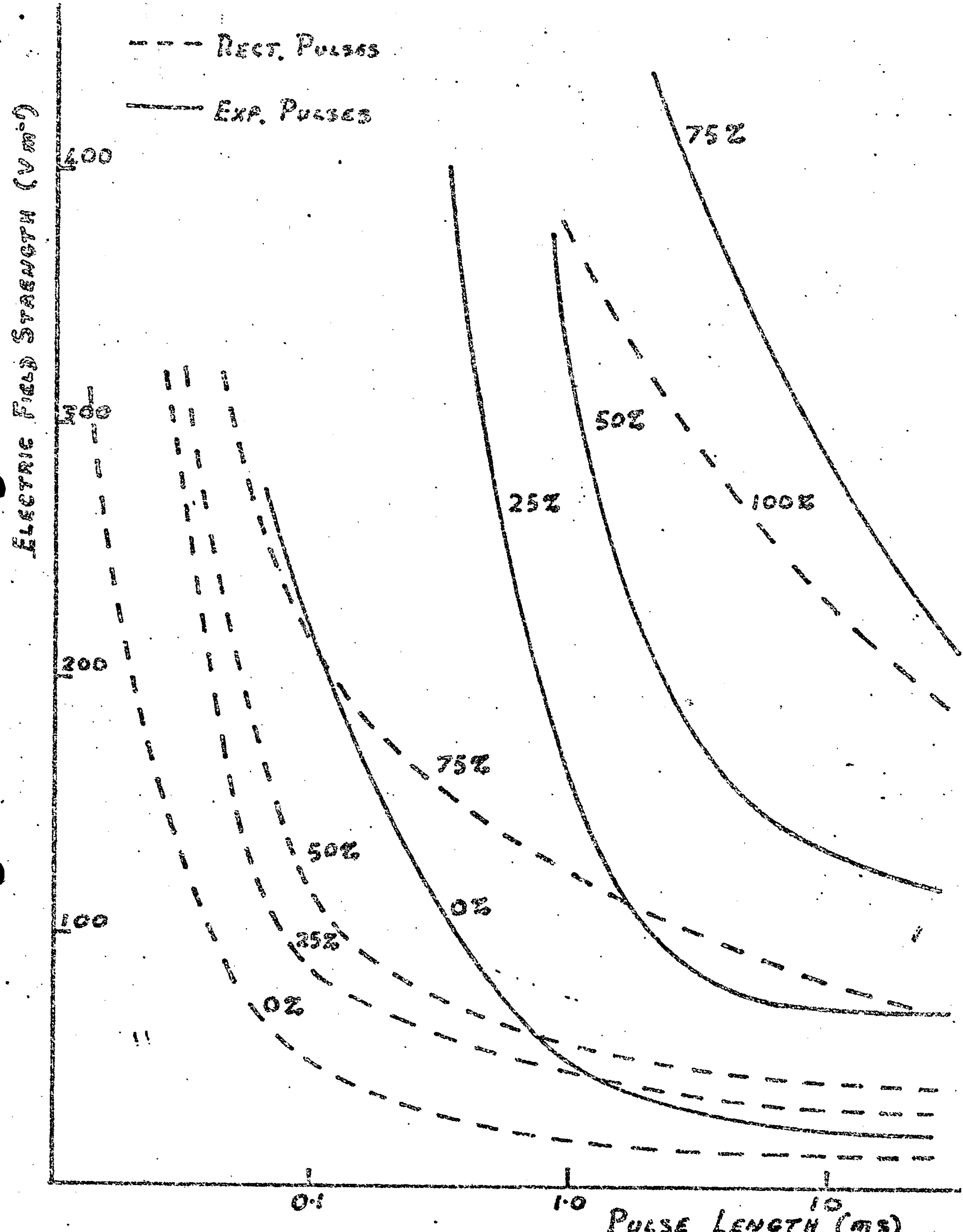

Figure 2 Electrical field strength as a function of pulse length required to produce various degrees of tension in cod muscle.

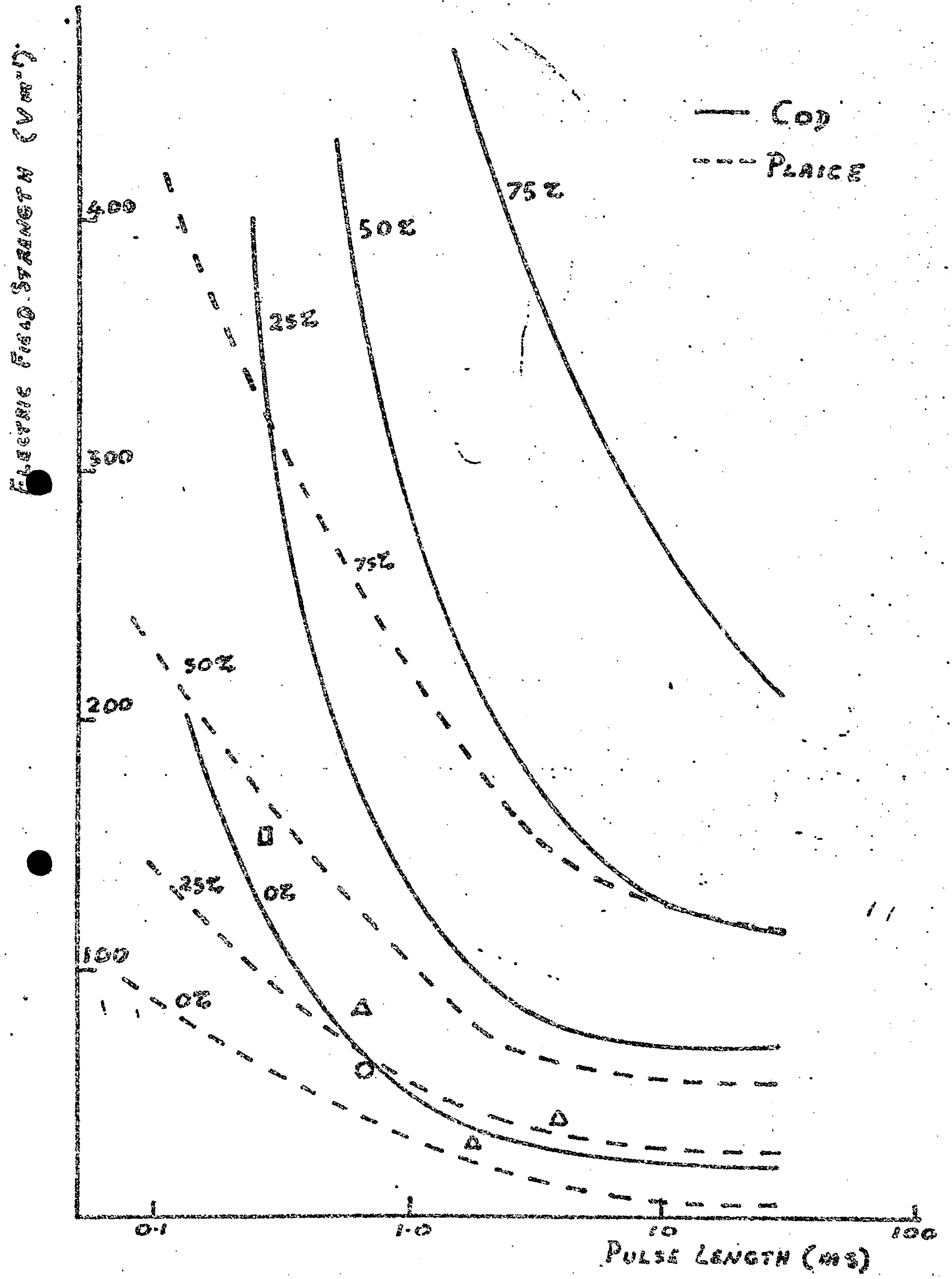

Figure 3 Electric field strength as a function of exponential pulse length required to produce various degrees of tension in cod and plaice muscle. (Experimental parameters: △ – Marine Lab., □ – WFA, O – RIVO

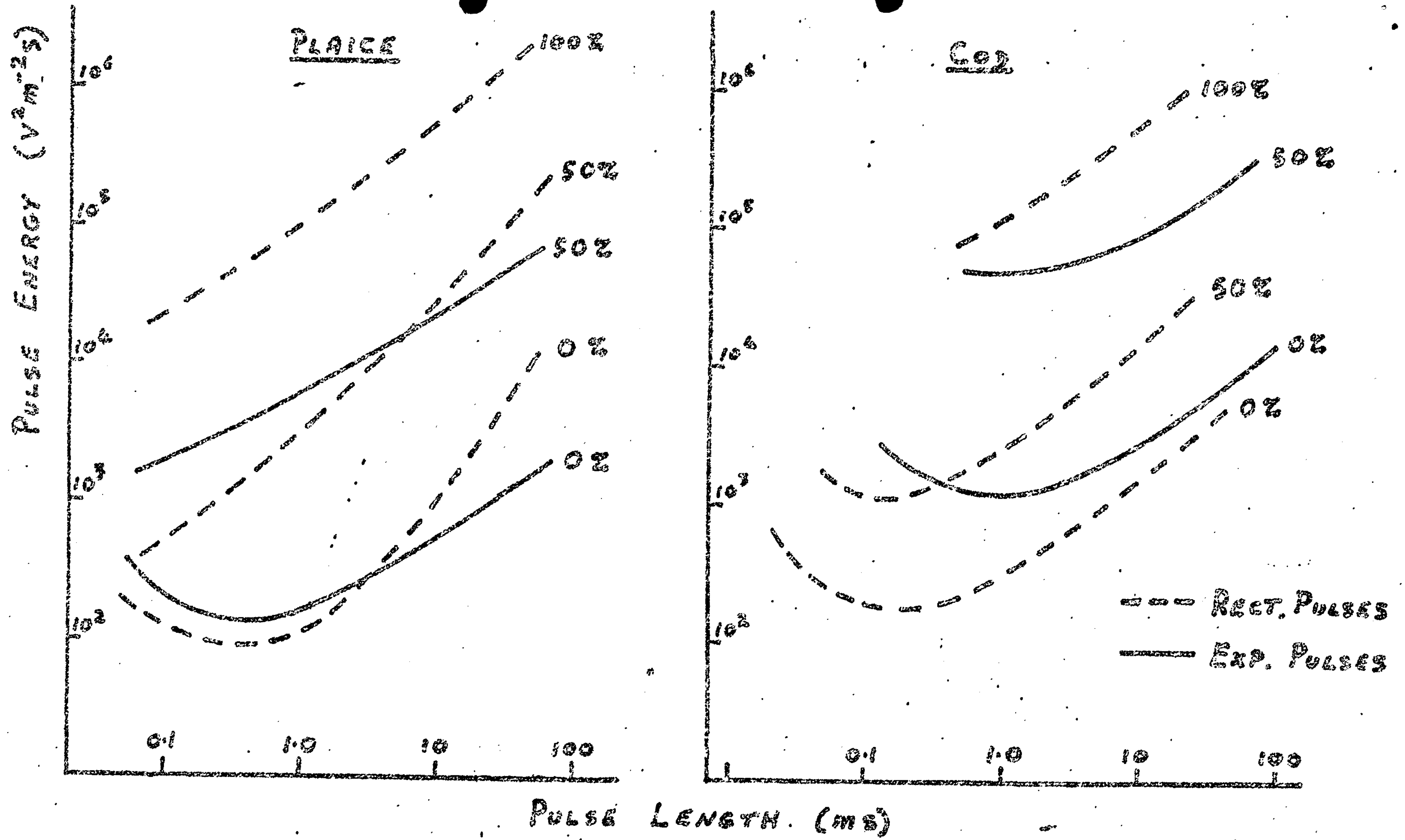

Figure 4 Pulse energy as a function of pulse length required to produce various degrees of tension in cod and plaice muscle.