EMP Theoretical Notes

Note XI

JUN 17 1965

Air Inelastic, Neutron Induced Contributions to Currents and Conductivity

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Abstract

A simplified model of the air inelastic (14 Mev) neutron collisions and the resultant gamma ray effects has been developed to calculate the current and conductivity associated with nuclear detonations at low altitudes. This model assumes a monoenergetic, isotropic point source of fast neutrons in a homogeneous air scattering medium. These neutrons are allowed to collide only once, and the resultant gamma ray is assumed to be monoenergetic and isotropically scattered from the collision point. Further, it is assumed that the gamma ray will collide only once to create an electron current and ionization. This simple model predicts a rise in local ionization as the neutrons arrive at any observation point. No ground effects have been included in this analysis.

I. Introduction

There are at least two significant and distinct contributions to both the Compton current and the conductivity which must be considered in calculating the sources of the nuclear electromagnetic pulse. The first contribution is the result of multiple Compton collisions of the prompt gamma rays which are emitted from the nuclear device during detonation. The second contribution comes from the distributed source of gamma rays which is created by the inelastic collisions of the high energy fusion neutrons (14 Mev). Since the neutrons travel slowly relative to the gamma rays, the resulting total Compton current and ionization at any distance from the detonation will be complex functions of time. These functions reflect the arrival times of multiply scattering gammas from both the device and the slowly expanding, distributed source. Thus, at a distance of 500 meters from the detonation point, the Compton current and ionization pulses received may be on the order of 1000 shakes (10 msec) wide while the prompt gamma ray pulse at the detonation is only a few shakes wide (1 shake = 10^{-8} seconds).

Therefore, in order to accurately describe the Compton current and ionization as functions of position and time, the neutron induced, distributed gamma source should be considered separately from the prompt gamma ray, point source. This paper presents an analysis of the fast neutron induced contributions to current and ionization.

II. The Air-Inelastic Neutron Collision Model

Fast Neutrons (those with energy above a few Mev) are produced during both fission and fusion reactions. However, since the fusion reactions produce many more fast neutrons per kiloton of energy, this analysis will be limited to fusion neutrons. These neutrons are further assumed to be monoenergetic at 14.1 Mevs.

Consider an isotropic source of neutrons represented by No(t) neutrons/steradian-second. These neutrons spend their energy in capture, elastic, and wide-angle inelastic collisions and are lost from the "fast" category. The "mean free path", λ_R, for removal from the fast category is about 202 meters at STP. Thus, at any distance, R meters, from the origin, the number of fast neutrons is

$$N(R,t) = No[t - \frac{R}{V_n}] \cdot \exp[-R/\lambda_R] \frac{\text{neutrons}}{\text{steradian-second}} \qquad (1)$$

where V_n is the neutron velocity (= 5.2 (10^7) meters/sec)

Inelastic collisions of these fast neutrons produce gamma rays in several energy ranges. To approximate the total effect, however, a single gamma energy, E_g, with a single mean free path, λ_g, is assumed. A total cross section for gamma ray production, σ_g, is also used. The values to be used in subsequent calculations are as follows:

E_g = 7 Mev

λ_g = 400 meters/REL

$\sigma_g = 500\ (10^{-31})$ meter^2/target nuclei (500 millibarns)

$D_t = 5.39\ [10^{25}] \cdot$ REL nuclei/meter^3

= the target nuclei density

REL = the relative air density

The number of gamma rays produced per steradian-meter-second, NG, is

$$NG(R,t) = \sigma_g \cdot D_t \cdot N(R,t) \qquad (2)$$

$$= \sigma_g \cdot D_t \cdot No(t - \frac{R}{V_n}) \cdot \exp(-R/\lambda_R)$$

These gamma rays are assumed to be scattered isotropically from their point of creation[1].

The problem remaining consists of calculating the amount of current and ion-pair production due to the distributed source of isotropically scattered gammas expressed in equation (2).

A. Ion-Pair[2] Production from 14 Mev Neutrons.

A volume element at point R, at time t (t = o at detonation), receives ion-pairs from all elemental volumes, dV, in the source-region (for which t > $Z/V_n - R'/C$). Let QN be the number of ion-pairs produced per unit volume per second due to the prompt neutron induced gamma rays.

$$QN = \int_{V\ source} \frac{NG[Z, t-R'/C]}{Z^2} \cdot \frac{QG(R')}{4\pi R'^2} \cdot dV \quad \frac{\text{ion-pairs}}{m^3\text{-sec}}$$

where QG(R') is the ion-pair production per meter for a gamma at R' meters from its origin

Z is the point of creation of the 7-Mev gamma

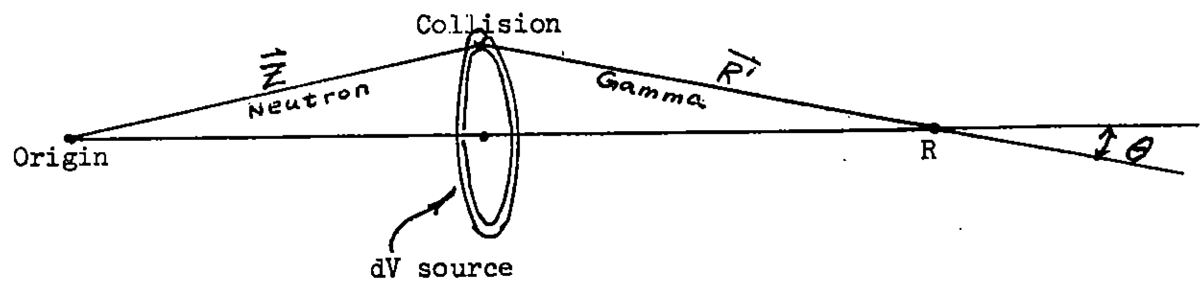
$\vec{R}' = \vec{R} - \vec{Z}$

V source is the volume occupied by neutrons. It is defined by $|Z| \leq V_n \cdot t$

[1]This is not a necessary condition for the calculation, however, it is convenient.

[2]It is here assumed that an ion-pair, consists of one electron and one positive N_2^+ or O_2^+ ion, for each 34 e.v. deposited.

Graphically the situation is as shown:



The assumptions for the one gamma collision model will be that the average electron energy is deposited in each first collision and that the scattered photon is ignored. The volume element, dV, can be represented by $(2\pi R' \sin\theta) \cdot (R' d\theta) \cdot dR'$, NG as given in equation (2) can also be substituted into equation (3) to yield:

$$QN(R,t) = \int_0^{R+V_n \cdot t} \int_0^{\pi} \sigma_g \cdot D_t \cdot No(t - Z/V_n - R'/C) \cdot \quad (4)$$

$$\frac{\exp(-Z/\lambda_R)}{Z^2} \cdot \frac{QG(R')}{4\pi R'^2} \cdot 2\pi\, R'^2 \sin\theta d\theta\, dR'$$

θ, Z, R, and R' are not independent. They are related as in the following equation:

$$Z^2 = (R' \sin\theta)^2 + (R - R' \cos\theta)^2 \quad (5)$$

To change the theta variable of integration in (4) from θ to Z, dθ must be expressed as a function of dZ.

$$Z = \sqrt{R'^2 (\sin^2\theta + \cos^2\theta) + R^2 - 2RR' \cos\theta}$$

$$Z = \sqrt{R'^2 + R^2 - 2RR' \cos\theta}$$

$$dZ = \frac{1}{Z} (-RR' (-\sin\theta d\theta))$$

$$\frac{ZdZ}{RR'} = \sin\theta d\theta$$

Then new limits of integration are

when $\theta = 0$, $Z = R-R'$

when $\theta = \pi$, $Z = R+R'$

Upon substituting the new limits and changing variable of integration, equation (4) becomes

$$QN(R,t) = \int_{o}^{R+V_n \cdot t} \int_{R-R'}^{R+R'} \sigma_g \cdot D_t \cdot No(t-Z/V_n-R'/C) \cdot \frac{\exp(-Z/\lambda_R)}{Z^2} \cdot \frac{QG}{4\pi R'^2} \, 2\pi R'^2 \left(\frac{ZdZ}{RR'}\right) dR' \tag{5}$$

which, upon cancellation of like terms and removal of constants from the integrand, becomes

$$QN(R,t) = \frac{\sigma_g \cdot D_t}{2 \cdot R} \int_{o}^{R+V_n \cdot t} \left[\int_{|R-R'|}^{R+R'} No(t-|Z|/V_n-R'/C) \cdot \frac{\exp(-Z/\lambda_R)}{Z} \, dZ \right] \cdot \frac{QG(R')}{R'} \, dR' \tag{6}$$

The absolute value of $|R-R'|$ must be used if the lower limit is to hold for $R' > R$. It is also necessary for the exponential decay and time retardation. $QG(R')$, which is the ion-pair production per meter-steradian at R' meters from a 7 Mev gamma source, is:

$$QG(R') = \frac{4.55\,(10^6)}{34 \cdot \lambda_g} e^{-R'/\lambda_g} \ \frac{\text{ion-pairs}}{\text{gamma-meter}} \tag{7}$$

where it has been assumed that:

1. 34 e.v. are absorbed per ion-pair
2. 4.55 Mev are lost to the recoil electron

B. Compton Current Production from 14 Mev Neutron

The distributed source of gamma rays, $NG(R,t)$, as given in equation (2), produces a "lingering" Compton electron current in addition to the ionization mentioned above. This lingering current, together with currents due to neutron scattering in the ground, represents the dominant driving term for EMP generation at later times, The fast neutron induced current, JN(R,t), can be expressed in the form of equation (6) with JG(R') substituted for QG(R') and a cos(θ) factor inserted in the integrand to account for the non-radial direction of the gamma rays (see picture after equation (3)). JG(R') is defined as the charge displacement (per steradian) at R' meters from a 7Mev gamma source.

$$JG(R') = \frac{1.6\ (10^{-19})\cdot\lambda e}{\lambda_g}\, e^{-R'/\lambda_g}\ \frac{\text{coulombs}}{\text{gamma-steradian}} \qquad (8)$$

where λe is the electron range of a 4.55 Mev electron

$$\lambda e \cong 10.15$$

The cos (θ) factor can be expressed in terms of the R, R', and Z variables.

$$\cos\ (\theta) = \frac{R'^2+R^2-Z^2}{2RR'}$$

The neutron induced current, JN(R,t), is

$$JN(R,t) = \frac{\sigma_g\cdot D_t}{2\cdot R}\int_0^{R+V_n t}\left[\int_{|R-R'|}^{R+R'} No(t-|Z|/V_n - R'/C)\cdot \frac{\exp\ (-Z/\lambda_R)}{Z}\cdot\left(\frac{R'^2+R^2-Z^2}{2RR'}\right)\cdot dZ\right]\cdot\frac{JG(R')}{R'}\,dR' \qquad (9)$$

III. Results of the Evaluation of the Current and Ionization Rates

Equations (6) and (9) have been programmed and evaluated on the IBM 7044 computer. Sample results at 500 meters are shown in Figures 1 and 2. These graphs assume a relative air density of .803. The first peak is due to a dense spherical neutron shell just outside of the weapon. The second peak is due to the low $\frac{1}{R^2}$ fall off from the point of creation of the gammas to the observation point. The time of second peak corresponds to the arrival time of 14 Mev neutrons at 500 meters.

A curve fit to these results has been used in AFWL computer prediction of the electromagnetic pulse fields.

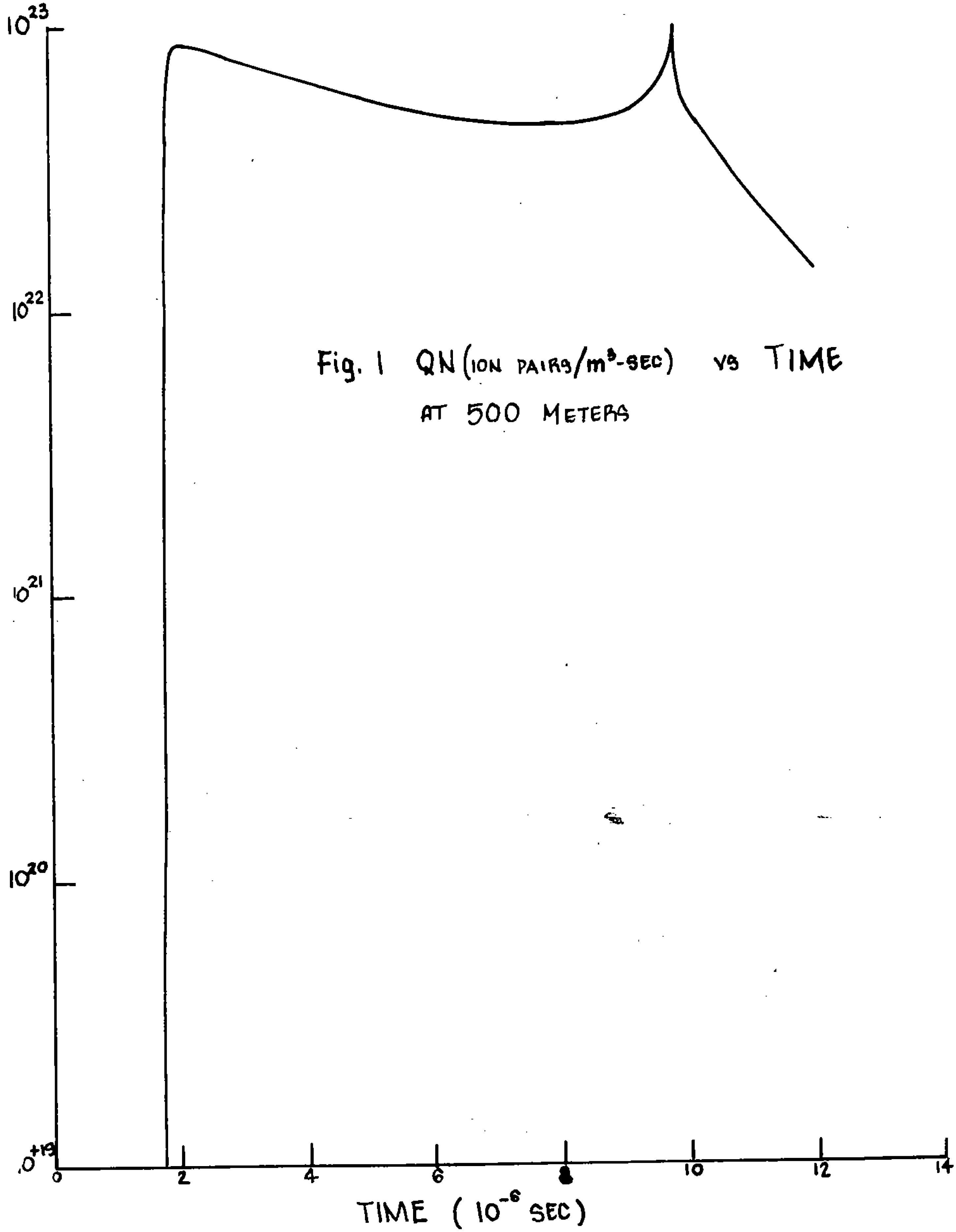


Fig. 1 QN (ION PAIRS/m³-SEC) VS TIME AT 500 METERS

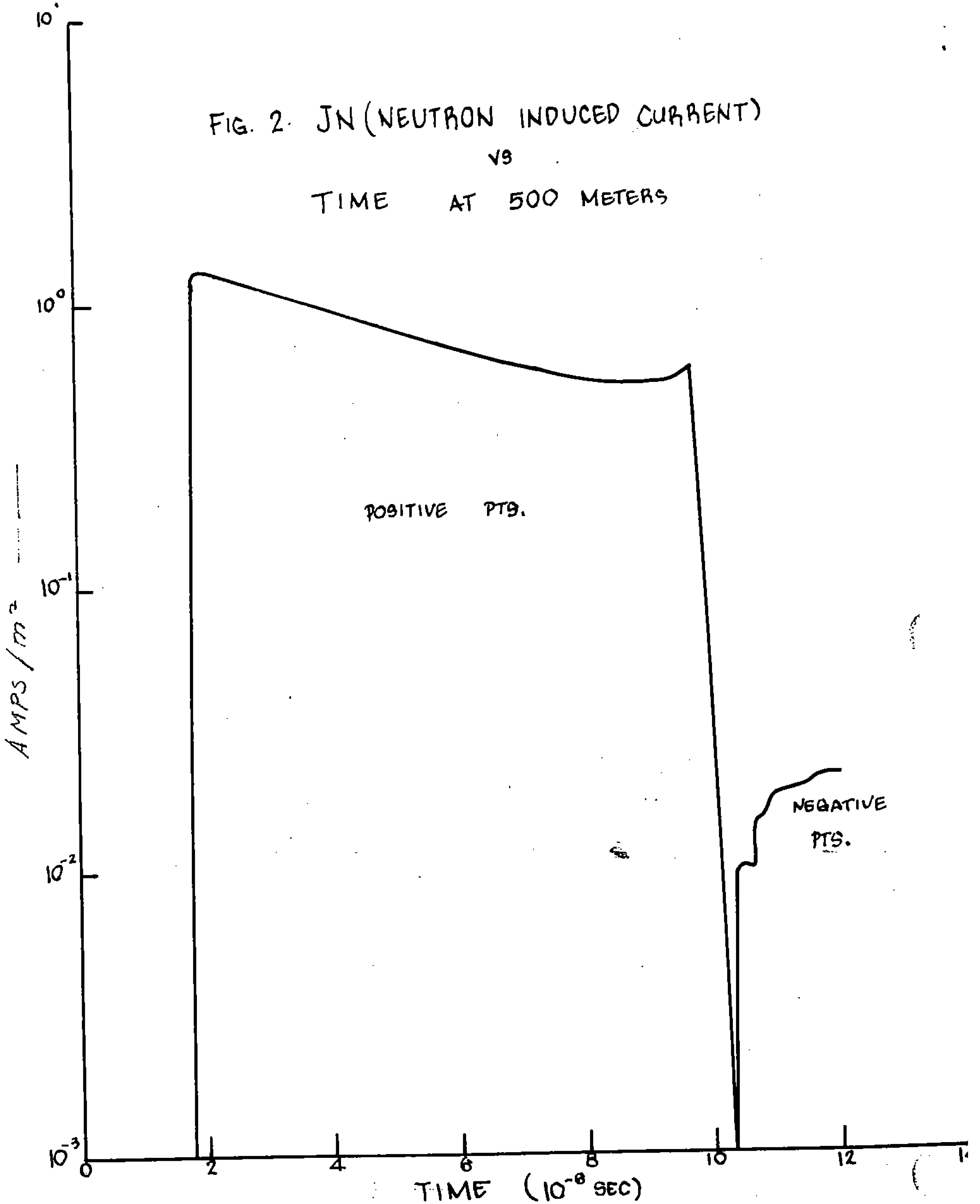


FIG. 2 JN (NEUTRON INDUCED CURRENT)
VS
TIME AT 500 METERS
POSITIVE PTS.
NEGATIVE
PTS.
AMPS / m^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
2
4
6
8
10
12
TIME (10^{-8} SEC)