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A SEARCH FOR SESR.(U)
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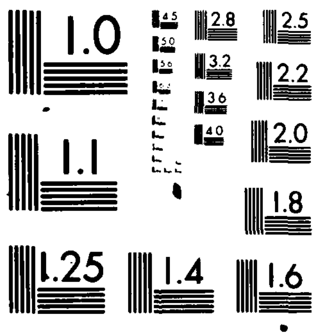

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Dielectric materials transparent at visible wavelengths are irradiated with relativistic electrons, with infra-red radiation from a ND:YAG laser, and with both of these radiations simultaneously. The radiation resulting from these interactions is observed, measured, and discussed in the light of recent theories.

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CONTENTS

A SEARCH FOR SESR

I. INTRODUCTION

A continuous spectrum of electromagnetic radiation is produced when electrons traverse a dispersive medium at speeds exceeding the speed of light in the medium. This phenomenon is the well known Cerenkov Effect and has been studied extensively (1). On the other hand, a discrete spectrum is produced when electrons travelling in vacuum encounter intense laser light (2). Although these are two unrelated phenomena, Schneider and Spitzer (3) have claimed that, for relativistic electrons interacting with coherent polarized electromagnetic waves in a weakly dispersive medium, the two effects act synergistically to produce Stimulated Electromagnetic Shock Radiation (SESR). They claimed that SESR is a tunable, narrow-band radiation; that its intensity is highly enhanced over that of Cerenkov radiation; that its intensity peaks as the electron speed crosses the Cerenkov threshold. Subsequent work disagreed with many of these conclusions. Kroll (4) obtained no enhancement. Zachary (5) obtained enhancement near threshold, but this result may be an artifact of a first order approximation. Soln (6) also used first order and obtained some enhancement at threshold. Becker (7), who used a quantum approach and calculated to all orders, obtained no significant enhancement of Cerenkov type radiation, but reported enhancement of the high intensity Compton Scattering over that in vacuum.

In the Spitzer-Schneider approach, the E-field of the polarized coherent wave (produced by a laser or magnetic wiggler) produces an oscillating transverse component in the motion of the electron through the medium, and thereby endows the electron with a radiation field in addition to its normal

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Coulomb field. The polarizable charges in the medium respond collectively to these two fields, the one producing SESR and the other, Cerenkov Radiation. At a given wavelength, the wave fronts of the two radiations form a conical surface moving with the electron (Figure 1). The half angle of the cone is given by

$$\sin\phi = \frac{1}{\beta n} \tag{1}$$

where n = refractive index at the given wavelength
and β = the electron speed in light speed units

According to Schneider and Spitzer, the frequency of the SESR radiation is given by

$$\nu_s = \nu_o \frac{1 + \beta n_o}{\beta^2 n_s^2 - 1} \tag{2}$$

where ν_o = the frequency of the incident radiation
n_o = the refractive index at the incident frequency
n_s = the refractive index at the SESR frequency

The goal of this experiment was the verification of the existence of SESR and the study of its potential use as a source of intense, tunable, coherent radiation. Parameters were selected to place the radiation in the visible spectrum.

II. THE EXPERIMENT

The experiment was performed in two stages. Initially, a qualitative search was made for gross effects. When none was observed, more precise, quantitative work was undertaken. In the first stage, targets were made of various transparent glasses; the differing dispersion curves were to produce different SESR frequencies. The targets were in the shape of disks, beveled on edge, set in conical mirrors (Figure 2), and centered in a scattering chamber. The angles were selected to permit Cerenkov and SESR light to exit the disk after several internal reflections and to strike the mirror. The mirror would then direct the light in directions parallel to the electron drift motion. The scattering chamber was located in one of the beam lines of the NRL Linac. The experimental layout is shown in Figure 3. The dotted

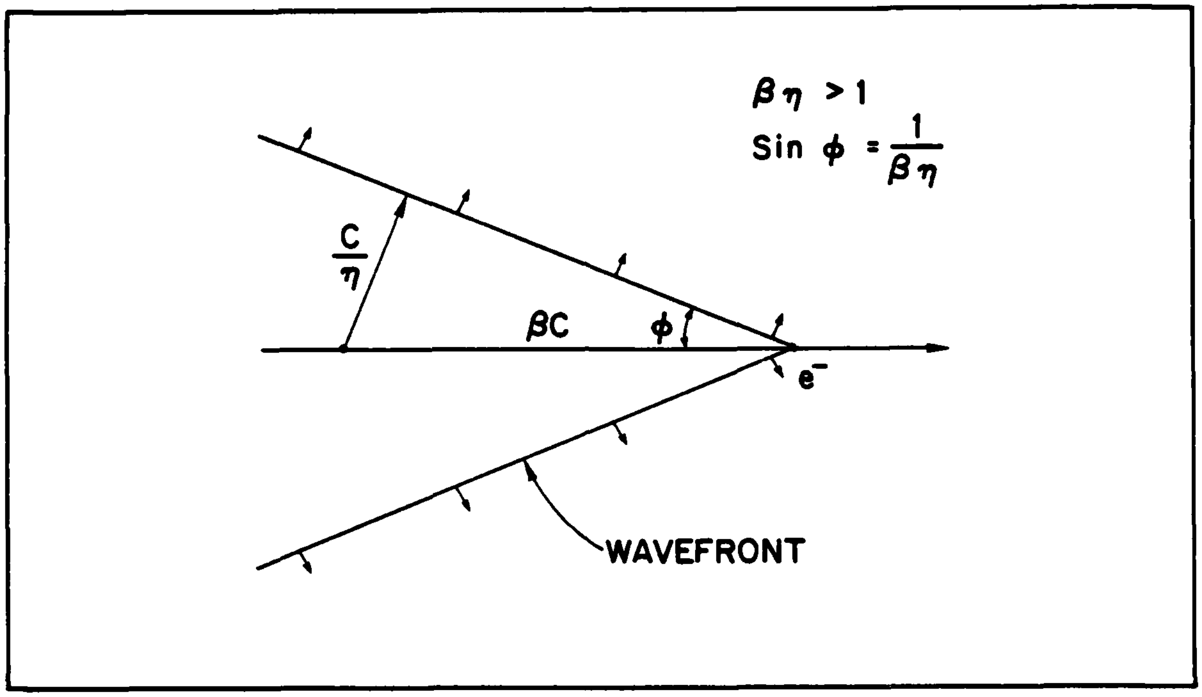

Fig. 1 - The Cerenkov wavefront

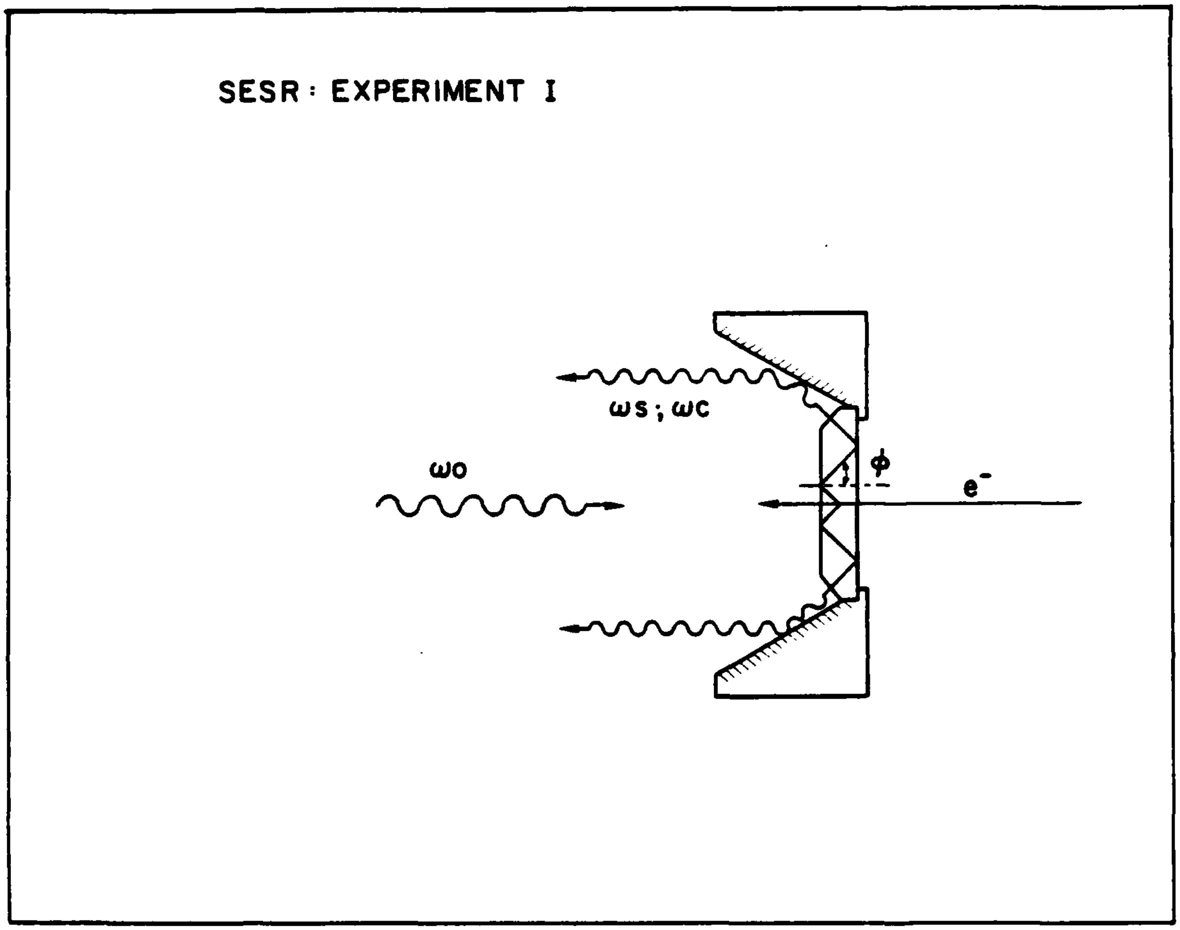

Fig. 2 - The target/mirror combination. The mirror diameter is of the order of 1 inch.

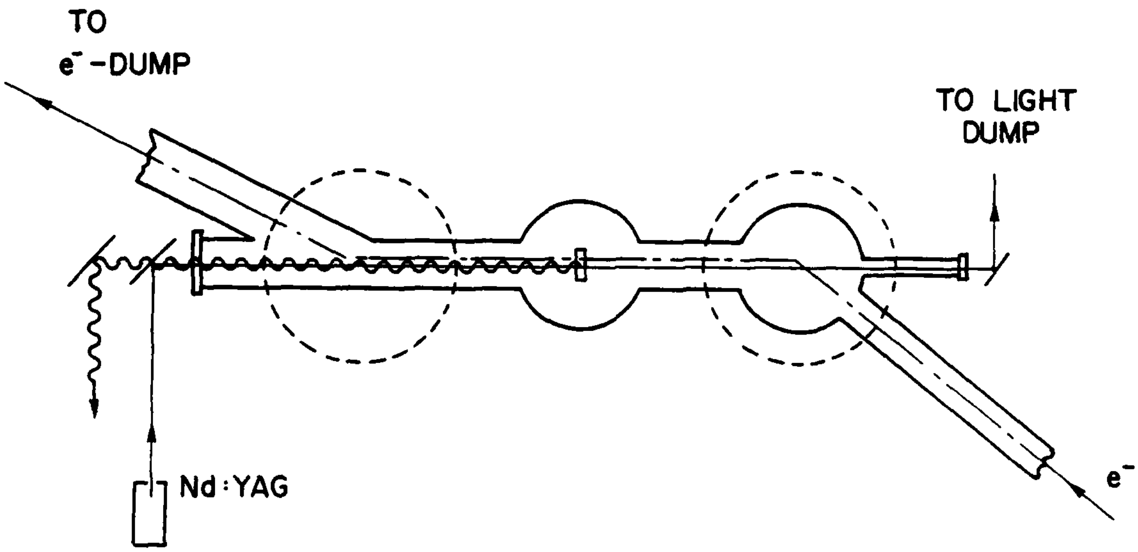

Fig. 3 - The experimental arrangement

circles represent deflection magnets which guided electrons into and then out of the optical path. The beam dump contained the radiation from the electrons and also served as a Faraday cup to monitor the current. A Quanta-Ray Nd:YAG pulsed laser was the source of 1.06 μm coherent radiation. A harmonic beam splitter directed the beam through a quartz window, into the evacuated line, to and through the target. The beam then passed through an exit window to an absorber. The sought-for light from the target was to pass back through the entrance window, through the beam splitter, to a mirror, to a TV camera. The camera was part of a Panasonic closed-circuit color TV system. Light from the disk was observed when the disk was irradiated by electrons alone as well as with both electrons and laser beam superposed. The electron pulses were varied in duration from 0.1 μsec to 1.0 μsec. Each consisted of a train of 1 cm long packets spaced 10 cm apart. The beam spot on target was about 1 mm to 2 mm in diameter; and the current in the micropulse was of the order of 50 mA. Each laser pulse had a 10 nsec duration, an energy of about 0.7 J, and a spot size of about 0.7 cm in diameter. The two beams were synchronized at a repetition rate of 15 Hz utilizing the linac control circuitry and the pulser network shown in the block diagram of Figure 4.

Approximately every 77 msec, the master timer of the linac gave a pretrigger pulse to initiate the timing sequence. This pulse triggered both pulsers I and II. The output of pulser I fired the flashlamps of the laser. The rest of the circuitry triggered the Q-switch of the laser 250 μsec later, but pulsed the electron gun of the linac a few microseconds earlier than that to compensate for delays in the control circuitry. In order to reduce jitter while achieving the above, the outputs of pulser II were made 1 msec long. The positive output gated pulser III which was set at a repetition rate of 10 MHz. The 10 MHz output was directed to the scaler which was preset to make 2500 counts approximately equivalent to 250 μsec. At the end of the 250 μsec counting interval, the preset scaler sent a signal to both the pulser IV (which fired the Q-switch after an adjustable delay) and the linac master timer which then pulsed the electron gun. In the meantime, the negative output from pulser II was differentiated; and, together with the gate generator, the differentiated pulse provided a reset pulse to the preset scaler. The system was thereby prepared for the next

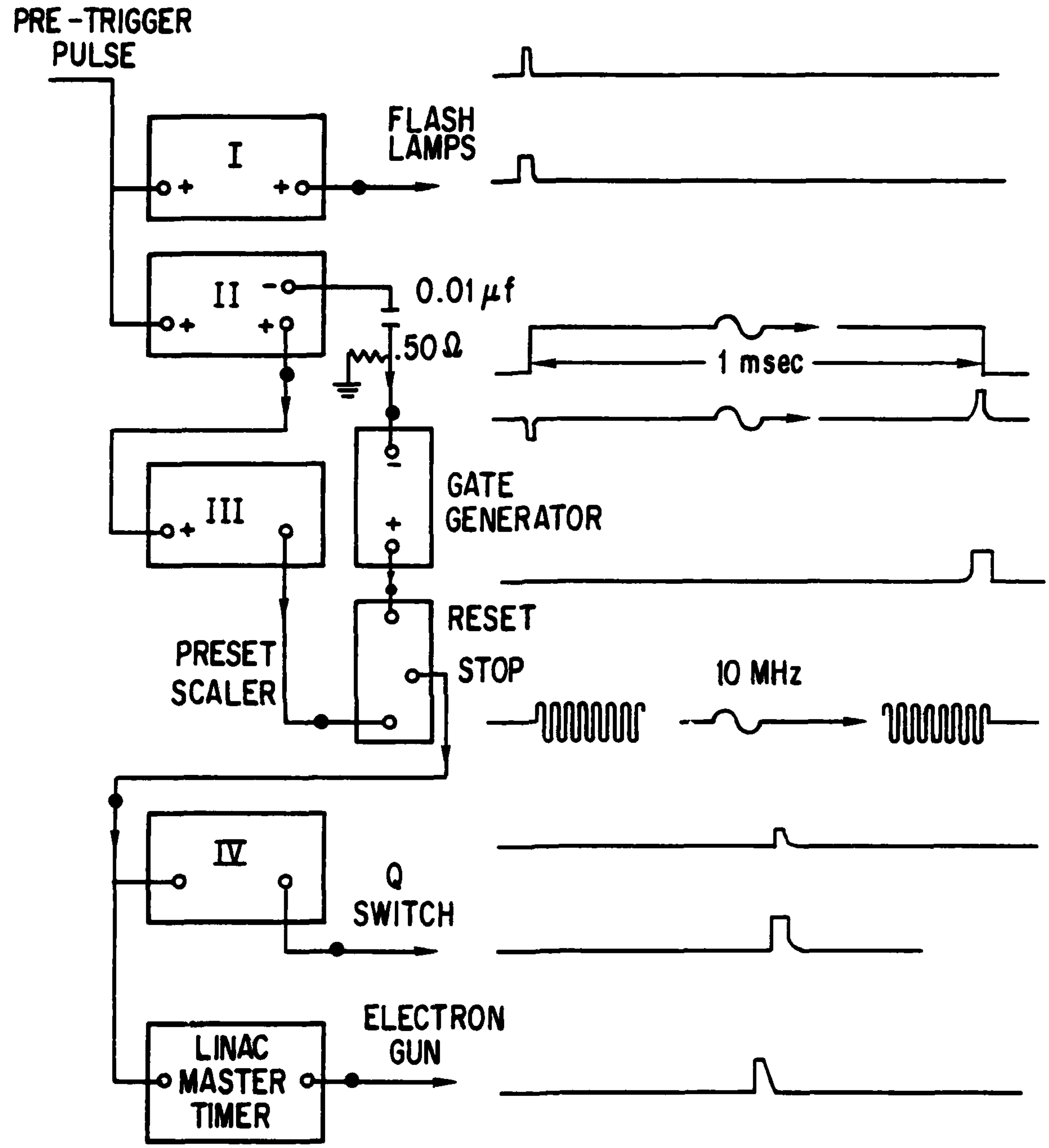

Fig. 4 - Block diagram of the control circuitry and time sequence of the pulses

sequence of events. A multiplier phototube and a PIN photodiode, observing both Cerenkov radiation and scattered laser light from the target, were both used to aid in the timing adjustment for simultaneity.

In the quantitative experiment, spectra were measured. The medium, fused silica, was formed into a strip (6 in. long by 0.625 in. wide by 0.125 in. thick) to serve as both target and light pipe. At the target end, it was rounded, and the edges were silvered. At the upper end (where it passed through a slotted flange from vacuum to air), the strip was given an inverted-vee structure to enable the exiting of the internally reflected light. An aluminum reflector directed the exiting light to the entrance slit of an Oriel 7241 Monochromator. A lead-shielded Amperex XP-1110 multiplier phototube was coupled to the exit slit of the monochromator. See Figure 5. In the various runs, the electron pulses were adjusted to have lengths of either 0.1 μsec or 0.2 μsec, and they were generally triangular in shape. A Quantel YG481 Nd:YAG laser system supplied the coherent radiation. Its pulses (monitored with a Scientech 362 Power Energy Meter) were 15 nsec long, had an energy of 0.8 J, and a repetition rate of 15 Hz. The network to achieve simultaneity was similar to that in Figure 4 with but one modification. One additional pulser was used to initiate a 45 msec interval during which a condenser bank in the laser was charged. A Keithley 610CR Electrometer monitored the current to the electron beam dump. A voltage to frequency converter digitized the output of the electrometer. A TSI 1535 Scaler registered the output of the converter. The output of the multiplier phototube was integrated using an Ortec 113 Preamp (modified to provide a 7 μsec time constant) and was then amplified by a Canberra 1412 Research Amplifier and fed to an 80 MHz ADC. The output of the latter was registered in a second TSI 1535 Scaler. The arrangement is diagrammatically outlined in Figure 6. For each run, the counts in the two TSI scalers were taken as proportional to the number of electrons traversing the target and the number of photons emitted by it, respectively.

III. RESULTS

For all measurements, the linac was operated at an energy of (37.0 ± 0.2) MeV and a repetition rate of 15 Hz. The lasers provided intensities

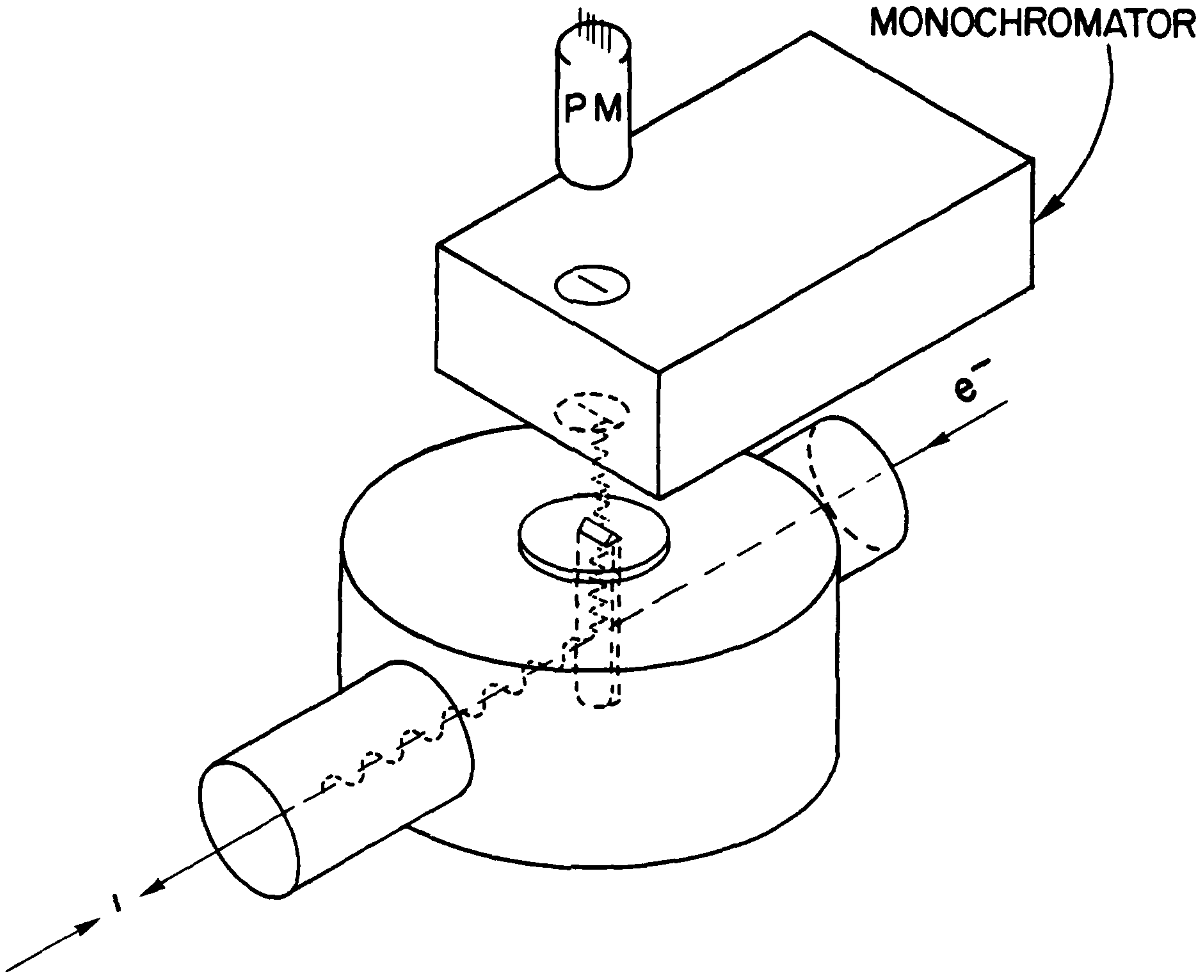

Fig. 5 - Layout of target chamber and monochromator

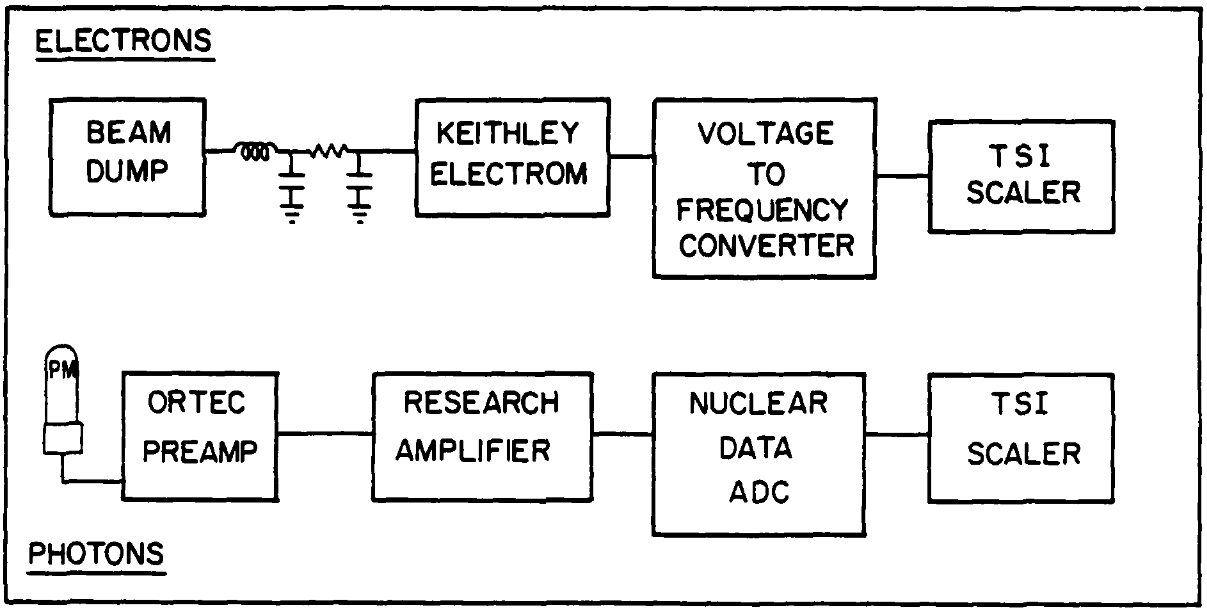

Fig. 6 - Block diagram of data collection system

of the order of 100 MW/cm2 in both experiments. In the first, target disks were made of several Schott glasses including BSC2, BK7G25, and F2G12 and also of Dynasil 1000 (a pure fused silica). Calculations for these materials yielded SESR wavelengths ranging from 495 nm to 715 nm. It was anticipated that when the target was irradiated by electrons, a ring of light would be observed by interposing a ground glass screen between target and camera. That such was not the case is most likely attributable to scattering in the target. With the camera focused on target, a bright ring of blue light was observed on the mirror with a width almost filling the mirror. A small central spot of blue light was observed at the point of electron beam impact. It was least intense for silica and was attributed to either surface contamination or phosphorescence. The ring was attributed to Cerenkov radiation from electrons experiencing some scattering. With only the laser beam on, no light was observed. With both beams on, there was no discernible difference in color or intensity of the observed light over what was seen with the electron beam alone.

In the second experiment, the monochromator and phototube were coupled to the strip target, and the slits were set to give a resolution of 3 nm full width at half maximum. Measurements were made at every 2.5 nm setting from 400 nm to 700 nm. No light was observed at any setting with only the laser beam on. With only the electron beam on, data were recorded at every 100 nm. The ratio of the two scalers (which is proportional to light yield per electron) was plotted as a function of wavelength and is given by the solid curve in Figure 7. The readings above 650 nm were averaged as a constant background, and that value was subtracted from each point in the curve. The result is the dotted curve in the same figure. The shape of this curve is strongly dependent on the responses of both the blazed grating in the monochromator and of the S11 photocathode. To transform the ordinates to spectral intensity, a calibration curve was obtained with the aid of a pre-calibrated 45 W tungsten lamp from Optronic Laboritories and the Keithley Electrometer. The resulting energy spectrum is shown in Figure 8. Superposed are circles representing the $\frac{1}{\lambda^3}$ shape characteristic of Cerenkov radiation. The good fit, and the fact that no light signal was observed on the oscilloscope outside of the 0.1 μsec window

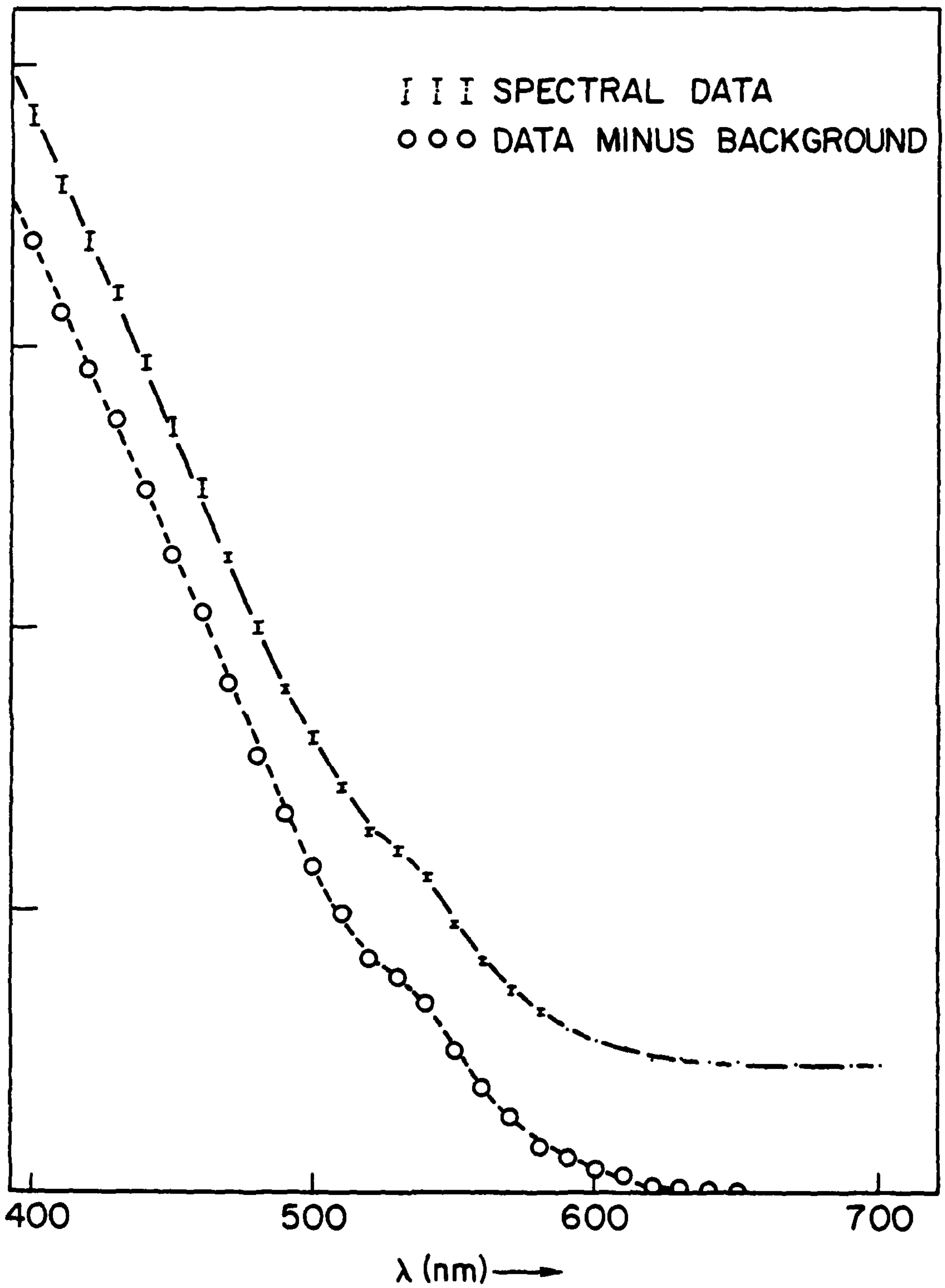

Fig. 7 - Light output versus wave length

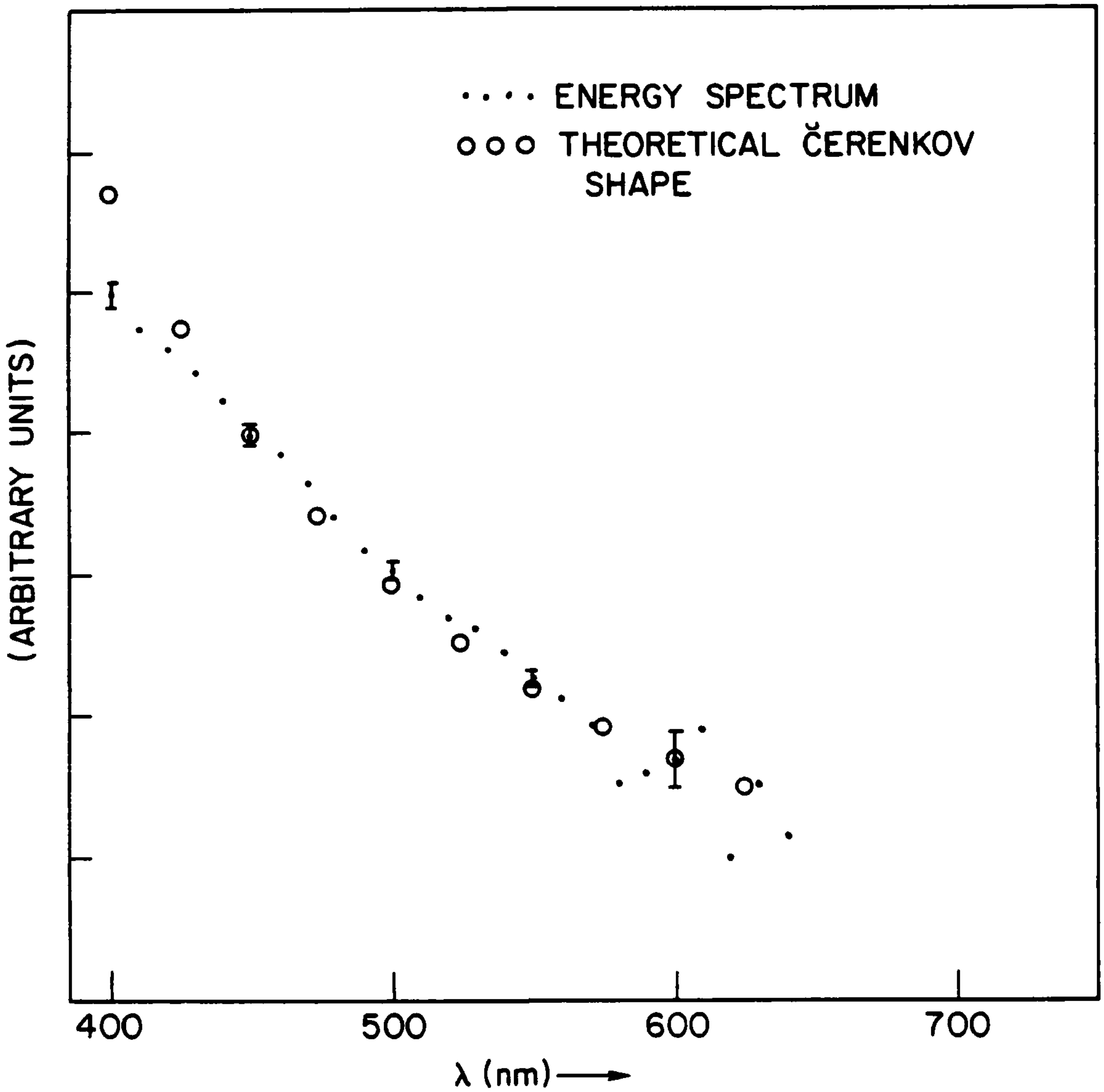

Fig. 8 - Energy spectrum of radiation emitted by irradiated target

during which the target was irradiated, is consistent with the conclusion that the observed light is due solely to Cerenkov radiation.

The electron beam and the laser were both turned on; and the laser was set to give an average power density in the spot on target of approximately 150 MW/cm^2. The ratio of light yield per electron with laser on to that with laser off was obtained at each 2.5 nm setting from 400 nm to 600 nm for several runs. For each measurement, oscilloscope traces corresponding to both light and electron pulses were observed; a measurement was rejected when a significant deviation from the mean correlated with electron beam changes and concomitant increases in background. Results are shown in Figure 9; error bars reflect statistical uncertainties only.

Using equation (2) and the dispersion curve for fused silica[8], the SESR wavelength is calculated to be

$$\lambda_s = 495\text{nm} \tag{3}$$

An examination of Figure 9 reveals no wavelength at which the ratio is inconsistent with unity. However, if SESR were present within 5 nm of the expected wavelength, an estimate can be made of its maximum possible intensity. The extremum of the error bars would yield a ratio of about 1.02. That ratio, the 10% overlap in time of the electron and laser pulses, and the triangular shape of the electron pulse combine to give a maximum intensity for SESR of no more than 10% of the Cerenkov intensity. If an error in the dispersion curve or a perturbation in the theory put λ_s somewhere from 450 nm to 550 nm, the experimental uncertainties would raise the SESR intensity estimate to no more than 20% of the Cerenkov intensity. It should be stressed that these estimates compare SESR to the Cerenkov intensity in a 3 nm bin at the same wave length. If SESR were in a narrow line the estimate would be much higher. In any event, for the parameters of this experiment, SESR, if it exists, is not a source of intense, coherent radiation.

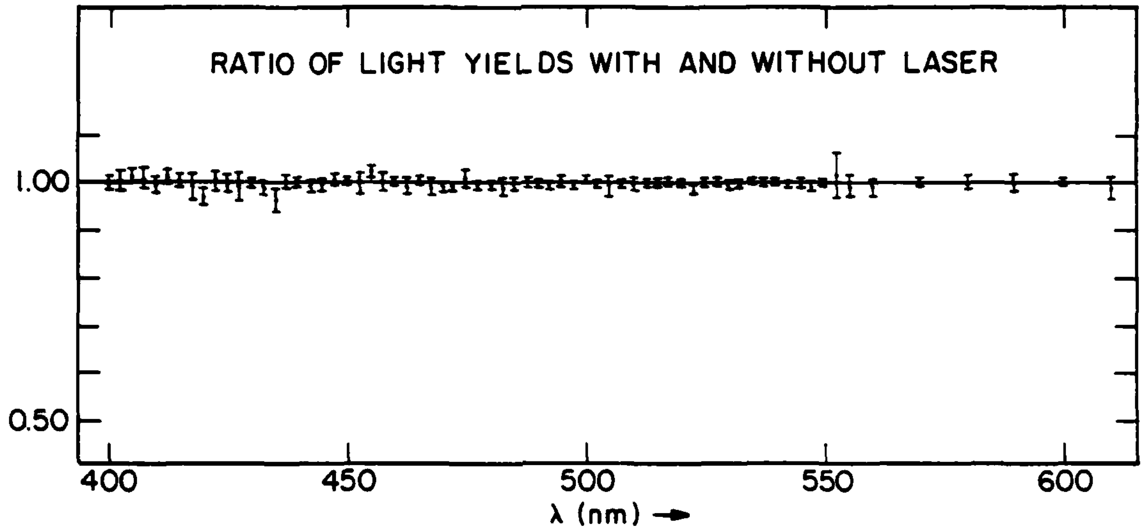

Fig. 9 - Ratio of light output of target irradiated simultaneously by laser and e-beam to output when irradiated solely by e-beam

IV. ACKNOWLEDGMENTS

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