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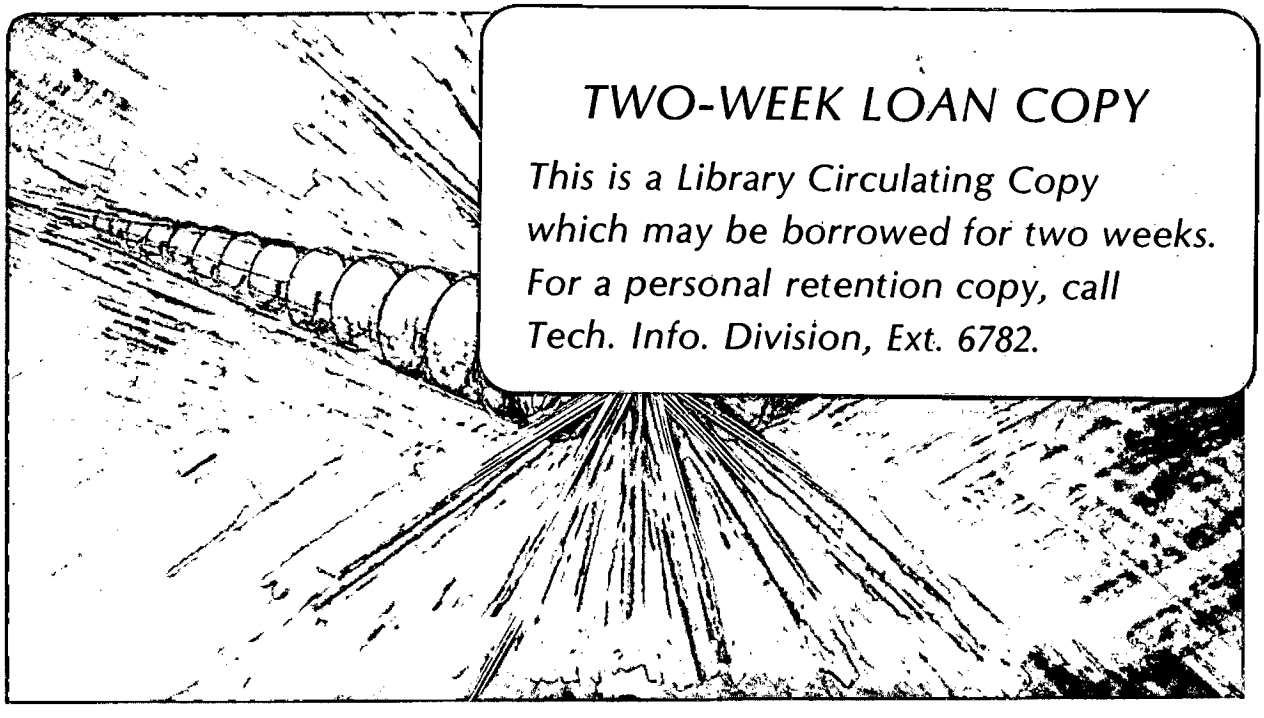

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A PULSED VAPOR SOURCE FOR USE IN ION SOURCES FOR HEAVY ION ACCELERATORS

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Abstract

A pulsed cesium vapor source for use in ion sources for high current heavy ion accelerators is described. The source employs a vacuum spark in Cs and its properties are measured with a hot-filament Cs detector.

Recent developments in inertial confinement fusion have called for the use of heavy ion beams as drivers. These beams will consist of heavy ions accelerated in conventional accelerators to energies of ~ 10 GeV at ~ 10 kA current level.[1,2,3] One of the approaches, now underway at this laboratory, will utilize an induction linear accelerator and requires an ion source with low emittance and high current (1 - 10 Amp.). At present, a Cs^{+1} ion source is being used which delivers a beam of 30 cm diameter, 500 keV energy and 1 Amp. current.[4] The beam is produced by contact ionization of neutral Cs on the surface of a hot iridium plate, which serves as an anode in a diode configuration. A 500 kV, 2 μs pulse from a Marx generator is applied across the diode to produce a space charge limited current beam of 1 Amp.

In order for the beam current to be at the space charge limit - and therefore reproducible from pulse to pulse - it is necessary that the emission limit of the anode be higher than the space charge limit. The Cs^{+1} emission limit for contact ionization of cesium on tungsten, as a function of temperature and cesium surface coverage - θ (fraction of a monolayer), is discussed in Ref. 5. At a temperature of 1300°K the emission limit is maximum at $\theta \sim 0.015$ (4 mA/cm^2) and is above the desired current density of 1.5 mA/cm^2. The emission limit falls off rapidly at lower surface coverages and temperatures. It is possible to reach $\theta \sim 0.015$ by using a steady state supply of Cs vapor; however, such a coverage requires a high partial pressure of Cs in the vacuum chamber which in turn causes a breakdown of the high voltage insulators. Moreover, a steady state coverage of Cs on the hot plate would cause a constant neutral emission of Cs. In a repetitively pulsed heavy ion fusion driver[1,2,3] the neutral emission will result in the accumulation of large amounts of Cs in the vacuum system that will interfere with the normal operation of the accelerator. The need to minimize the neutral emission in between pulses also rules out the use of a rear fed porous tungsten as a surface ionizer. It is thus desired to

introduce the necessary amount of neutral Cs in a short burst prior to the high voltage pulse. A novel method of doing so with the use of a Cs vacuum spark is described in this paper.

A schematic of the Cs Spark Vapor Source (SVS) is shown in Figure 1. A 2.5 nF capacitor charged to a voltage of 15-25 kV is discharged through a spark gap into a 2 mm gap between a sharp tungsten electrode and a small Cs (~ 1 g) reservoir. A 1:1.75 cable transformer insures a reproducible breakdown of the gap at the above charging voltage range. The current reaches a peak of 200 Amp at 25 kV charging voltage and oscillates at a frequency of 1.2 MHz with a damping constant of 10 μs. Under normal operation the spark source is fired 20 ms before the 500 kV Marx generator so that the Cs vapor created by the spark has enough time to reach the hot plate (50 cm away from the spark source) and get adsorbed onto the surface. This allows enough time, too, for most of the unwanted vapor to leave the diode region. The Cs reservoir is kept at a temperature of 18°C by circulating cold water through the unit in order to minimize the steady state vapor pressure (exposure to thermal radiation from the hot plate would normally heat the Cs to a temperature above 40°C). The Cs coverage of the hot plate can be controlled by varying the energy in the capacitor and the time delay between the spark and the Marx generator voltage.

The transient Cs vapor pressure created by the spark was measured with a Cs detector which consisted of a 0.5 mm diameter, 2 cm long tungsten filament and a collector plate biased at -300 V with respect to the filament. Neutral Cs that reaches the hot filament (kept at a temperature of 1100°C) is contact-ionized and collected on the collector plate. The neutral Cs burst lasts ~ 1 ms at the detector (located 5 cm from the spark source). The total number of particles per pulse is obtained by integrating the detector output signal, and taking into account the exposed filament surface area and its

location with respect to the SVS. The results are shown as a function of the charging voltage in Figure 2. At a charging voltage of 18 kV the number of Cs particles per pulse is 1.5×10^{16} which corresponds to a flux of 2×10^{12} cm^{-2} at the hot plate. Such coverage will supply more than 2 mA/cm^2 of Cs^{+1} at a temperature of 1300°K. The number of ions in the beam is two orders of magnitude smaller than the number of adsorbed Cs ions on the surface, so that the emission limit is not changed during the pulse. The adsorbed Cs ions on the surface of the hot plate are not in equilibrium with the Cs partial pressure surrounding the plate. As a result, Cs atoms will leave the surface at a rate that is determined by the surface temperature and coverage. The high voltage must be applied before the emission limit is decreased below the desired space charge limit. The measured Cs^{+1} ion current as a function of the time delay between firing of the SVS and the Marx is shown in Figure 3 for three different hot plate temperatures. For delays of 0.2 ms or less, the vapor burst has not reached the hot plate and the observed current is emission limited at all temperatures. In these cases the Cs surface coverage is below 0.01 and is in equilibrium with the low steady state Cs pressure in the system. For delays of 1-100 ms the current is space charge limited at all temperatures. There are two competing effects of the temperature on the emission limit: higher temperature on the one hand, increases the emission limit for a given surface coverage θ, and on the other hand, causes faster evaporation of the adsorbed Cs atoms off the hot plate. Figure 3 shows that the maximum delay time (with the emission limit > space charge limit) occurs at T = 1240°K whereas at higher and lower temperatures the current is reduced below the space charge limit at shorter delay times.

The experimental results were compared to the predictions of a simple model for the evaporation of Cs atoms from the SVS surface. We assume a constant power density input to the Cs surface. The evaporation rate Q as a function of temperature T (°K) is: [6)]

$$(1) \qquad \log Q = 6.7 - \frac{3774}{T} - \frac{\log T}{T} \quad \text{gram/cm}^2\text{/sec.}$$

The temperature is determined by the 1-dimensional diffusion equation:

$$(2) \qquad \frac{\partial^2 T}{\partial x^2} - \frac{1}{D}\frac{\partial T}{\partial t} = (P - W)\delta(x)$$

where P is the power density delivered by the spark to the cesium surface, W is the power density lost to the evaporated particles and D is the diffusion coefficient.

Eq. (2) was solved numerically to find the surface temperature which in turn was used to calculate the rate of Cs evaporation as well as the total number of evaporated atoms. The surface temperature as a function of time for four values of power density input is shown in Figure 4a. Figure 4b shows the integrated number of evaporated particles. The temperature saturation after 10 μs corresponds to a constant rate of emission or a linear rise in the integrated number of evaporated particles. The actual power density delivered to the SVS is between 0.3 - 0.5 MW/cm^2 in a spot of ~ 1 mm in diameter, and the experimental results are in agreement with the model predictions.

Under normal operation the ion source works reliably at a repetition rate of 1 Hz without any breakdown problems. After 10000 pulses a substantial crater (1-2 mm in diameter, 3 mm deep) is developed in the cesium and in order to restore the original conditions, the gap is shortened, or the cesium is reshaped by melting it at a temperature above 30°C.

The cesium SVS could be extended to other elements that can undergo contact-ionization, such as uranium[7], which might be desired in the future for a heavy ion fusion driver.

References:

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5. J. B. Taylor and I. Langmuir, Phys. Rev. 44, 423, 1933.

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7. M. Hashmi, A. Van der Houven van Oordt, Conference on U Isotope Separation, London, (March 1975).

Figure Captions

1. Cs spark source - schematic.

2. Total number of Cs atoms emitted per pulse, as a function of the charging voltage.

3. Cs^{+1} ion current as a function of the delay between the spark and firing of the Marx generator (Marx voltage - 200 kV) for three different hot plate temperatures. The base line shifts are caused by the presence of background cesium vapor. The flat top represents the space charge limit.

4. a) Cs surface temperature calculated for four different power density inputs.

   b) Total number of Cs atoms evaporated per pulse from a 1 mm surface area.

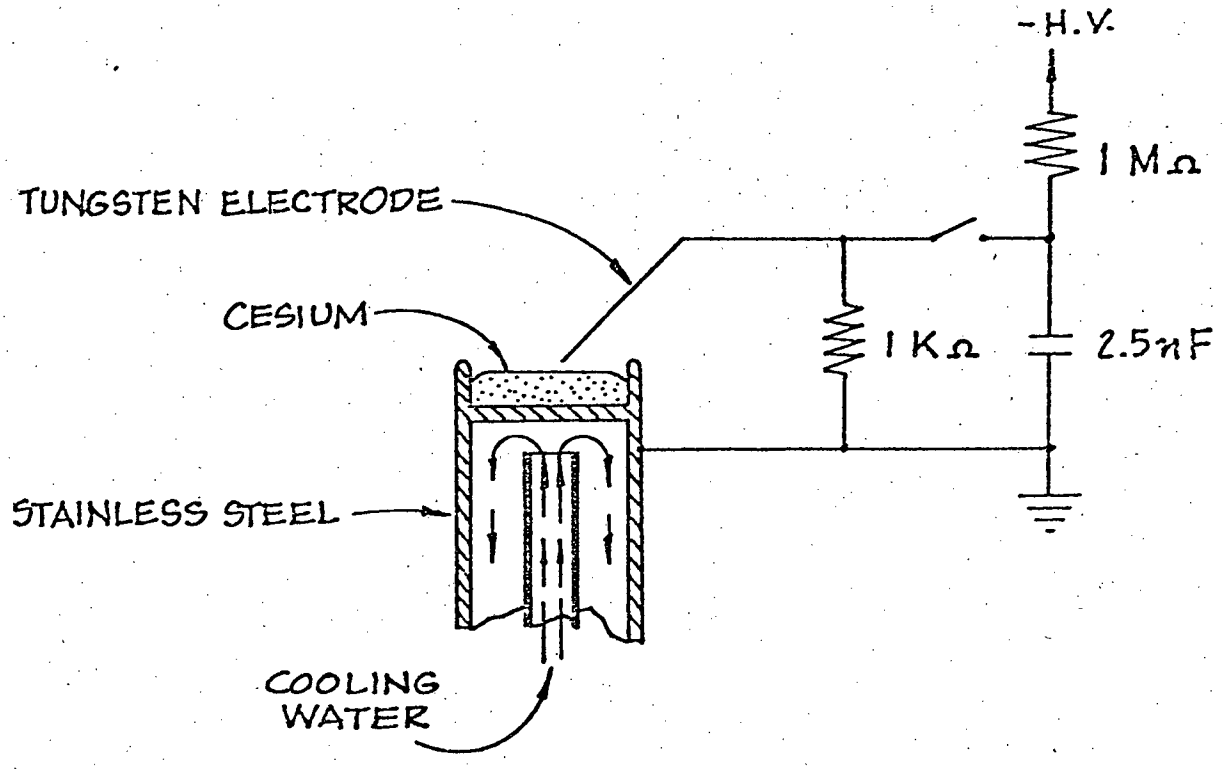
-H.V.
1 MΩ
TUNGSTEN ELECTRODE
CESIUM
1 KΩ
2.5nF
STAINLESS STEEL
COOLING
WATER

Figure 1

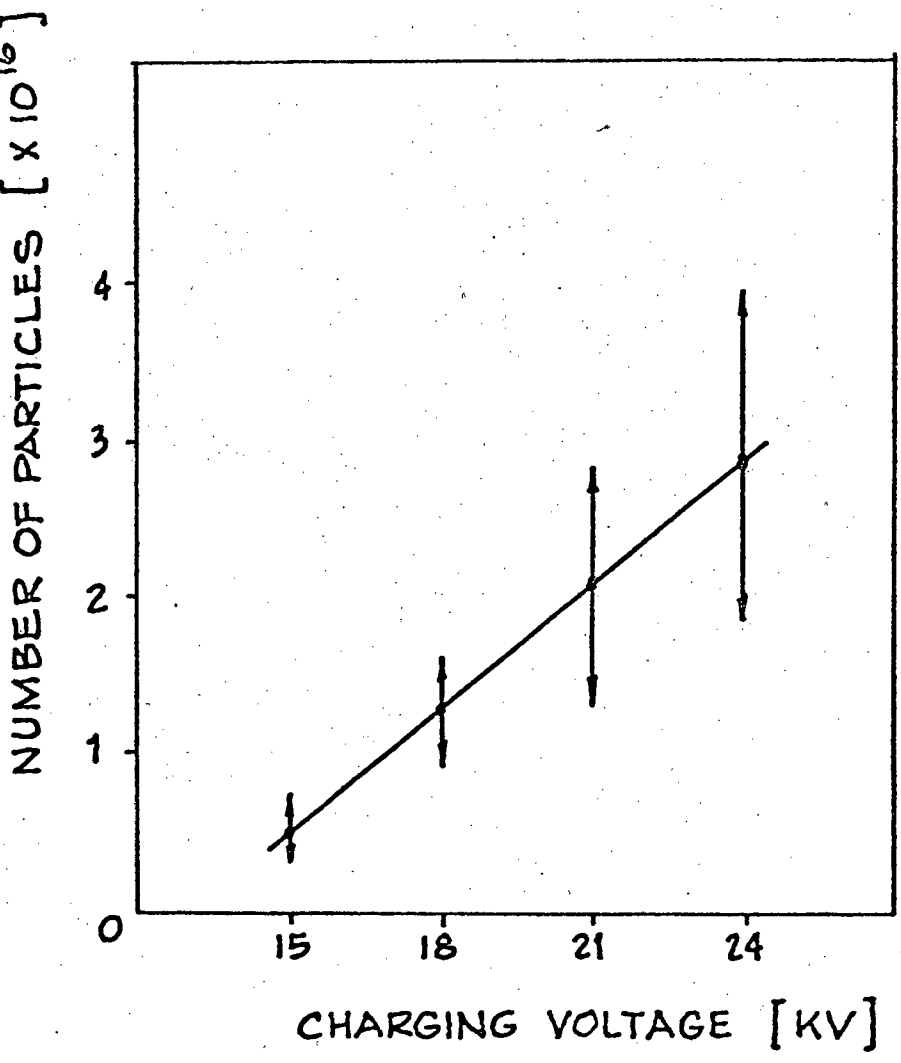
NUMBER OF PARTICLES [X 10^16]
0
1
2
3
4
15
18
21
24
CHARGING VOLTAGE [KV]

Figure 2

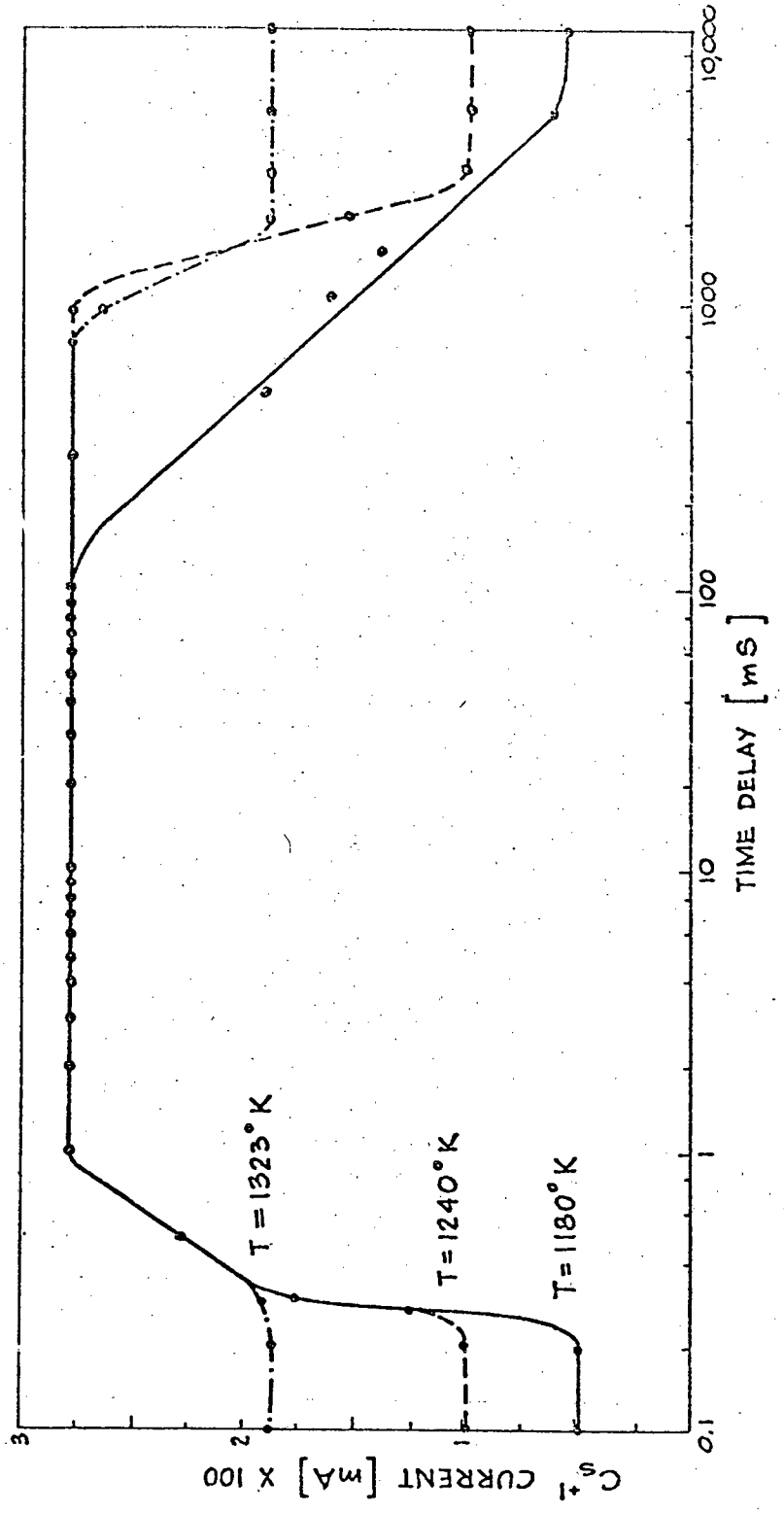
C_s^+ CURRENT [mA] x 100
TIME DELAY [mS]
T = 1323° K
T = 1240° K
T = 1180° K
0.1
1
10
100
1000
10,000
1
2
3

Figure 3

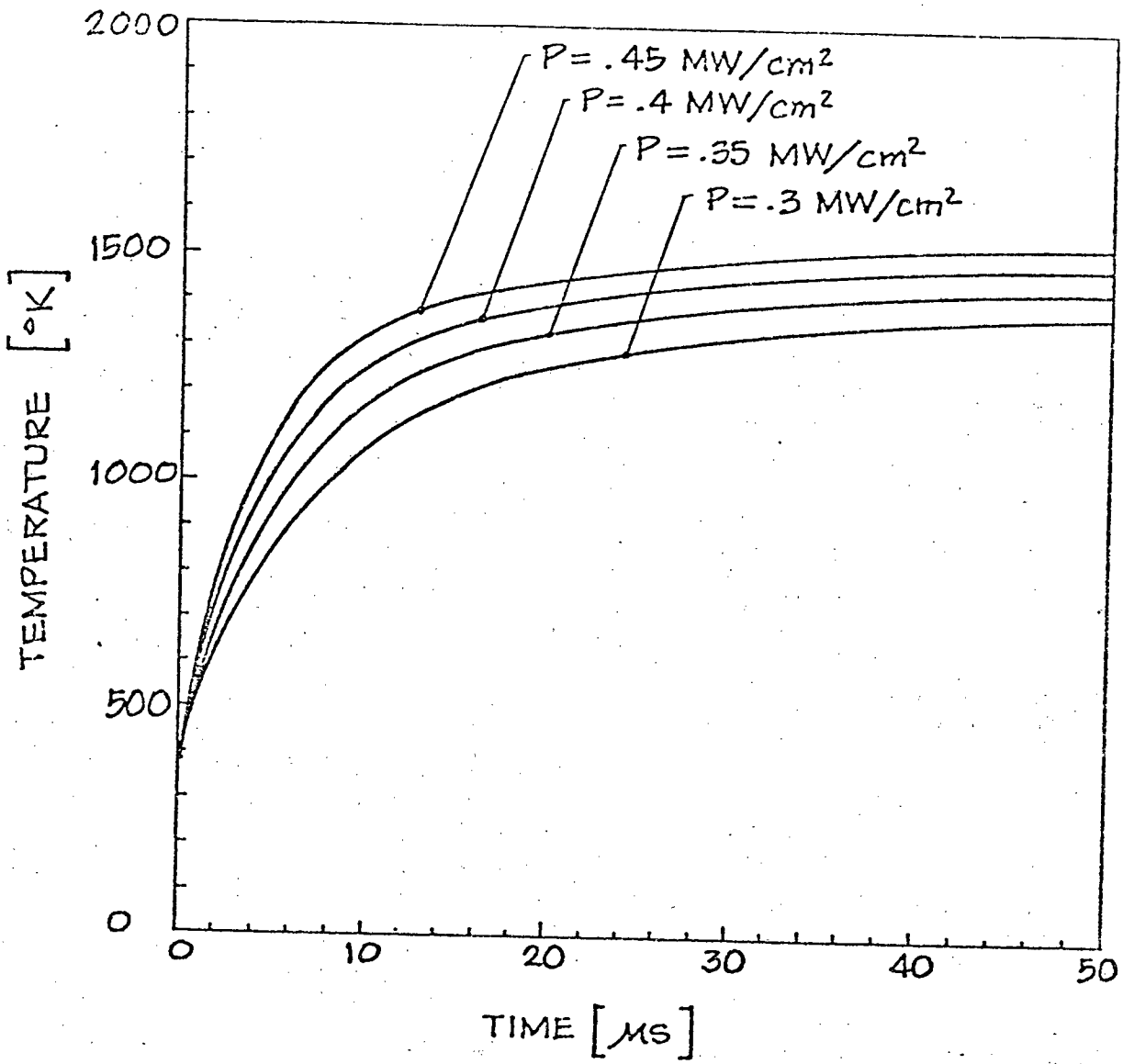
2000
1500
1000
500
0
TEMPERATURE [°K]
P= .45 MW/cm²
P= .4 MW/cm²
P= .35 MW/cm²
P= .3 MW/cm²
0
10
20
30
40
50
TIME [MS]

Figure 4a

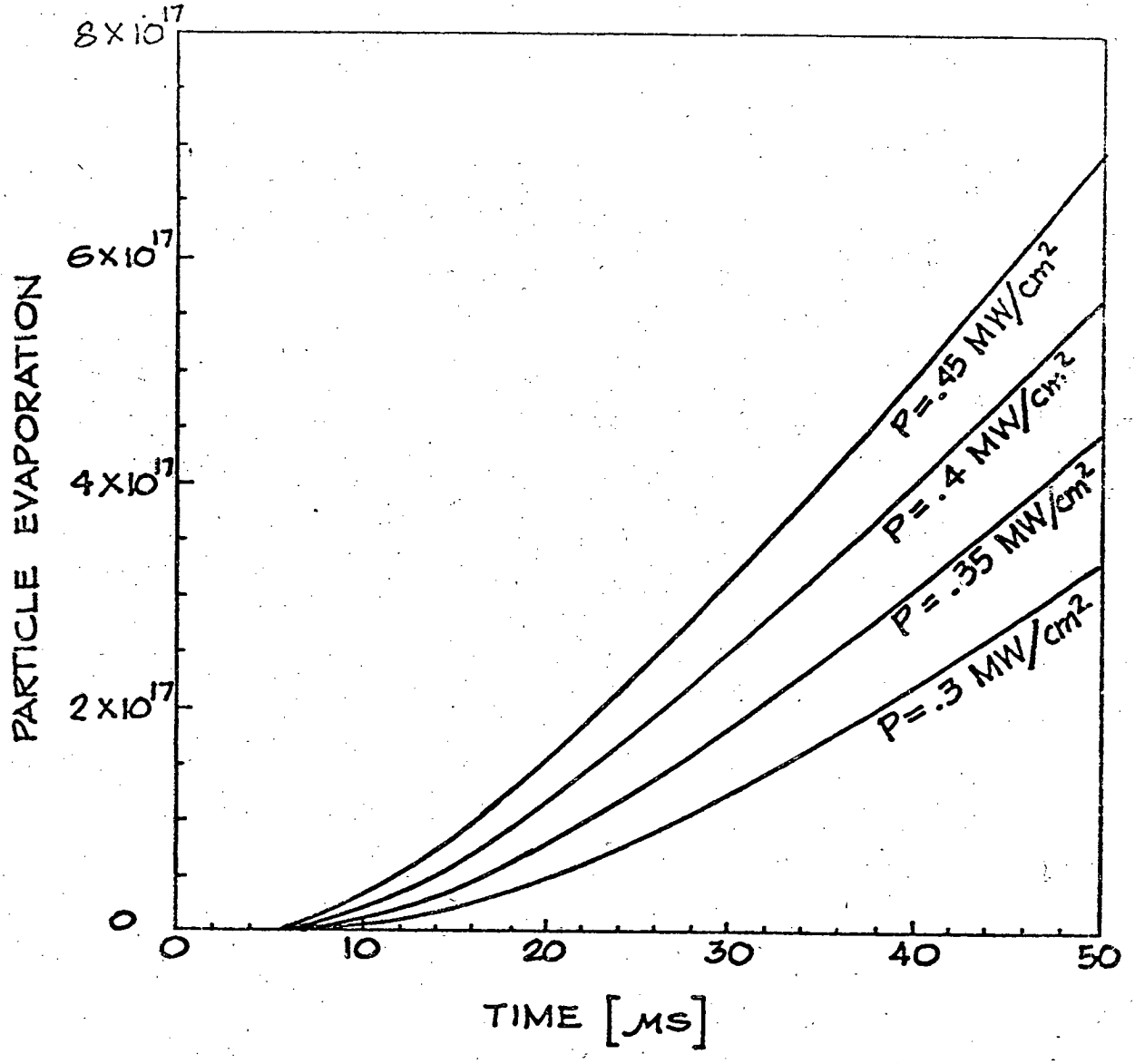
8 X 10^17
6 X 10^17
4 X 10^17
2 X 10^17
0
PARTICLE EVAPORATION
0
10
20
30
40
50
TIME [MS]
P=.45 MW/cm2
P=.4 MW/cm2
P=.35 MW/cm2
P=.3 MW/cm2

Figure 4b

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