γ

PREPRINT UCRL- 77072

CONF-751130--24

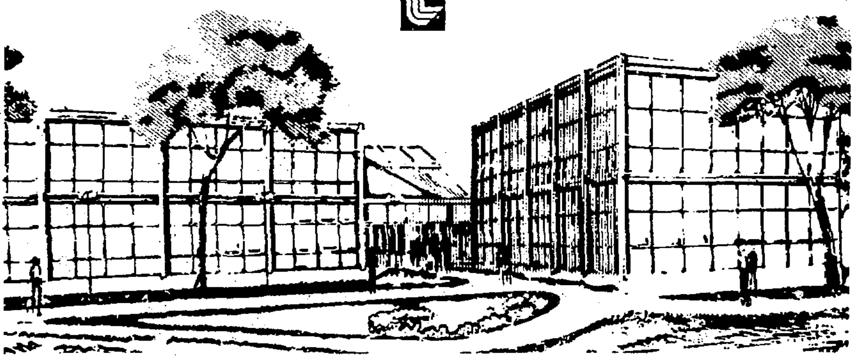
Lawrence Livermore Laboratory

Neutron Time-of-Flight Spectrometer for Laser-Fusion Experiments

R. A. Lerche, L. W. Coleman and J. W. Houghton

October 15, 1975

This paper was prepared for submission to the American Physical Society, 1975 Annual Meeting of the Division of Plasma Physics, November 10-14, 1975, St. Petersburg, FL.



MASTER

NEUTRON TIME-OF-FLIGHT SPECTROMETER FOR LASER-FUSION EXPERIMENTS*

R. A. Lerche, L. W. Coleman and J. W. Houghton
University of California
Lawrence Livermore Laboratory
Livermore, Calficrnia 94550

One of the immediate goals of laser-fusion research is to demonstrate conclusively the origin of the 14.1 MeV neutrons emitted from D-T targets that are irradiated and compressed by short duration, high intensity laser pulses. This can be accomplished directly by measuring the energy distribution of the D-T reaction neutrons. As shown in slide 1, the spectral shape is nearly Gaussian for neutrons generated in a plasma in which the particles have a Maxwell-Boltzmann velocity distribution. The line shape is square for a beam-target interaction. A recent investigation of the energy spectrum of the 3.52 MeV α particles from the D-T reaction in laser-fusion targets indicates that the ions are heated and interact within the glass microsphere and that the line width is comparable to that expected from a Maxwell-Boltzmann plasma with a temperature of approximately 3 keV[1]. The 100 μm size and subnanosecond interaction time of the laser-produced plasma makes possible the use of time-of-flight techniques to measure the line shape. In this talk, a neutron time-of-flight experiment which is designed to measure the 14.1 MeV neutron energy spectrum on a single laser shot will be described.

The basic concept of a time-of-flight spectrometer is illustrated in slide 2. The time t_0 of arrival of a particle with an energy E_0 that comes from a spatial and temporal point source is recorded by a detector located a distance D from the source. A small spread in source particle energies about a mean energy E_0 results in a time dispersion at the detector of Δt.

The constraints listed in slide 3 were used in the design of the time-of-flight spectrometer: 1) the total spectrum must be recorded on a single shot so that there is no question about the reproducibility of the plasma, 2) the spectrum should contain a minimum of 100 events, and 3) the system should be able to detect a neutron energy spectrum broadening ΔE of 150 keV FWHM, which corresponds to a plasma temperature of 1 keV. For example, for a collection time Δt of 5 nsec

*Worked performed under the auspices of the U.S. Energy Research and Development Administration. W-7405-Eng.-48

(corresponding to the FWHM of the signal) a 150 keV energy spread of the D-T neutrons requires a 50 meter flight path. The high count rate of 20 events/nsec suggests the use of an integral rather than counting type of detector.

The initial system design was done postulating the use of our standard neutron yield measurement detector shown in slide 4. It consists of an 18 cm diameter, 10.2 cm thick, NE-111 fluor coupled to an Amperex XP-2020[2] photomultiplier tube whose output is read on an oscilloscope. The package has a 50% efficiency and a time response Δt of 4.5 nsec FWHM. By using smaller fluors and photomultipliers a system response of about 3 nsec is possible but with a serious decrease in detector efficiency. To evaluate the TOF system energy resolution, the detector time response was folded with Gaussian energy distributions to obtain representative detector output signals. On slide 5, the line width ΔE of a D-T neutron source versus the time broadening of the detector signal above that of the system response is plotted for several target to detector distances. A minimum detectable signal change of 0.5 nsec implies that a 300 keV FWHM neutron pulse can be detected with a 10 meter system and a 60 keV neutron pulse width can be detected with a 50 meter system. On slide 6, the minimum detectable neutron line width which corresponds to a 0.5 nsec signal broadening is plotted versus the flight path length. Also plotted on the slide is the required number of source neutrons necessary for 100 neutrons to be detected by the 18 cm diameter fluor versus the detector distance assuming no signal attenuation. An energy spread of 100 keV is possible using a 30 meter flight path with 10^8 source neutrons. We have elected to build a 50 meter TOF flight system that will require a source strength of 2.5×10^8 neutrons but will be capable of detecting a minimum neutron energy spread of 60 keV.

The mean free path of a 14.1 MeV neutron in air is 130 meters and beam attenuation thru a thin aluminum vacuum window is several percent. For flight paths greater than 10 or 20 meters, it is advantageous to include an evacuated flight tube in the system to minimize signal attenuation. Without a flight tube on the 50 meter system, the signal is attenuated by 32%.

The discussion up to this point has considered only the detection of 14.1 MeV neutrons coming directly for the D-T plasma. It has not included the effects of neutron scattering by the air and ground or (n,n') and (n,γ) reactions with the various structures within the vicinity of the flight path. A Monte Carlo neutron-γ-ray transport computer code was used to examine the effects of neutron scattering and neutron reactions on the ratio of 14.1 MeV neutron events to the number of other events entering the detector fluor. First the scattering of neutrons emitted in the solid angle subtended by the detector was studied. It was found that the ratio of 14.1 MeV events to scattered events was 1000:1. Thus, even without the flight tube, beam scattering along the flight path is unimportant. Next, the effects of air scattering, shielding, and time discrimination on the signal to noise (S/N) ratio of the system was examined. The results for the 50 meter system are summarized in slide 7. For a system which contains only a source, a detector, and air, a signal to noise ratio of 3 to 4 is expected. The addition of a 1 meter thick, 1 meter radius H_2O shield 4 meters from the source results in an improved S/N ratio of 16. For the time-of-flight system, we are not interested in pulses which occur significantly after the arrival of the TOF-spread D-T neutrons, thus time discrimination may be used to eliminate some of the scattered events. For the air scattering case, if only background counts which arrive within 20 nsec of the 14.1 MeV neutron pulse are counted, the S/N ratio is 10. The time discrimination is approximately equivalent to considering scattering centers only in an ellipse in which the distance from the target to the ellipse surface to the detector is equal to the distance between the target and the detector plus the distance that the neutron travels in 20 nsec. For the case where shielding and time discrimination is used the S/N ratio increases to 55. The combination of shielding and time discrimination is quite effective in improving the system S/N ratio. In slide 8, the S/N ratio for a H_2O shield of constant size is plotted versus its distance from the target. The effectiveness of the shield is observed to be greatest for positions either very close to the target, or very close to the detector.

Additional physical constraints imposed by our irradiation facility which are listed in slide 9,helped determine the final design of the system and the location of our shields. They include 1) a meter diameter steel target chamber in whose walls 20% of the source neutrons undergo (n, n') or (n, γ) reactions, 2) a building wall and roof at about 7 meters and 3) additional scattering centers which are in the vicinity of the 50 meter flight path including the ground.

Sketches of the final system design are shown in slides 10 and 11. An H_2O tank 4M by 4M by 1 M thick at 45 meters was selected to minimize the effect of scattering from the ground, the building wall,and any structures that might be placed in the general vacinity of the detectors. Because of its proximity to the detector, collimation at this point would introduce unnecessary background events and the large aperture would not shield out the (n, γ) and (n, n') events that occur in the vacuum chamber wall 0.5 M from the target A second wall 10 meters from the target was added. The system aperture which is located at this wall presents less scattering problems than one located at 45 meters and effectively shields out n's and γ's produced in the steel chamber. To minimize the signal attenuation, a 45 meter flight tube evacuated to about 100 microns is provided between the target and the fluor. All air-vacuum interfaces including the chamber wall are provided with thin Al windows. The expected signal attenuation at the detector is about 10%. The resulting system is expected to have a signal to noise ratio greater than 100 for the time interval within 20 nsec of the arrival of the D-T neutrons.

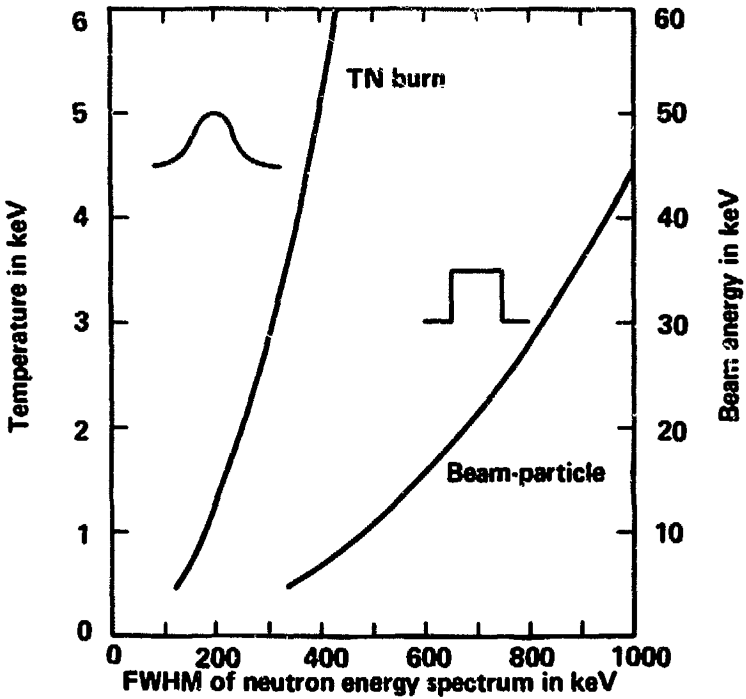
The true energy spectrum of the neutron source is obtained from the detector output recorded on an oscilloscope. The process is shown in slide 12. The output signal Y(t) is the convolution of the true signal y(t) with the system response R(t) to an impulse function. We have several computer codes which do the reverse process. That is, given a system response and a recorded signal, the true function y(t) is found. The true time distribution is readily transformed to an energy distribution. We expect to make our first energy spectra measurements in the near future and hope to be able to determine the origin of the D-T neutrons in our laser-fusion experiments.

FOOTNOTES

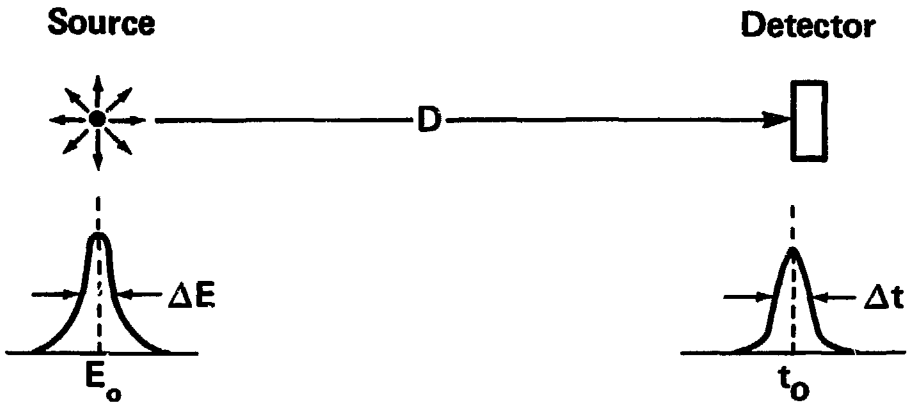
1. V. W. Slivinsky, H. G. Ahlstrom, K. G. Tirsell, J. Larsen, S. Glaros, G. Zimmerman, H. Shay, Lawrence Livermore Laboratory Report, UCRL 76938.

2. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research and Development Administration to the exclusion of others that may be suitable.

LINE BROADENING OF D-T NEUTRON SPECTRUM



TIME OF FLIGHT CONCEPT



$$t_o = D\sqrt{\frac{m}{2E_o}}$$

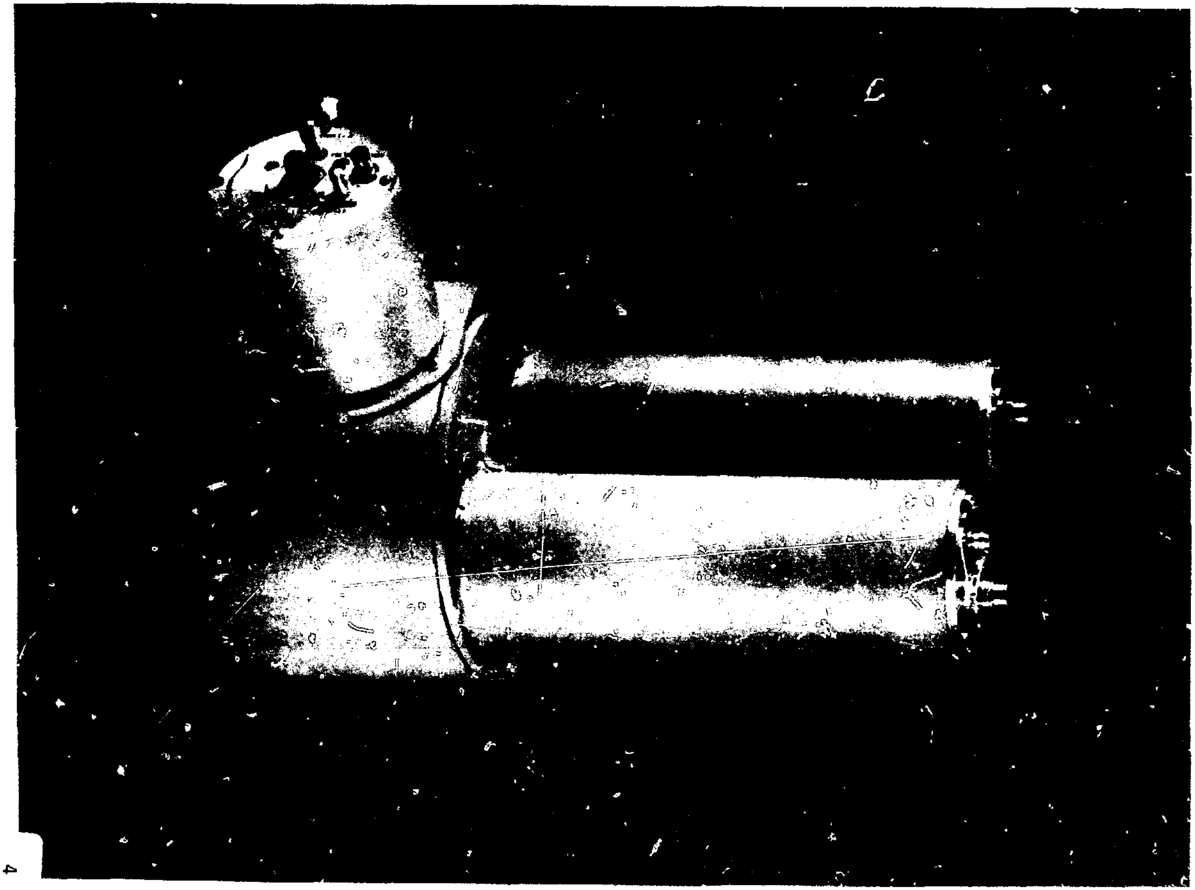
$$\Delta t = \frac{\Delta E}{2E_o} \cdot t_o$$

DESIGN CONSTRAINTS

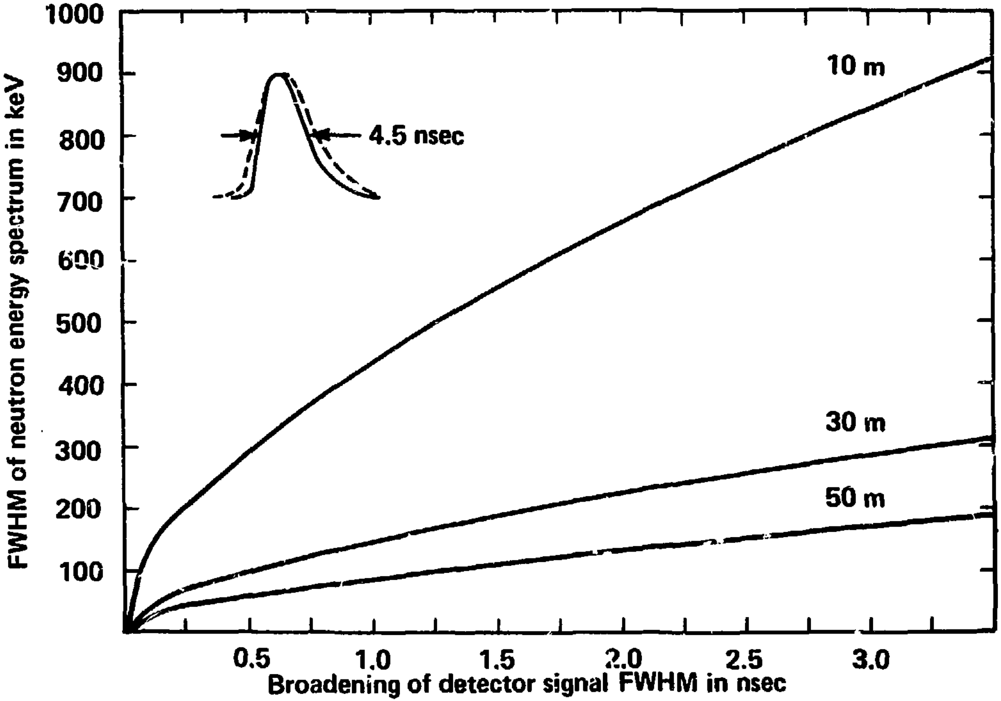
Total spectrum to be recorded on each laser shot

Energy spectrum should contain a minimum of 100 events

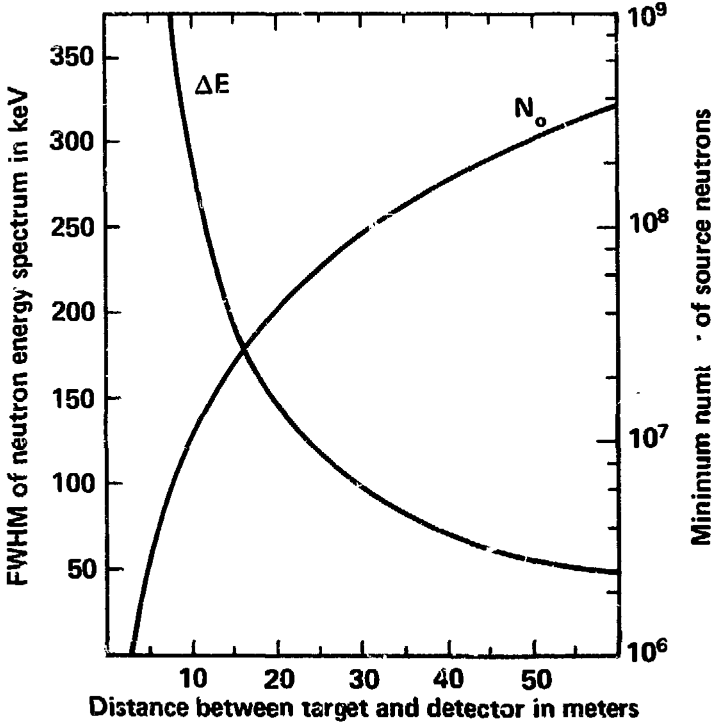
Spectrometer should be able to discern a neutron energy spectrum FWHM of 150 keV



WIDTH OF NEUTRON ENERGY SPECTRUM VERSUS DETECTOR SIGNAL BROADENING



MINIMUM DETECTABLE NEUTRON ENERGY SPREAD AND REQUIRED SOURCE STRENGTH

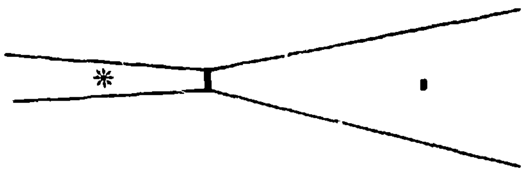


EFFECT OF SHIELDING AND TIME DISCRIMINATION ON S/N

A.

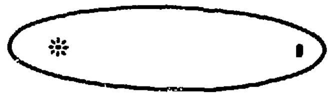
Air scattering S/N = 3

B.



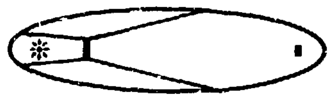
H_2O shield S/N = 16

C.



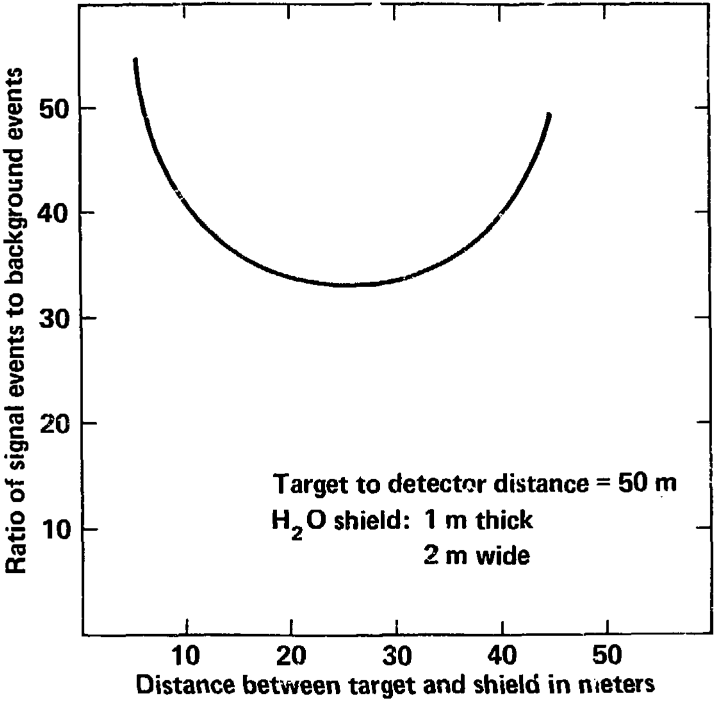
Time discrimination S/N = 10

D.



H_2O shield and time discrimination S/N = 55

EFFECT OF SHIELD POSITION ON S/N



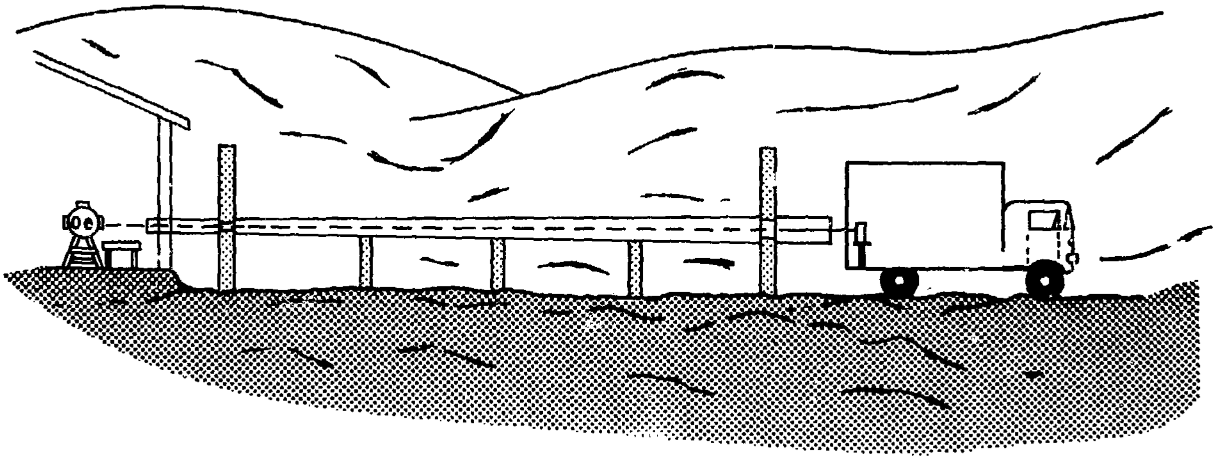
PHYSICAL CONSTRAINTS OF TARGET FACILITY

1 meter diameter steel vacuum chamber around target

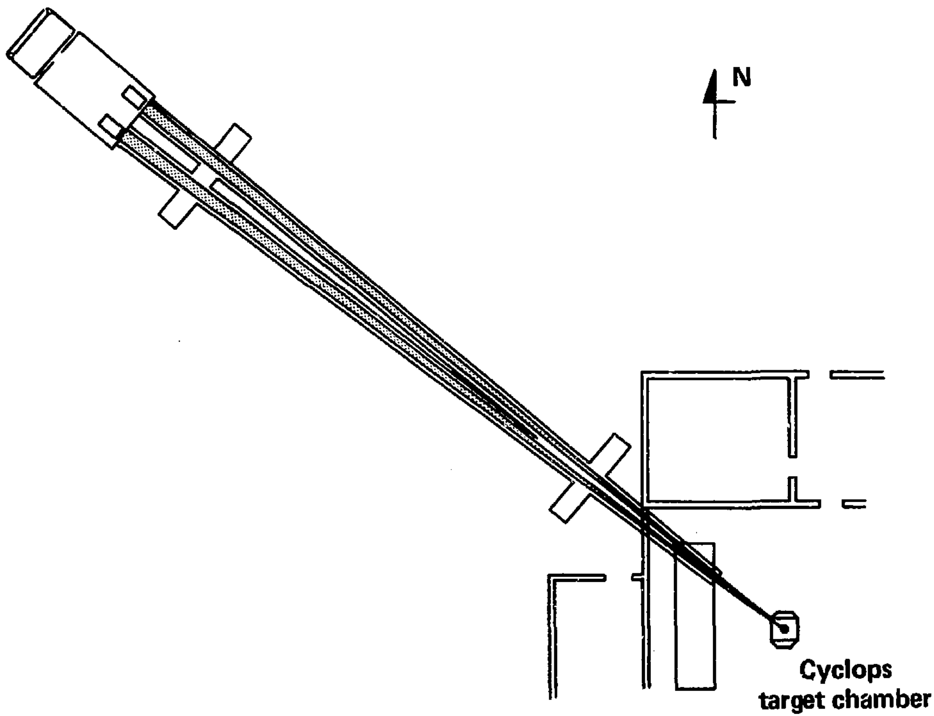
Building wall 7 meters from target along flight path

Many possible neutron scattering sites along flight path including the ground

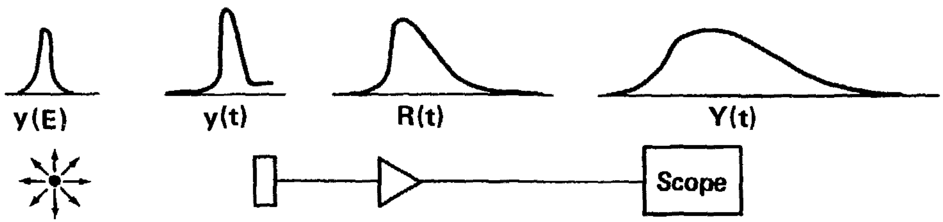
NEUTRON TIME-OF-FLIGHT SPECTROMETER



50 METER TIME-OF-FLIGHT SPECTROMETER



DATA REDUCTION



$$Y(t) = \int_{-\infty}^{\infty} y(\lambda)\, R(t - \lambda)\, d\lambda$$

1. Find y(t) given Y(t) and R(t)
2. Transform to y(E)