

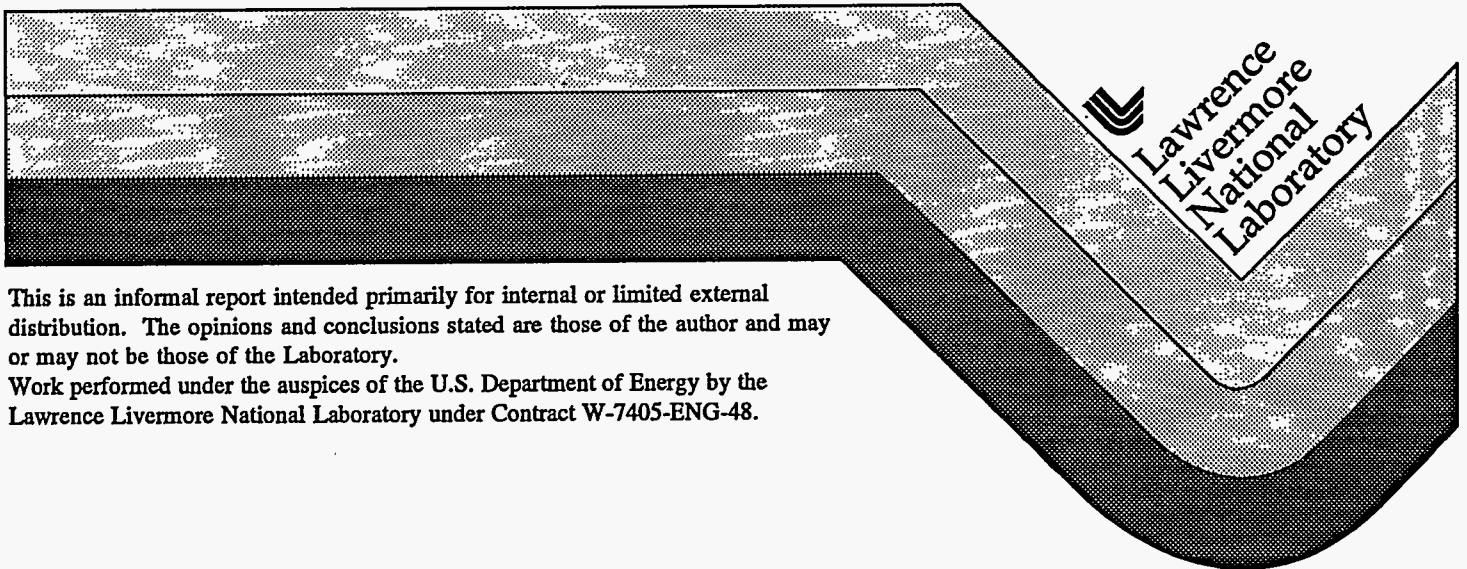
Pinex - The Pinhole Neutron Experiment

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November 21, 1958



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MEMORANDUM

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November 21, 1958

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SUBJ: PINEX, the PInhole NEUtron EXperiment

The pinhole neutron experiment is sometimes called "Pinex", a name which has also been used to describe the pin method of measuring the time required for imploding metals to travel to certain locations in space. The two experiments are not related and should not be confused with each other. The pinhole neutron experiment is very similar to the optical pinhole camera in which light on passing through a pinhole in an opaque screen produces an inverted image of the source.

In the pinhole neutron experiment 14 Mev neutrons from a thermonuclear device travel in straight lines from their respective points of origin outward in all directions. Those which pass through a pinhole in an opaque neutron shield make an inverted neutron image of the source. Some of the neutrons which form the image are captured by threshold detector plates which have been suitably located behind the pinhole. Neutrons which have sufficient energy react with the nuclei of the detector plate to form radioactive nuclei which by their decay locate the position of the image on the plate. The image may be made visible by autoradiography or by counting techniques.

In the autoradiograph, an x-ray film is placed in contact with the image plate. As the radioactive nuclei decay, they expose the film.



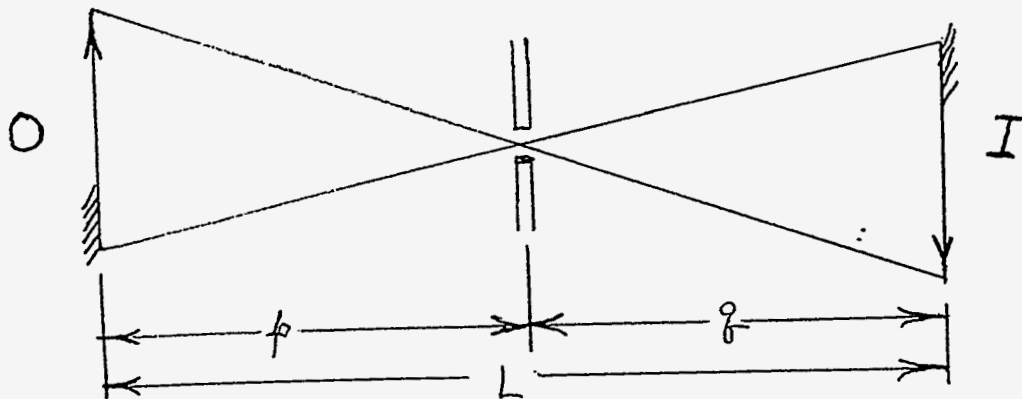
The image is visible when the film has been adequately exposed and developed.

In the counting method, the image plate is cut into small pieces; each the size of a resolution element. Each piece is separately counted. The number of neutrons causing its radioactivity is determined and plotted on a drawing of the plate. These numbers indicate the shape of the D-T plasma at the time of "burn".

It is the object of this paper to discuss the factors affecting the various parameters in the experiment and what information is required to optimize these parameters for a given set of conditions. Formulae are written in many alternative ways to emphasize the effect to be expected from a change in any one of the many parameters.

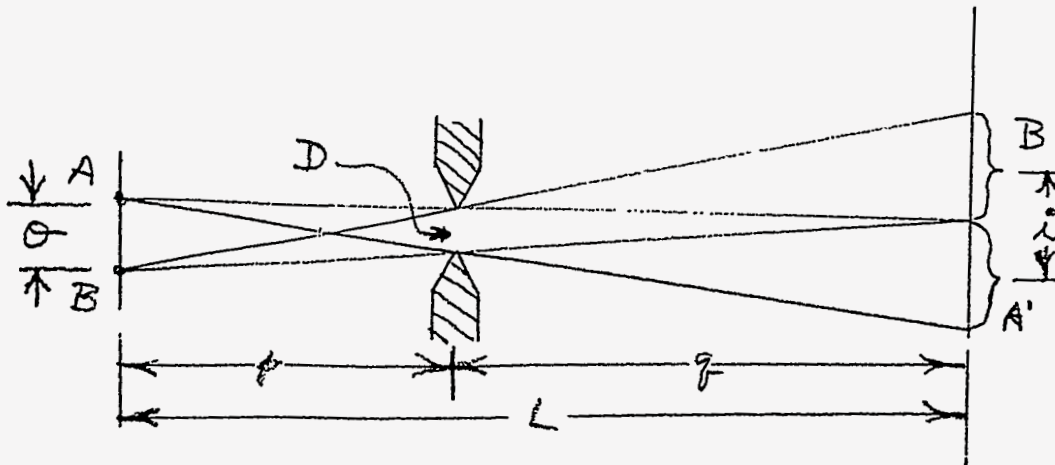
Consider an extended source which emits a quantity N_0 of 14 Mev neutrons. Let the source be a distance p from a pinhole in an opaque neutron shield. Let a threshold detector plate be placed so that a neutron image of the source is formed at a distance q from the pinhole. Then $L = p + q$ is the distance from the source to the image. As in optics, the magnification is given by

$$M = I/O = q/p$$



Let d equal the diameter of the circular pinhole.

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Consider two points A and B on the object. Point A transforms into the circle A^1 and point B transforms into the circle B^1 . A and B are just resolved if the circles are tangent. Let o be the distance between A and B, two points which are just resolved.

Let i be the distance between the centers of the circles A^1 and B^1 . Now the circles A^1 and B^1 have equal radii, so i equals the diameter of either circle.

∴

$$m = i/o = q/p$$

$$o = \frac{pi}{q} = i/m$$

Consider the similar triangles having a common vertex A and bases which are the diameter of the pinhole and the circle A^1 .

$$i/D = \frac{q+p}{p} = \frac{L}{p} = \frac{m+1}{p}$$

$$i = (m+1) D$$

Since $o = i/m$, then

$$o = \frac{m+1}{m} D = \frac{L}{q} D$$

$$\text{or } D = \frac{m}{m+1} o = \frac{q}{L} o = \frac{i}{m+1}$$

Hence, the diameter of the pinhole is fixed by the size of the resolution element and by the magnification of the system.

The fraction of the total neutrons which pass through the pinhole is determined by the solid angle subtended by the pinhole.

$$\Omega = \pi/4 \frac{D^2}{4\pi p^2} = \left(\frac{D}{4p}\right)^2 = \left(\frac{i}{4L}\right)^2 = \left(\frac{m_0}{4L}\right)^2$$

The neutrons are attenuated by the device, by the air or other medium, and by the blast shield placed in front of the image plate (detector plate). Let the fraction of the neutrons transmitted by these materials be respectively t_d , t_a , and t_s .

Then the number N_n of neutrons which pass through the pinhole and impinge on the detector plate is given by

$$N_n = N_o t_d t_a t_s \Omega$$

Let the product $t_d t_a t_s = t$

$$N_n = N_o t \Omega = N_o t \left(\frac{D}{4p}\right)^2 = N_o t \left(i/4L\right)^2 = N_o t \left(m_0/4L\right)^2$$

Before a device has been tested, the exact size and shape of the source of 14 Mev at the time of burn is not known. However, Φ , the average number of neutrons per unit area at the image can be obtained by dividing N_n by A_i the area of the image. A_i is the product of R the number of resolution elements times the area of one resolution element.

$$A_i = R \cdot \pi \frac{i^2}{4}$$
$$\Phi = \frac{N_n}{A_i} = \frac{N_o t \left(i/4L\right)^2}{R \cdot \pi i^2/4} = N_o t / 4\pi L^2 R$$
$$= \frac{N_o t}{A_i} \left(\frac{i}{4L}\right)^2 = \frac{N_o t}{A_o} \left(\frac{o}{4L}\right)^2 = \frac{N_o t}{A_i} \left(\frac{D}{4p}\right)^2$$

The number of neutrons per unit area is inversely proportional to the square of the distance between the device and the image plate and inversely proportional to the number of resolution elements into which

the device has been divided.

The number of neutrons per resolution element may be found by noting that the solid angle subtended by one resolution element is

$$\Omega = \pi/4 i^2 / 4\pi L^2 = (i/4L)^2 = (D/4p)^2$$

Hence the number of neutrons per resolution element is

$$\frac{N_n}{R} = N_{Ot} \frac{\Omega}{R} = \frac{N_{Ot}}{R} \left(\frac{D}{4p}\right)^2 = \frac{N_{Ot}}{R} \left(\frac{i}{4L}\right)^2$$

Alternatively,

$$\frac{N_n}{R} = \frac{\text{no. of neutrons-}}{\text{cm}^2} \times \frac{\text{cm}^2}{\text{resolution element}} = \Phi \cdot \pi/4 i^2$$

$$\frac{N_n}{R} = \frac{N_{Ot}}{4\pi L^2 R} \cdot \frac{\pi}{4} i^2 = \frac{N_{Ot} i^2}{16 L^2 R} \text{ as before.}$$

$$\frac{N_n}{R} = \frac{N_{Ot}}{A_i} \left(\frac{i}{4L}\right)^2 \cdot \frac{\pi}{4} i^2 = \frac{\pi N_{Ot}}{64 A_i} \frac{i^4}{L^2}$$

Now $i = m_0 = (m + 1) D$ and $L = (m + 1) p$

Therefore,

$$\begin{aligned} \frac{N_n}{R} &= \frac{\pi N_{Ot} (m+1)^4 D^4}{64 A_i L^2} = \frac{\pi N_{Ot} (m_0)^4}{64 A_i L^2} = \frac{\pi N_{Ot} (m+1)^2 D^4}{64 A_i p^2} \\ &= \frac{N_{Ot} A_i}{4\pi L^2 R} = \Phi A_i \end{aligned}$$

In choosing values for the above quantities for a given set of test conditions, it appears that L should be chosen first. L should have the minimum value consistent with a good probability of recovering the image plate intact. Fixing L also fixes t, since t_d is a function of the device, t_a is a function of L, and indirectly t_s is a function of L. After L has been fixed, one needs to consider the number of neutrons per unit area.

$$\Phi = N_{Ot}/4\pi L^2 R$$

The number of resolution elements is inversely proportional to the number of neutrons per unit area. Now Φ determines the "exposure" available for autoradiography. $R = \text{area of image}/\text{area of resolution element at the image} = \text{area of object}/\text{area of resolution element at object}$, so R fixes the size of the resolution element o . Therefore, the resolution element can be made as small as is consistent with obtaining a sufficient number of activated atoms per unit area to give the photographic density required for the photograph.

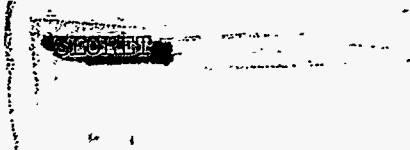
The counting rate over background per resolution element fixes the limit of detection of the system for obtaining an image by counting and plotting. The counting rate per resolution element is determined ultimately by the number of neutrons per resolution element $N_n/R =$

$$N_o t/R \cdot \left(\frac{i}{4L}\right)^2$$

After L has been selected for safe recovery and R for best photography, then i the size of the resolution element at the image should be selected large enough to give an adequate counting rate. Of course i must be small enough to go into the counter. Now o has been fixed by the requirement for photography, so choosing i fixes the magnification m , and the pinhole diameter D . Since L has been fixed, m fixes p and q , the object and image distances from the pinhole.

Summary

1. The requirement for the recovery of the pinex image plate intact fixes L the distance between the device and the image plate.
2. The requirement for adequate photographic density fixes Φ the number of neutrons per unit area at the image. This fixes R the total number of resolution elements seen by the photograph and o the linear dimension of the resolution element at the object.



3. The counting rate over background per resolution element fixes i the size of the resolution element at the image, m the magnification, D the pinhole diameter, p and q the object and image distances from the pinhole, and Ω the solid angle subtended at the device by the pinhole.

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