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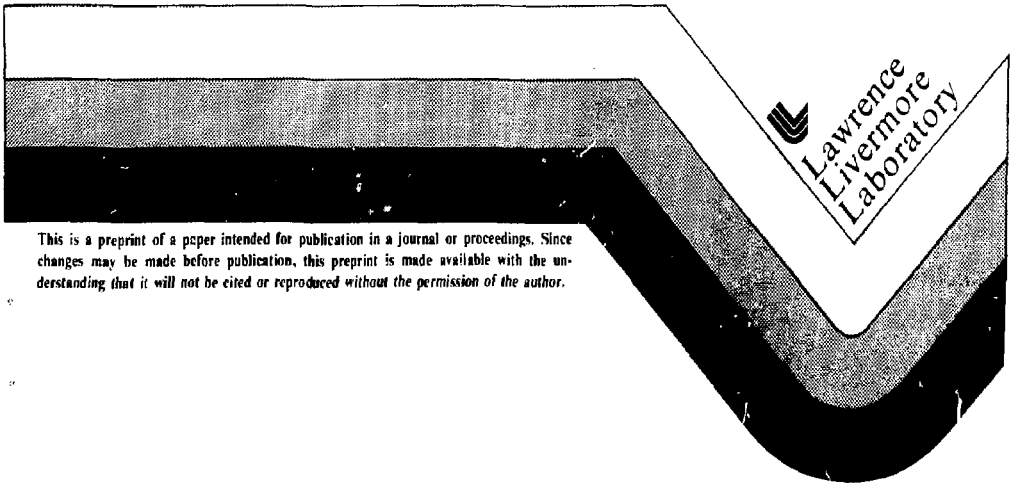
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DESIGN OF NEUTRON STREAK CAMERA  
FOR FUSION DIAGNOSTICS

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## DESIGN OF NEUTRON STREAK CAMERA FOR FUSION DIAGNOSTICS\*

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## I. Introduction

In laser fusion, such as with the NOVA under construction at the Lawrence Livermore National Laboratory, the D-T reaction is expected to be complete within 100 ps. It is important to measure the time-dependence of the neutron flux from the fusion target. We describe the design of a new neutron detector of 20 ps resolving time that can be used to study the "history of fusion burn."

## II. Neutron Streak Camera

The neutron streak camera is essentially the same as the optical or x-ray streak cameras except that (1) the cathode is sensitive to neutrons, and (2) the cathode is curved such that the difference in the neutron path lengths from a point source to various parts of the cathode is compensated by the electron transit time from the cathode to the focal point. In this way the cathode can be made large (several  $\text{cm}^2$ ) for high sensitivity without jeopardizing the time resolution.

The basic relation for compensating the transit time dispersion of neutrons with that of secondary electrons is shown in Figure 1. A possible configuration of the neutron streak camera is shown in Figure 2. The cathode is coated with  $1 \mu\text{m}$   $\text{UO}_2$  (or up to  $10 \mu\text{m}$  for higher detection efficiency, but with poorer time resolution). Each fission fragment leaving the  $1 - 10 \mu\text{m}$   $\text{UO}_2$  cathode generates 400-200 secondary electrons that are all less than  $20 \text{ eV}$ . The energy spread of these electrons are estimated to be  $\Delta E_e \approx 6 \text{ eV}$  FWHM. The electrons are focused at the first pinhole with the extractor and the anode, and are refocused with the first electrostatic lens at the second pinhole. The vertical deflector separates the electrons from surviving positive ions if any, due to  $0(n, p)$  and  $0(n, \alpha)$  reactions in the  $\text{UO}_2$  cathode. The electron beam can now be streaked and detected with the standard streak camera techniques.

The electron beam optics were computed with the GUNSLC code.<sup>2</sup> The result shows that with a 2 cm diameter cathode of 2.5 cm radius of curvature placed at 30 cm from a 14 MeV neutron source, and by focusing the secondary electrons at 3.7 cm at the first pinhole with a 10 kV extractor and a 30 kV anode, the neutron and electron transit time dispersions can be compensated to within 4.2 ps. However, the resolving time of the neutron streak camera is dominated by the following two factors.

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1.  $\Delta t_k$ , the transit-time dispersion<sup>3</sup> due to the electron energy spread  $\Delta E_e$ .  $\Delta t_k = 23000 \sqrt{\Delta E_e} / E = 11$  ps for the electric field  $E$  of 5000 V/cm at the cathode.
2.  $\Delta t_t$ , the electron transit-time differences in the cathode material. For 1  $\mu\text{m}$   $\text{UO}_2$ , this is 10 ps, assuming an electron scattered-limited velocity of  $10^7$  cm/s.

The overall time resolution of the neutron streak camera is then  $(4.2^2 + 11^2 + 10^2)^{1/2} = 16$  ps.

Using the above geometry, for  $10^{11}$  neutrons emitted isotropically from the point source, 31 fission fragments would leave the cathode, generating 12400 secondary electrons. However, in the ray trace with GUNSLC, the secondary electron angular spread was restricted to within  $\pm 10^\circ$  with respect to the normal to the cathode. Under this restriction, the transmission of the secondary electrons through the 0.2 mm first pinhole is 27%.

X-rays from the fusion target can be adequately shielded with a 1 cm W. A Monte Carlo calculation for the neutron transport shows that the neutrons inelastically scattered in the shielding into the cathode and the X-rays generated in the shielding contribute less than 1% background.

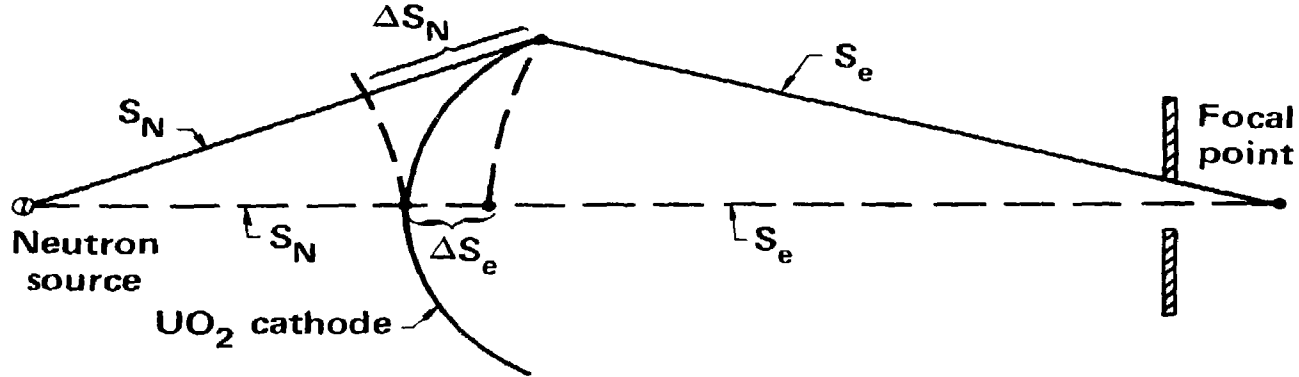
### III. Discussion

It is known that the optical streak camera works well at 80 cm from the target (outside the target chamber). With a reentry hole in the target chamber and with adequate shieldings for the electro-magnetic pulse (EMP) we expect the neutron streak camera to function properly at 30 cm from the target. We are planning an EMP shielding test with an optical streak camera. Should it prove necessary, the electron beam in the neutron streak tube can be guided out of the target chamber without difficulty. We expect the neutron streak camera to be a viable and unique tool for studying temporal history of fusion burns in D-T plasmas of a few keV ion temperature. For higher ion temperatures, the dispersion of the neutron energy due to Doppler broadening would require the streak camera to be placed closer to the target. How close it can be placed near the target and still remain operational can be answered perhaps only with experiments.

### IV. References

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# BASIC RELATION FOR COMPENSATING NEUTRON AND ELECTRON TRANSIT TIME DISPERSIONS



Let  $\begin{cases} \beta_N = \text{neutron velocity} \\ \beta_e = \text{electron velocity} \end{cases}$

Then  $\begin{cases} \Delta t_N = \frac{\Delta S_N}{\beta_N} = \text{neutron transit time dispersion} \\ \Delta t_e = \frac{\Delta S_e}{\beta_e} = \text{electron transit time dispersion} \end{cases}$

Choose  $\beta_e$  such that

$$\beta_e = \beta_N \frac{\Delta S_e}{\Delta S_N}$$

Then  $\boxed{\Delta t_e = -\Delta t_N}$

Figure 1

# A NEUTRON STREAK CAMERA

