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CALCULATED DOSAGE ISOPLETHS AND DOSAGE AREA-COVERAGE FOR THE PROPOSED NASA GRAPHITE PARTICLE TRIALS

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Dosage

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16. Abstract

Procedures are described for calculations of dosage isopleths and area coverage for the dissemination of carbon fiber released from a unit source in aviation fuel fires. Results are presented of calculations using the Dugway Proving Ground Volume Source Diffusion Model Program with the following conditions:

Aviation jet fuel fires of 500, 1000, and 2000 gallons;
Burn rates of 100 and 200 gallons per minute;
Particle settling velocities of 0.02, 0.5, and 1 meters per second;
Stable, neutral, and unstable meteorological inputs.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

NASA is considering a field program at Dugway Proving Ground (DPG) to measure concentrations/dosages of graphite particles. DPG requested the H. E. Cramer Company provide dosage isopleths and area coverage calculated by means of the DPG Volume Source Diffusion Model Program to assist DPG in determining the feasibility of the proposed field measurement program and in designing the program. This report describes the procedures used to make the calculations and contains the results of the calculations.

1.2 STUDY OBJECTIVES

The purpose of the study described in this report was to calculate dosage isopleths and area coverages, assuming a unit source strength of graphite particles, for the following conditions:

- Fuel oil fires of 500, 1000 and 2000 gallons
- Burn rates of 100 and 200 gallons per minute
- Particle settling velocities of 0.02, 0.5 and 1 meters per second
- Stable, neutral and unstable thermal stratifications at DPG

1.3 CONTENTS OF THE REPORT

Section 2 contains a description of the dosage and deposition models and the cloud-rise model used in the calculations. Source and meteorological inputs used in the calculations are given in Section 3 and the results of the calculations are presented in Section 4.

SECTION 2

DOSAGE, DEPOSITION AND CLOUD-RISE MODELS USED IN THE CALCULATIONS

2.1 DOSAGE MODEL

The dosage model used in the Volume Sources Diffusion Model Program is expressed as the product of four terms:

$$\text{Dosage} = \{\text{Peak Dosage Term}\}\ \{\text{Vertical Term}\}\ \{\text{Lateral Term}\}\ \{\text{Depletion Term}\} \tag{2-1}$$

The Peak Dosage Term is defined by the expresseion

$$\frac{K\,Q}{2\,\pi\,\sigma_y\,\sigma_z\,\bar{u}} \tag{2-2}$$

where

K = parameter used to convert inputs into dimensionally consistent units

Q = total source strength

σ_y = standard deviation of the crosswind distribution of material

σ_z = standard deviation of the vertical distribution of material

$\bar{u}$ = mean wind speed in the layer containing the cloud

The Vertical Term is given by the expression

$$f_i \left\{ \sum_{a=0}^{\infty} \left[\gamma_i^a \exp\left[-\frac{1}{2}\left(\frac{2aH_m - H' + z + V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] + \gamma_i^{a+1} \exp\left[-\frac{1}{2}\left(\frac{2aH_m + H' + z - V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] \right] \right. \tag{2-3}$$

$$\left. + \sum_{a=0}^{\infty} \left[\gamma_i^a \exp\left[-\frac{1}{2}\left(\frac{2aH_m + H' - z - V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] + \gamma_i^{a-1} \exp\left[-\frac{1}{2}\left(\frac{2aH_m - H' - z + V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] \right] \right\}$$

where

f_i = fraction of the total source strength comprised of material in the i^{th} size category

γ_i = fraction of material in the i^{th} size category reflected at the ground surface (1 for complete reflection and 0 for no reflection)

H_m = depth of the surface mixing layer

H' = effective source height

z - height above ground

V_{si} = gravitational settling velocity of the i^{th} size category

x = distance from the source

For convenience in writing Equation (2-3), 0^0 (zero to the zeroth power) has been defined equal to unity. Inspection of Equation (2-3) shows that the Vertical Term accounts for cloud depletion due to gravitational settling ($V_{si} > 0$) and due to retention of material at the surface ($\gamma_i < 1$).

The Lateral Term refers to the crosswind expansion of the cloud and is given by the expression

$$\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \qquad (2\text{-}4)$$

where

y = lateral distance from the cloud centerline

The Depletion Term in Equation (2-1) refers to the loss of material by simple decay processes or by precipitation scavenging. The form of the Depletion Term for these two processes is:

$$(\text{Decay}) = \exp\left[-kt\right] \qquad (2\text{-}5)$$

$$(\text{Precipitation Scavenging}) = \exp\left[-\Lambda\left(\frac{x}{u} - t_1\right)\right] \qquad (2\text{-}6)$$

where

k = decay coefficient or fraction of material lost per unit time

t = cloud travel time

Λ = washout coefficient or fraction of material removed by scavenging per unit time

t_1 = time precipitation begins

The equations defining the distance dependence of the standard deviations of the crosswind and vertical distribution of material are given below.

The standard deviation of the crosswind distribution of material is given by the expression

$$\sigma_y = \left[\left(\sigma'_A \{\tau\} \, x_{ry} \left(\frac{x + x_y - x_{ry}(1-\alpha)}{\alpha \, x_{ry}} \right)^{\alpha} \right)^2 + \left(\frac{\Delta\theta' \, x}{4.3} \right)^2 \right]^{1/2} \qquad (2\text{-}7)$$

where

$\sigma'_A \{\tau\}$ = standard deviation of the aximuth wind angle in radians measured over the source emission time τ

where

$$\sigma'_A \{\tau\} = \sigma'_A \{\tau_o\} \left(\frac{\tau}{\tau_o} \right)^{1/5} \quad ; \quad 1 \leq \tau_o \leq 600 \text{ seconds} \qquad (2\text{-}8)$$

$\sigma'_A \{\tau_o\}$ = standard deviation of the azimuth wind angle in radians in the surface mixing layer measured over the reference time τ_o

x_{ry} = distance over which rectilinear crosswind cloud expansion occurs downwind from a virtual point source

α = crosswind diffusion coefficient

x_y = crosswind virtual distance

$$x_y = \begin{cases} \dfrac{\sigma_{yR}}{\sigma'_A\{\tau\}} - x_{Ry} & ; \sigma_{yR} \leq \sigma'_A\{\tau\} \, x_{ry} \\ \alpha \, x_{ry} \left(\dfrac{\sigma_{yR}}{\sigma'_A\{\tau\} \, x_{ry}} \right)^{1/\alpha} - x_{Ry} + x_{ry}(1-\alpha) & ; \sigma_{yR} > \sigma'_A\{\tau\} x_{ry} \end{cases} \qquad (2\text{-}9)$$

σ_{yR} = standard deviation of the crosswind concentration distribution at a distance x_{Ry} downwind from the source

$\Delta\theta'$ = aximuth wind direction shear in radians within the layer containing the cloud

$$= \frac{\Delta\theta}{\Delta z} \cdot \left(\frac{\pi}{180}\right) \left(z_2 - z_1\right) \tag{2-10}$$

$\frac{\Delta\theta}{\Delta z}$ = rate change of wind direction in degrees with height in the surface mixing layer where $\Delta\theta$ is positive in the clockwise sense

z_2 = effective upper bound of the cloud

$$= \left\{ \begin{array}{ll} H' + 2.15\ \sigma_z & ;\ z_2 < H_m \\ H_m & ;\ z_2 \geq H_m \end{array} \right\} \tag{2-11}$$

z_1 = effective lower bound of the cloud

$$= \left\{ \begin{array}{ll} H' - 2.15\ \sigma_z & ;\ z_1 > 2 \\ 2 & ;\ z_1 \leq 2 \end{array} \right\} \tag{2-12}$$

The standard deviation of the vertical distribution of material is given by the expression

$$\sigma_z = \sigma'_E\ x_{rz} \left[\frac{x + x_z - x_{rz}(1-\beta)}{\beta\ x_{rz}} \right]^{\beta} \tag{2-13}$$

where

σ'_E = standard deviation of the elevation wind angle in radians

x_{rz} = distance over which rectinlinear vertical cloud expansion occurs downwind from a virtual point source

β = vertical diffusion coefficient

x_z = vertical virtual distance

$$= \begin{cases} \dfrac{\sigma_{zR}}{\sigma'_E} - x_{Rz} & ; \ \sigma_{zR} \leq \sigma'_E \, x_{rz} \\ \beta \, x_{rz} \left(\dfrac{\sigma_{zR}}{\sigma'_E \, x_{rz}} \right)^{1/\beta} - x_{Rz} + x_{rz}(1-\beta) & ; \ \sigma_{zR} > \sigma'_E \, x_{rz} \end{cases} \qquad (2\text{-}14)$$

σ_{zR} = standard deviation of the vertical concentration distribution at a distance x_{Rz} downwind from the source

The mean wind speed $\bar{u}$ is defined by the expression

$$\bar{u} = \begin{cases} \dfrac{\bar{u}_R \left[(z_2)^{1+p} - (z_1)^{1+p} \right]}{(z_2 - z_1)(z_R)^p \, (1+p)} & ; \ \bar{u} > \bar{u}_R \\ \bar{u}_R & ; \ \bar{u} \leq \bar{u}_R \end{cases} \qquad (2\text{-}15)$$

where

$\bar{u}_R$ = mean wind speed at the reference height z_R

p = wind profile power-law exponent

2.2 CLOUD-RISE MODEL

The cloud-rise model described below is based on concepts in a paper by G. A. Briggs (1970) presented at the Second International Clean Air Congress. Because the burn time for the proposed NASA field trials varies from 2.5 to 20 minutes, a continuous source cloud-rise model has been used in the calculations. Dumbauld and Bjorklund (1975) have used the same model to calculate the cloud rise from on-pad aborts and from normal launches of NASA vehicles.

The maximum cloud-rise from a continuous source is given by the expression

$$H = \left[\frac{6F}{\bar{u}\,\nu_c^2\,s} + \left(\frac{r_R}{\nu_c}\right)^3\right]^{1/3} - \frac{r_R}{\nu_c} \qquad (2\text{-}16)$$

where

F = buoyancy flux

$$= \frac{gQ_c}{\pi\,\rho\,c_p\,T} \qquad (2\text{-}17)$$

g = acceleration due to gravity (9.8 m/sec^2)

Q_c = effective rate of heat release (cal/sec^{-1})

ρ = density of ambient air ($g\ m^{-3}$)

c_p = specific heat of air at constant pressure (.24 cal $g^{-1}{}^{o}K^{-1}$)

T = ambient air temperature (^{o}K)

ν_c = entrainment coefficient

r_R = radius of the area covered by the burning fuel

$$s = \frac{g}{T}\frac{\Delta\Phi}{\Delta z} \tag{2-18}$$

$\frac{\Delta\Phi}{\Delta z}$ = vertical gradient of ambient potential temperature

The radius of the cloud at the stabilization height H is

$$r_m = \nu_c H + r_R \tag{2-19}$$

and the downwind distance to stabilization is given by

$$x_m = \bar{u}\,\pi\, s^{-1/2} \tag{2-20}$$

The cloud-rise model given by Equation (2-16) strictly applies in near-neutral or stable stratification. However, experience in applying the model to predict the cloud rise from rocket launches has shown that, with the proper choice of $\Delta\Phi/\Delta z$, this model can also be used for all stabilities.

SECTION 3
SOURCE AND METEOROLOGICAL INPUT PARAMETERS

3.1 CLOUD-RISE MODEL INPUTS

Table 3-1 shows the source and meteorological inputs used in calculating the maximum cloud rise by means of the cloud-rise model described in Section 2.2. The values of the effective rate of heat release Q_c in Table 3-1 were obtained by assuming that each pound of fuel oil released 18,590 BTU or each gallon of fuel oil contained 3.1856×10^7 g cal for burn rates of 100 and 200 gallons per minute. The ambient air temperature T and air density ρ given in the table are typical average/daytime values for DPG during the spring of the year. The lapse rate of potential temperature $\Delta\Phi/\Delta z$ shown in Table 3-1 for stable stratification was selected to be representative of daytime inversion conditions at DPG. Values of $\Delta\Phi/\Delta z$ for neutral and unstable conditions respectively correspond to an approximate moist-adiabatic lapse rate and a near-adiabatic lapse rate. Similar values have been used to calculate the cloud-rise from launches of liquid-fueled rockets (Dumbauld and Bjorklund, 1975).

The values in Table 3-1 assigned to the entrainment parameter ν_c are based on experience with cloud-rise from rocket engine exhaust products. However, the data from large similated fires presented by Benech (1976) indicates that these entrainment parameters may be too large by a factor of two for very intense oil fires. Use of smaller values of ν_c results in larger cloud stabilization heights. In general, if the calculated cloud stabilization hieghts are too low, the calculated maximum ground-level dosages and surface deposition are too large. Also, the calculated ground-level dosages and surface deposition are too large close to the source and are too small at intermediate and long downwind distances. The radius r_R of the oil spill was obtained under the assumption that the oil covered a circular area of 2400 square feet or 223 square meters.

TABLE 3-1

MODEL INPUTS FOR THE CLOUD RISE CALCULATIONS

Parameter	Atmospheric Stability		
	Stable	Neutral	Unstable
Q_c (g cal sec^{-1})*	$5.31x10^7$, $1.06x10^8$	$5.31x10^7$, $1.06x10^8$	$5.31x10^7$, $1.06x10^8$
T (^oK)	297	297	297
ρ (g m^{-3})	1020	1020	1020
$\frac{\Delta\phi}{\Delta z}$ (^oK m^{-1})	$3.0x10^{-2}$	$5.0x10^{-3}$	$3.32x10^{-4}$
γ_c	0.66	0.66	0.60
r_R (m)	8.42	8.42	8.42
$\bar{u}$ (m sec^{-1})**	5.43, 5.74	7.65, 7.90	3.40, 3.47

* Q_c equals $5.31x10^7$ for a burn rate of 100 gallons per minute and $1.06x10^8$ for 200 gallons per minute.

** Mean wind speed between the surface and the cloud stabilization height H obtained by iteration (see text).

The mean wind speeds in Table 3-1 are the mean wind speeds between the ground surface and the cloud stabilization height H. They were calculated by using Equation (2-15) with $z_2 = H$ and iterating Equation (2-19) until the equality was satisfied. Values of the wind-profile exponent p used in Equation (2-15) for stable, neutral and unstable conditions were 0.25, 0.15 and 0.10, respectively. The corresponding values of $\bar{u}_R$ at a reference height z_R of 8 meters were 3.1, 5.1 and 2.3 meters per second, which are mean values for spring at DPG under these conditions (see Table D.3, page D-10, Handbook for Chemical Hazard Prediction).

The results of the cloud rise calculations are shown in Table 3-2 for the two burn rates of 100 and 200 gallons per minute and the three atmospheric stabilities.

3.2 METEOROLOGICAL INPUT PARAMETERS FOR THE DOSAGE MODEL

Meteorological inputs used in the calculation of dosage isopleths and dosage area-coverage are presented in Tables 3-3 and 3-4. Except for the values shown in Table 3-3 for stable atmospheric conditions and settling velocities V_s of 0.5 and 1 meter per second, the values of H_m in the table are based on median mixing depths measured at DPG during the spring (see Table D.3, page D-10, Handbook for Chemical Hazard Prediction). The cloud-rise calculations show that in stable conditions, the majority of the particles in the cloud would penetrate a mixing depth of 150 meters. Particles with small settling velocities and stabilizing above the mixing layer would tend to remain above the surface mixing layer during downwind cloud transport and thus not contribute to dosage levels near the ground. On the other hand, particles with settling velocities of 0.5 and 1 meter per second would settle into the surface mixing layer and would contribute to dosages near ground-level. For this reason, the value of H_m was arbitrarily set to 1000 meters in these cases.

TABLE 3-2

CALCULATED CLOUD STABILIZATION HEIGHT H AND THE DOWNWIND DISTANCE TO STABILIZATION x_m IN METERS

BURN RATE (gallons/ minute)	Atmospheric Stability					
	Stable		Neutral		Unstable	
	H	x_m	H	x_m	H	x_m
100	167.3	542.2	279.1	1870.6	992.5	3223.0
200	210.0	573.2	351.1	1932.2	1245.0	3293.6

TABLE 3-3

METEOROLOGICAL MODEL INPUT PARAMETERS FOR THE DOSAGE CALCULATIONS

Stability	Burn Rate ($gal\ min^{-1}$)	V_s ($m\ sec^{-1}$)	H_m (m)	$\bar{u}$ ($m\ sec^{-1}$)	$\frac{\Delta\theta}{\Delta z}$ ($deg\ m^{-1}$)	α	β
Stable	100	.02	150	5.31	0.066	0.9	1.0
		.5, 1	1000	5.43	0.025	0.9	1.0
	200	.02	150	5.31	0.066	0.9	1.0
		.5, 1	1000	5.74	0.025	0.9	1.0
Neutral	100	.02, .5, 1	300	7.65	0.005	0.9	1.0
	200	.02, .5, 1	800	7.90	0.005	0.9	1.0
Unstable	100	.02, .5, 1	2310	3.40	0.001	0.9	1.0
	200	.02, .5, 1	2310	3.47	0.001	0.9	1.0

TABLE 3-4

TURBULENCE PARAMETERS σ_A $\{\tau_o = 600 \text{ sec}\}$ and σ_E

Stability	Burn Rate (gallons/minute)	V_s (m sec^{-1})	$\sigma_A\{\tau_o=600 \text{ sec}\}$ (deg)	σ_E (deg)
Stable	100	.02	3.01	2.28
		.5, 1	2.80	2.12
	200	.02	3.01	2.28
		.5, 1	2.43	1.85
Neutral	100	.02, .5, 1	5.41	4.10
	200	.02, .5, 1	5.24	3.97
Unstable	100	.02, .5, 1	13.65	10.00
	200	.02, .5, 1	13.36	10.00

The mean wind speeds shown in Table 3-3 are identical to those used in the cloud-rise calculations except when the cloud stabilized above H_m. When the cloud stabilized above H_m, the mean wind speed was calculated from Equation (2-15) using the same reference wind speed $\bar{u}_R$ and wind profile exponents p used in the cloud rise calculations described in Section 3.1. Values for the change of wind direction in degrees with height $\Delta\theta/\Delta_z$ shown in Table 3-3 are typical of wind-direction shears measured over continental areas. Values of 0.9 and 1 were respectively assigned the lateral and vertical diffusion coefficients α and β.

The standard deviation of the azimuth wind angle σ_A in the surface mixing layer decreases with height except under very unstable atmospheric conditions. We have used the relationship

$$\sigma_A\{\tau_o\} = \frac{\sigma_A\{\tau_o, z_R\}\left[H^{1-p} - z_R^{1-p}\right]}{\left(H - z_R\right)\left(1-p\right)\left(z_R^{-p}\right)} \qquad (3\text{-}1)$$

to calculate the mean value of $\sigma_A\{\tau\}$ between the reference height z_R and the cloud stabilization height H for use in the dosage calculations when $H \leq H_m$. When $H \geq H_m$, we assumed a value for σ_A of 1 degree in the elevated inversion and used a height-weighted mean value of $\sigma_A\{\tau\}$ calculated from the expression

$$\sigma_A\{\tau_o\} = \frac{1}{H}\left[\frac{H_m\,\sigma_A\{\tau_o, z_R\}\left[H_m^{1-p} - z_R^{1-p}\right]}{\left(H_m - z_R\right)\left(1-p\right)\left(z_R^{-p}\right)} + H - H_m\right] \qquad (3\text{-}2)$$

In the dosage calculations, we used the following expression to obtain the value of σ_E:

$$\sigma_E = \begin{cases} \sigma_A \{\tau = 150 \text{ sec}\} \; ; & \sigma_A \{\tau = 150 \text{ sec}\} \leq 10 \text{ deg} \\ 10 \text{ deg} \; ; & \sigma_A \{\tau = 150 \text{ sec}\} > 10 \text{ deg} \end{cases} \qquad (3\text{-}3)$$

The procedures outlined above were used to specify the values of σ_A and σ_E in Table 3-4 for values of $\sigma_A \{\tau_o = 600 \text{ sec}, z_R = 8_m\}$ equal to 5, 8 and 20 degrees respectively for stable, neutral and unstable atmospheric conditions.

3.3 SOURCE INPUTS FOR THE DOSAGE MODEL

The source parameters used in the dosage and dosage area-coverage calculations are shown in Table 3-5. The effective source heights H' were calculated from the relationship

$$H' = \begin{cases} H \; ; & H_m \geq H \\ \dfrac{H + H_m - r_m}{2} \; ; & H_m < H \end{cases} \qquad (3\text{-}4)$$

The reflection parameter γ was set equal to 0.72 for particles with settling velocities equal to 0.02 meters per second and to 0 for particles with settling velocities of 0.5 and 1 meter per second. Thus, 28 percent of all particles with settling velocities of 0.02 meters per second reaching ground level at a given distance from the source were assumed to be retained and all particles with settling velocities of 0.5 and 1 meter per second were assumed to be retained.

The horizontal source dimensions σ_{xR} and σ_{yR} were determined from the expression

TABLE 3-5

SOURCE MODEL INPUT PARAMETERS FOR THE DOSAGE CALCULATIONS

Stability	Burn Rate (gal min^{-1})	V_s (m sec^{-1})	H' (m)	V	$\sigma_{x_R} = \sigma_{y_R}$ (m)	σ_{zR} (m)	Q (particles)
Stable	100	.02	99.23*	0.72	55.28	23.61*	0.38*
		.5, 1	167.32	0	55.28	55.28	1
	200	.02	106.49*	0.72	68.38	20.24	0.19*
		.5, 1	210	0	68.38	68.38	1
Neutral	100	.02	279	0.72	89.60	89.60	1
		.5, 1	279	0	89.60	89.60	1
	200	.02	351	0.72	112	112	1
		.5, 1	351	0	112	112	1
Unstable	100	.02	992.50	0.72	281	281	1
		.5, 1	992.50	0	281	281	1
	200	.02	1245	0.72	351	351	1
		.5, 1	1245	0	351	351	1

*Major portion of cloud above surface mixing layer. See text for explanation of H, σ_{zR} and Q for these cases.

$$\sigma_{xR} = \sigma_{yR} = \frac{r_m}{2.15} \tag{3-5}$$

and the vertical source dimension σ_{ZR} was calculated from

$$\sigma_{zR} = \left\{ \begin{array}{ll} \dfrac{r_m}{2.15} & ; \quad H_m \geq H \\ \dfrac{H_m - H + r_m}{4.3} & ; \quad H_m < H \end{array} \right\} \tag{3-6}$$

The dosage and area-coverage calculations were made assuming a normalized total source strength of unity ($Q = 1$). In those cases where $H > H_m$, the vertical distribution of material about the value of H calculated from the cloud-rise formula was assumed to be Gaussian and the effective normalized source strength as that fraction of the cloud contained in the surface mixing layer.

SECTION 4
RESULTS OF THE CALCULATIONS

4.1 DOSAGE ISOPLETHS

Dosage isopleths calculated using the cloud-rise and dosage models in Section 2 and the model inputs in Section 3 are presented in Figures 4-1 through 4-54. The figures are arranged by burn rate (100 and 200 gallons per minute), by particle settling velocities (0.02, .5 and 1 meter per second), by total gallons of oil burned (500, 1000 and 2000 gallons) and by atmospheric stability (stable, neutral and unstable). Dosage isopleths for stable atmospheric conditions are found in Figures 4-1 through 4-18, for neutral atmospheric conditions in Figures 4-19 through 4-36 and for unstable atmospheric conditions in Figures 4-37 through 4-54. In each figure, the isopleth dosage levels are identified by numbers and the key to the dosage levels for each number is given in Table 4-1.

TABLE 4-1

KEY FOR ISOPLETH LEVELS

(Particles minutes per cubic meter)

Isopleth Level Number	Atmospheric Stability		
	Stable	Neutral	Unstable
1	$1x10^{-8}$	$5x10^{-9}$	$5x10^{-10}$
2	$5x10^{-9}$	$1x10^{-9}$	$1x10^{-10}$
3	$1x10^{-9}$	$5x10^{-10}$	$5x10^{-11}$
4	$5x10^{-10}$	$1x10^{-10}$	$1x10^{-11}$
5	$1x10^{-10}$	$5x10^{-11}$	$5x10^{-12}$
6	$5x10^{-11}$	$1x10^{-11}$	$1x10^{-12}$
7	$1x10^{-11}$	$5x10^{-12}$	$5x10^{-13}$
8	$5x10^{-12}$	$1x10^{-12}$	$1x10^{-13}$
9		$5x10^{-13}$	$5x10^{-14}$

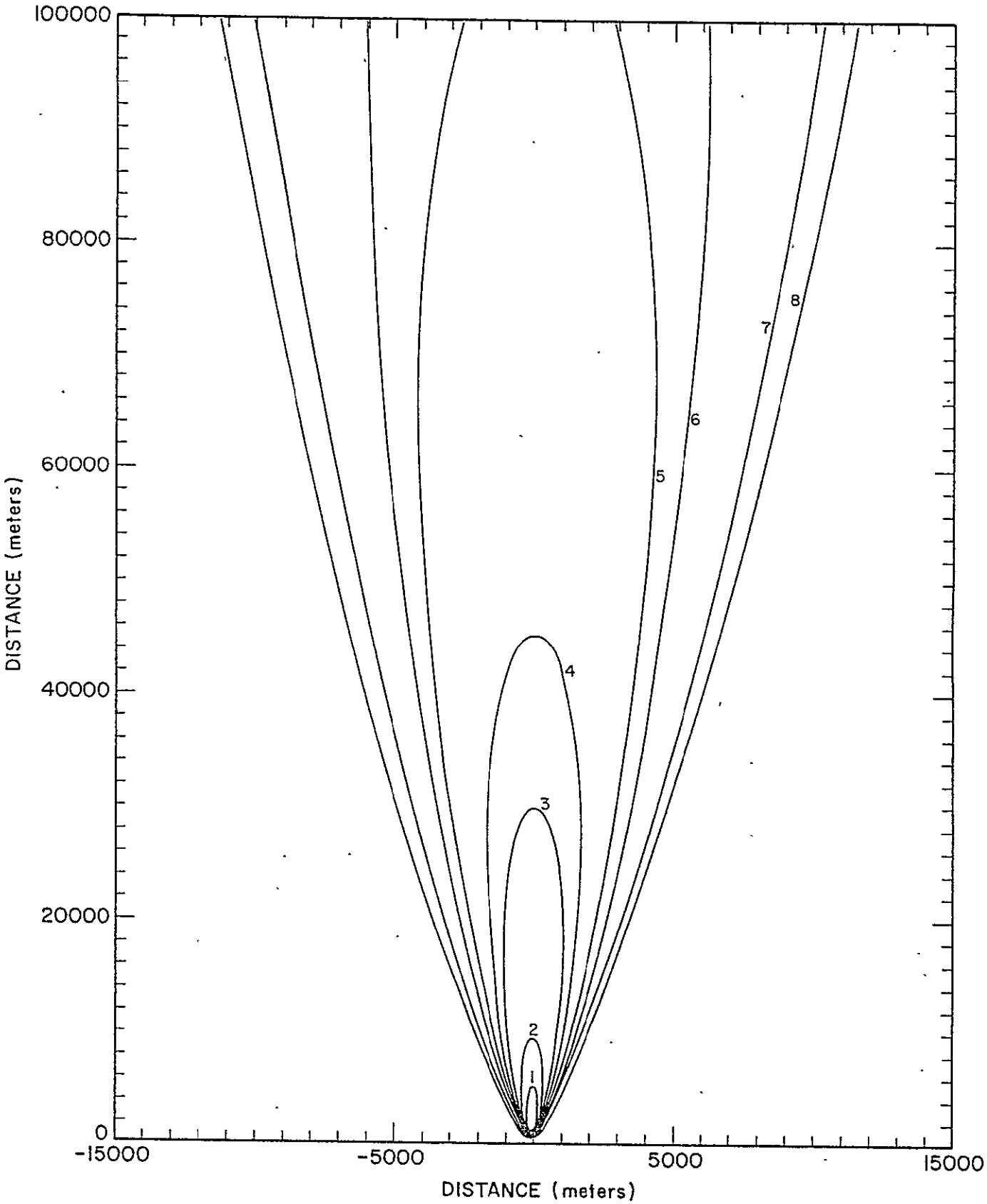

FIGURE 4-1. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second.

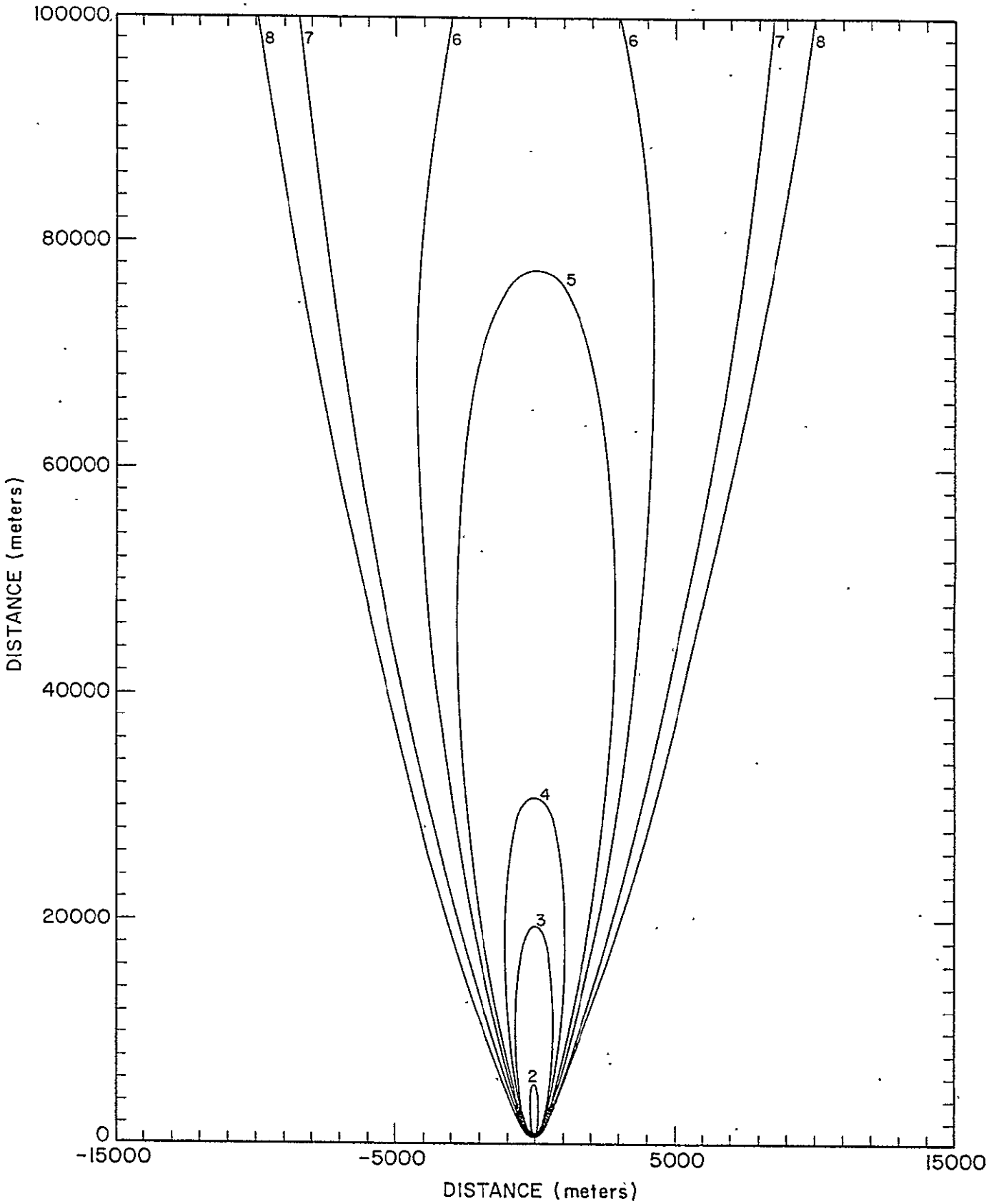

FIGURE 4-2. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second.

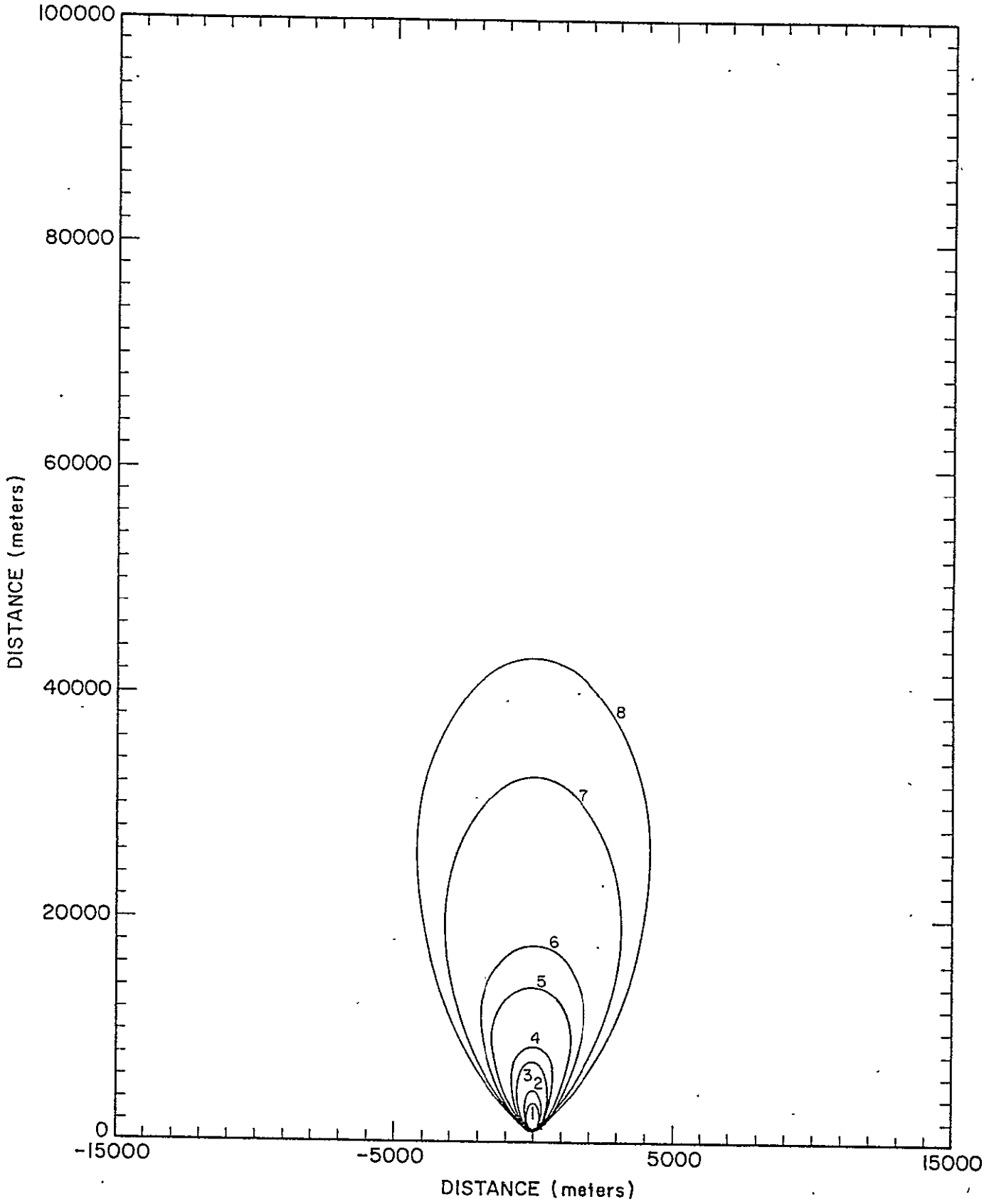

FIGURE 4-3. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second.

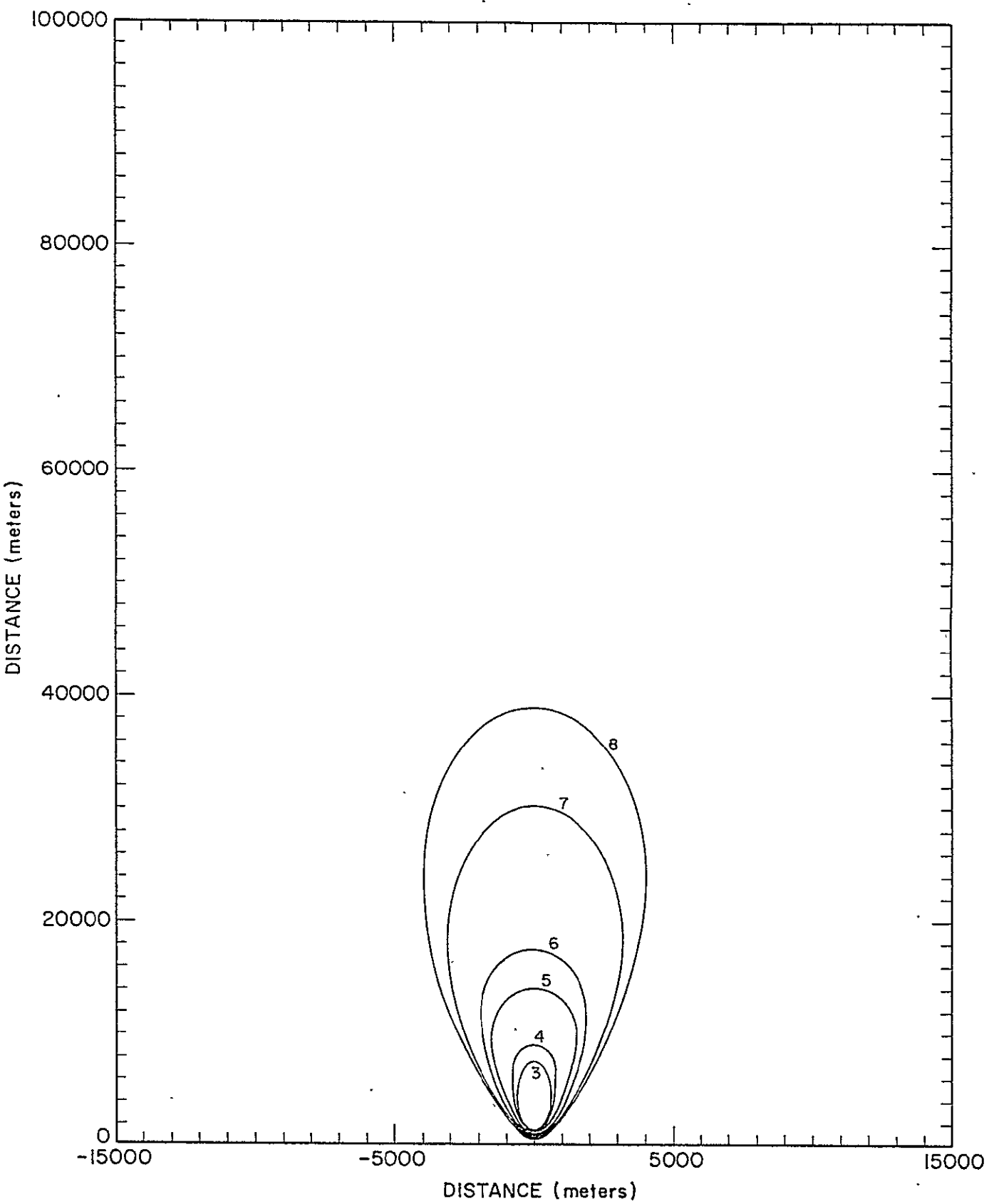

FIGURE 4-4: Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second.

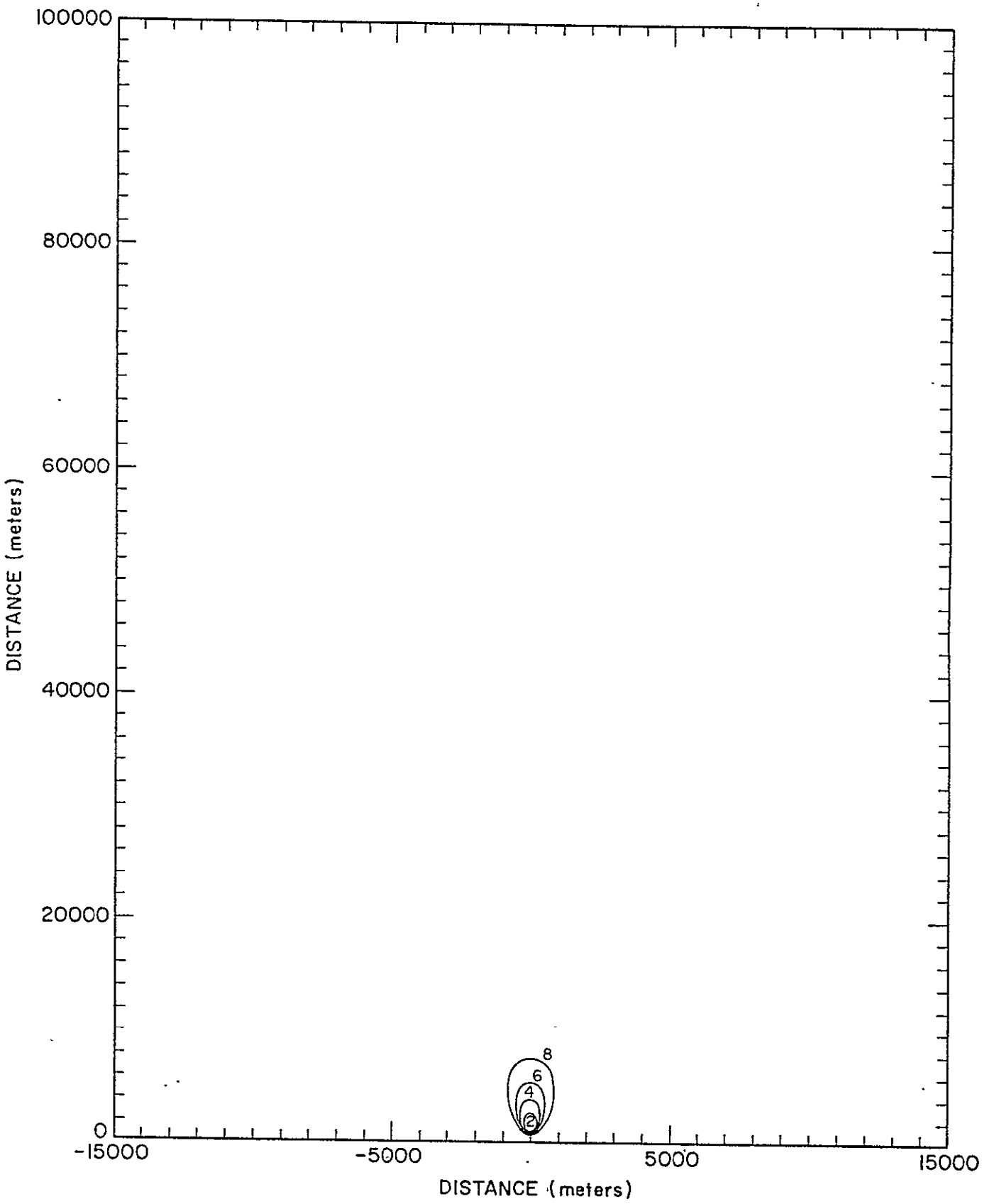

FIGURE 4-5. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 1 meter per second.

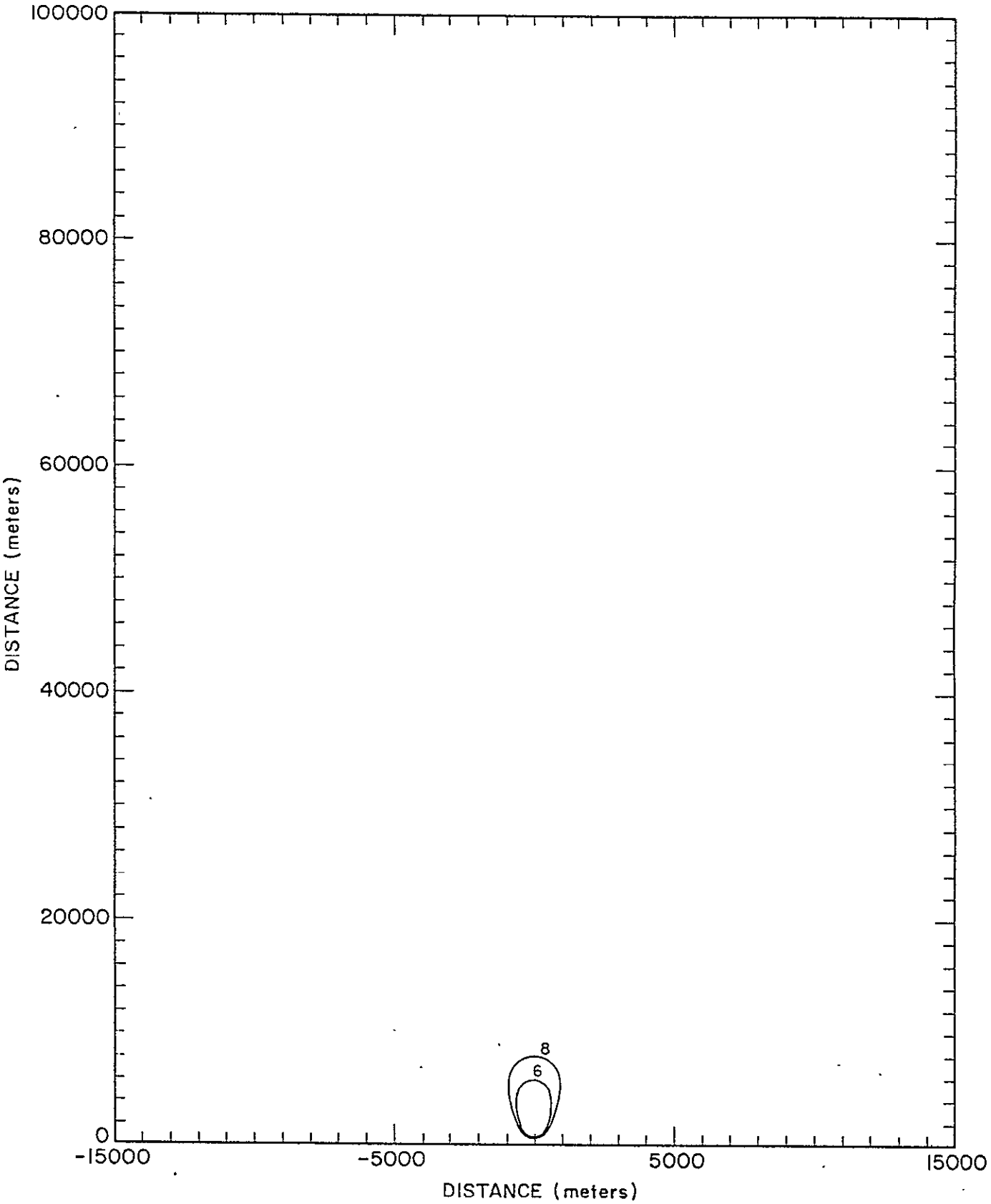

FIGURE 4-6. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 1 meter per second.

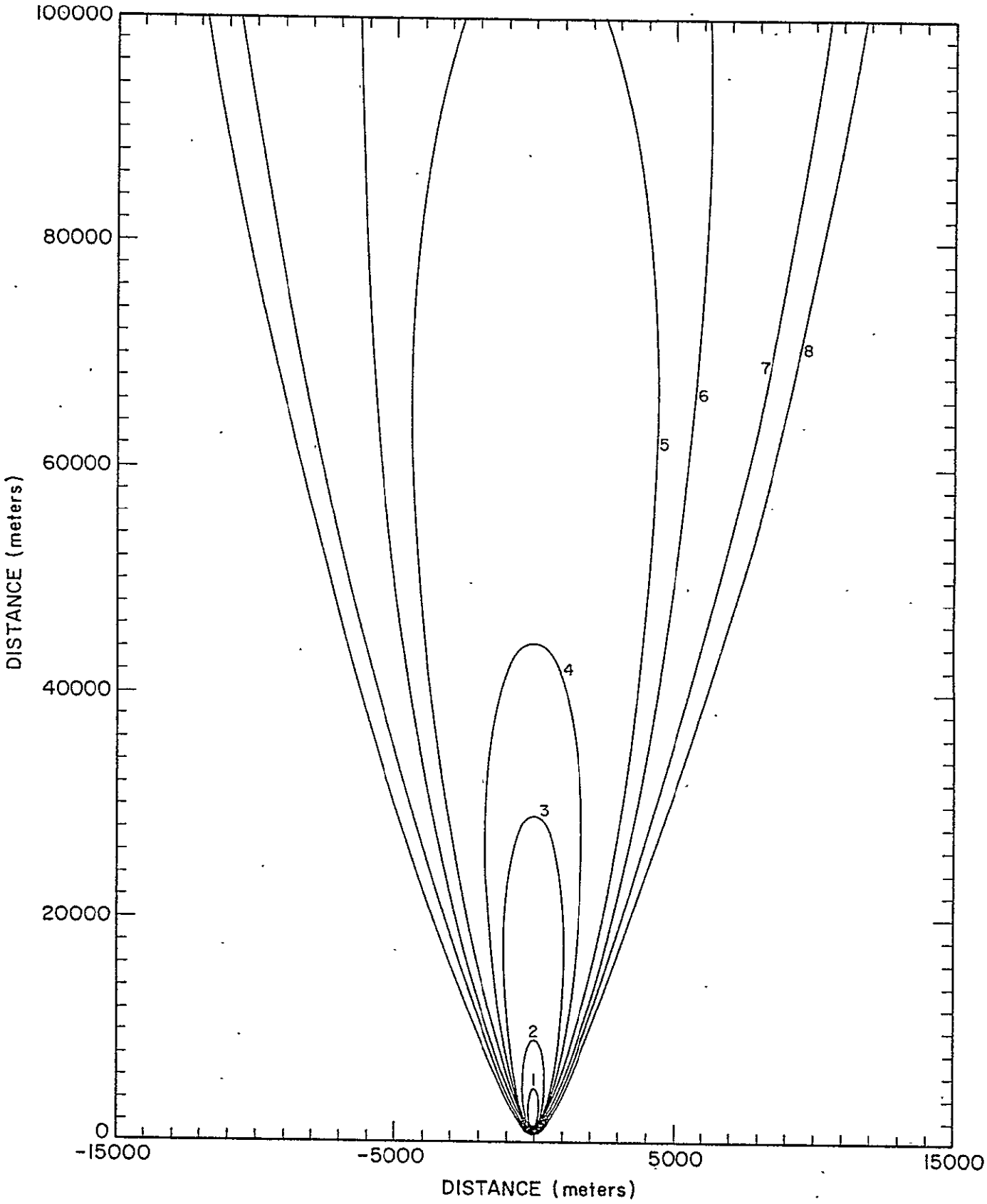

FIGURE 4-7. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 2 centimeters per second.

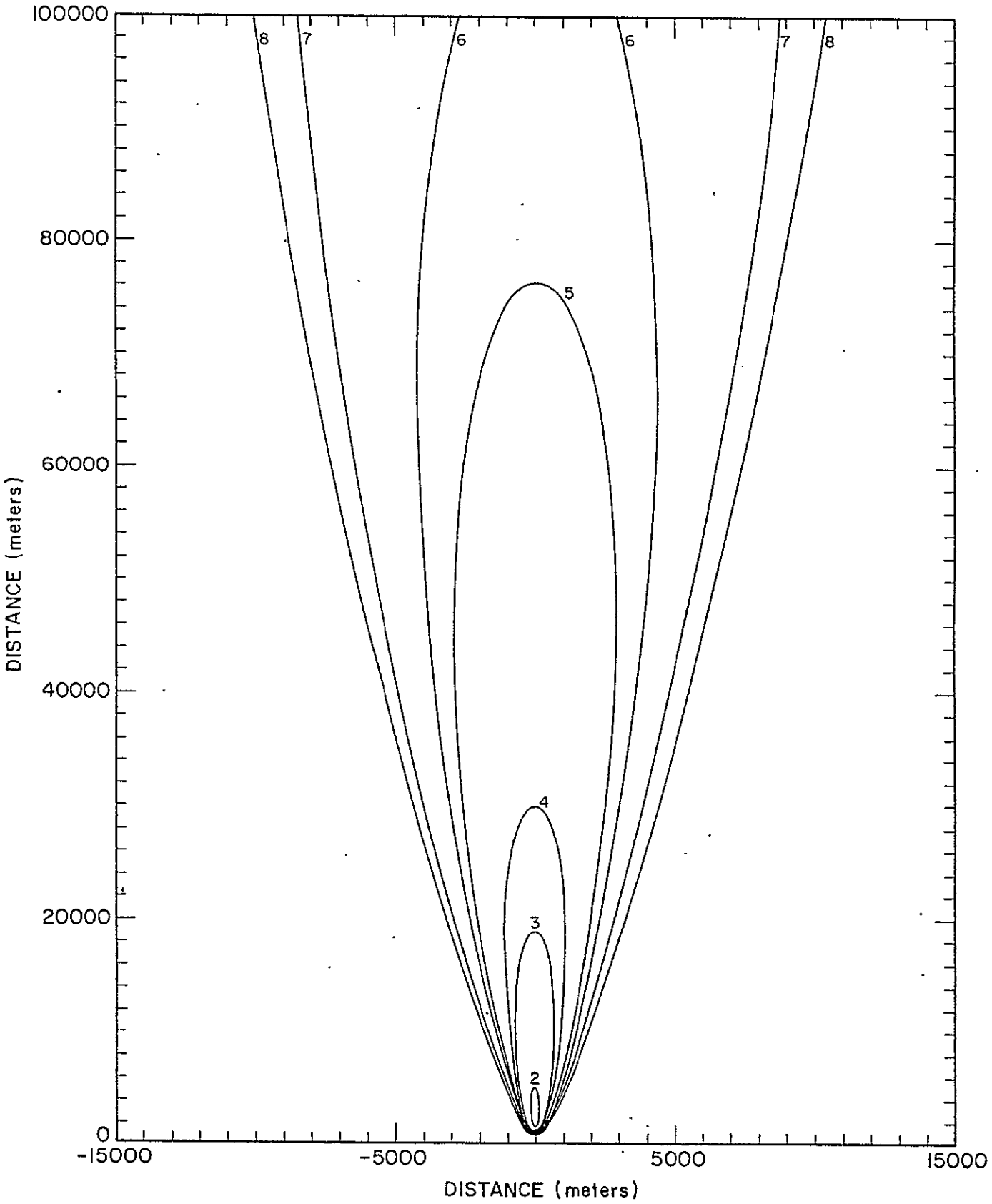

FIGURE 4-8. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 2 centimeters per second.

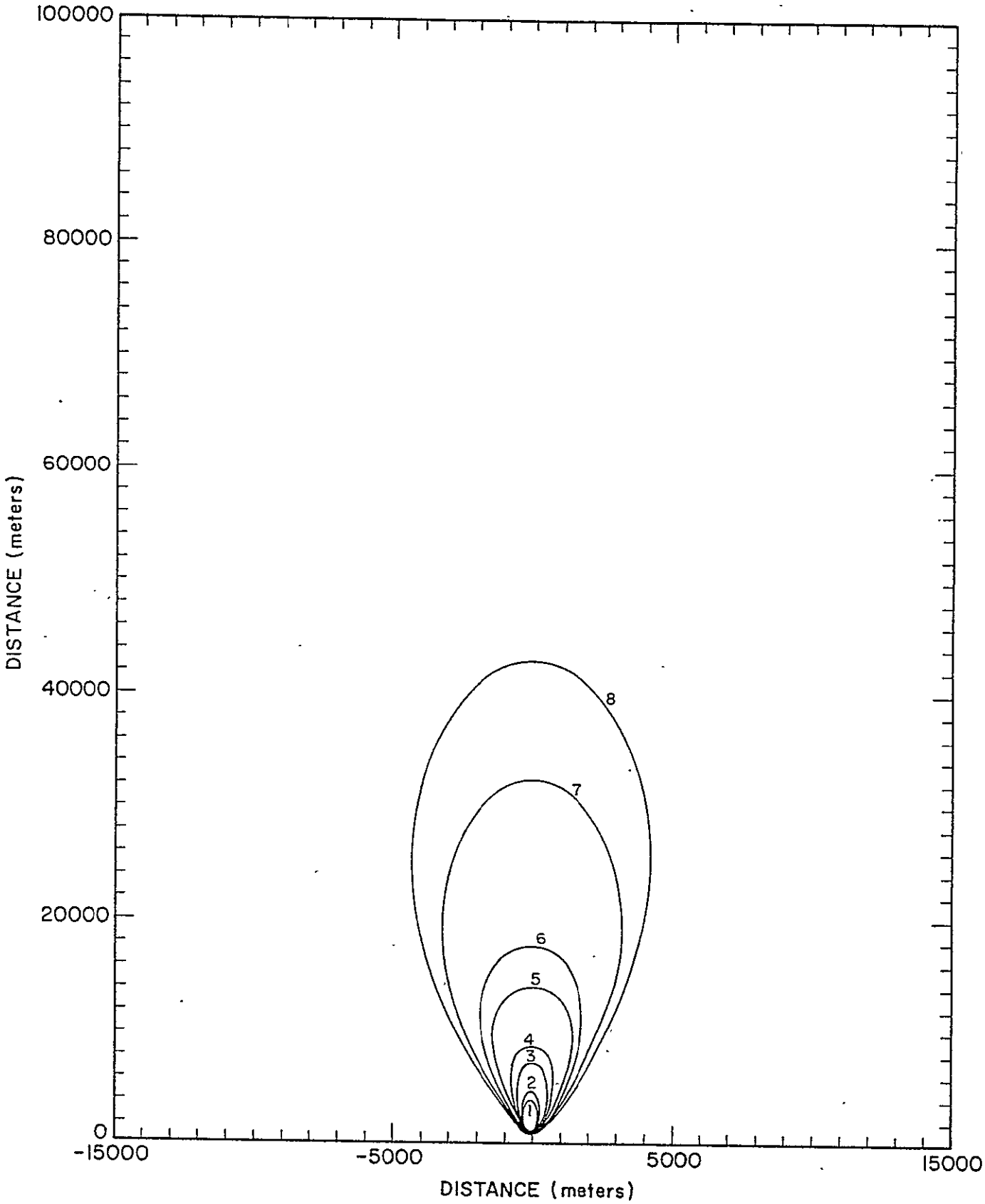

FIGURE 4-9. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second.

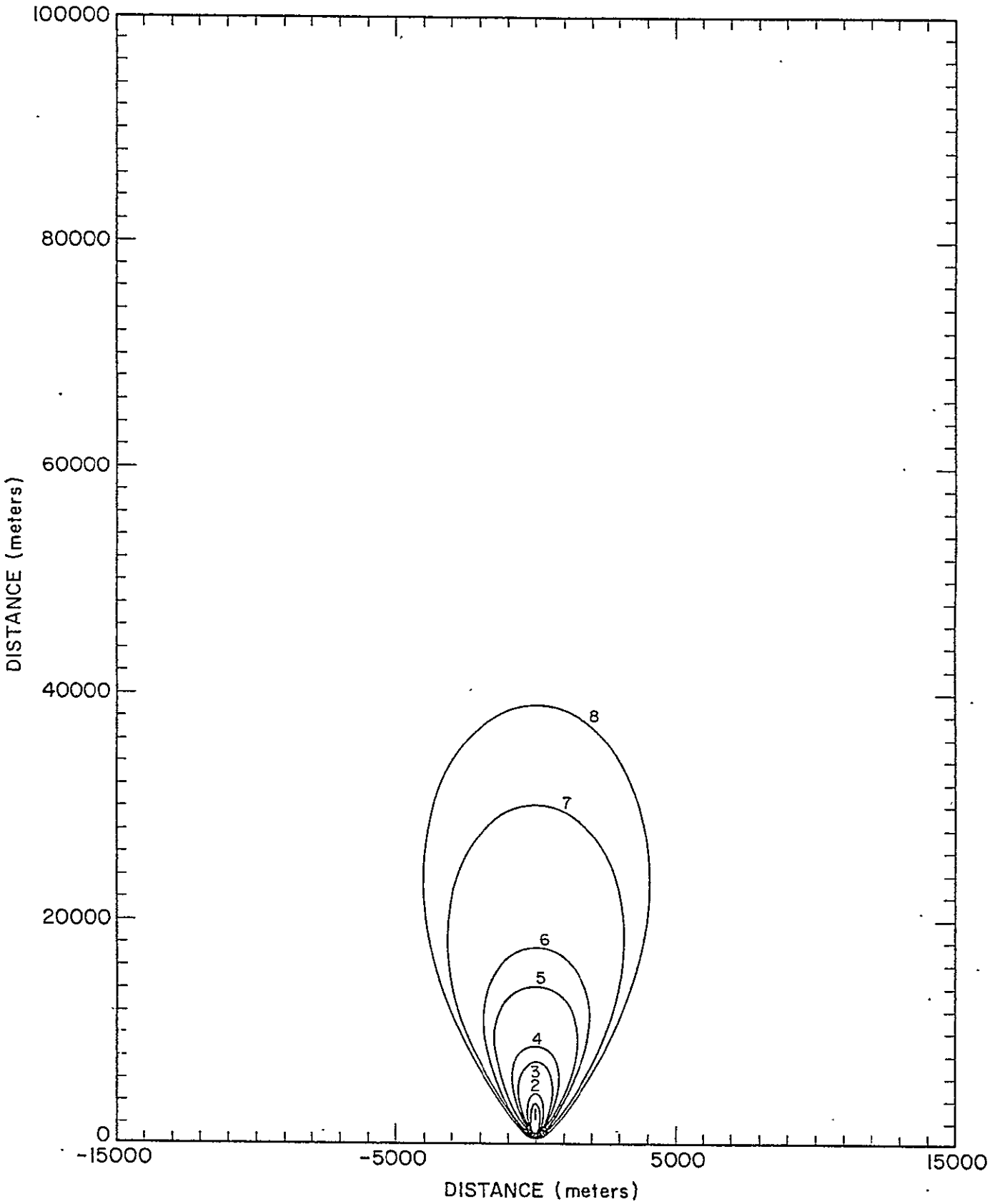

FIGURE 4-10. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second.

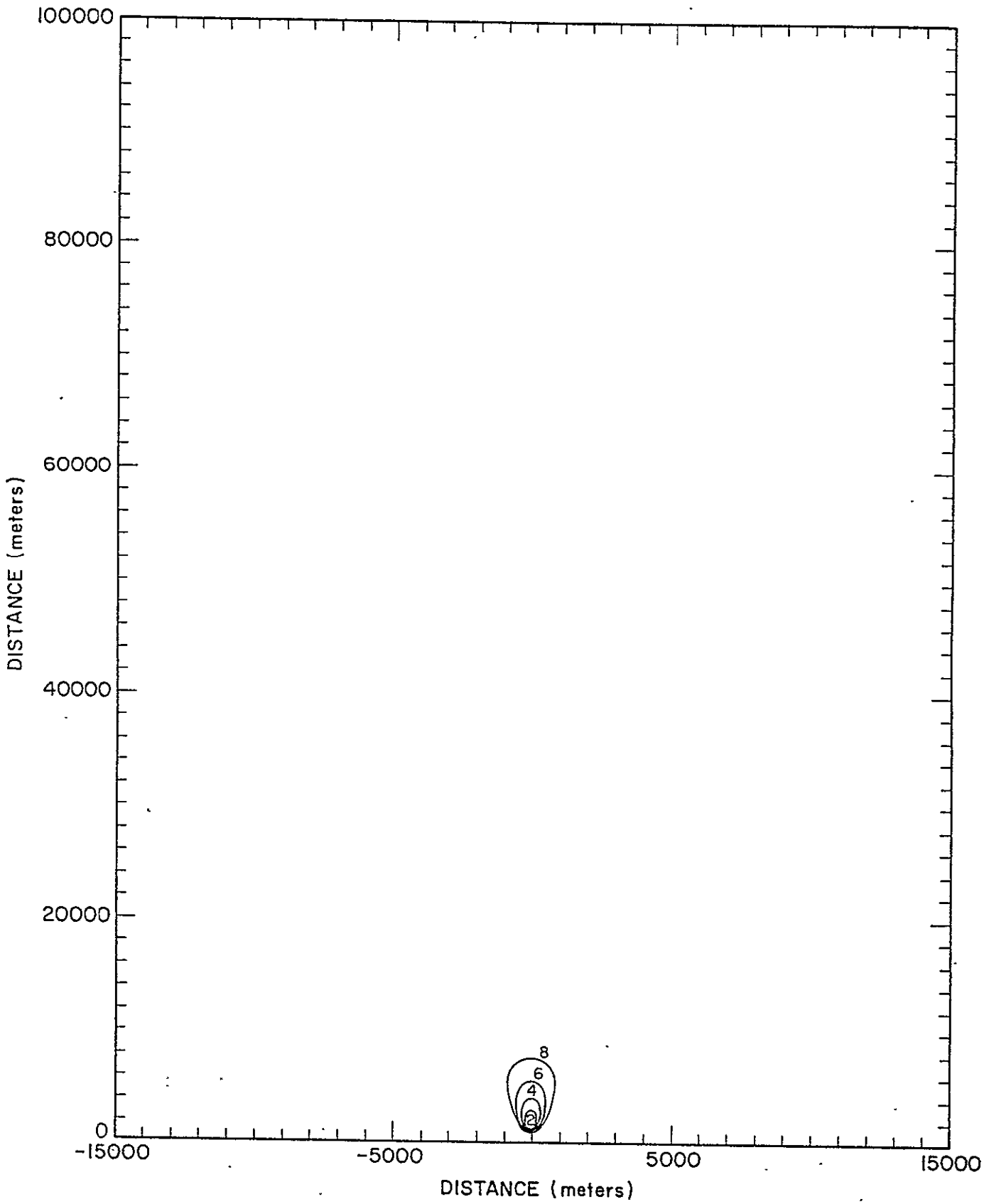

FIGURE 4-11. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second.

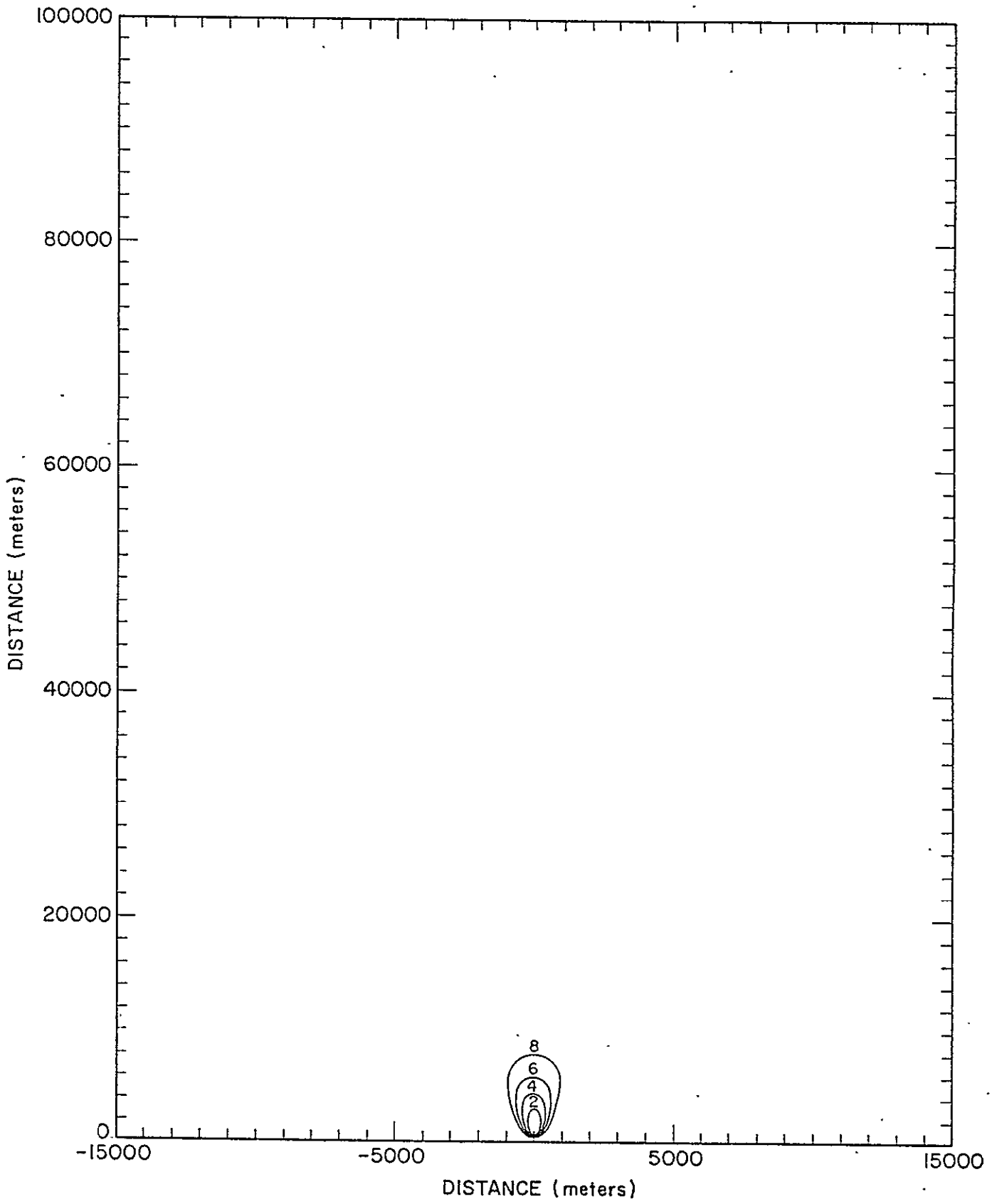

FIGURE 4-12. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second.

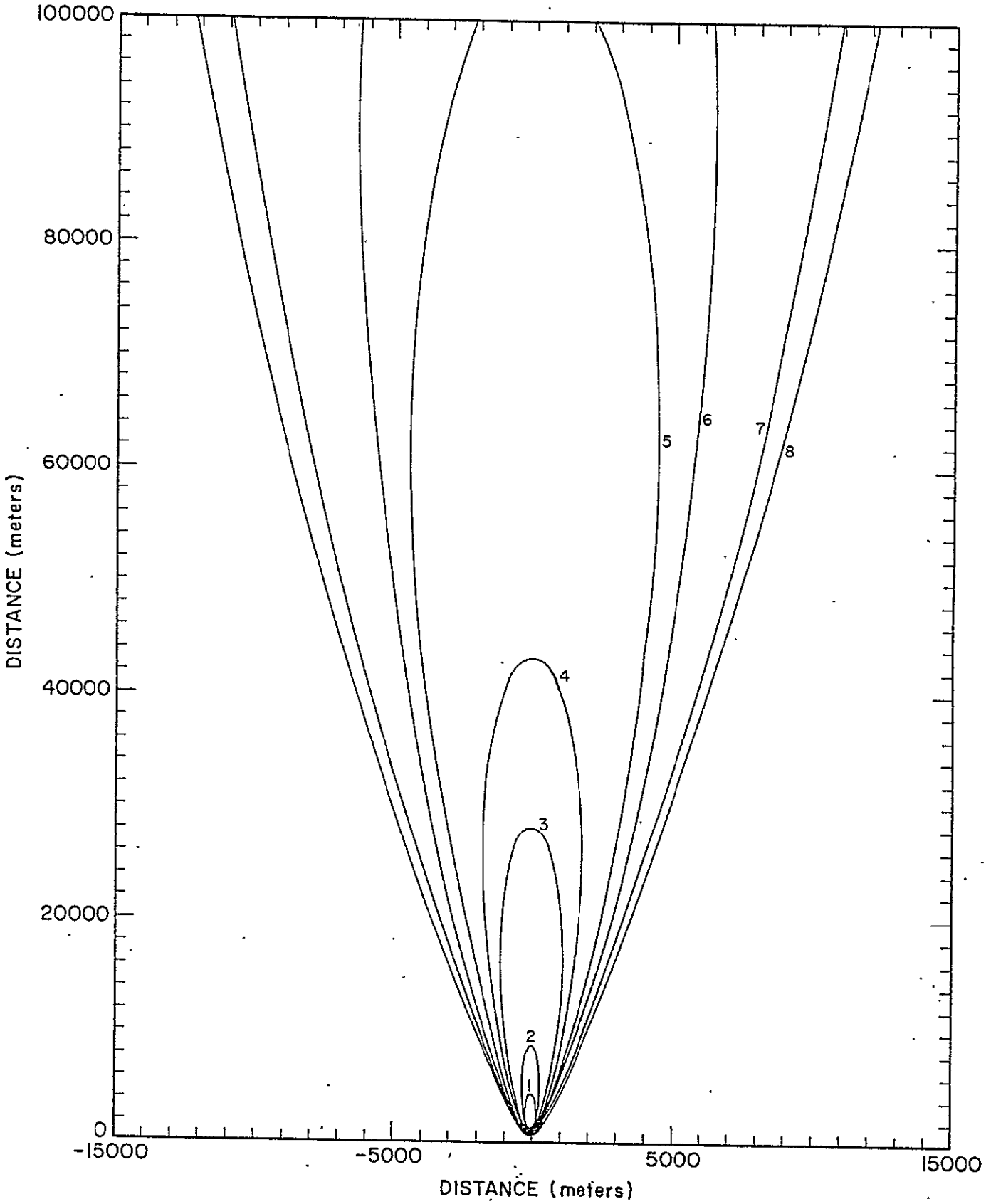

FIGURE 4-13. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 2 centimeters per second.

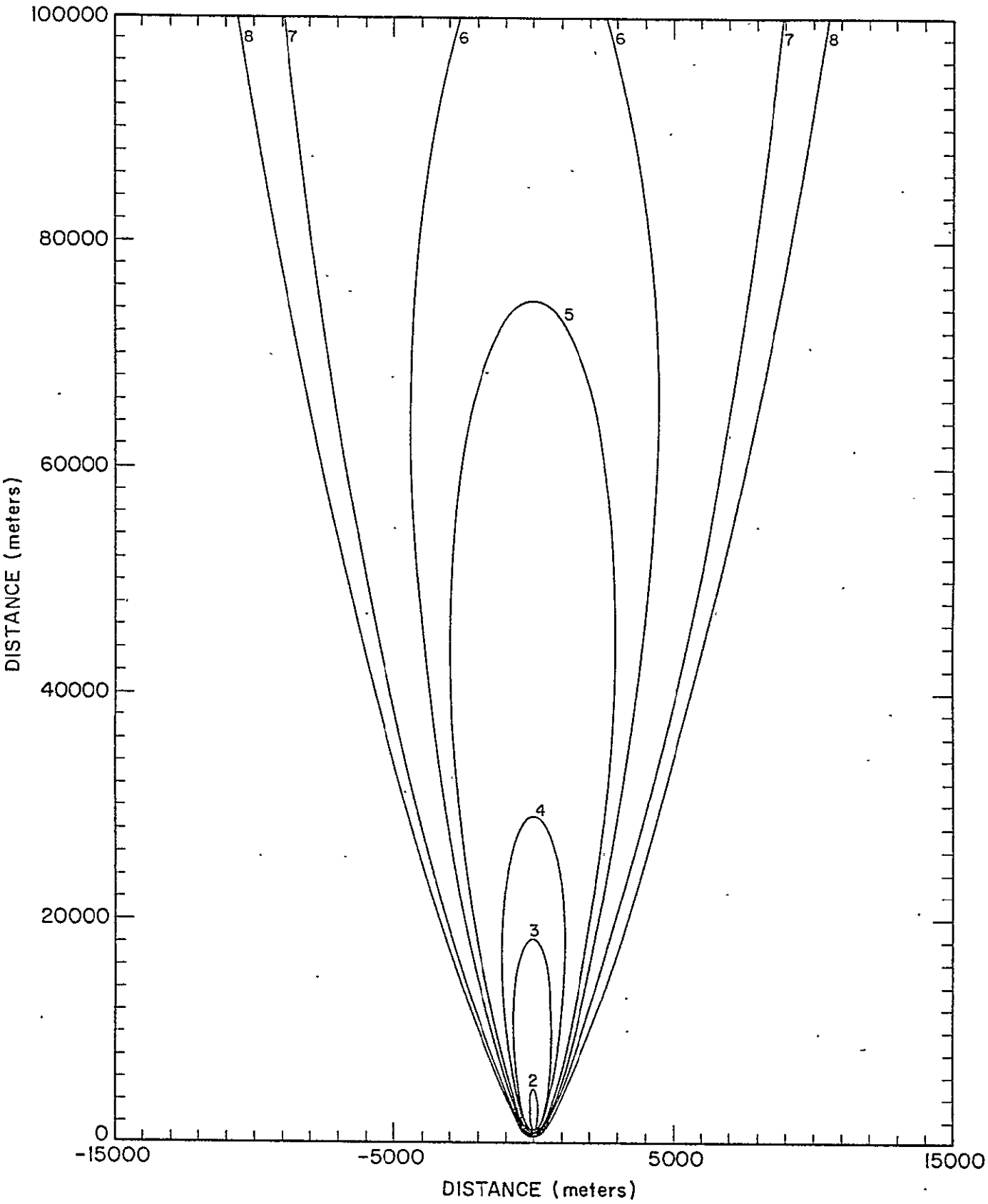

FIGURE 4-14. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 2 centimeters per second.

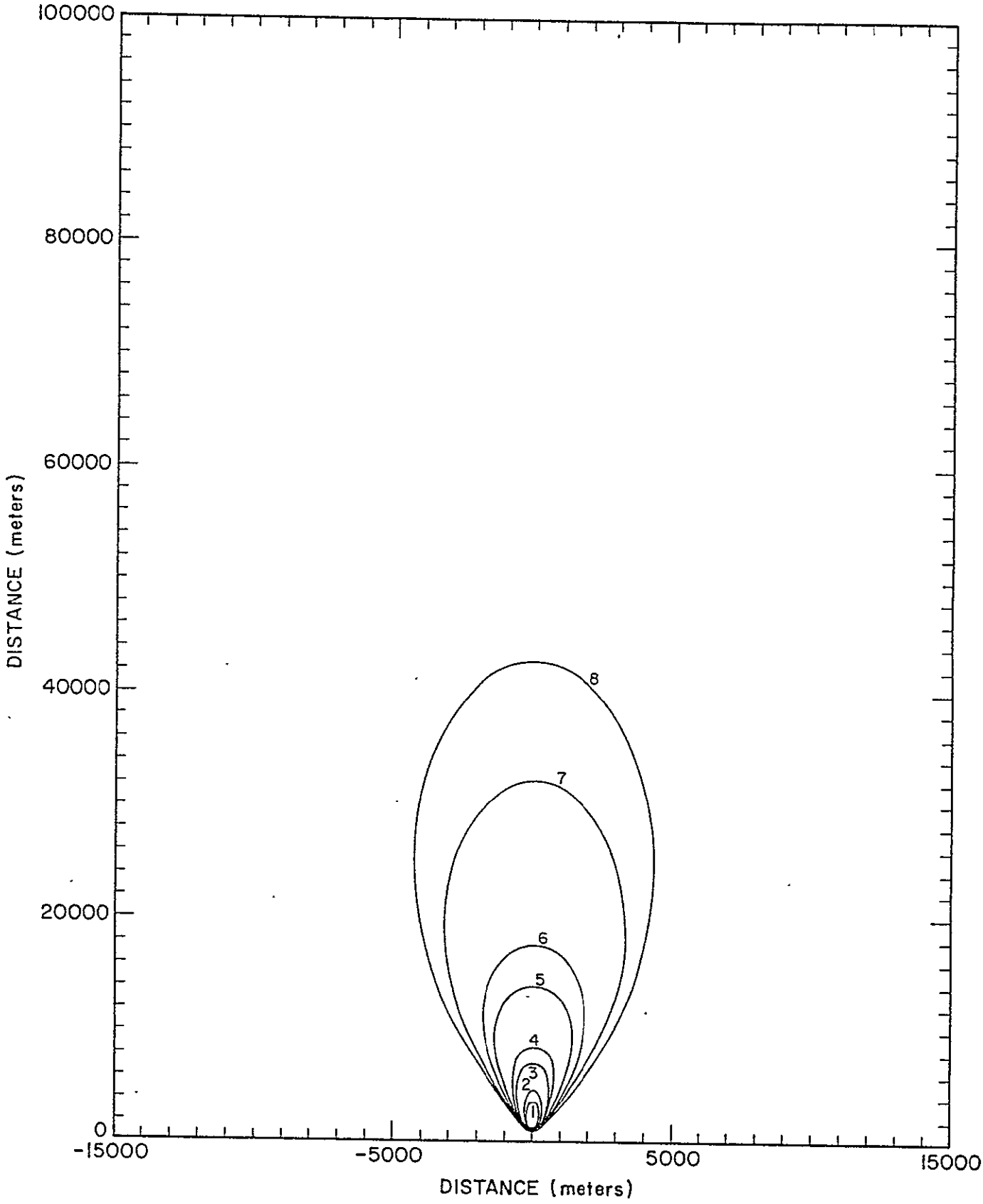

FIGURE 4-15. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second.

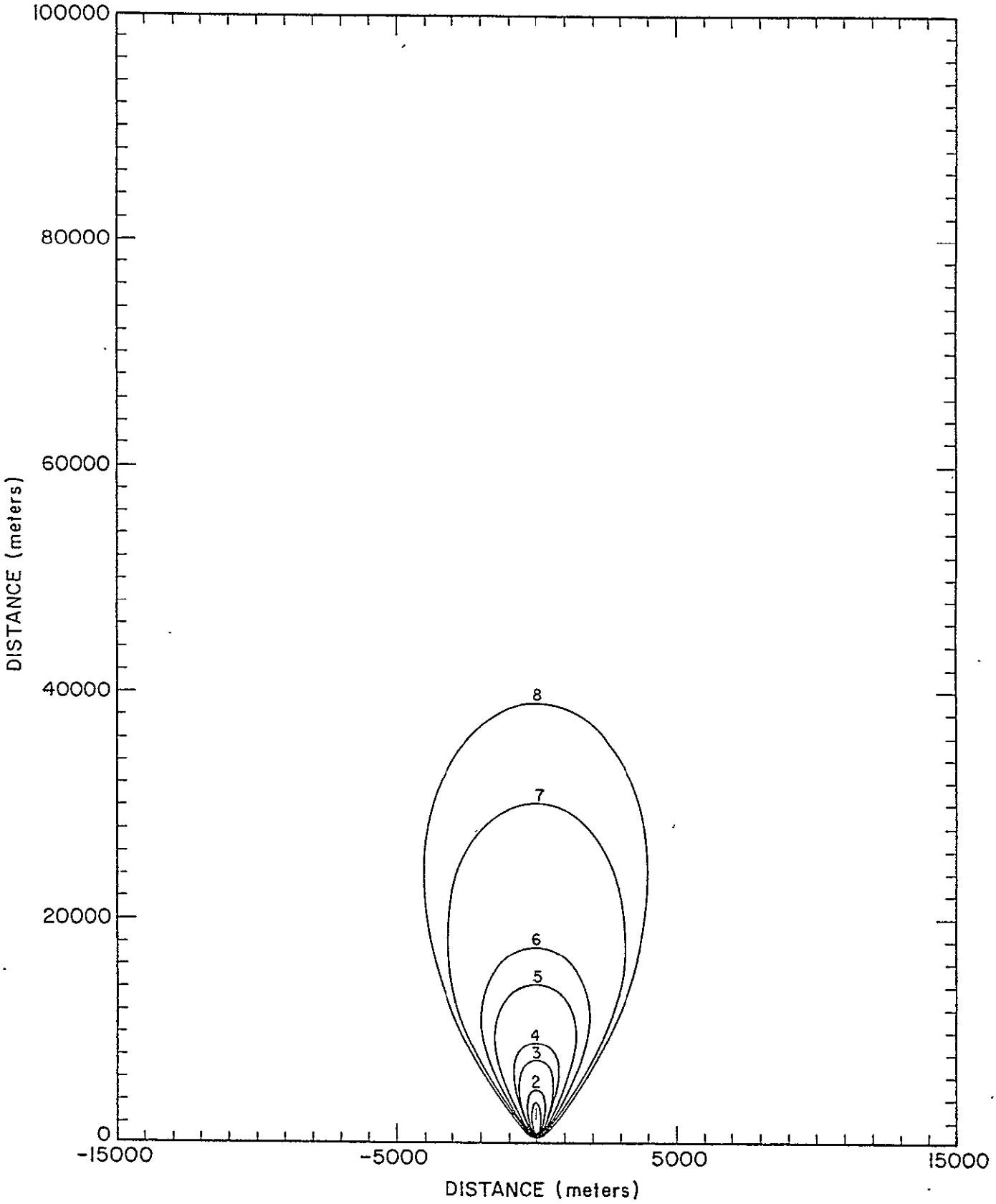

FIGURE 4-16. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second.

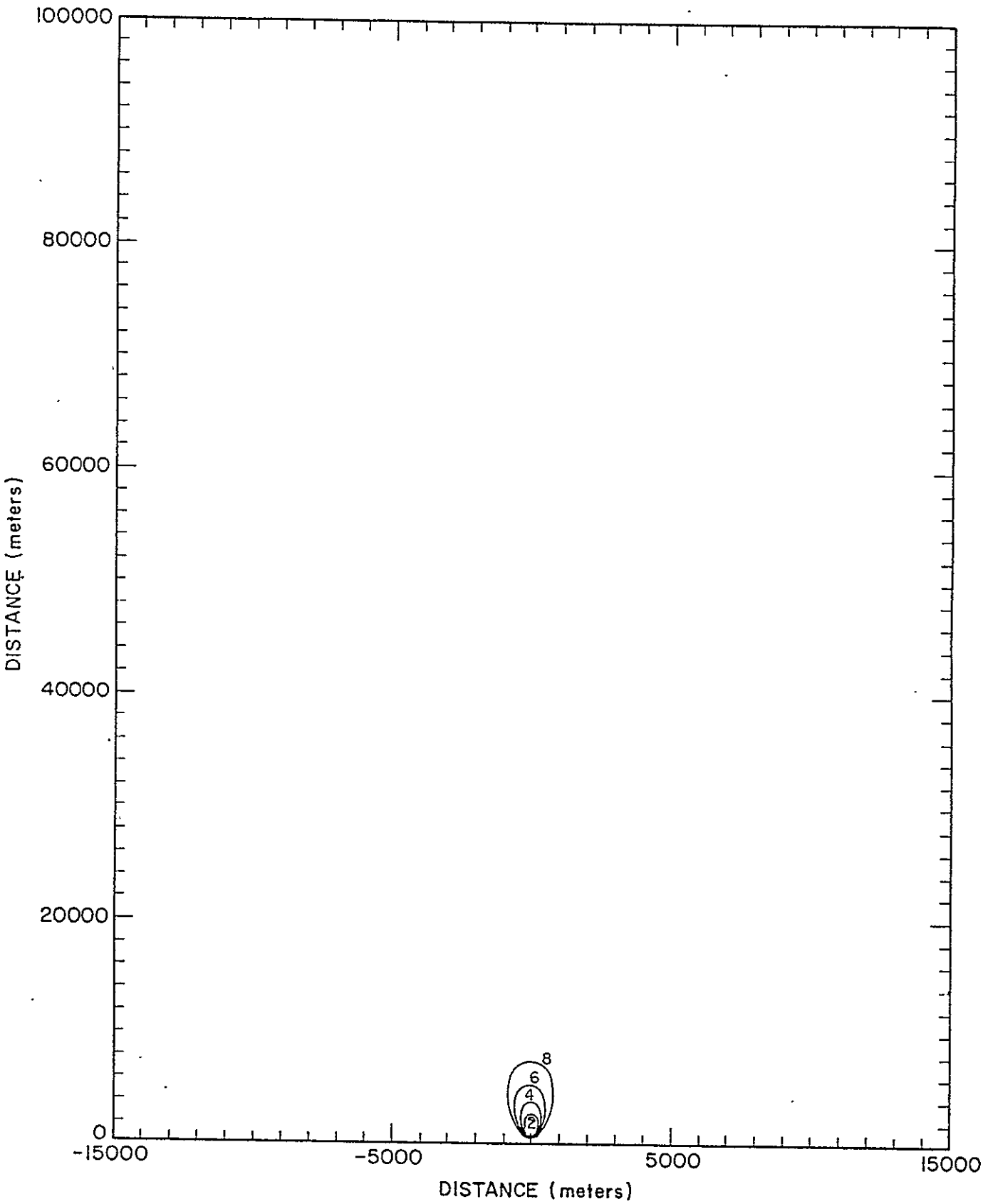

FIGURE 4-17. Dosage isopleths under stable conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second.

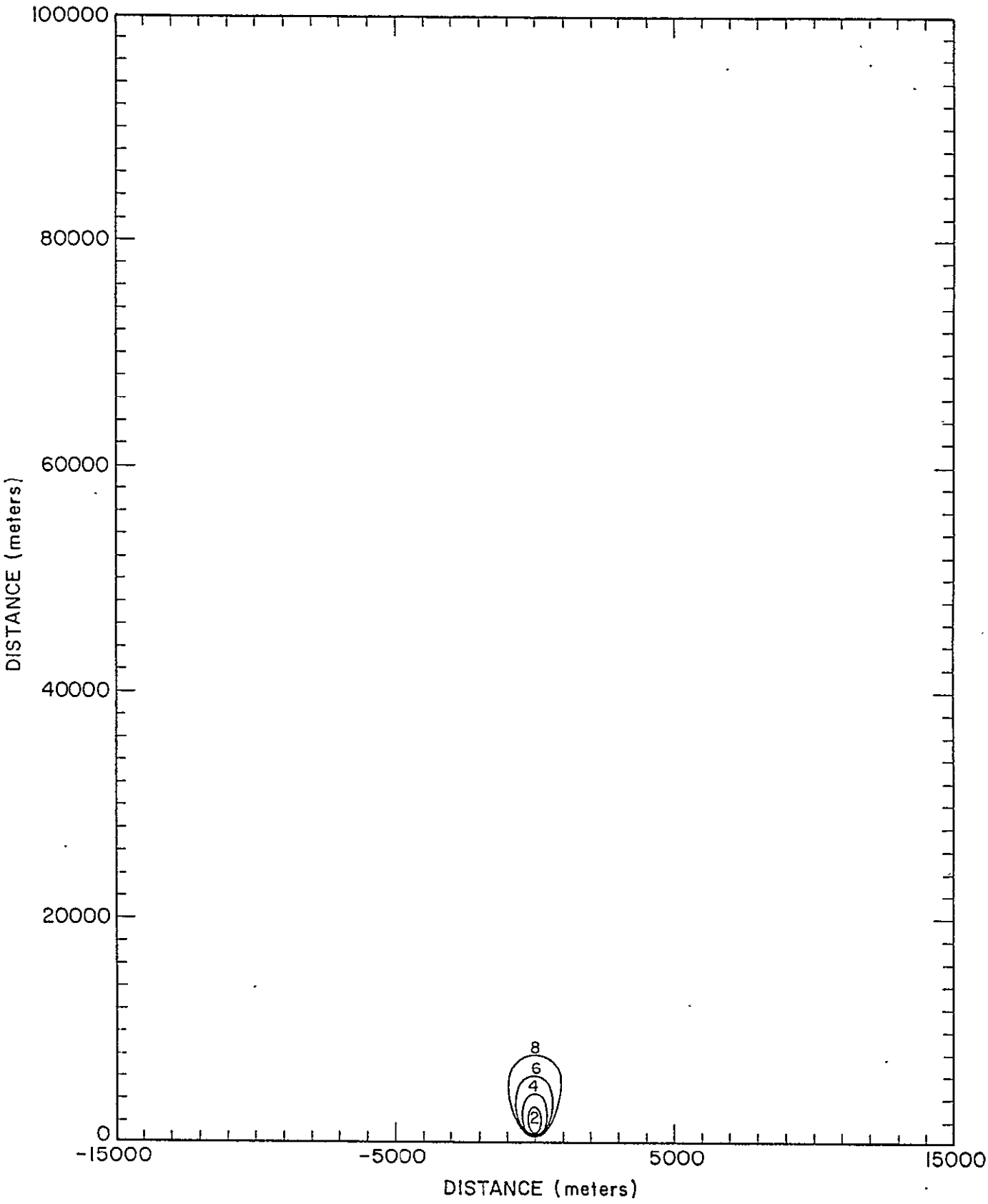

FIGURE 4-18. Dosage isopleths under stable conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second.

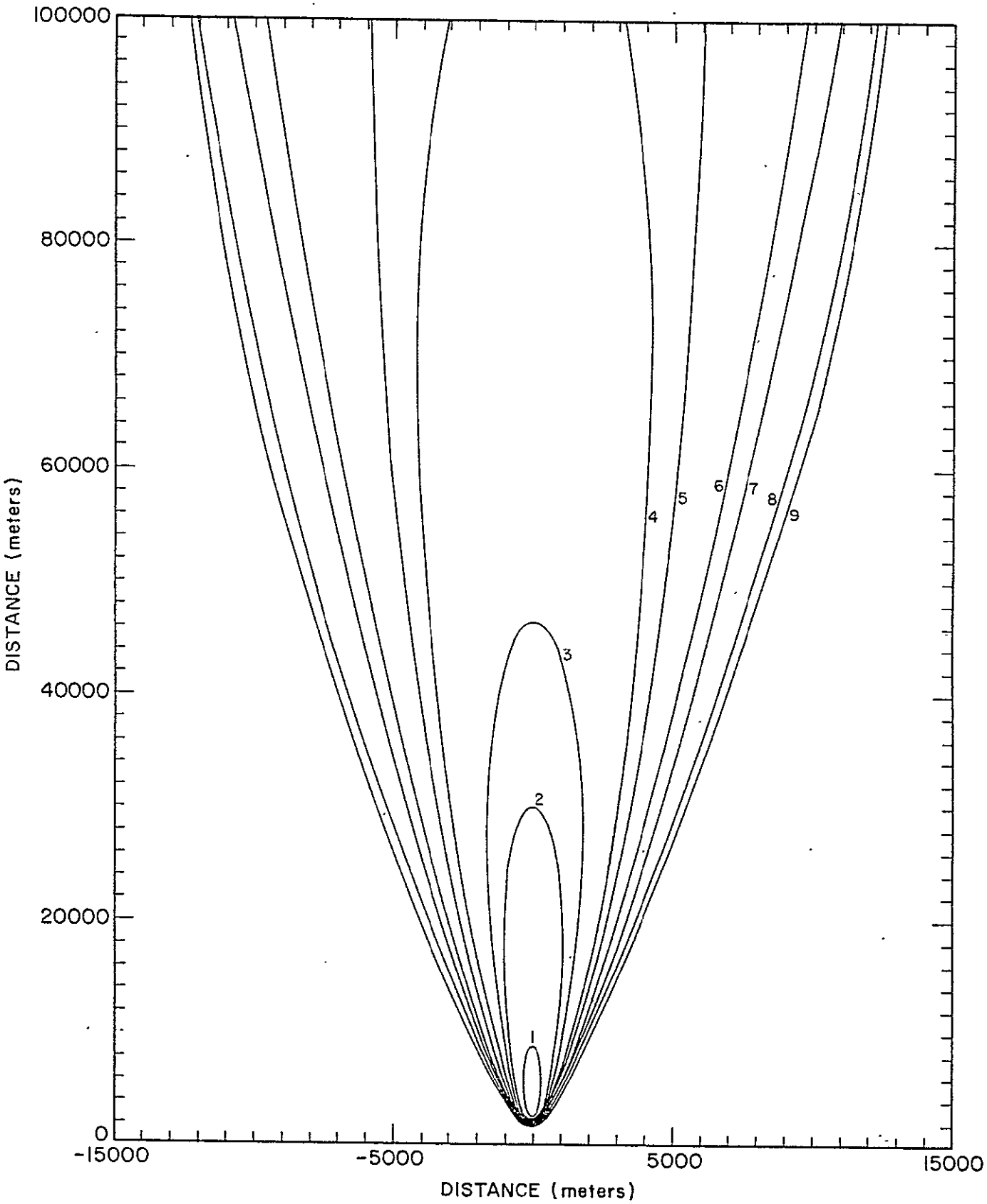

FIGURE 4-19. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second.

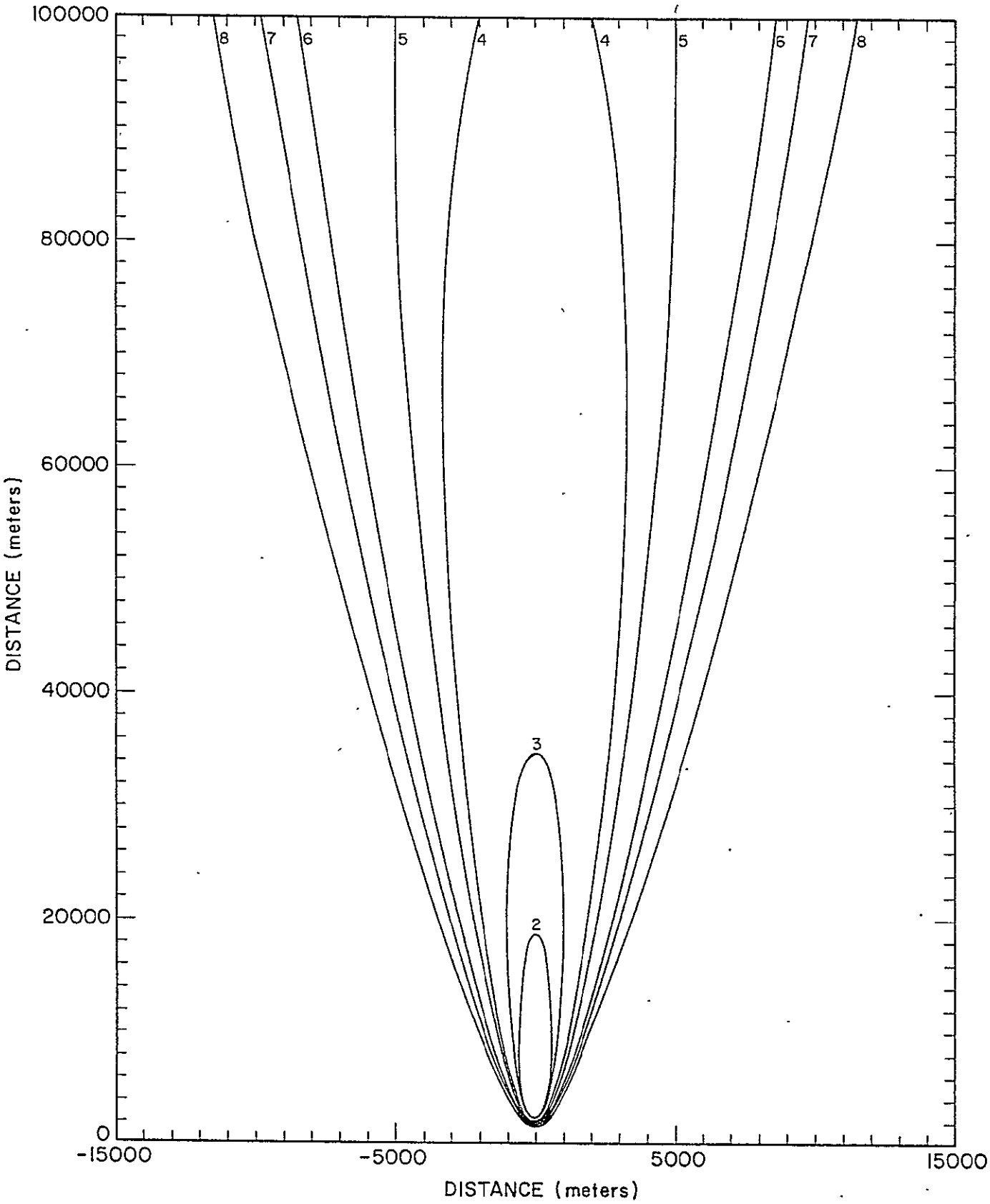

FIGURE 4-20. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second.

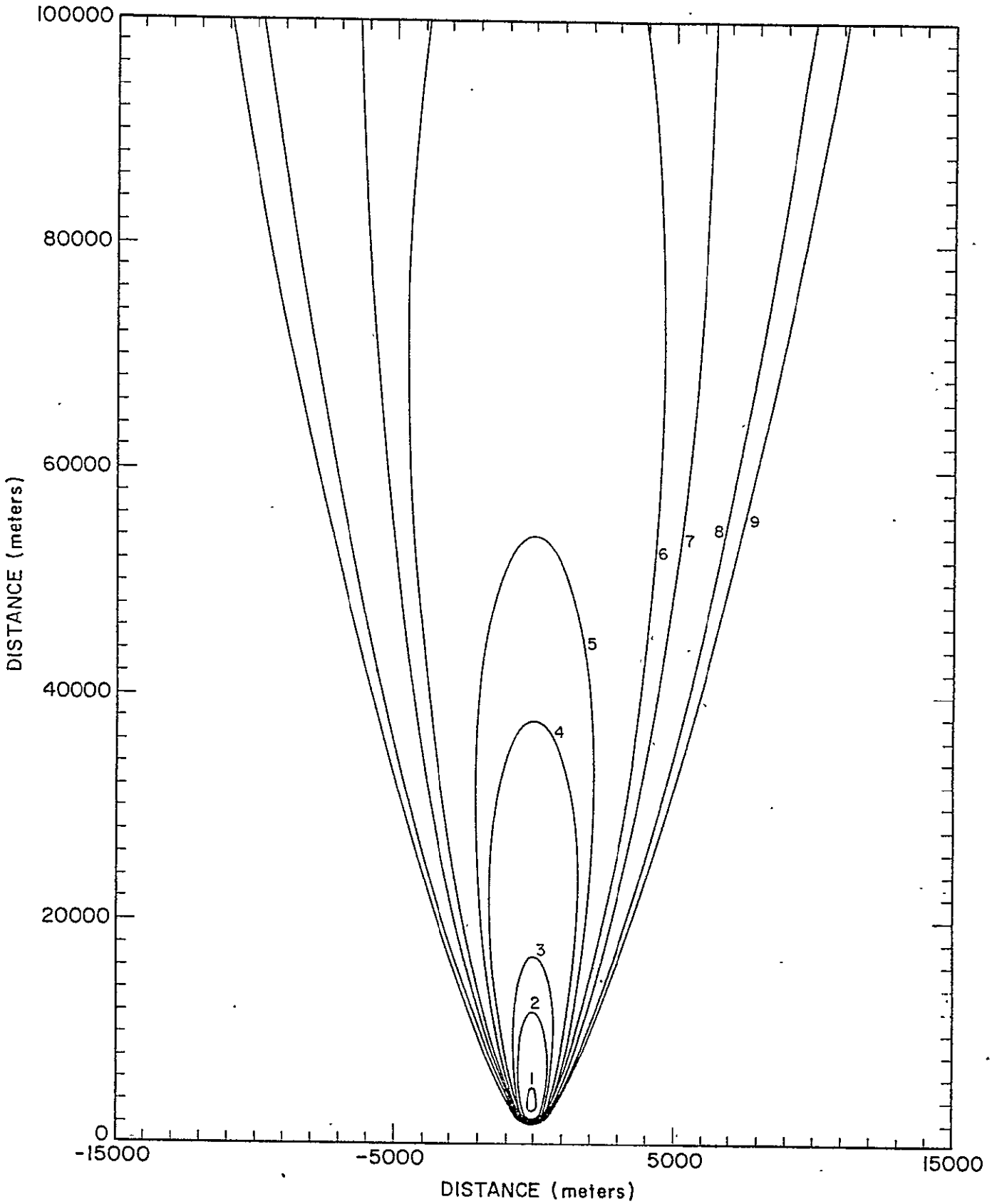

FIGURE 4-21. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second

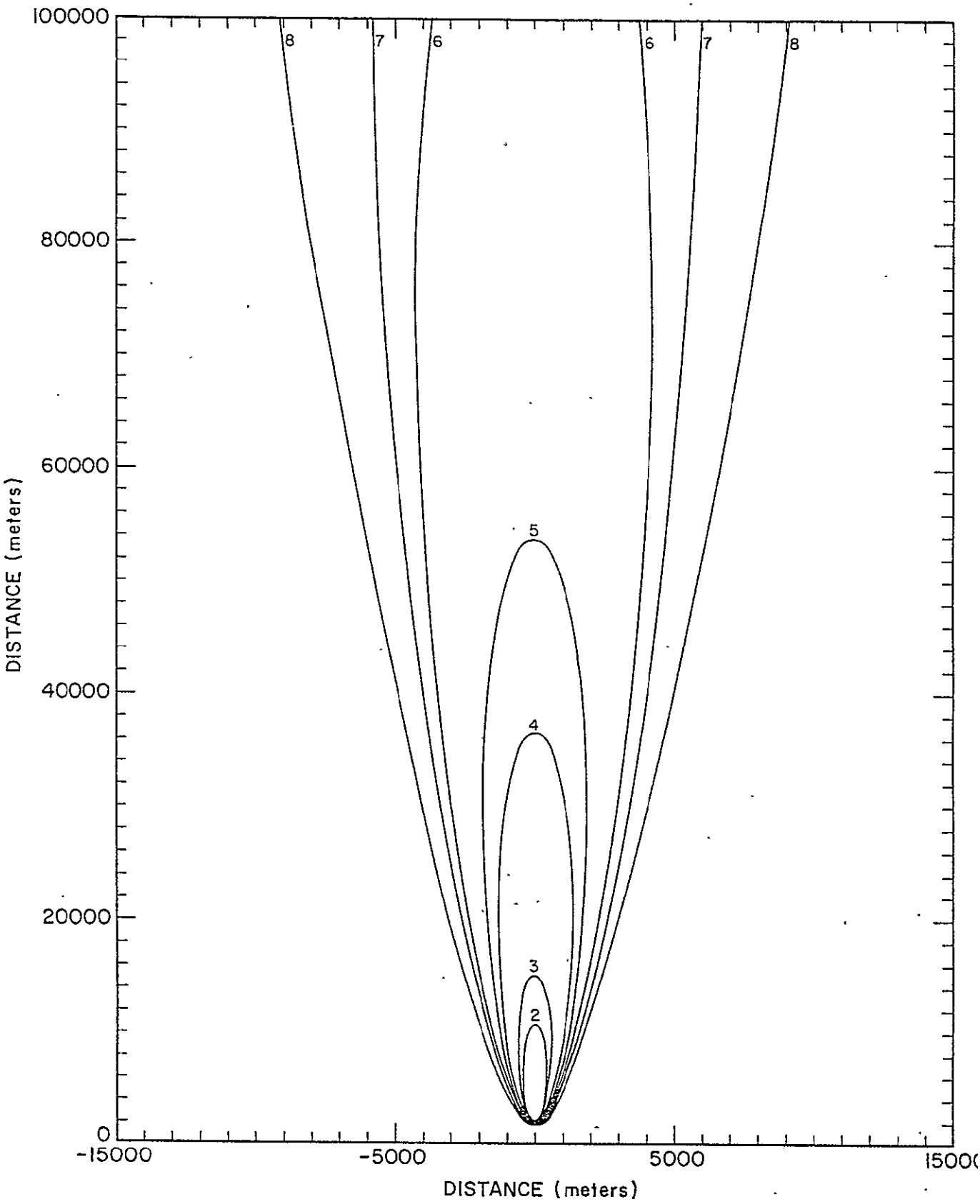

FIGURE 4-22. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second.

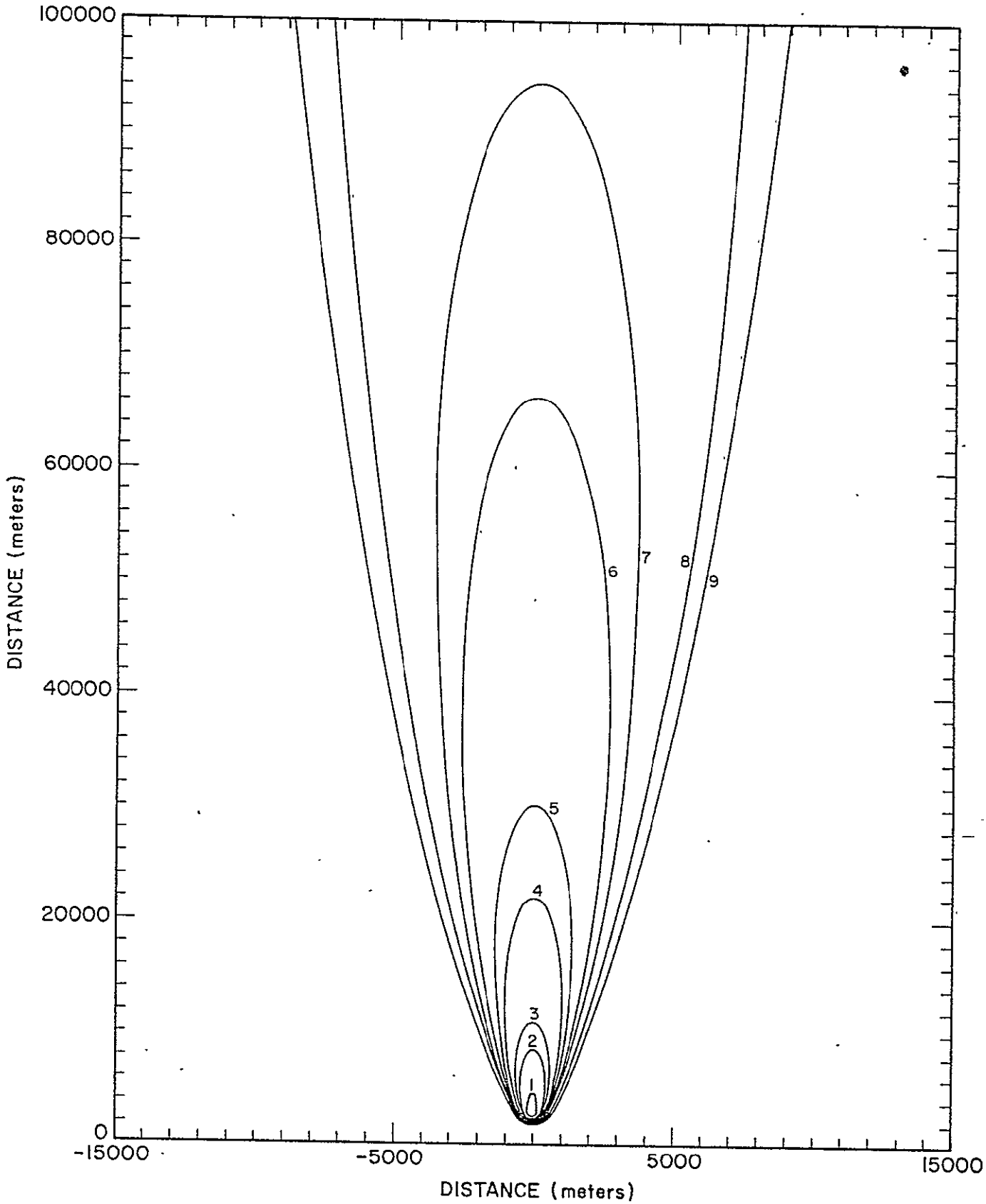

FIGURE 4-23. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 1 meter per second

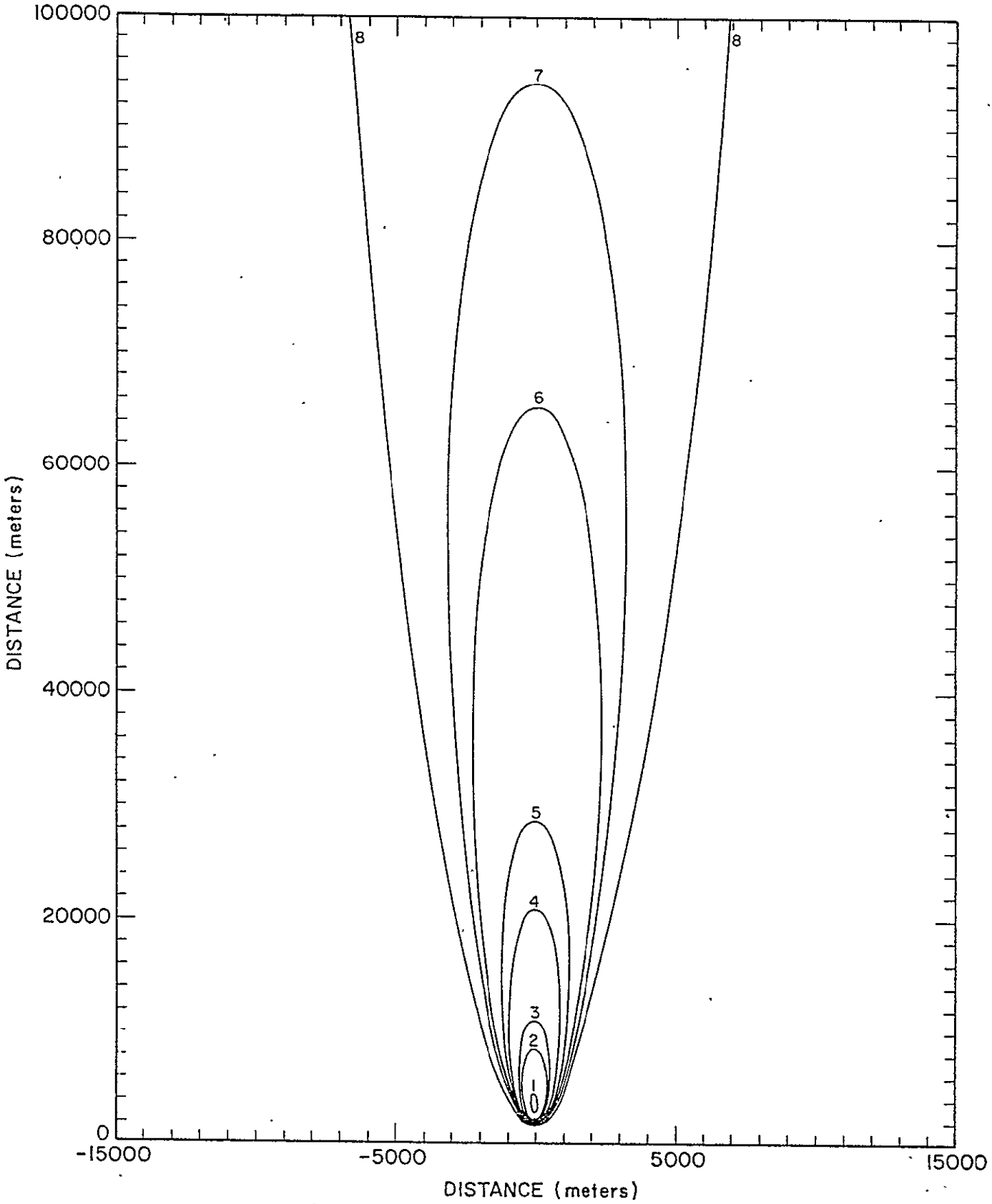

FIGURE 4-24. Dosage isopletes under neutral conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 1 meter per second.

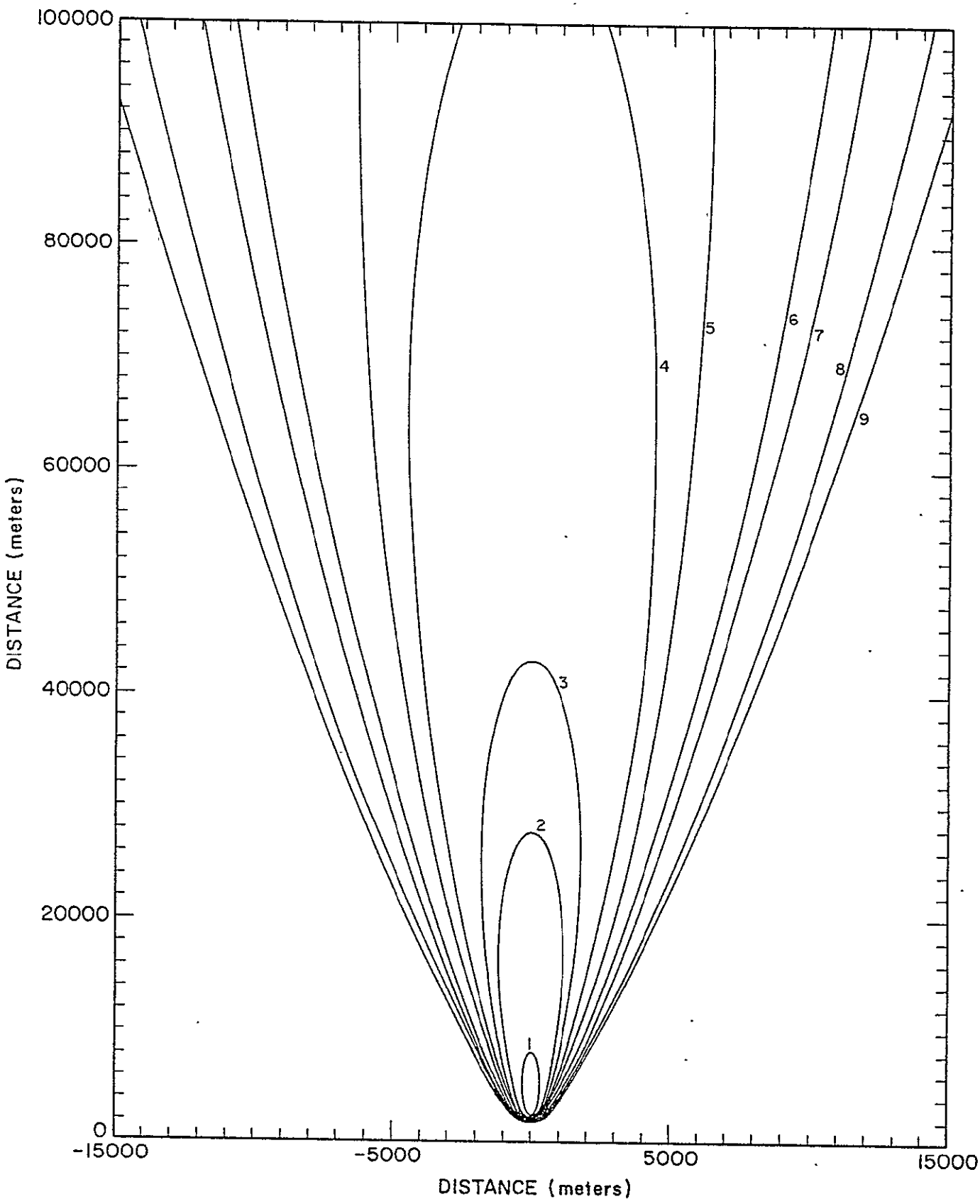

FIGURE 4-25. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 2 centimeters per second

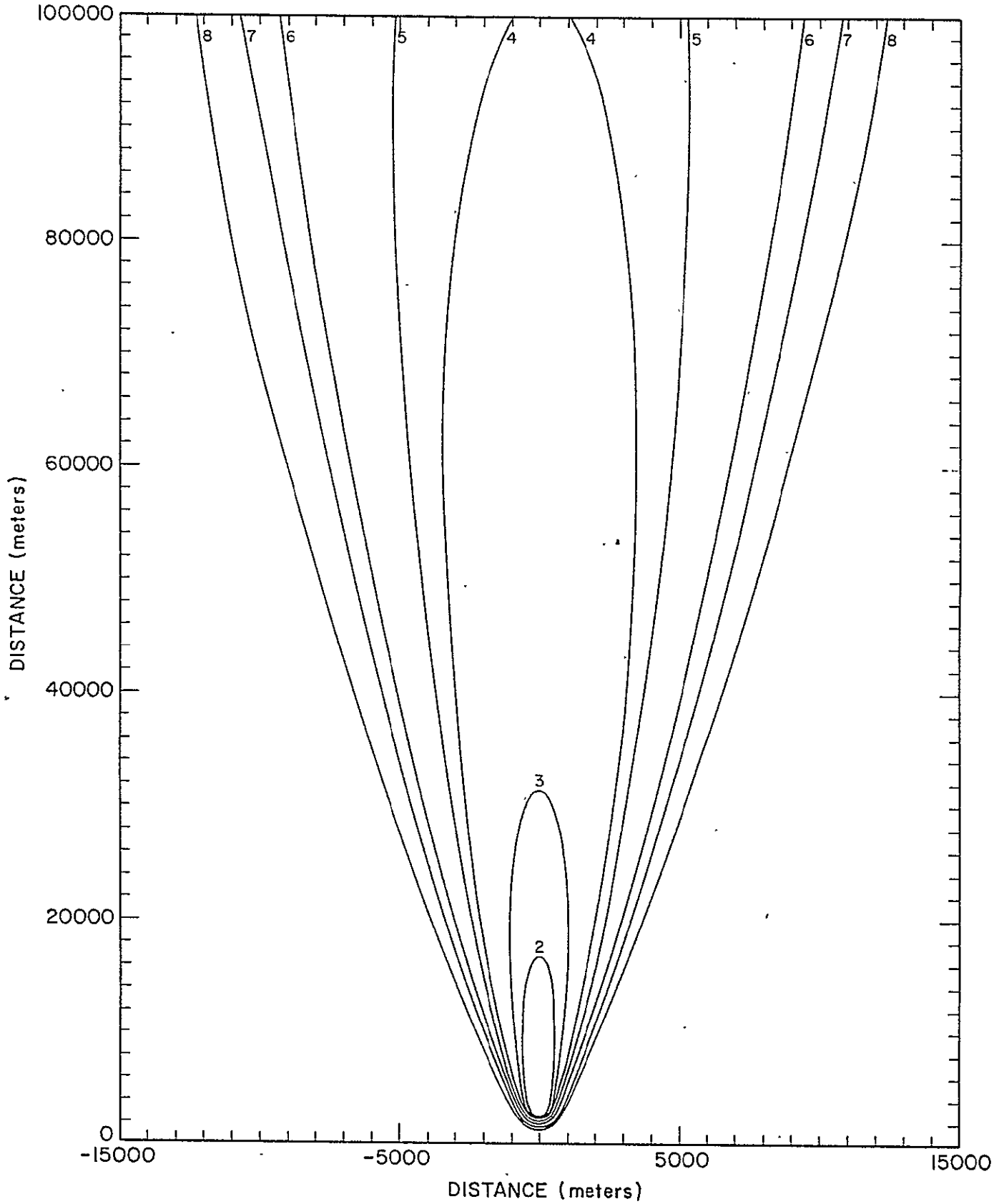

FIGURE 4-26. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 2 centimeter per second.

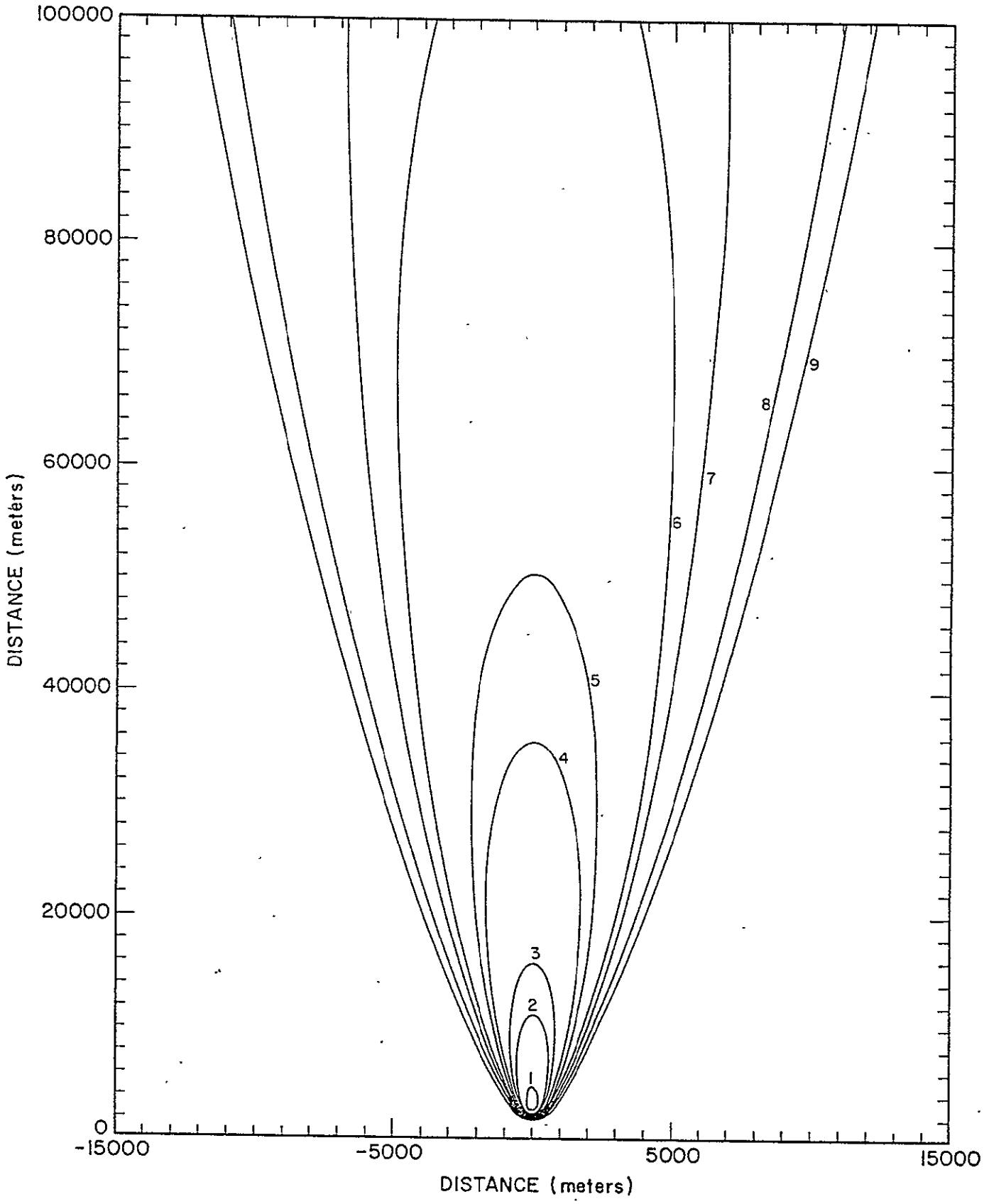

FIGURE 4-27. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second

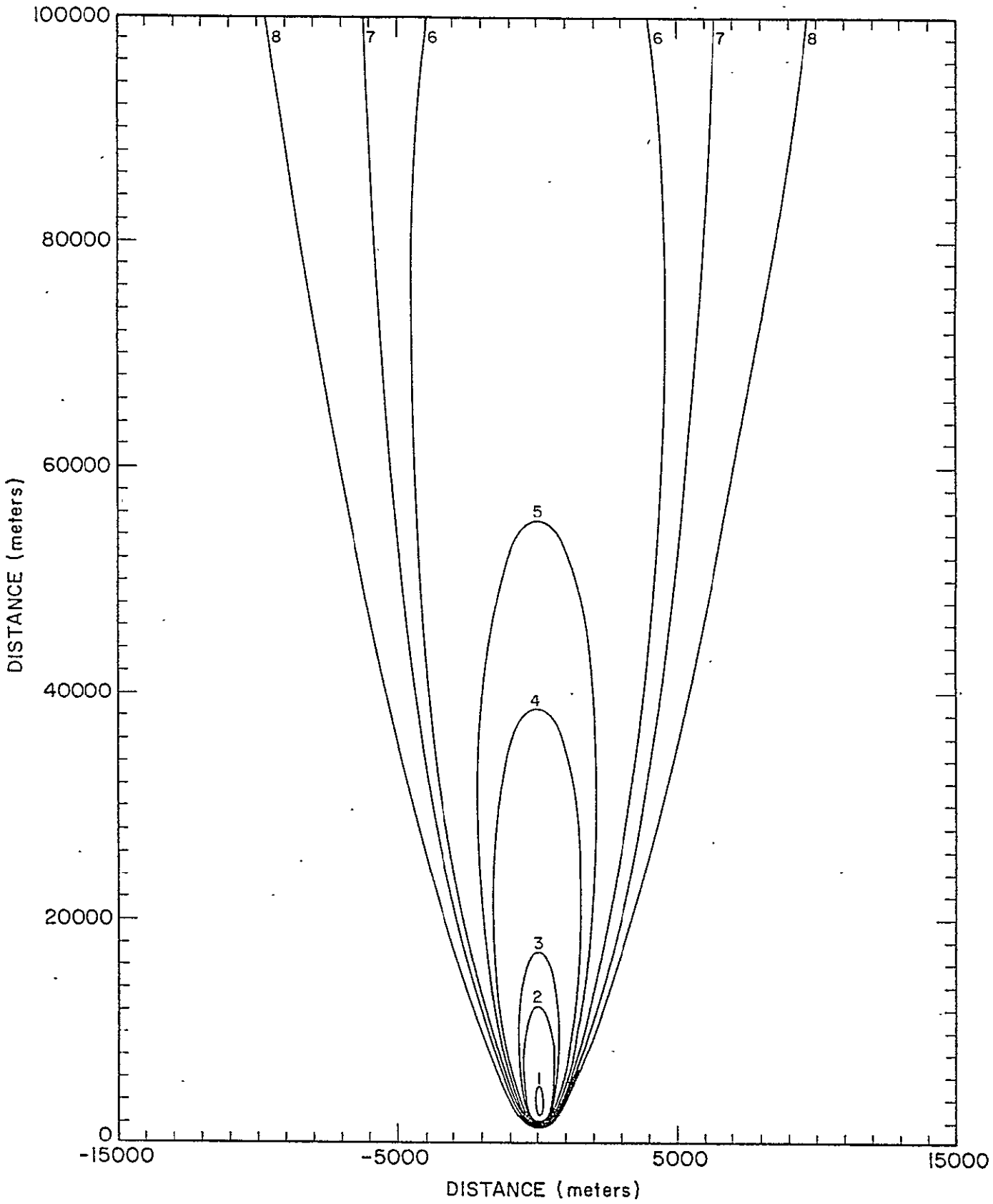

FIGURE 4-28. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second.

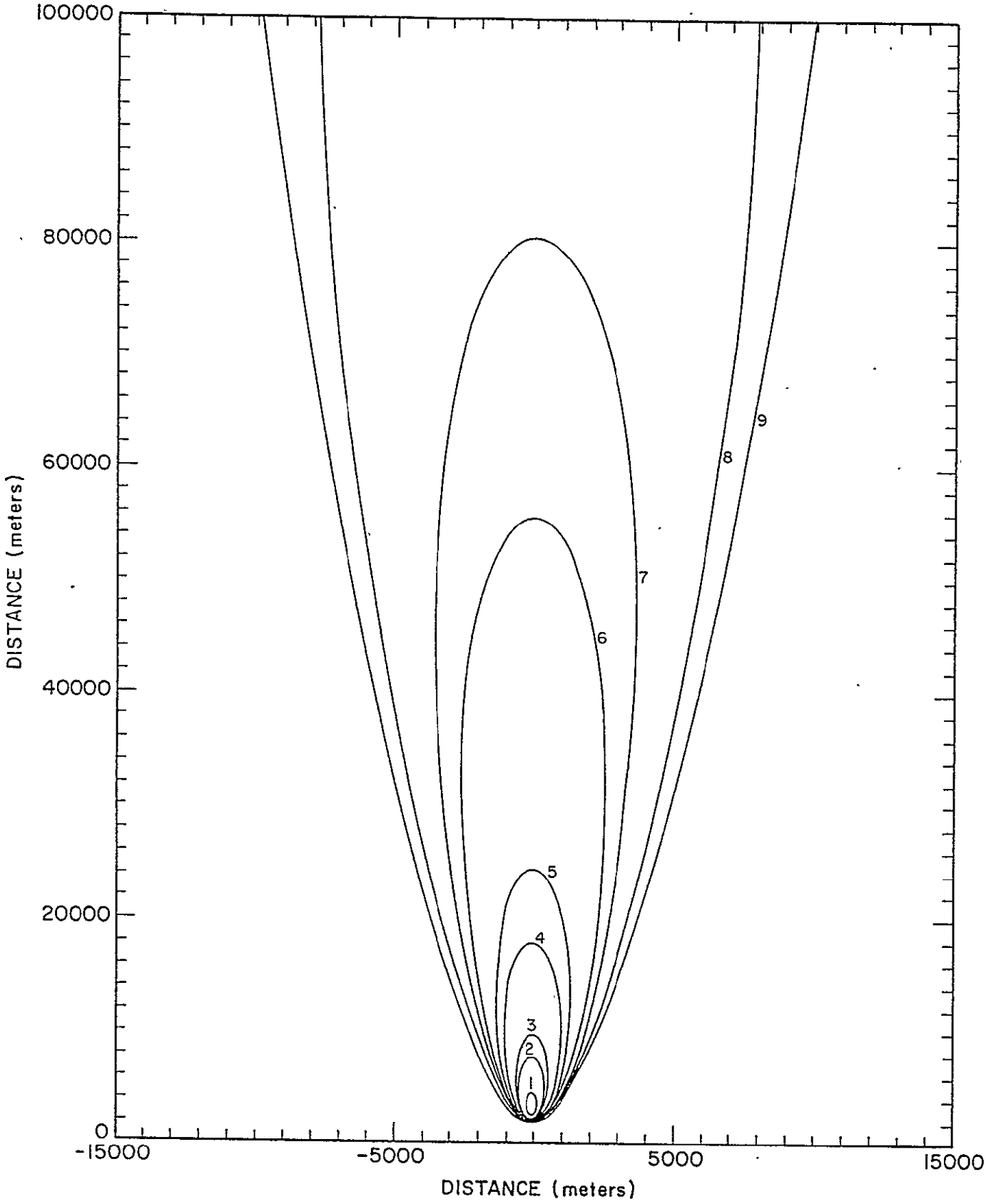

FIGURE 4-29. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second

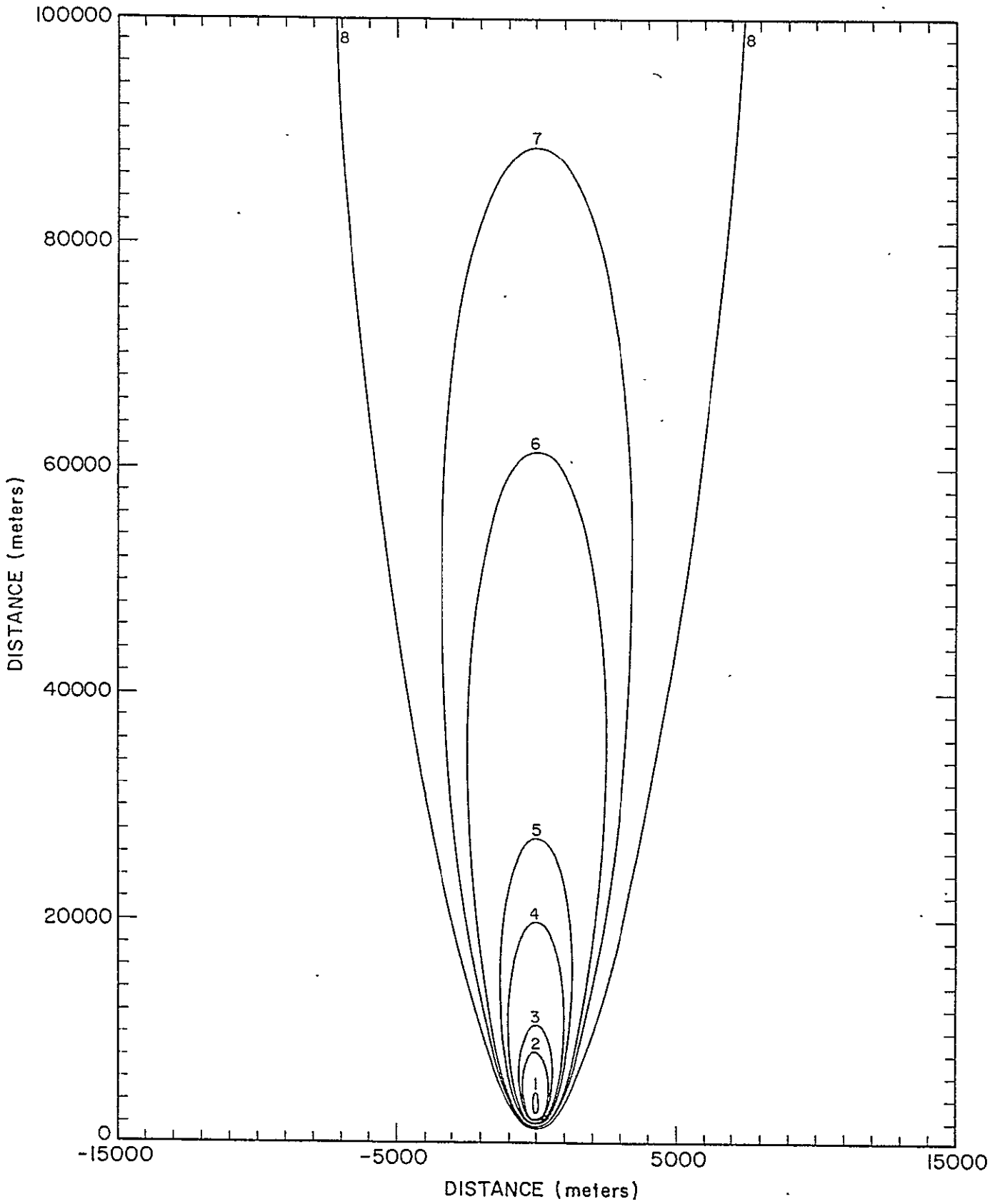

FIGURE 4-30. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second.

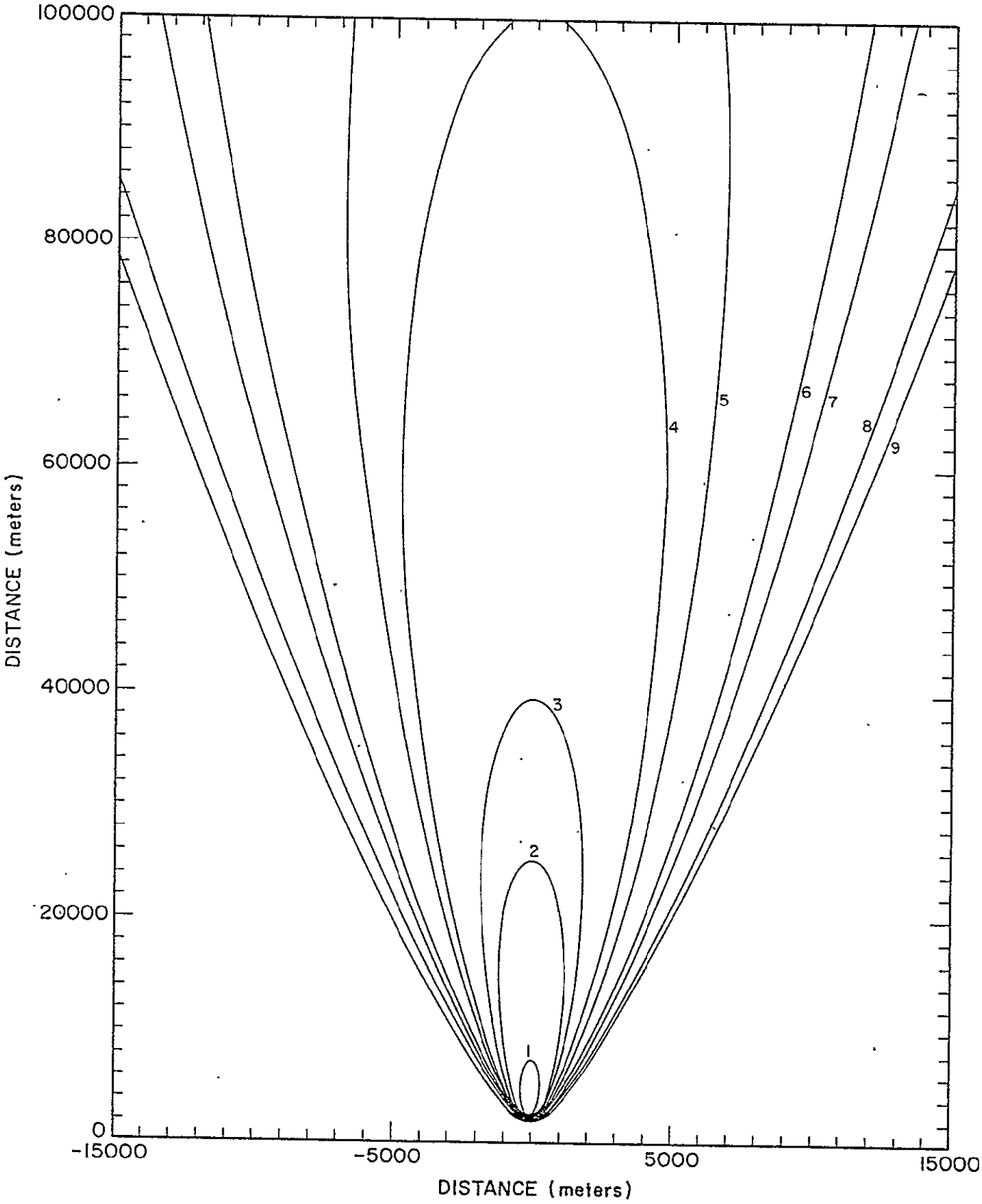

FIGURE 4-31. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 2 centimeters per second

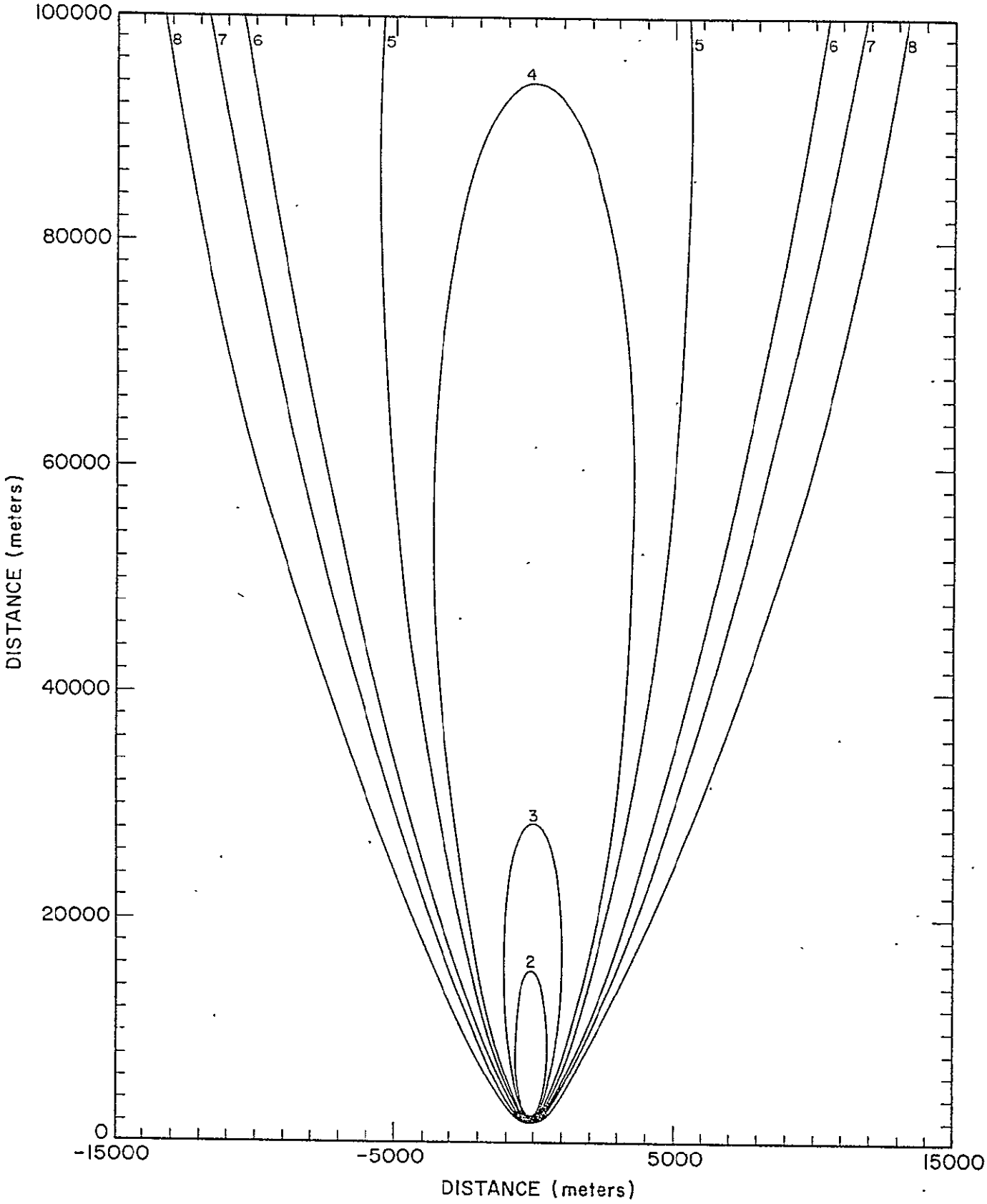

FIGURE 4-32. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 2 centimeters per second.

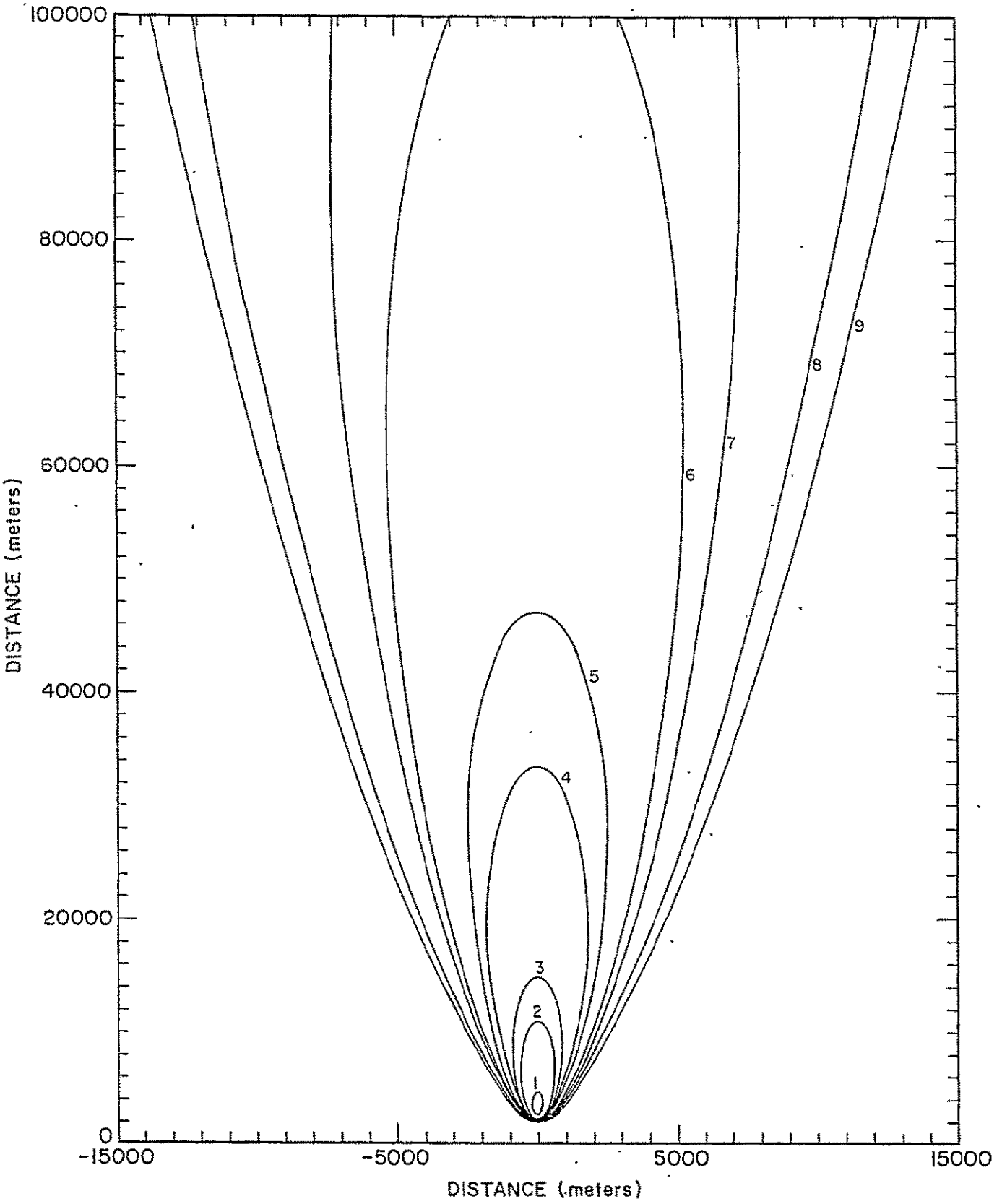

FIGURE 4-33. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second

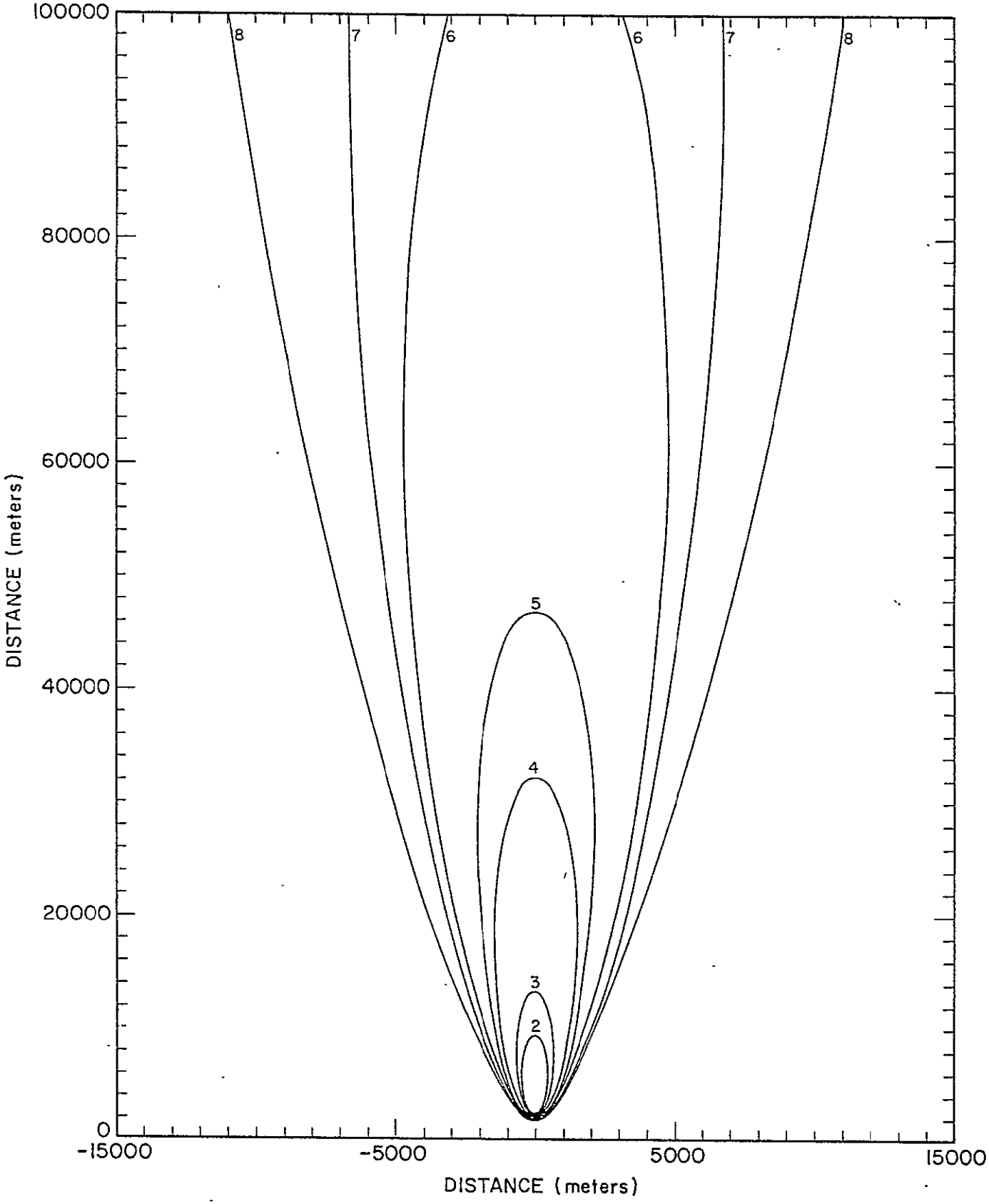

FIGURE 4-34. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second.

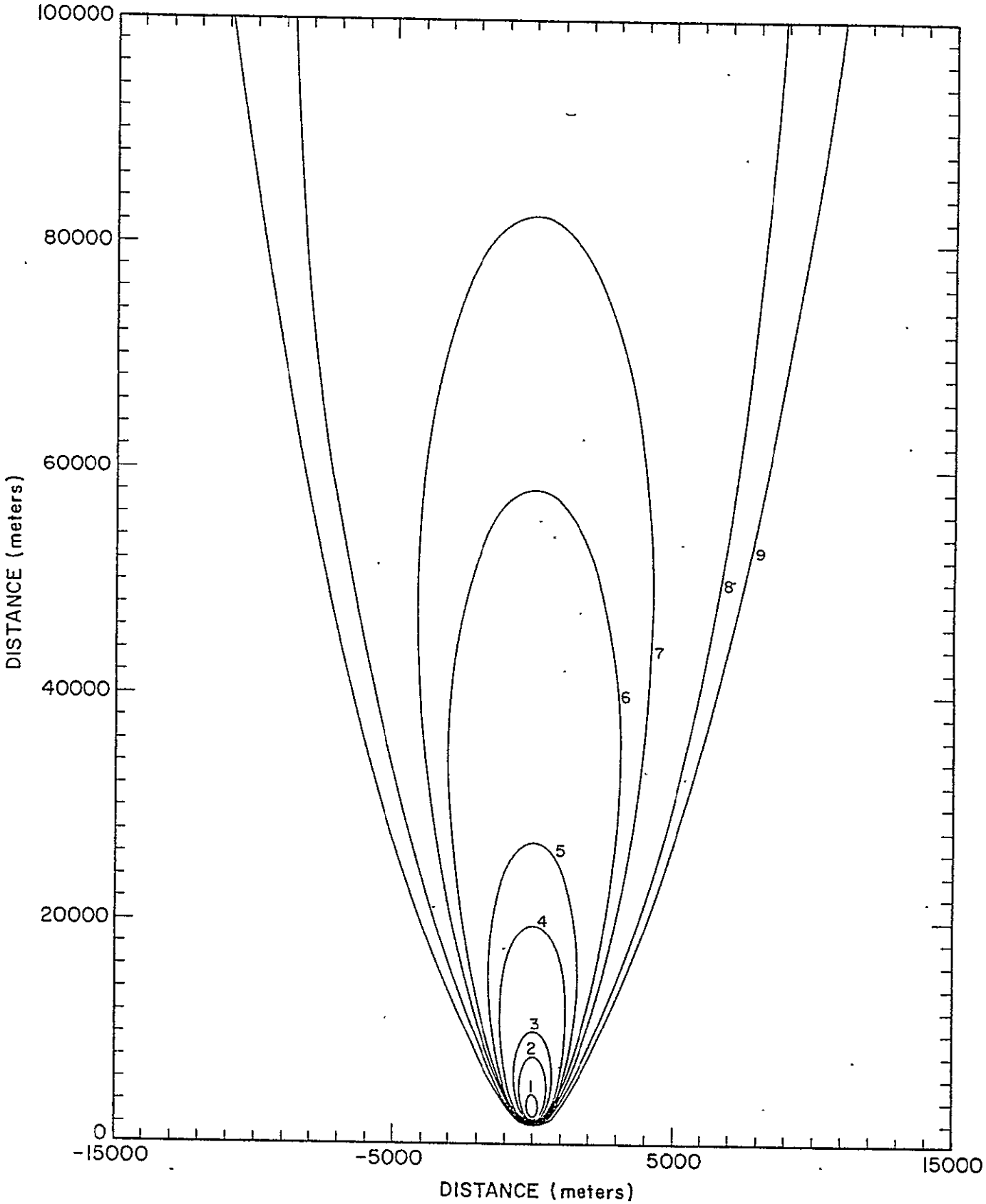

FIGURE 4-35. Dosage isopleths under neutral conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second

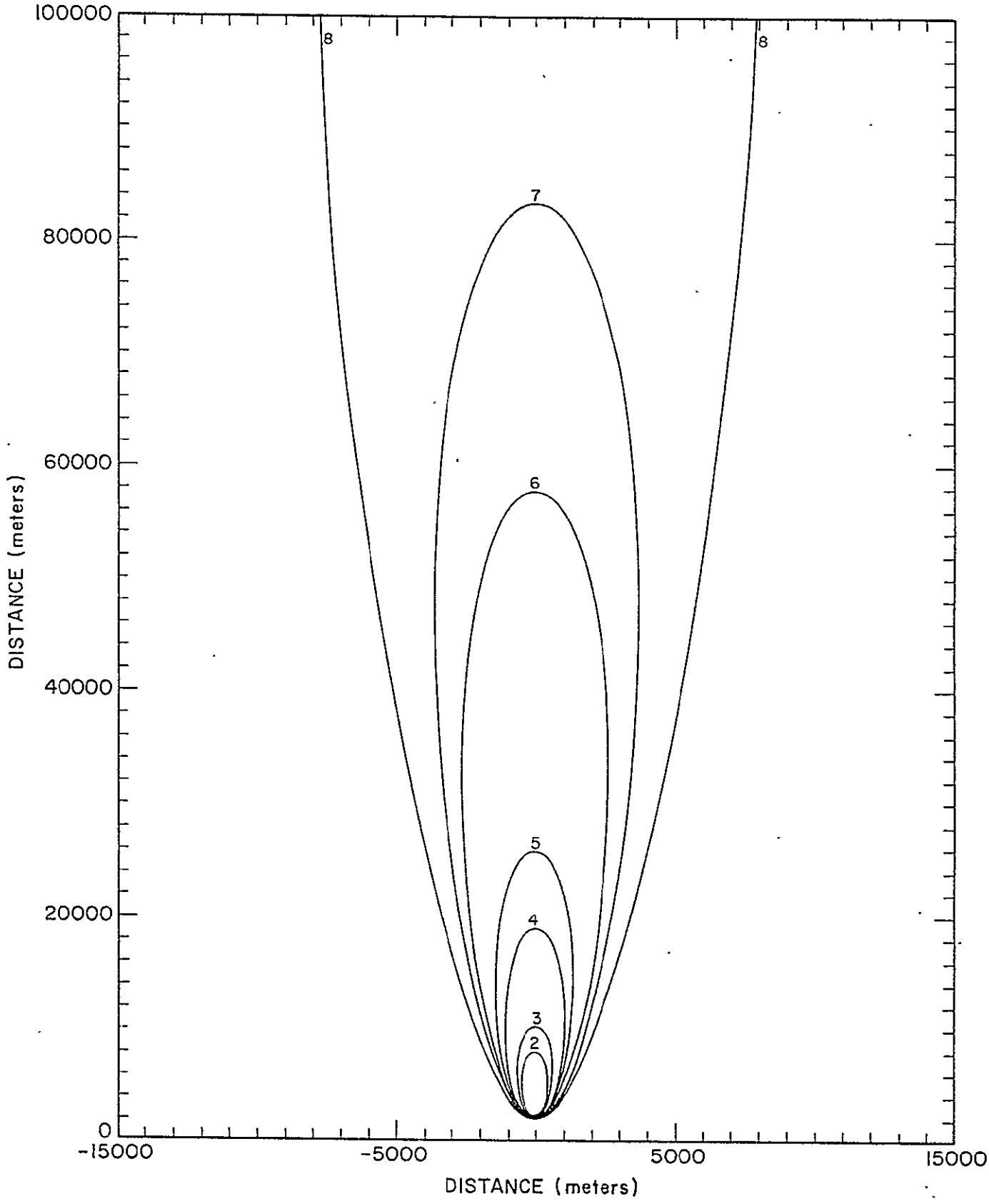

FIGURE 4-36. Dosage isopleths under neutral conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second.

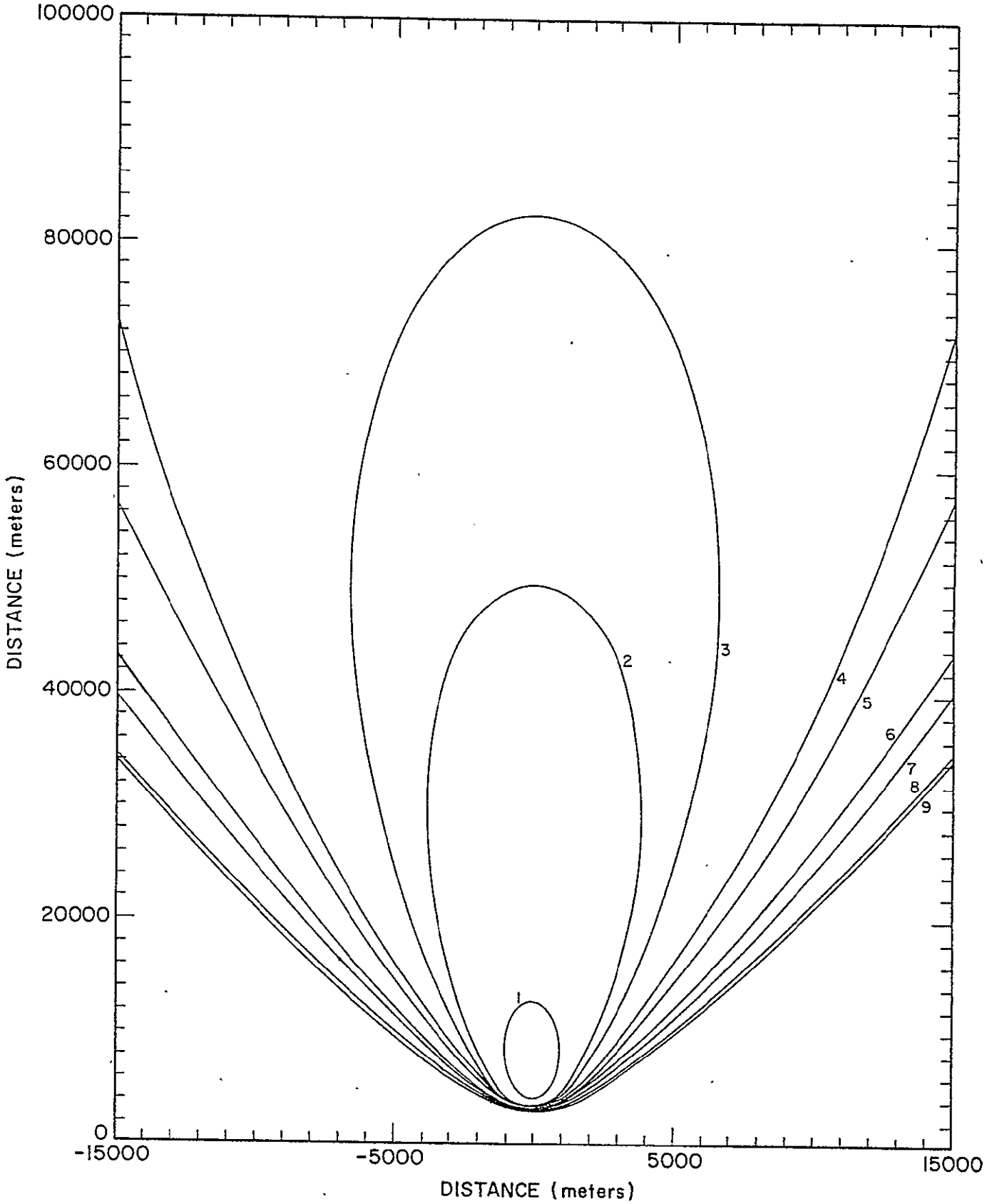

FIGURE 4-37. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second

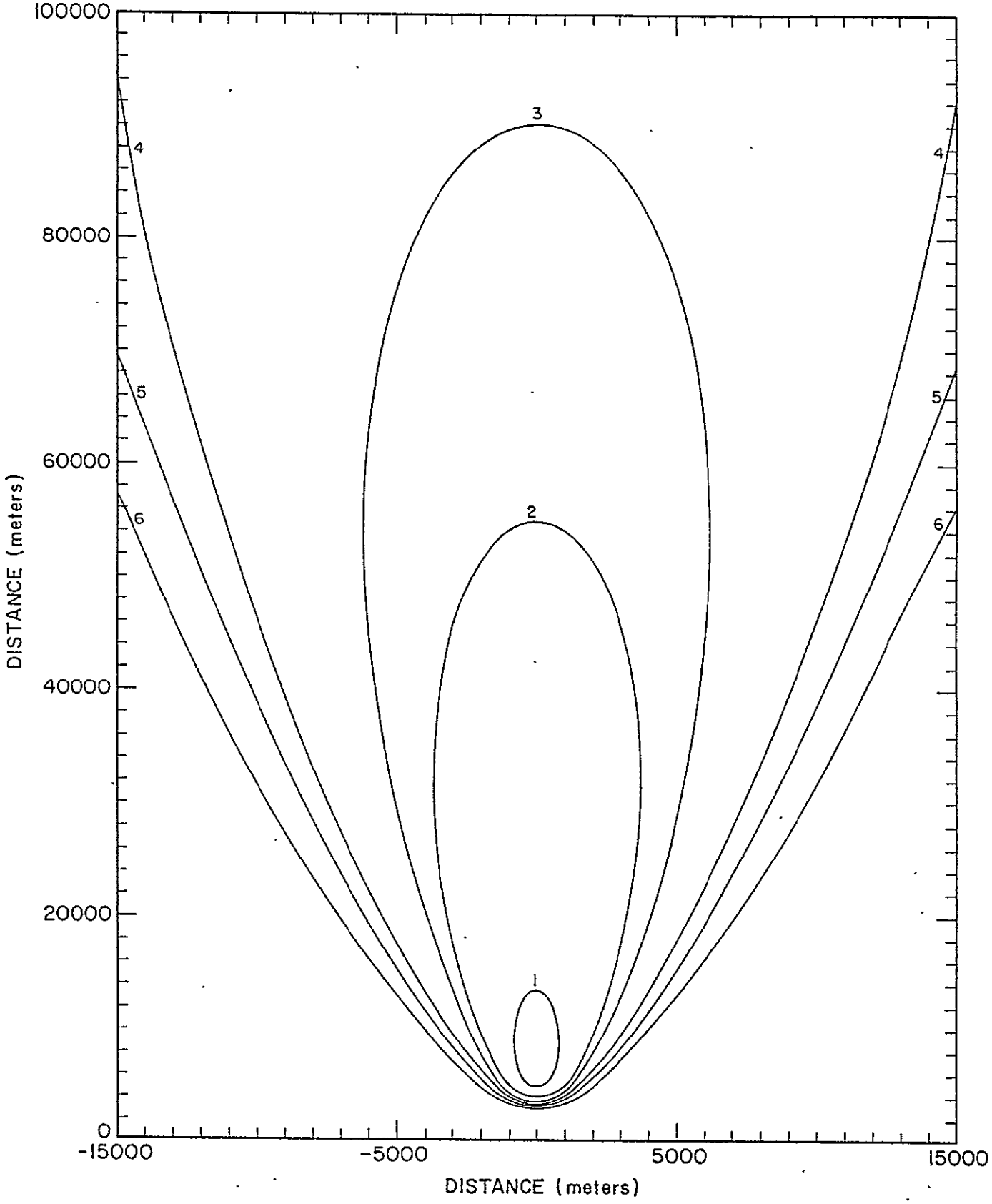

FIGURE 4-38. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second.

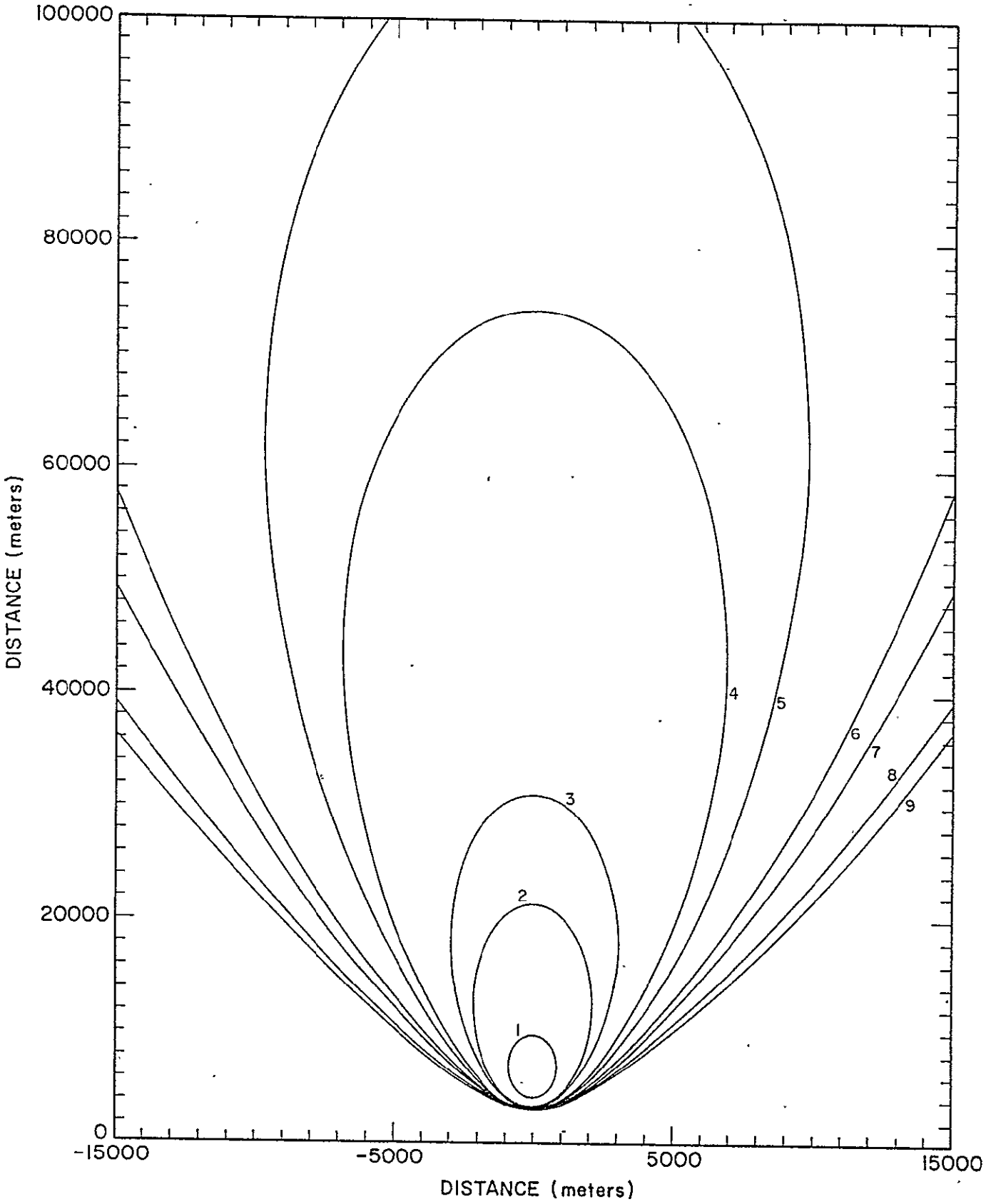

FIGURE 4-39. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second

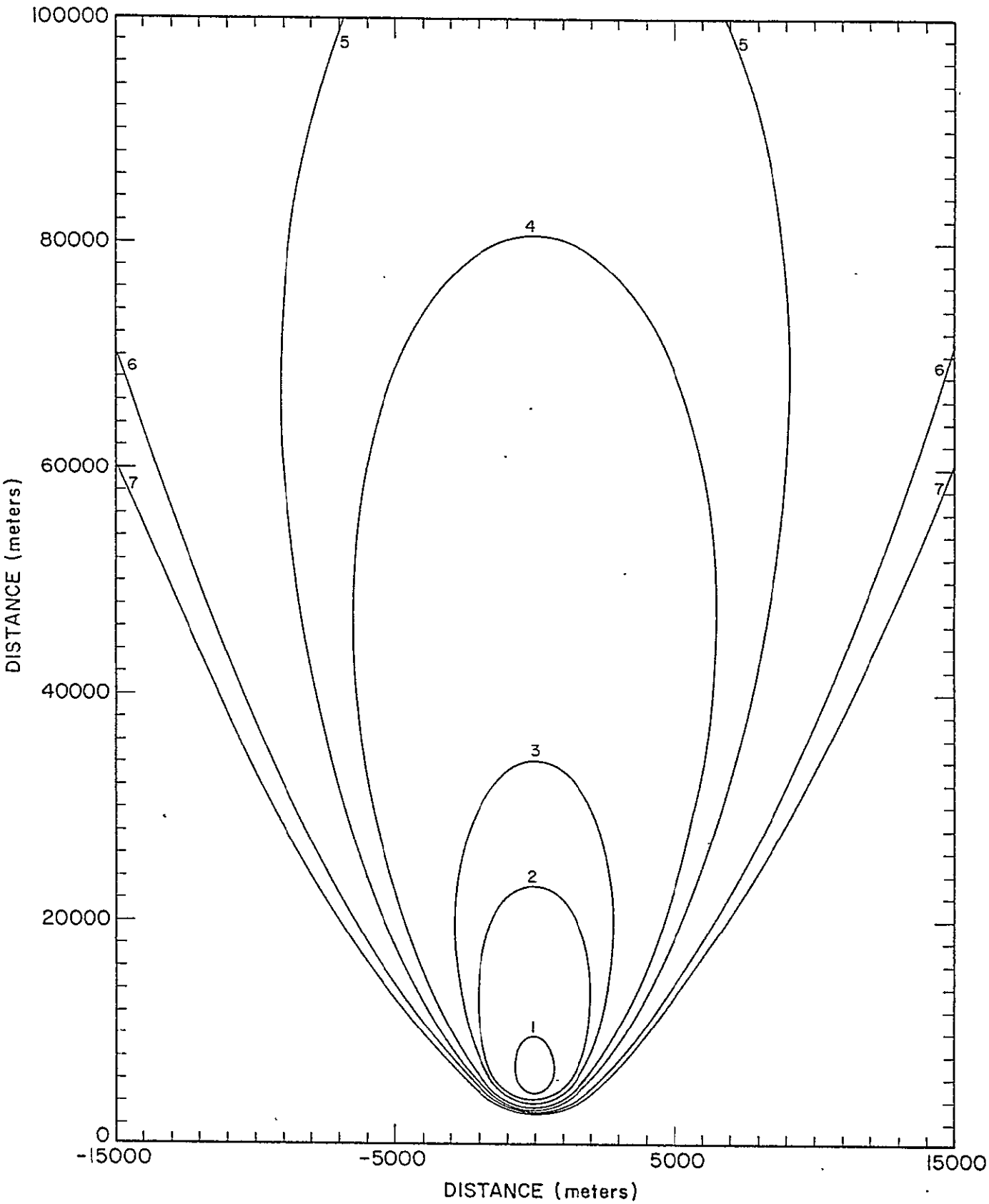

FIGURE 4-40. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second.

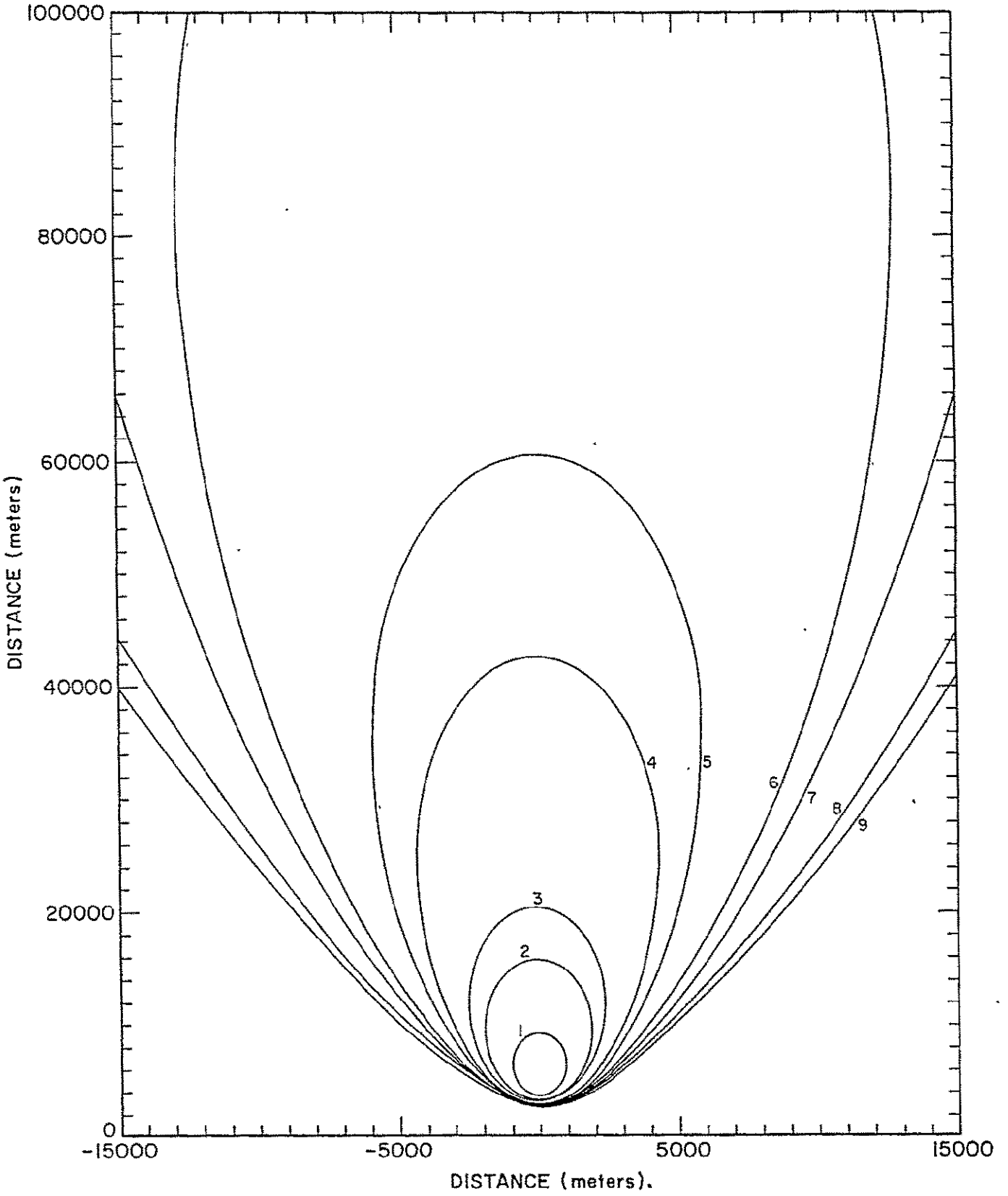

FIGURE 4-41. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 1 meter per second

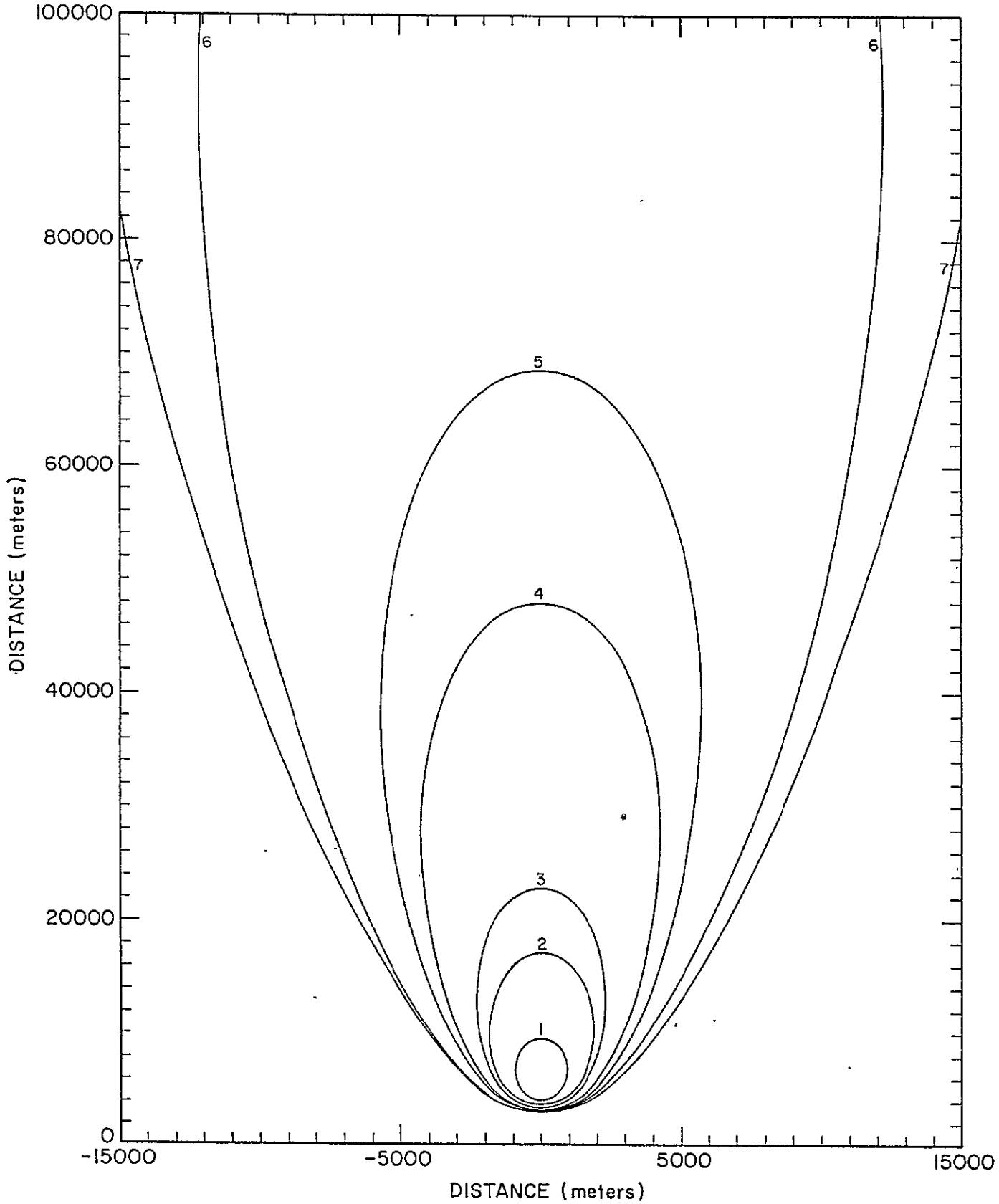

FIGURE 4-42. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 1 meter per second.

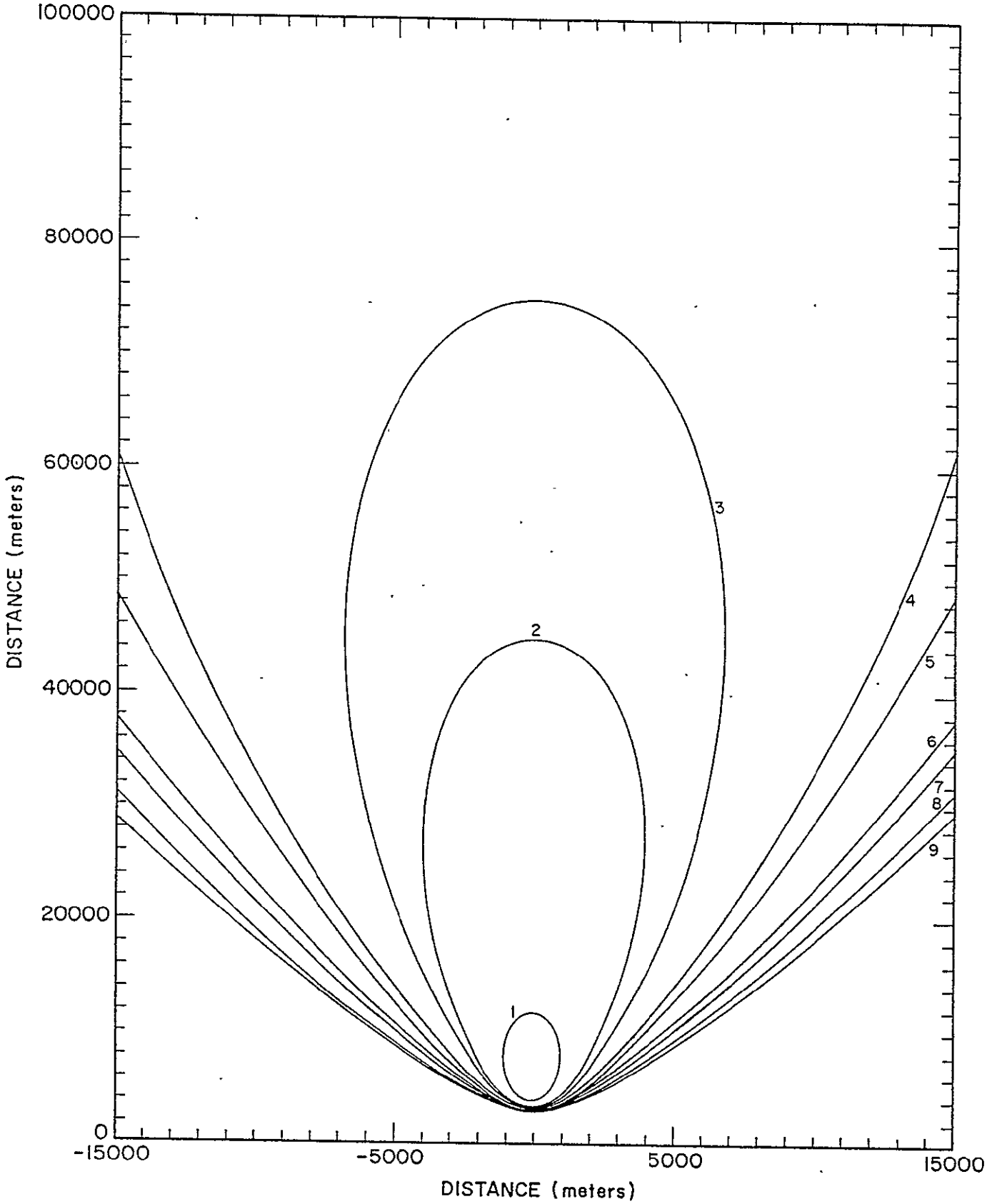

FIGURE 4-43. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 2 centimeters per second

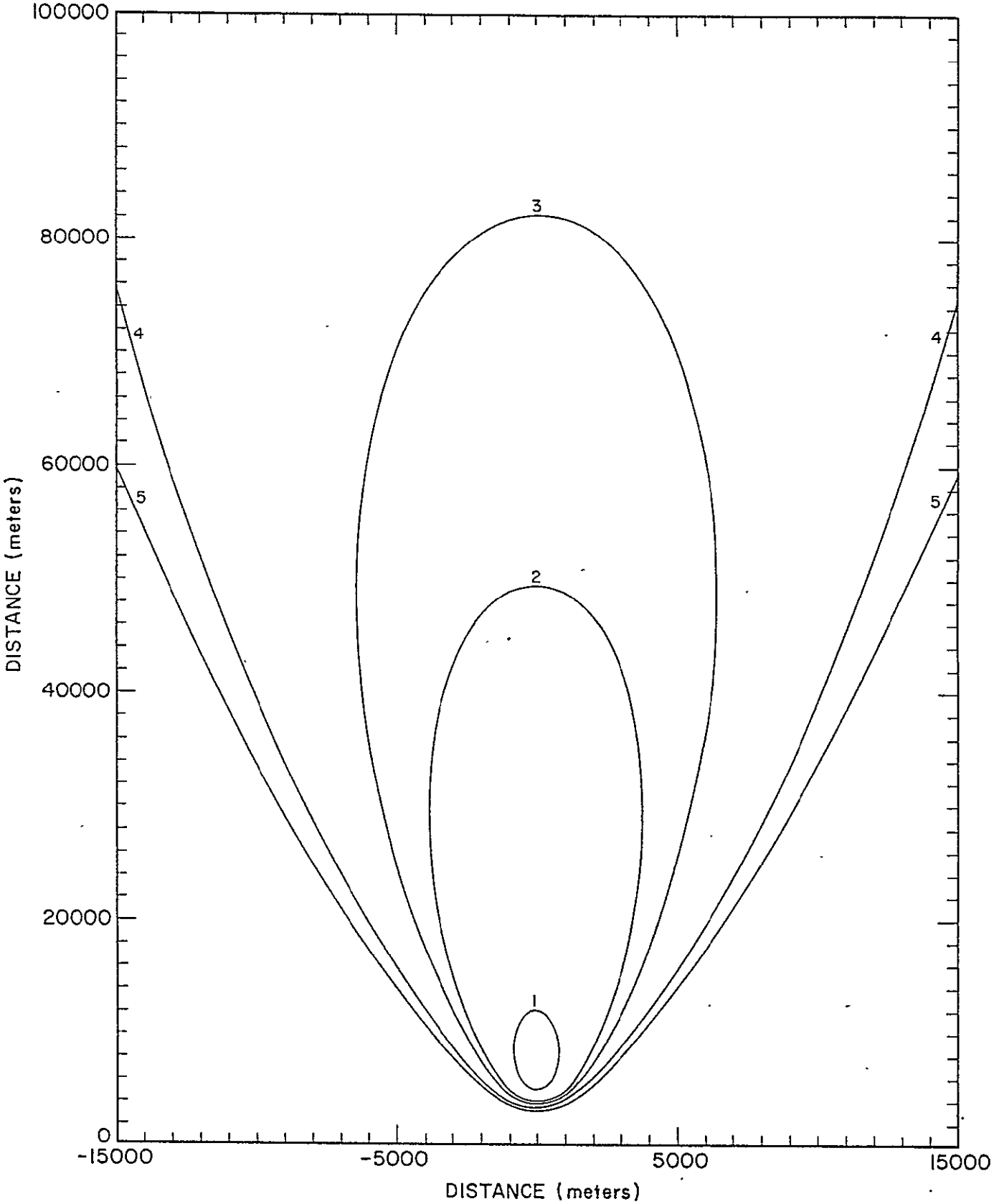

FIGURE 4-44. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 2 centimeters per second.

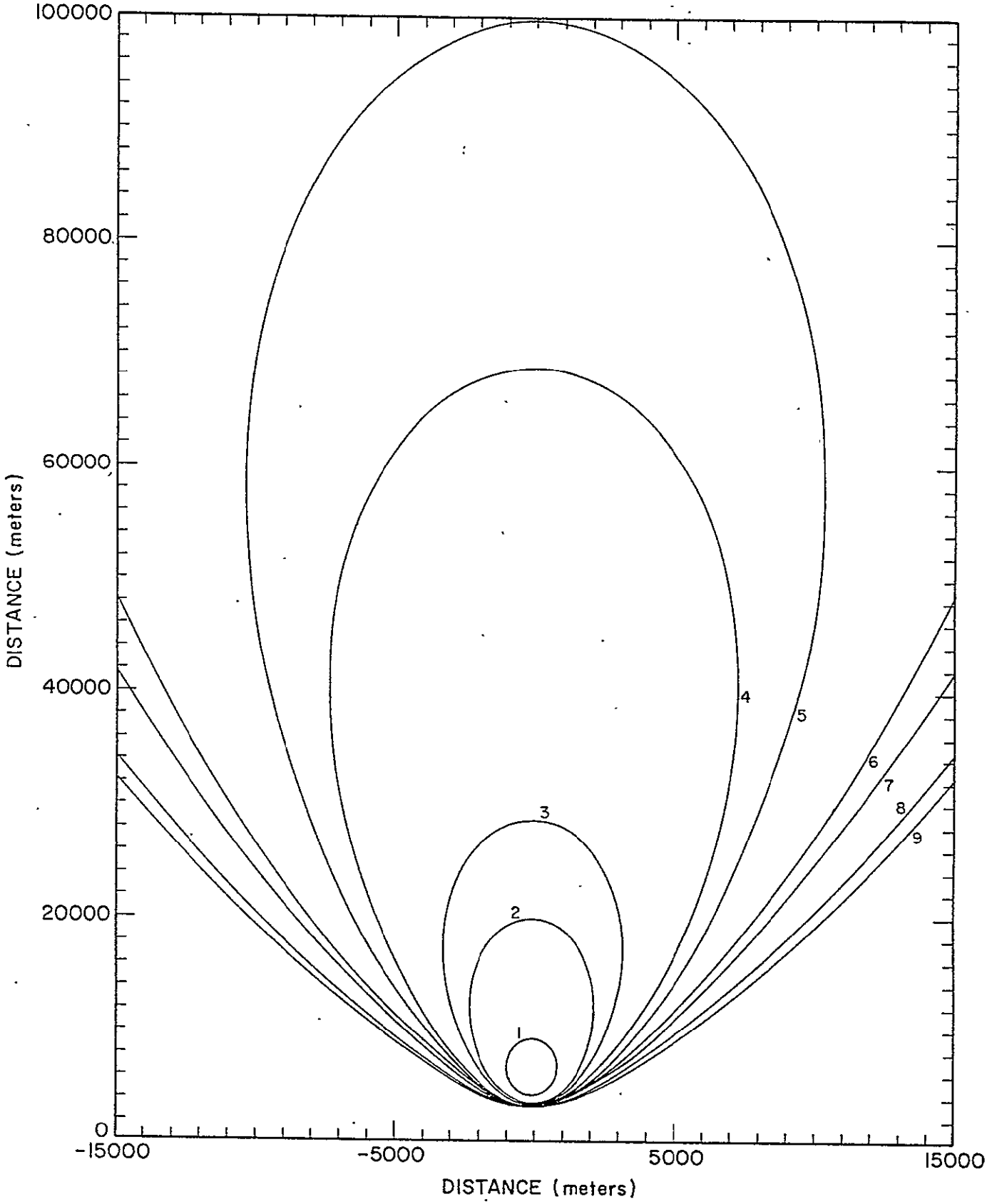

FIGURE 4-45. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second

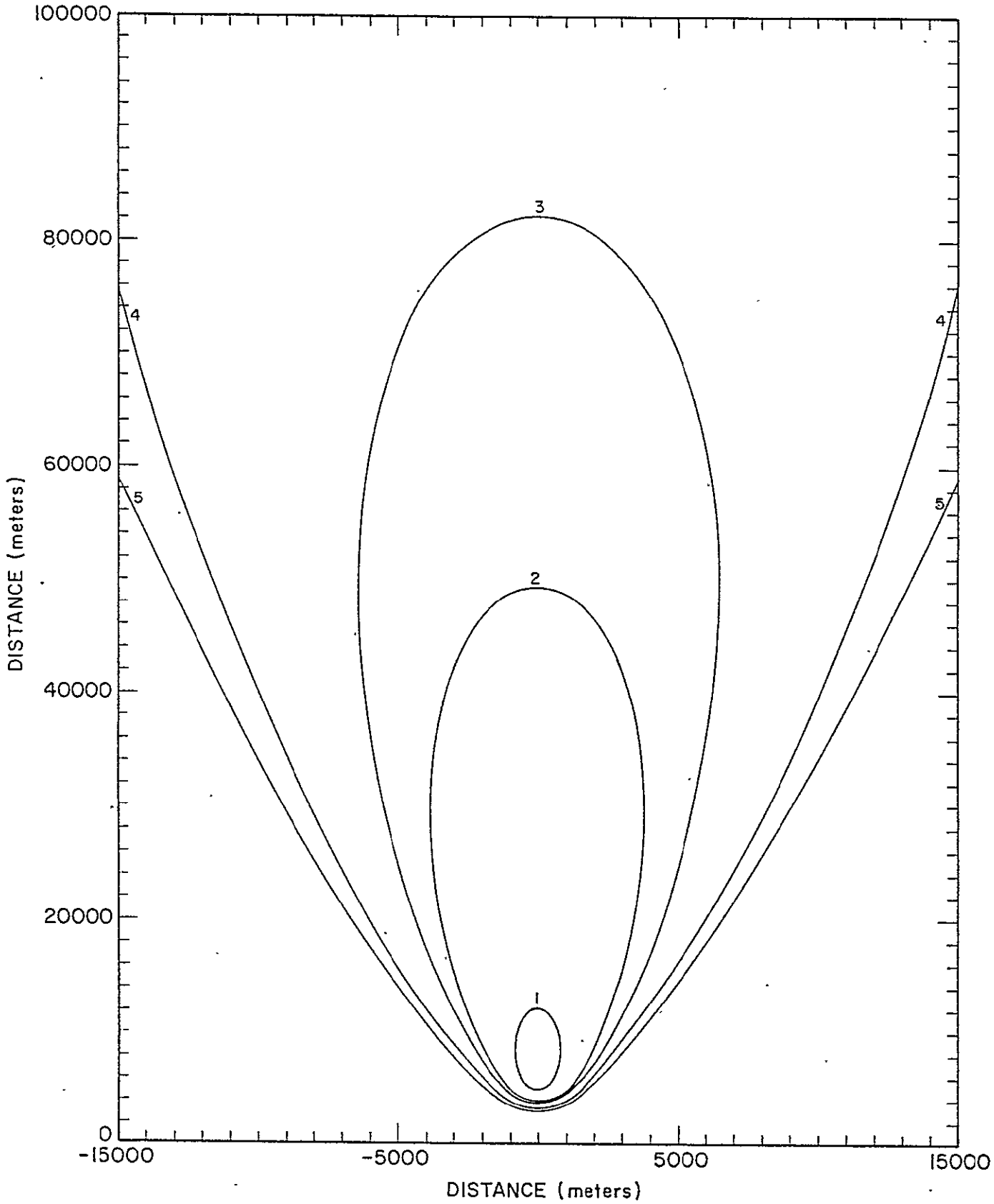

FIGURE 4-46. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second.

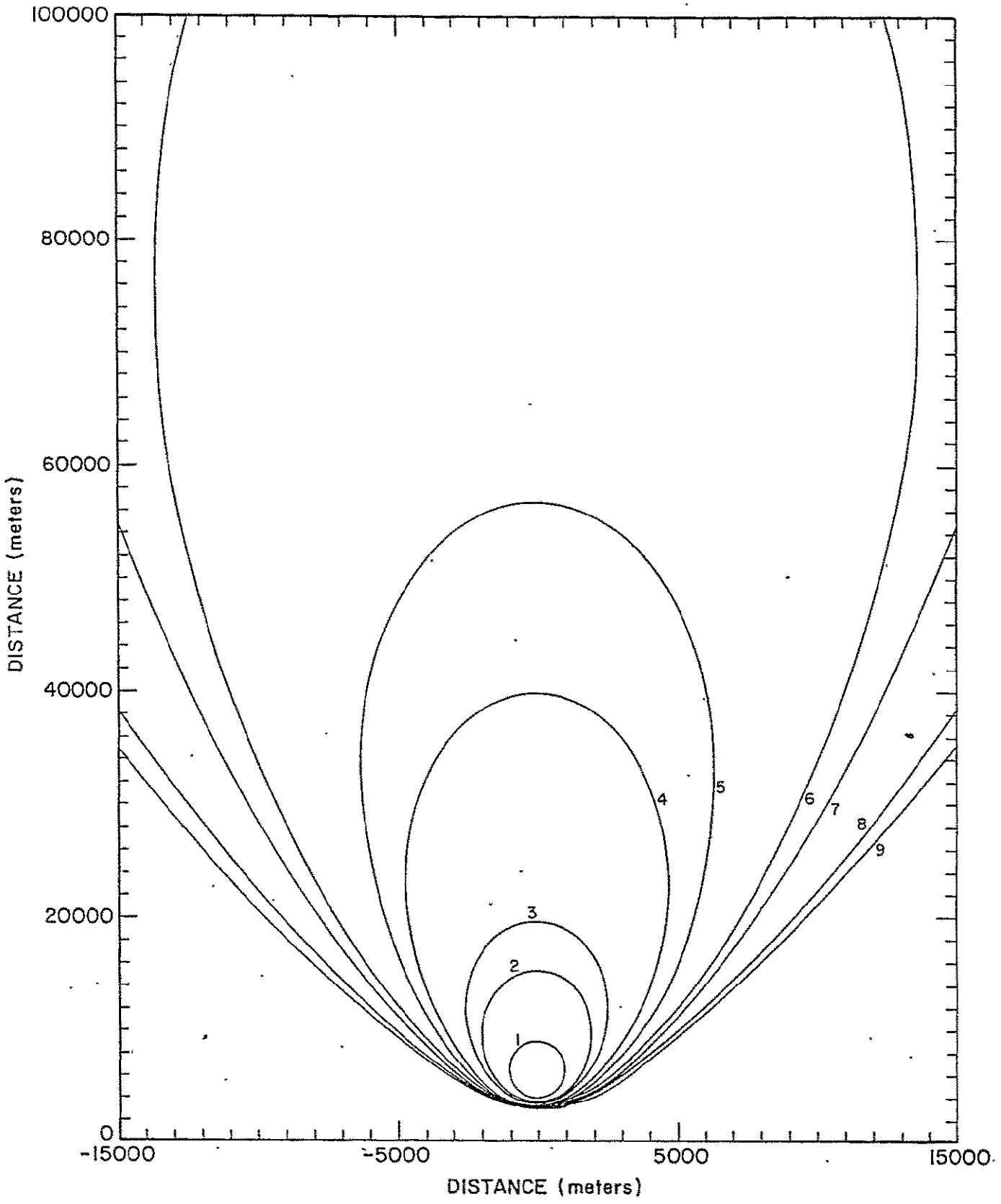

FIGURE 4-47. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second

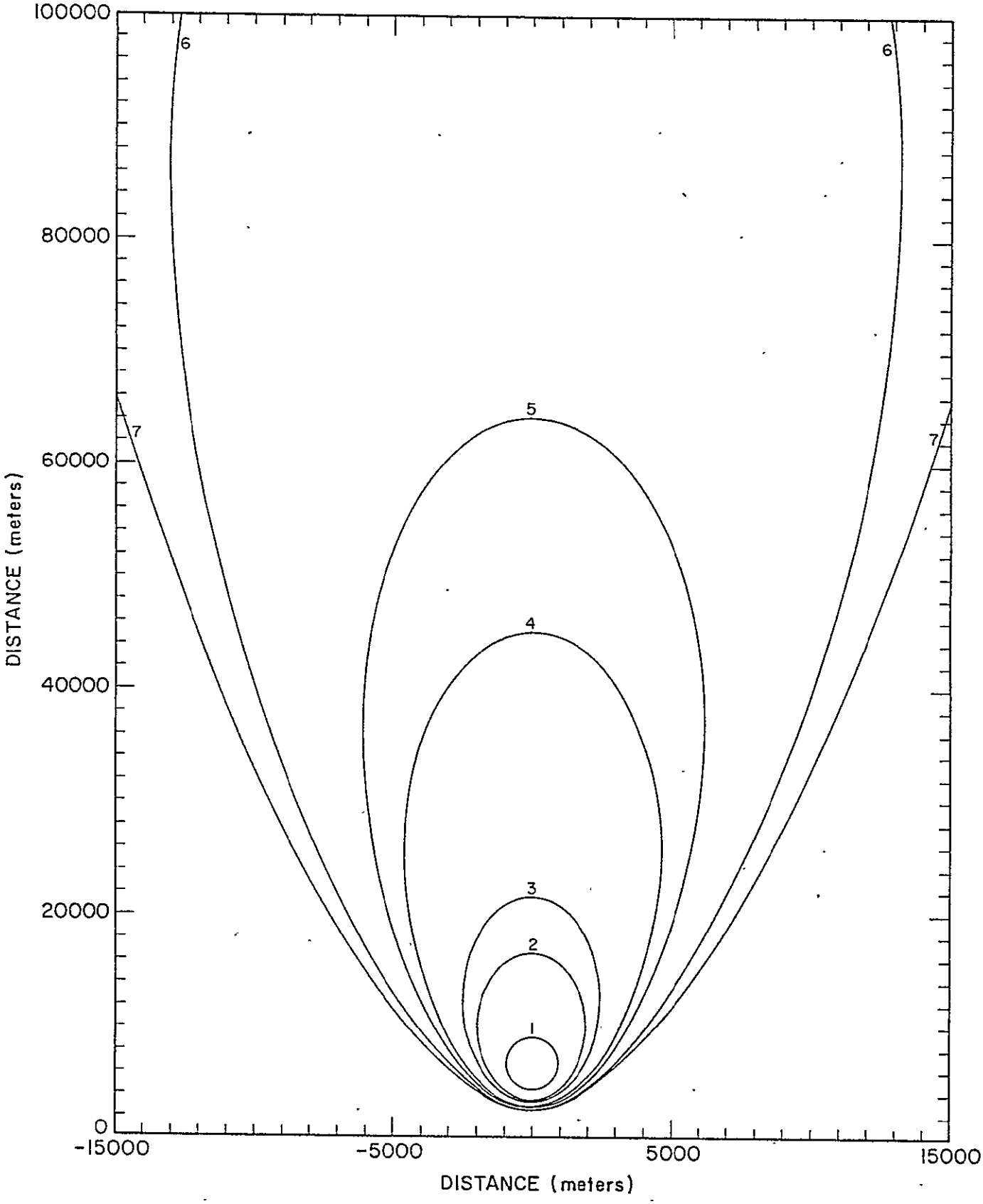

FIGURE 4-48. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second.

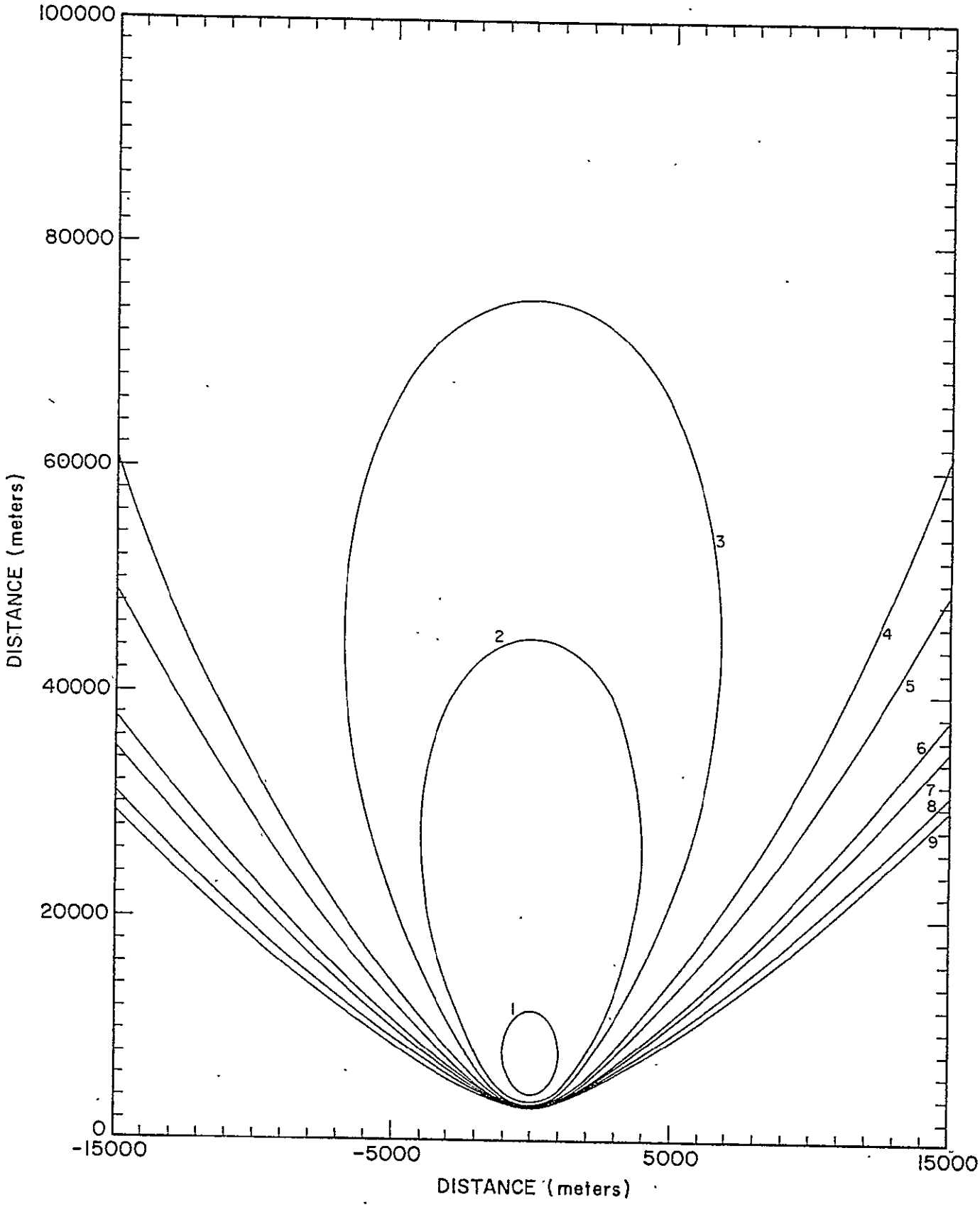

FIGURE 4-49. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 2 centimeters per second

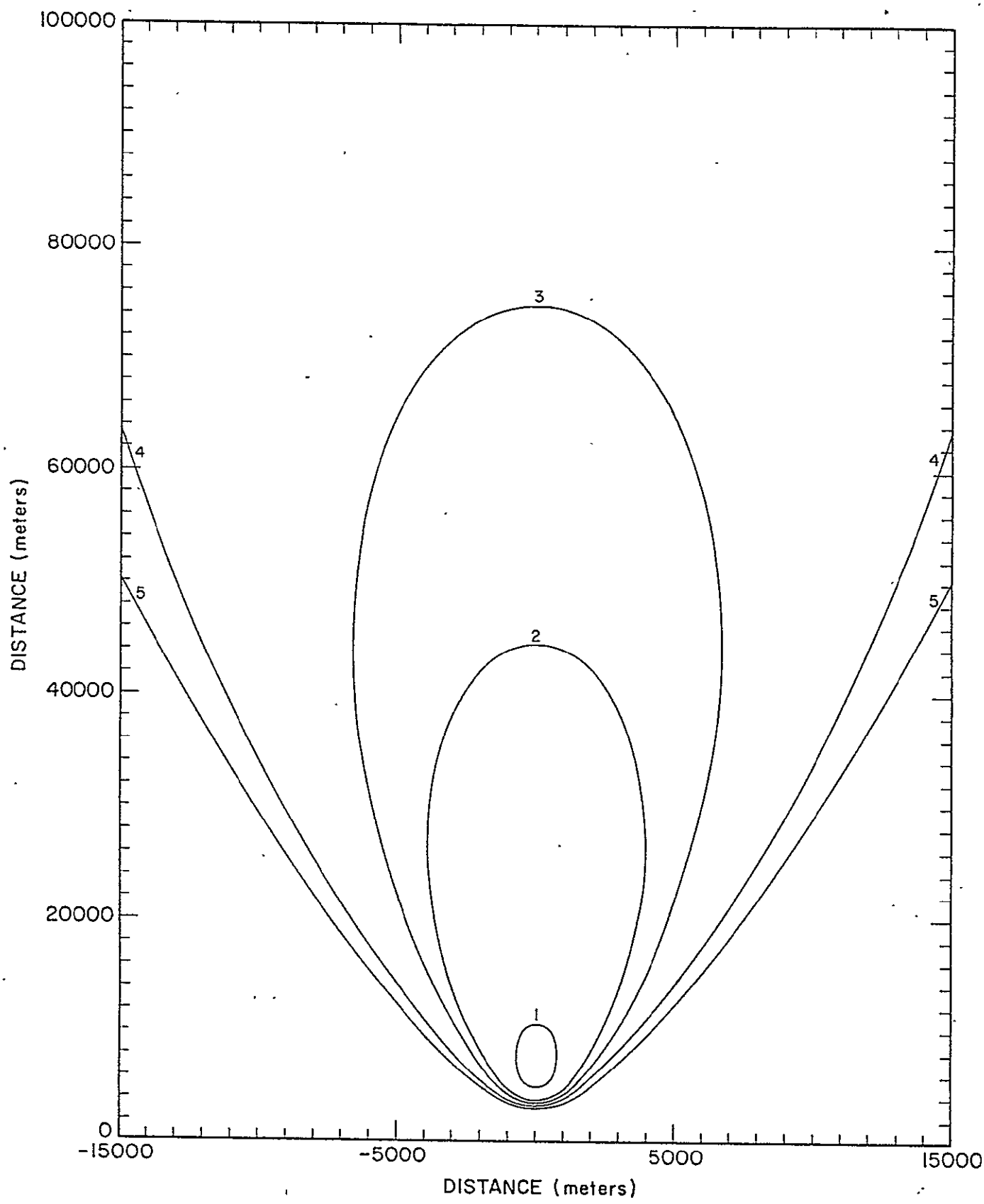

FIGURE 4-50. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 2 centimeters per second.

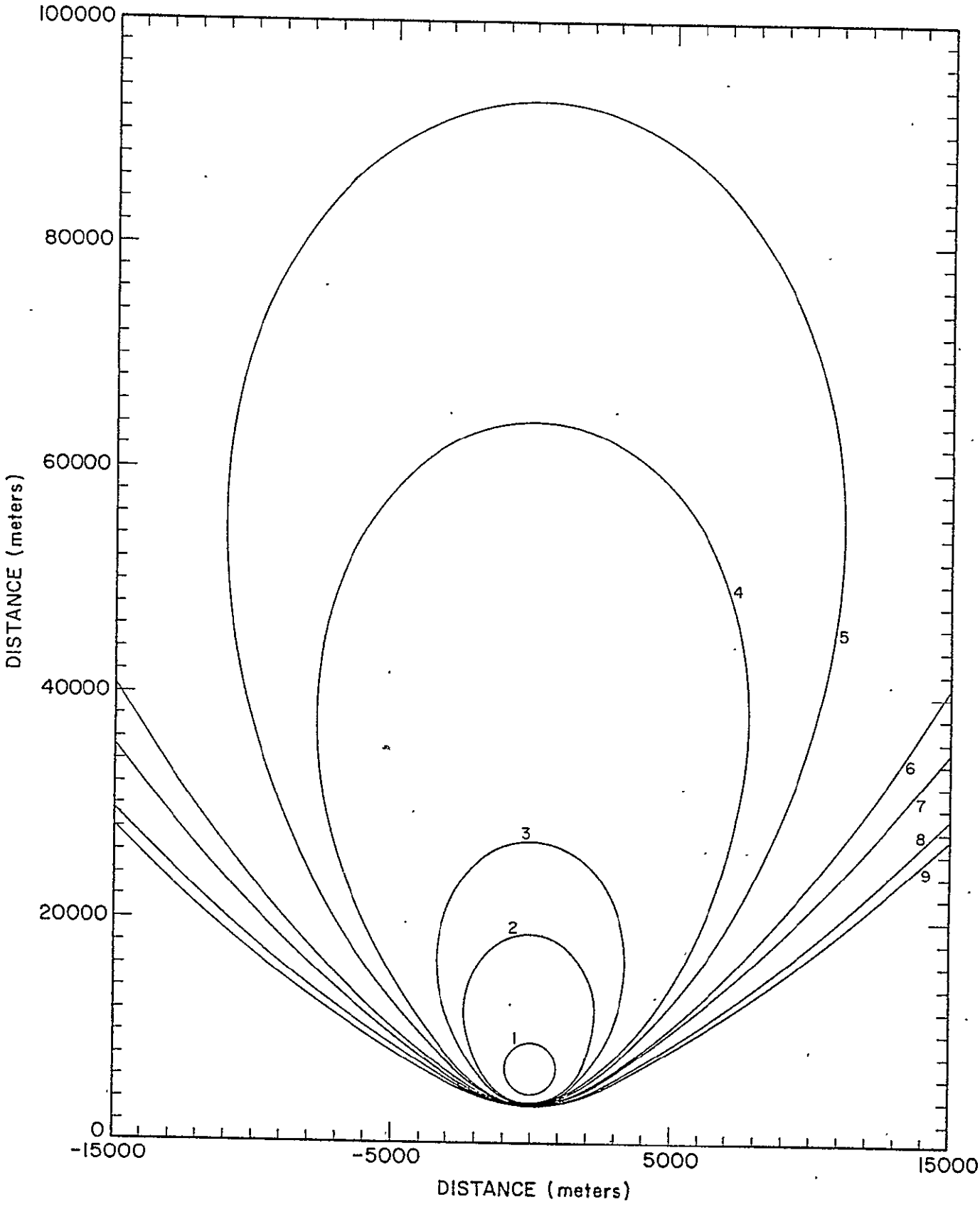

FIGURE 4-51. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second

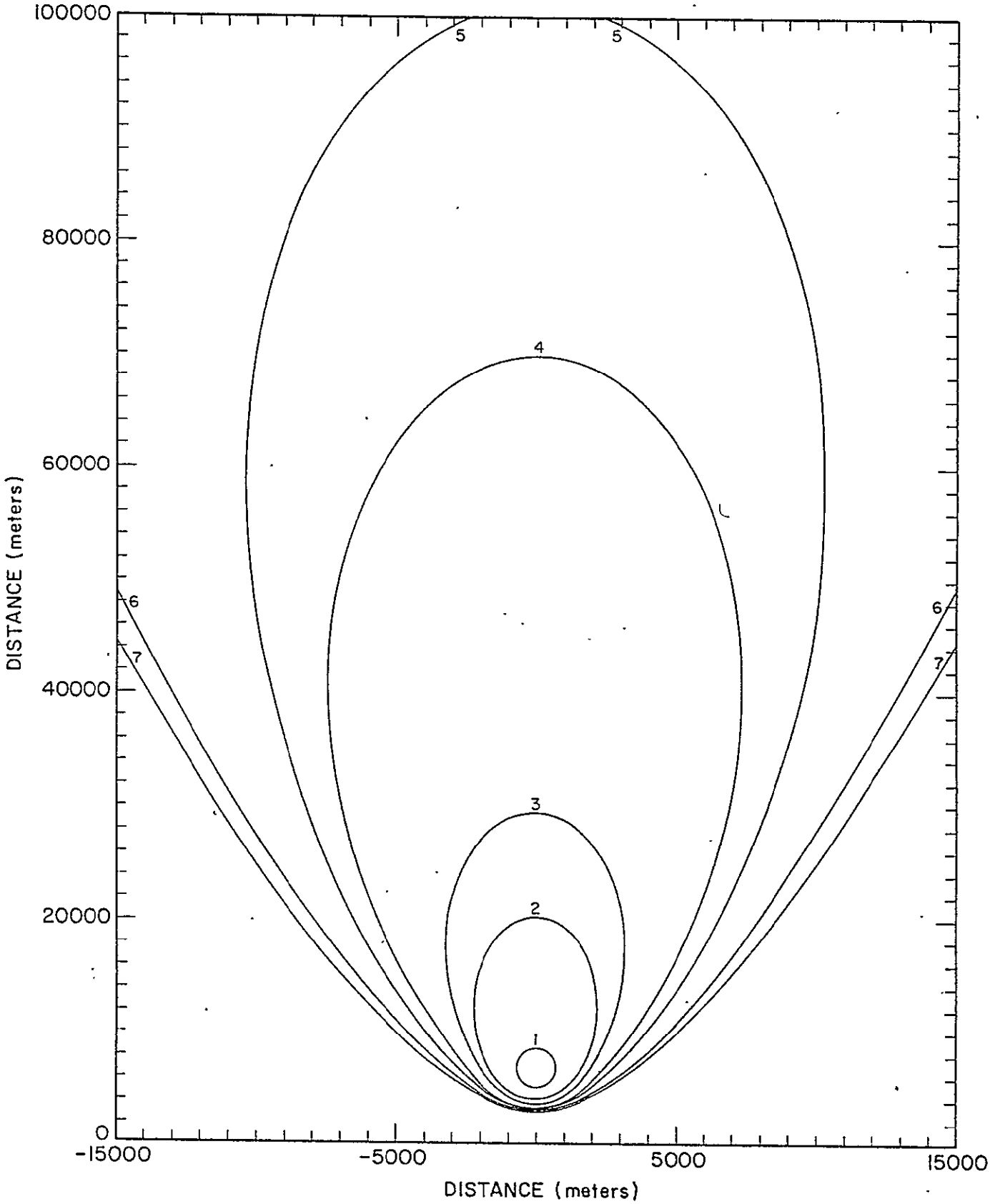

FIGURE 4-52. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second.

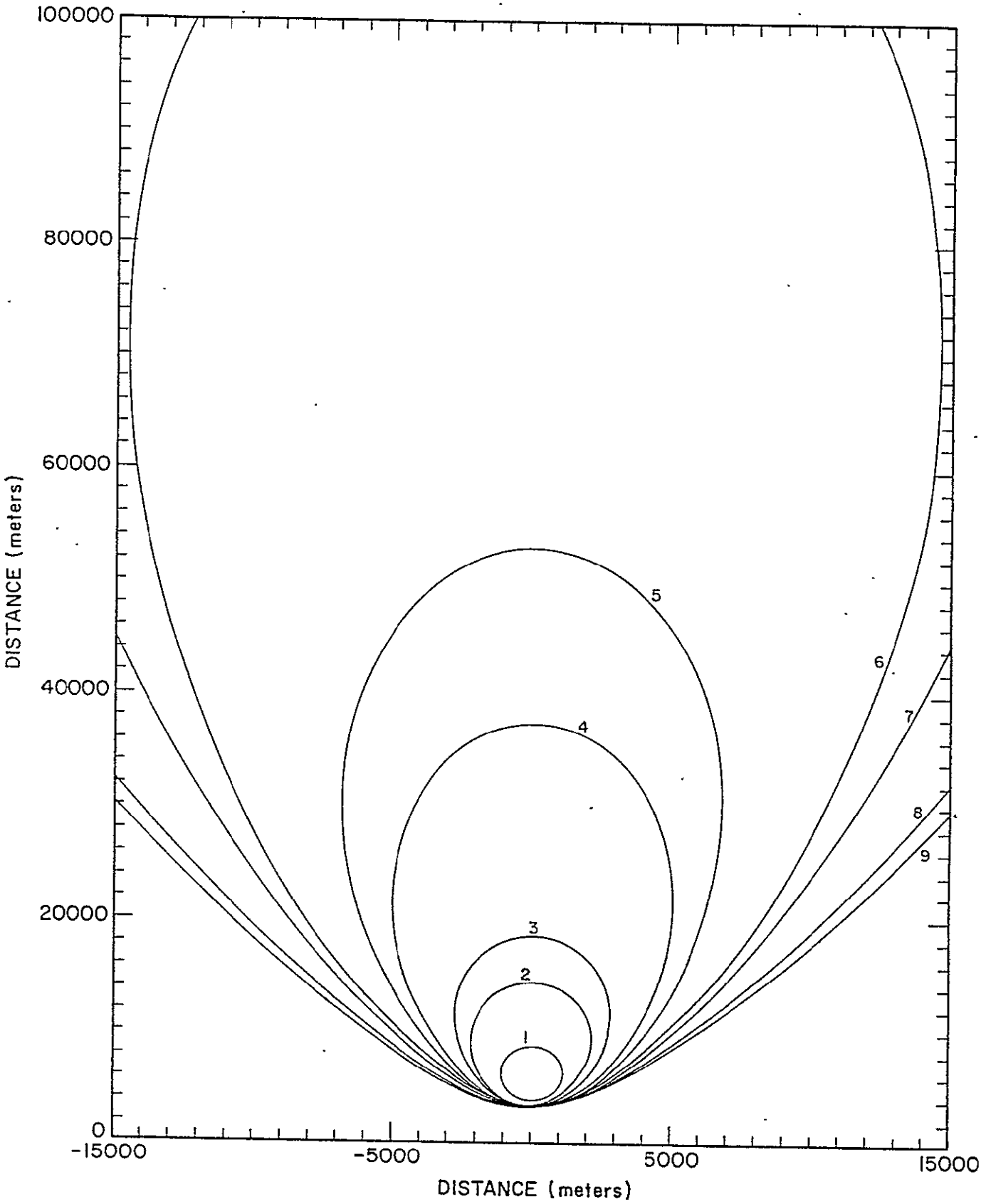

FIGURE 4-53. Dosage isopleths under unstable conditions for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second

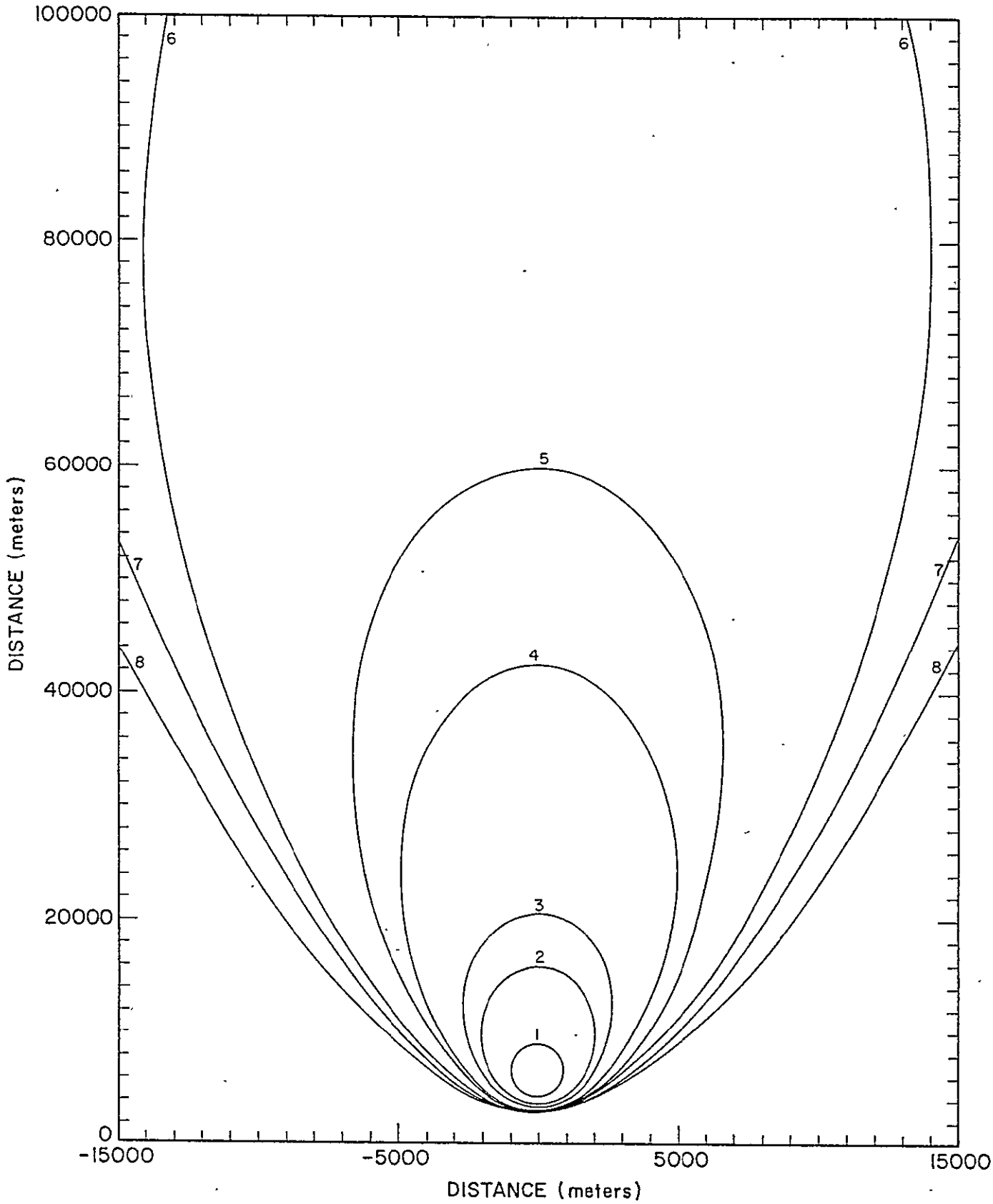

FIGURE 4-54. Dosage isopleths under unstable conditions for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second.

4.2 DOSAGE AREA COVERAGE

The computer program incorporating the dosage model described in Section 2 also has the capability of calculating the area covered by dosage levels equal to or greater than specified dosage levels of interest. This capability was used to determine the area coverage for various dosage levels. The results of these calculations are shown in Figures 4-55 through 4-72. As before, the figures are grouped by particle settling velocity, burn rate and total gallons of oil burned. The area-coverage for stable, neutral and unstable atmospheric conditions for a given settling velocity burn rate and total burned gallons burned are shown in a single figure.

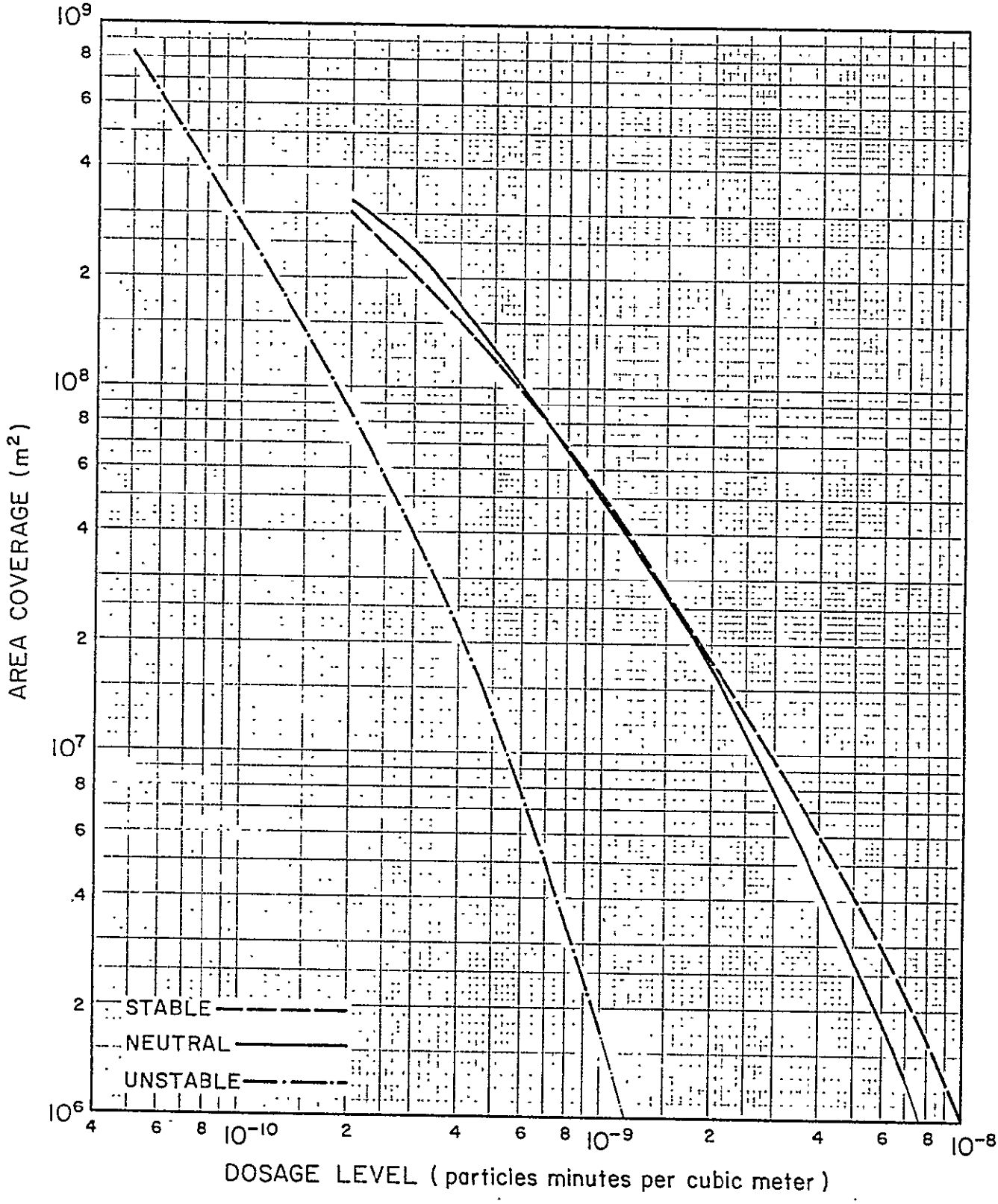

FIGURE 4-55. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second

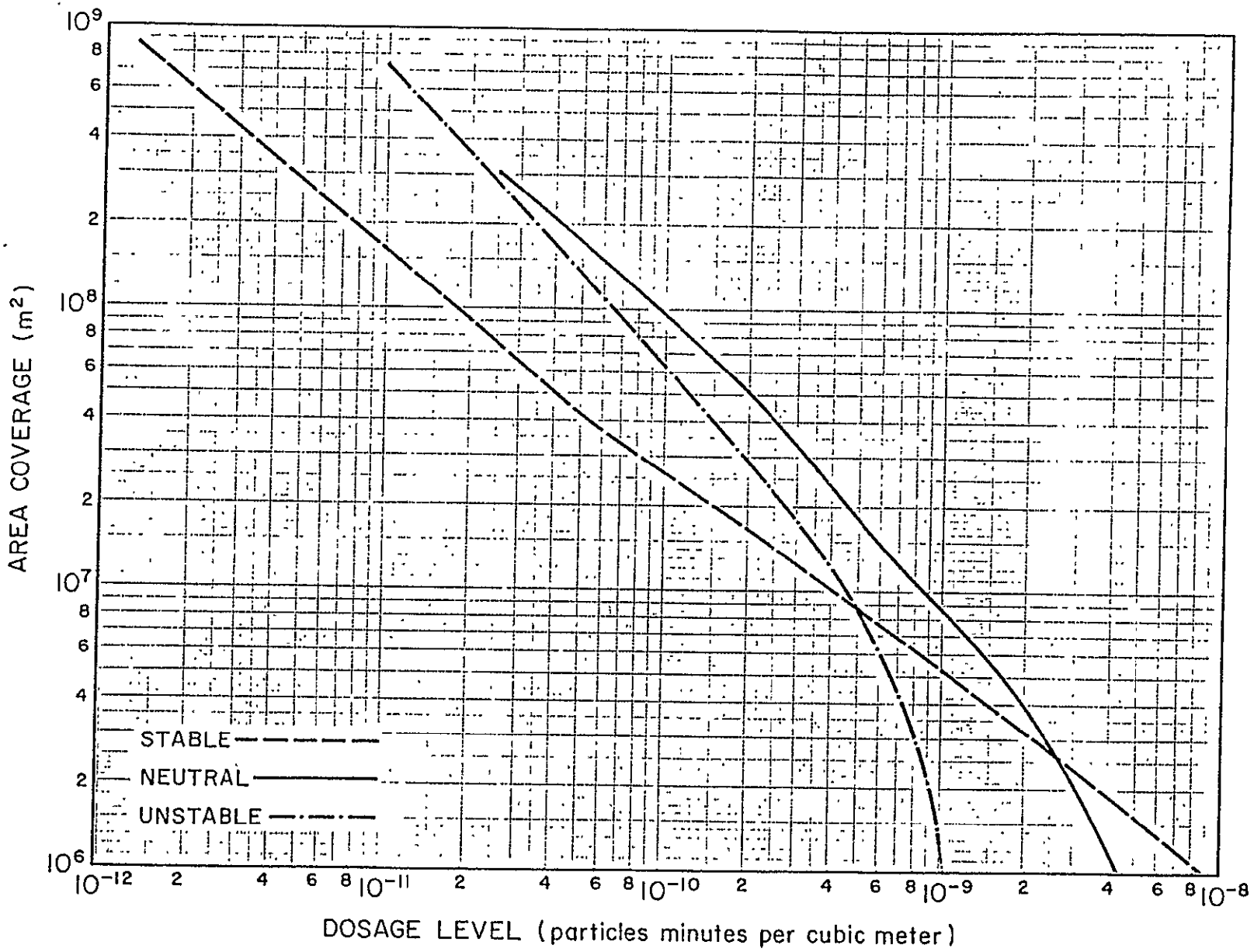

FIGURE 4-56. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second

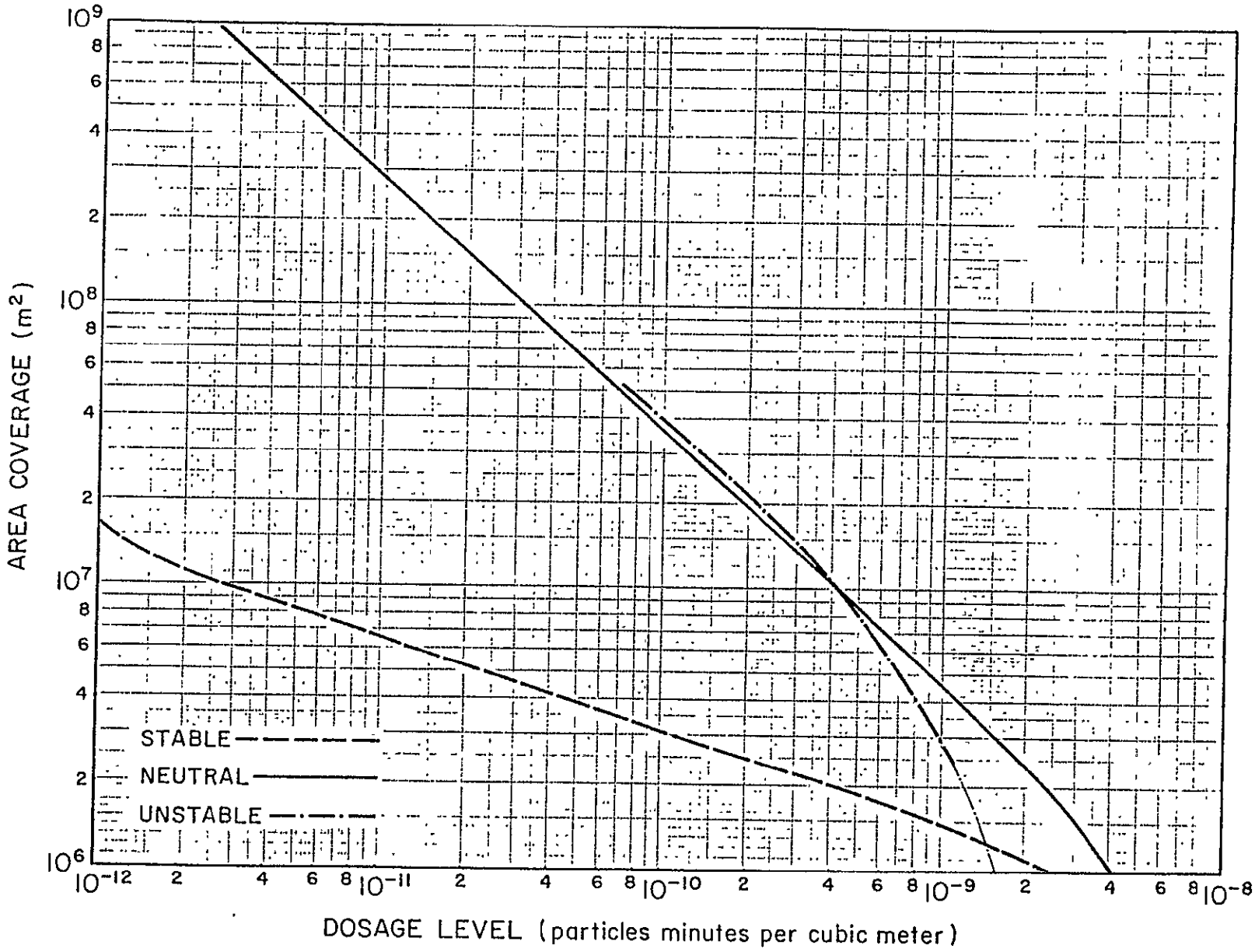

FIGURE 4-57. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of of 1 meter per second

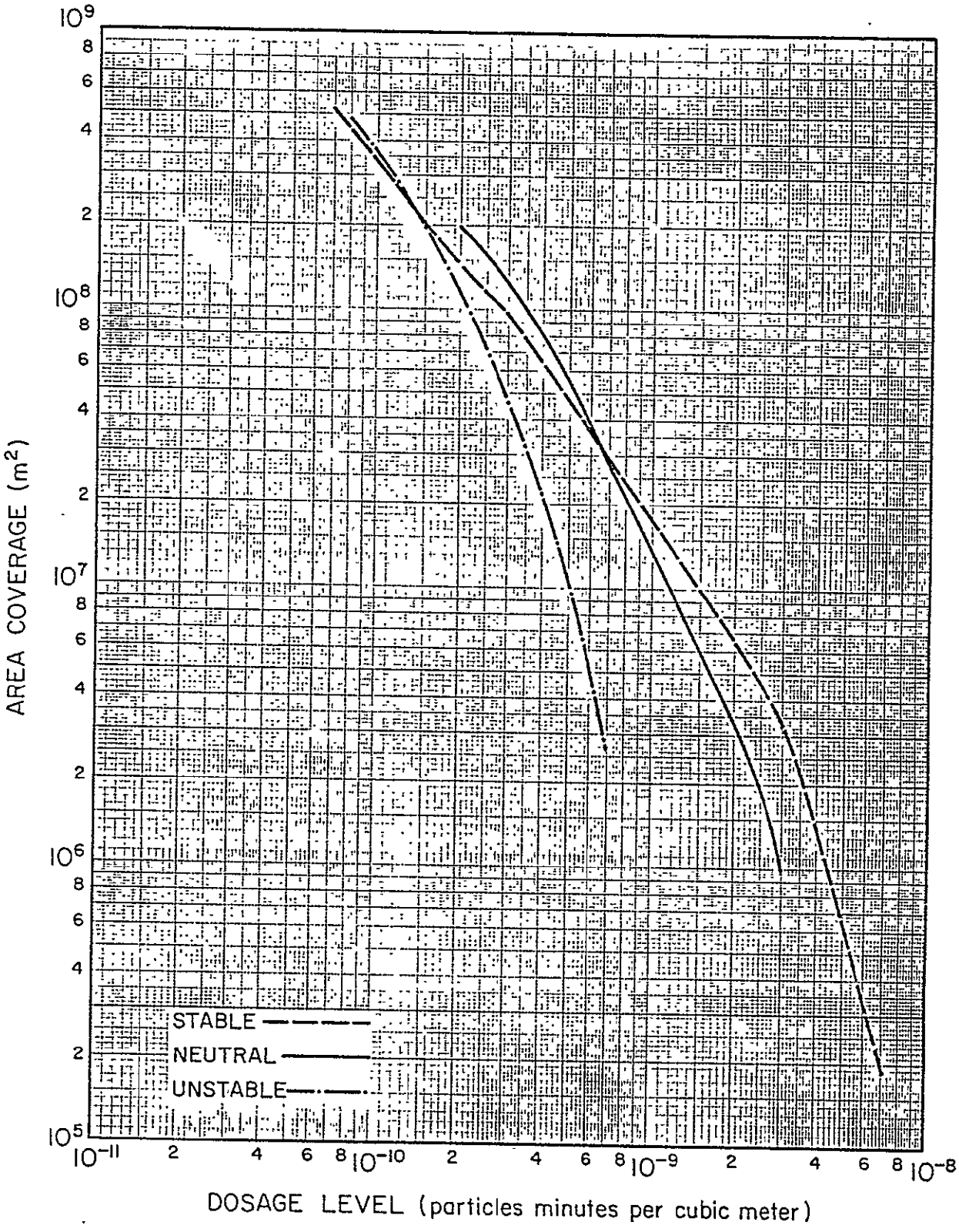

FIGURE 4-58. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 2 centimeters per second.

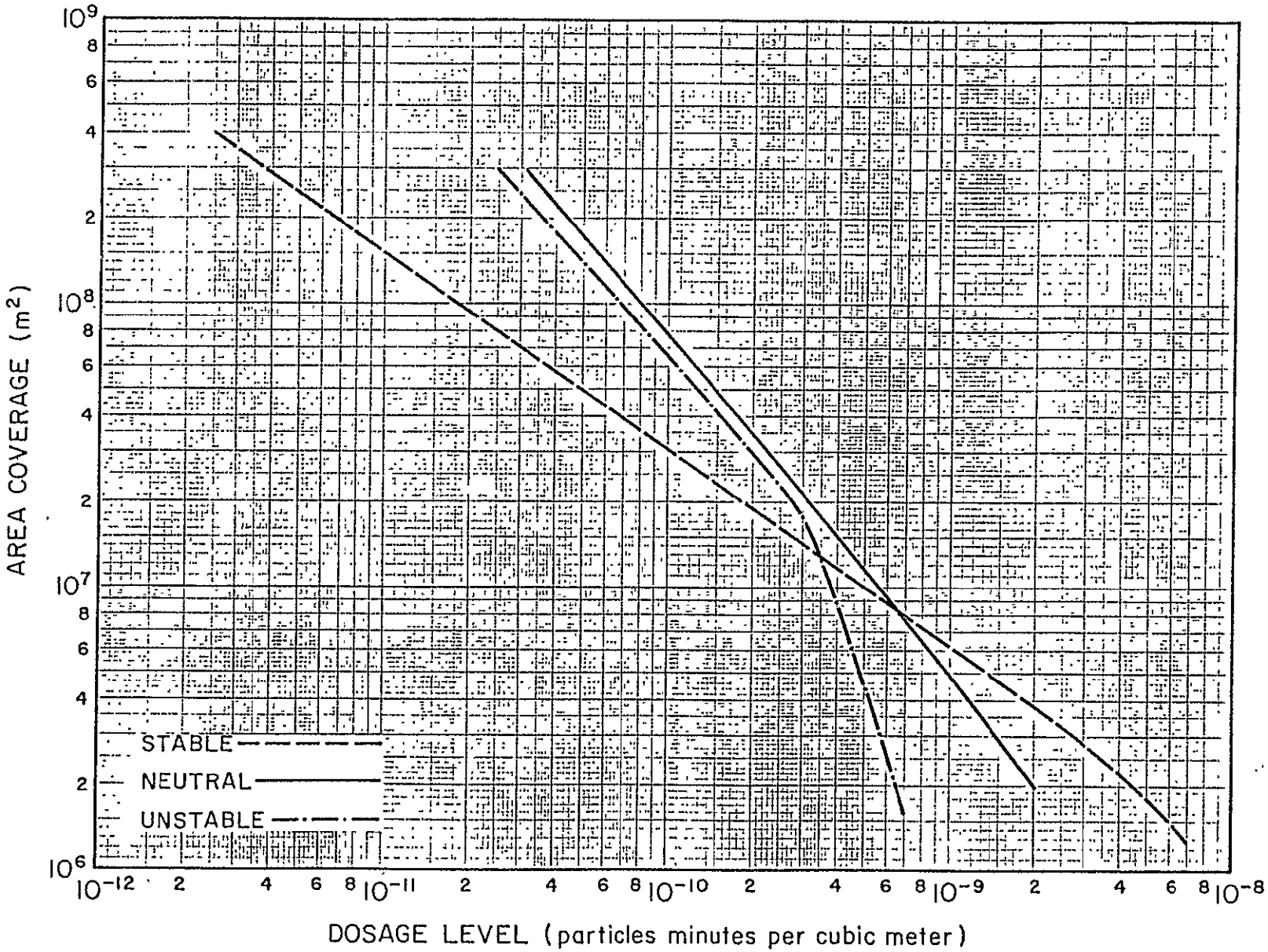

FIGURE 4-59. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 50 centimeters per second.

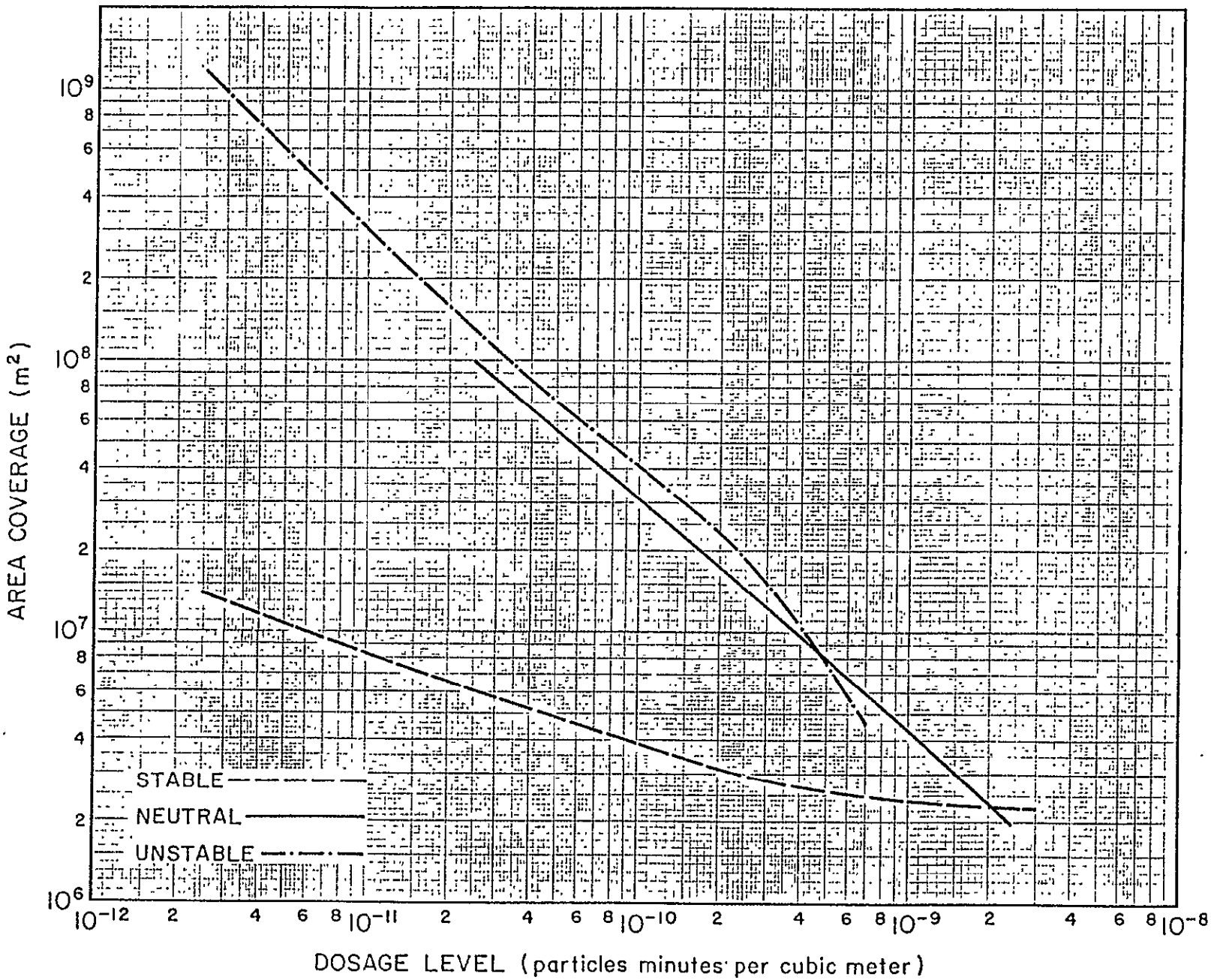

FIGURE 4-60. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 500 gallons, and gravitational settling velocity of 1 meter per second.

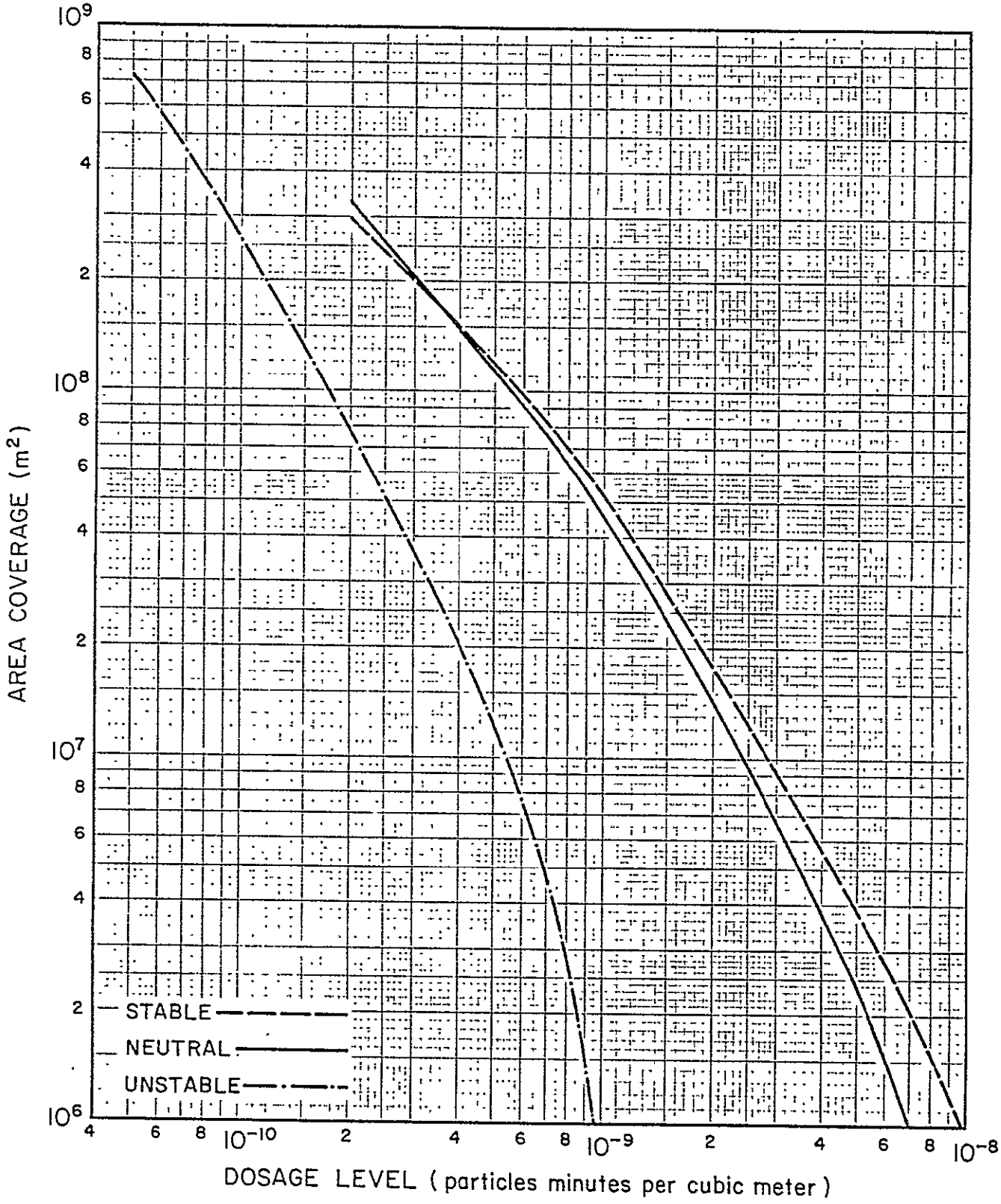

FIGURE 4-61. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 2 centimeters per second

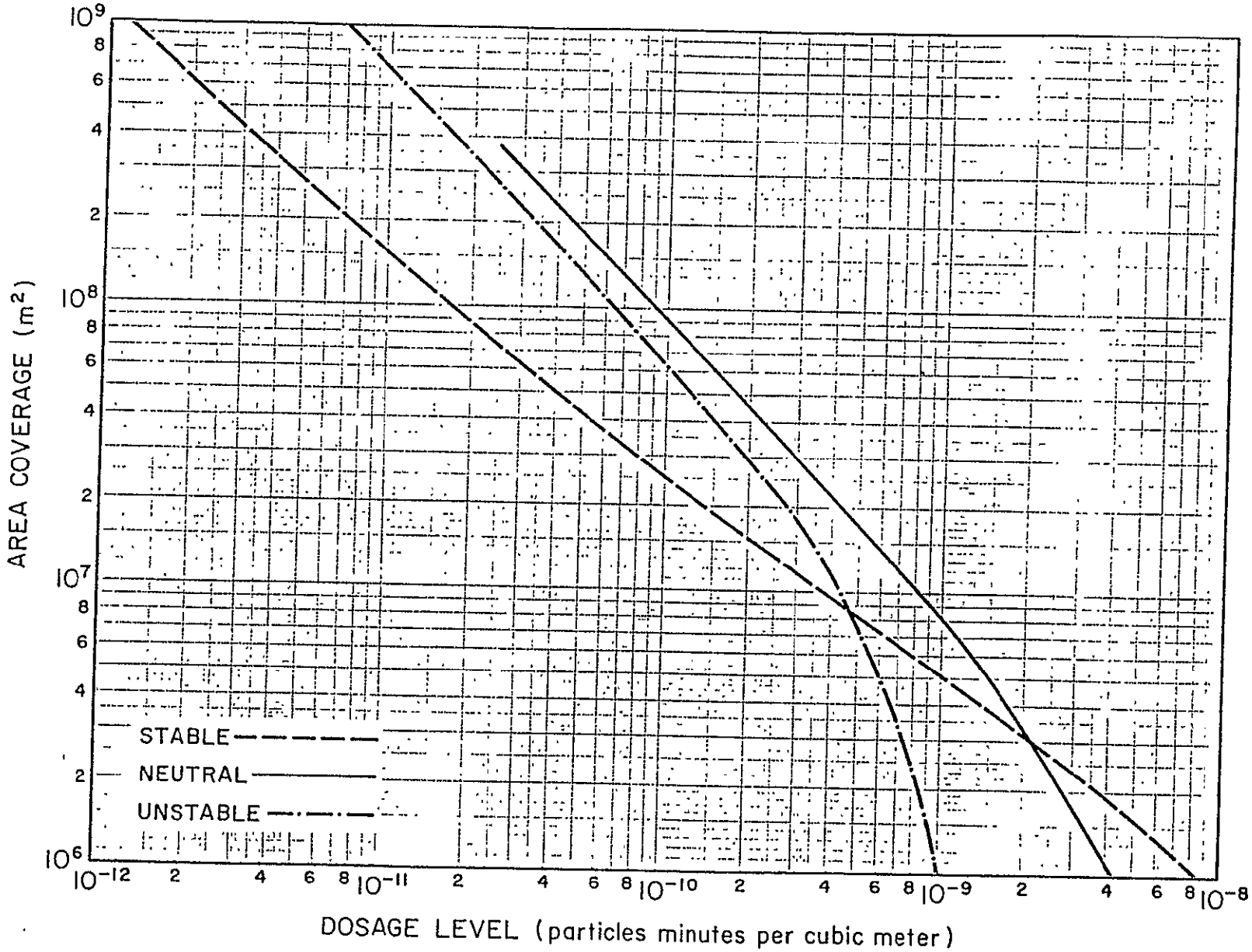

FIGURE 4-62. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second

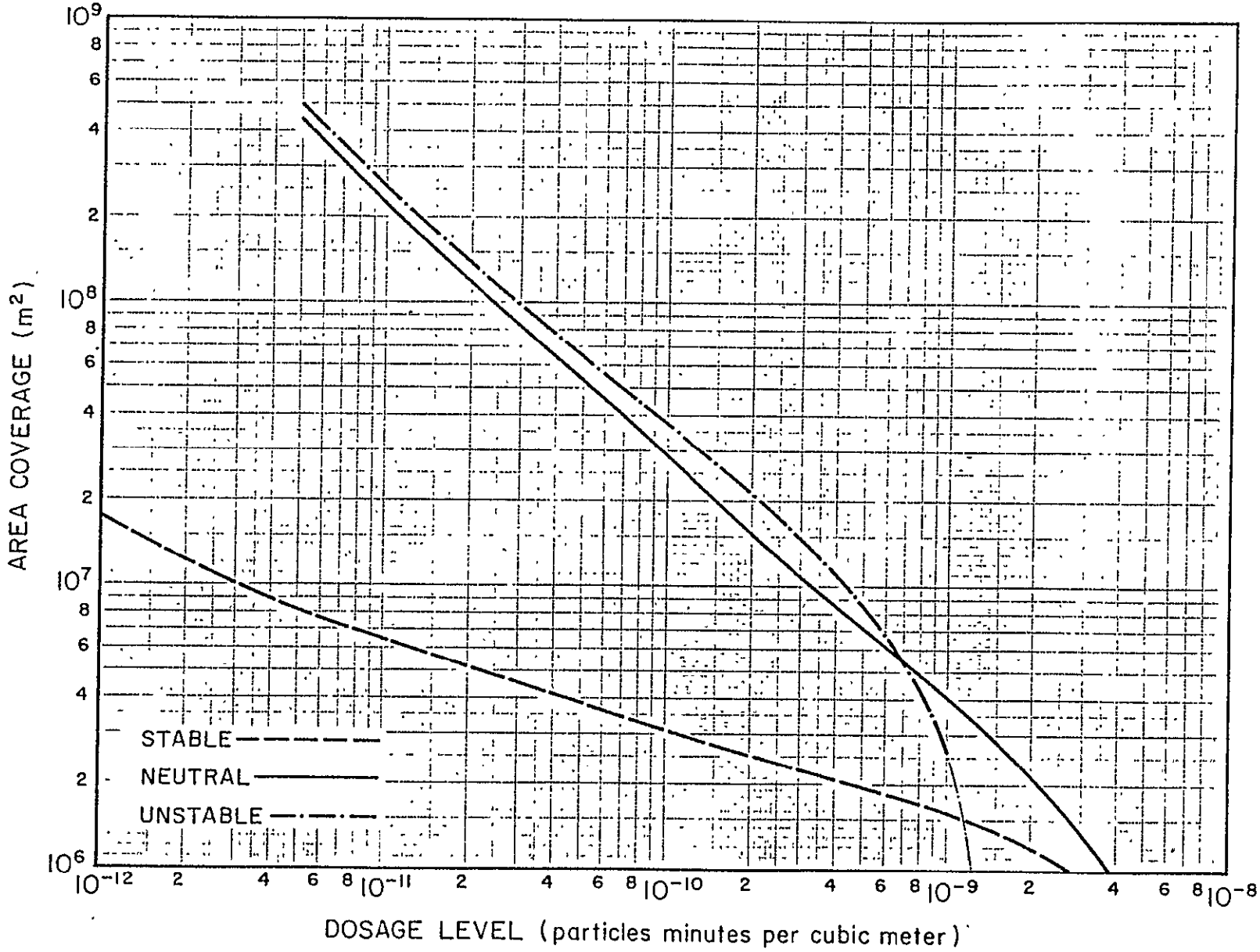

FIGURE 4-63. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second

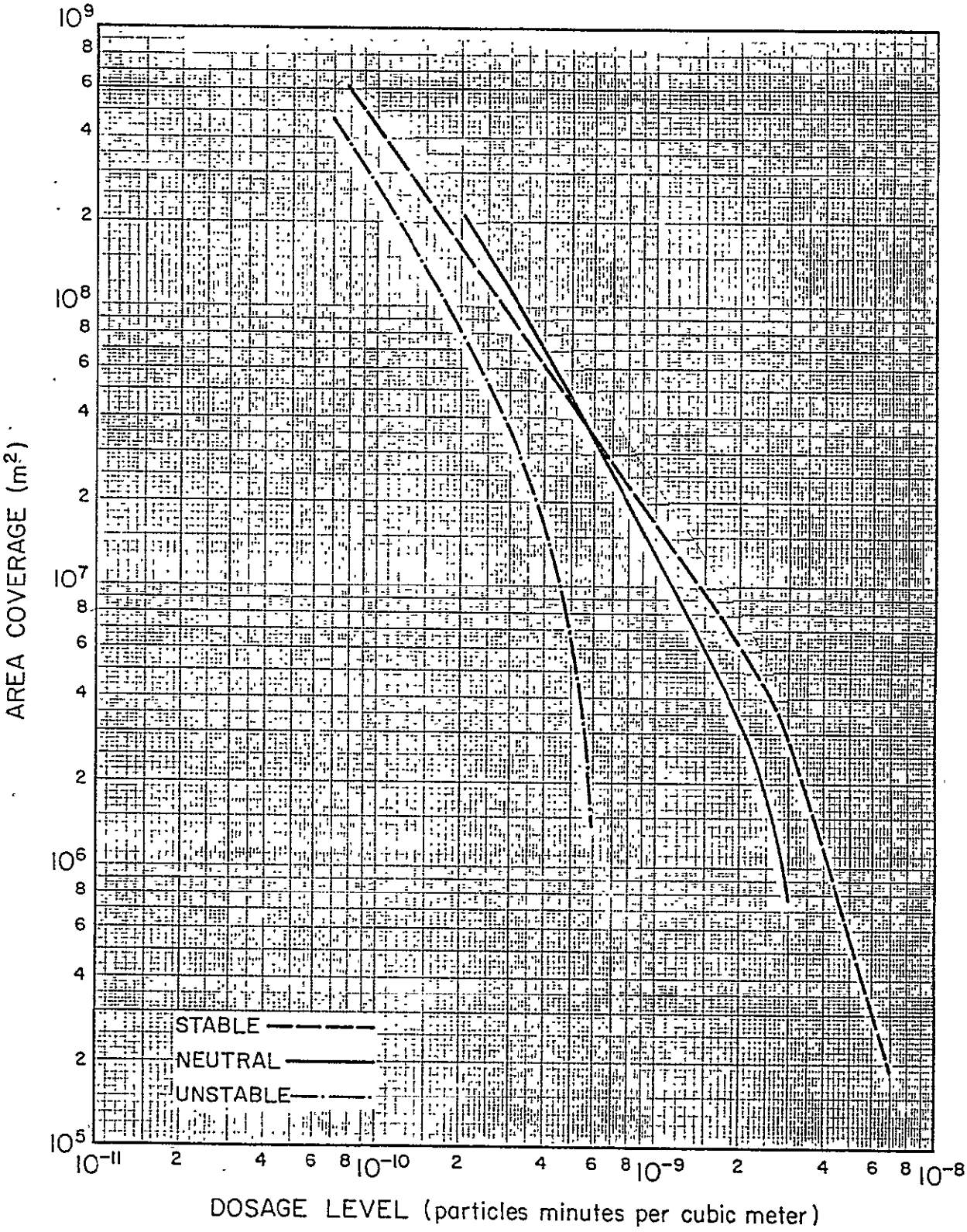

FIGURE 4-64. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 1000 gallons and gravitational settling velocity of 2 centimeters per second.

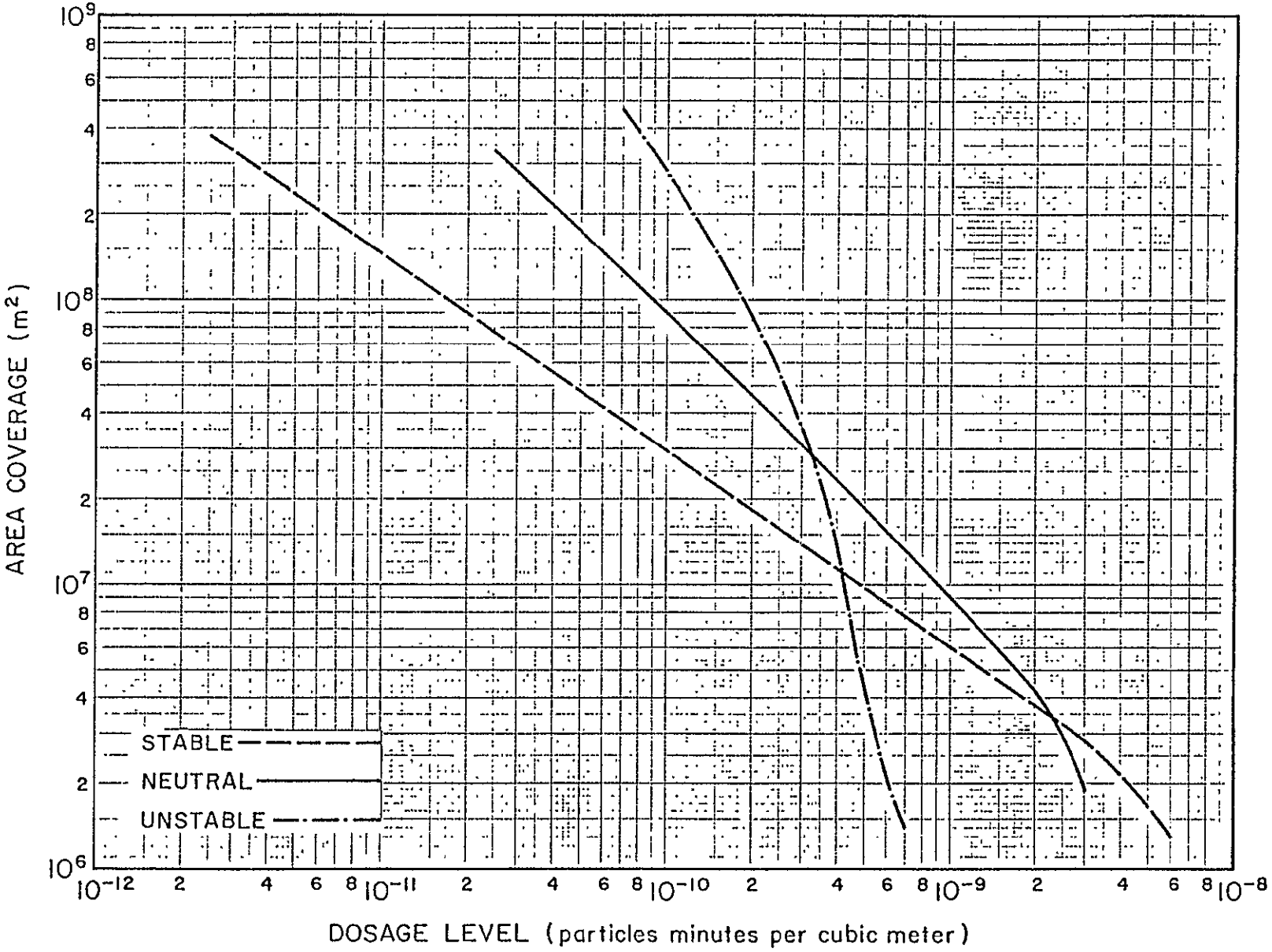

FIGURE 4-65. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 50 centimeters per second.

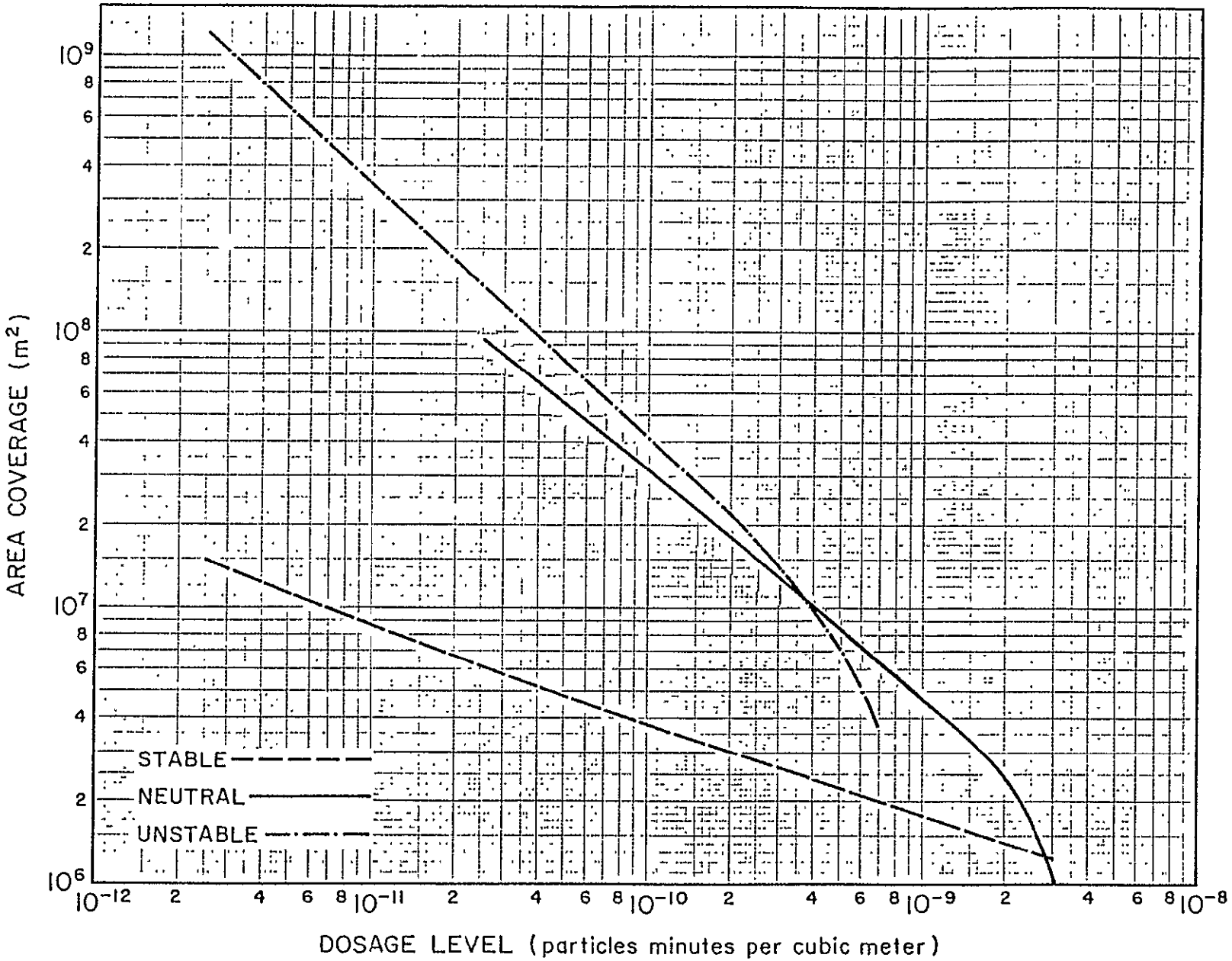

FIGURE 4-66. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 1000 gallons, and gravitational settling velocity of 1 meter per second.

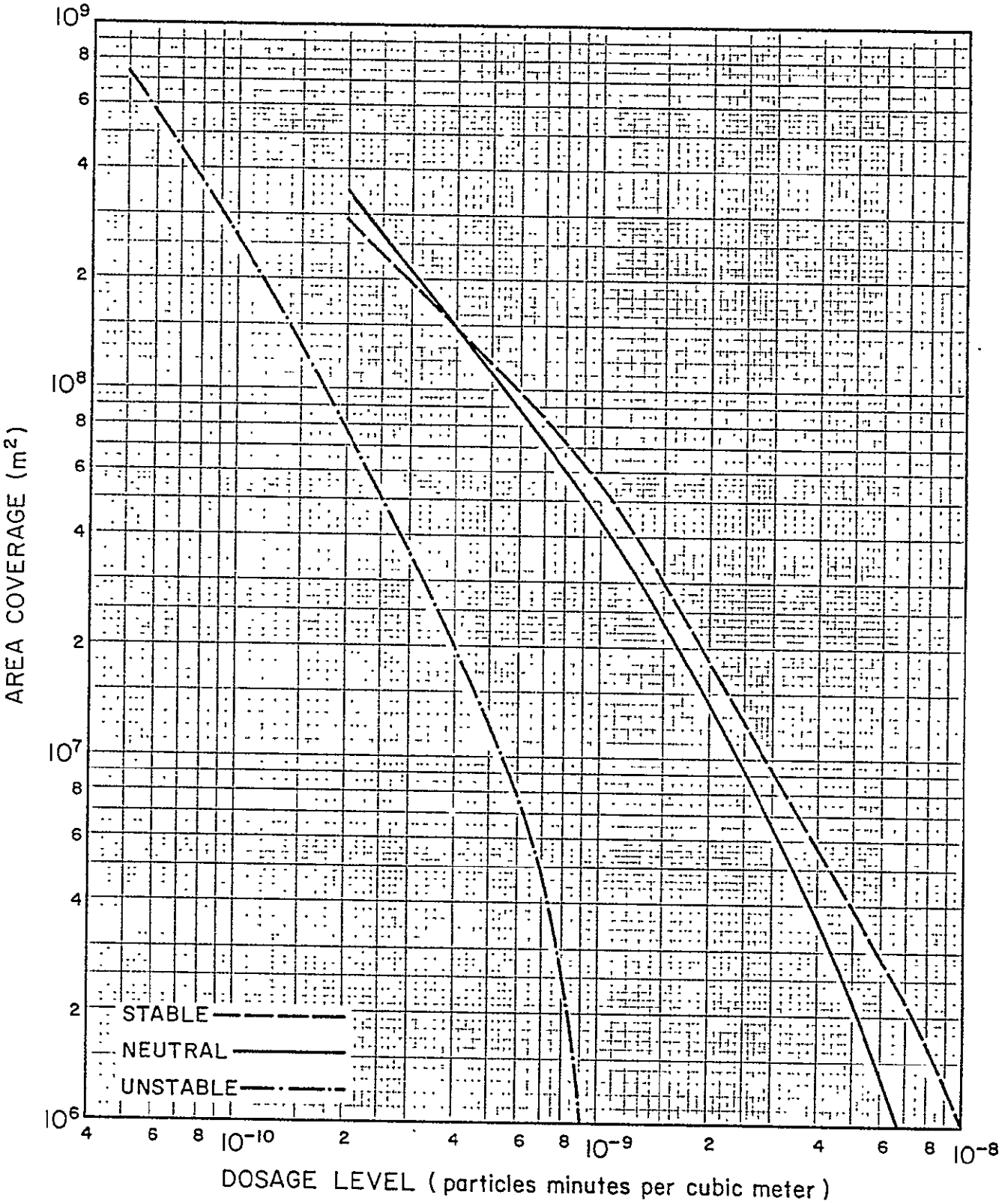

FIGURE 4-67. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitional settling velocity of 2 centimeters per second

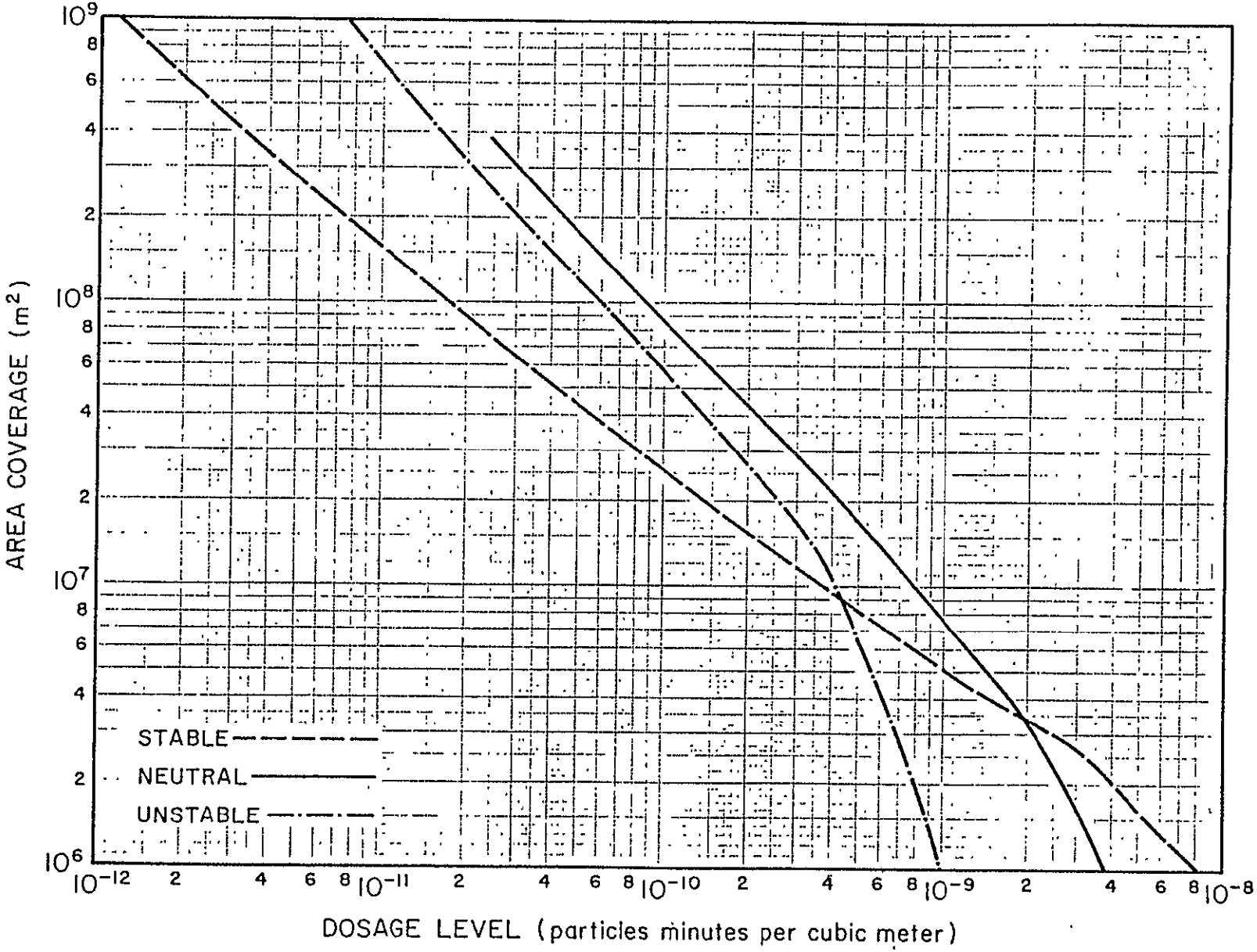

FIGURE 4-68. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second

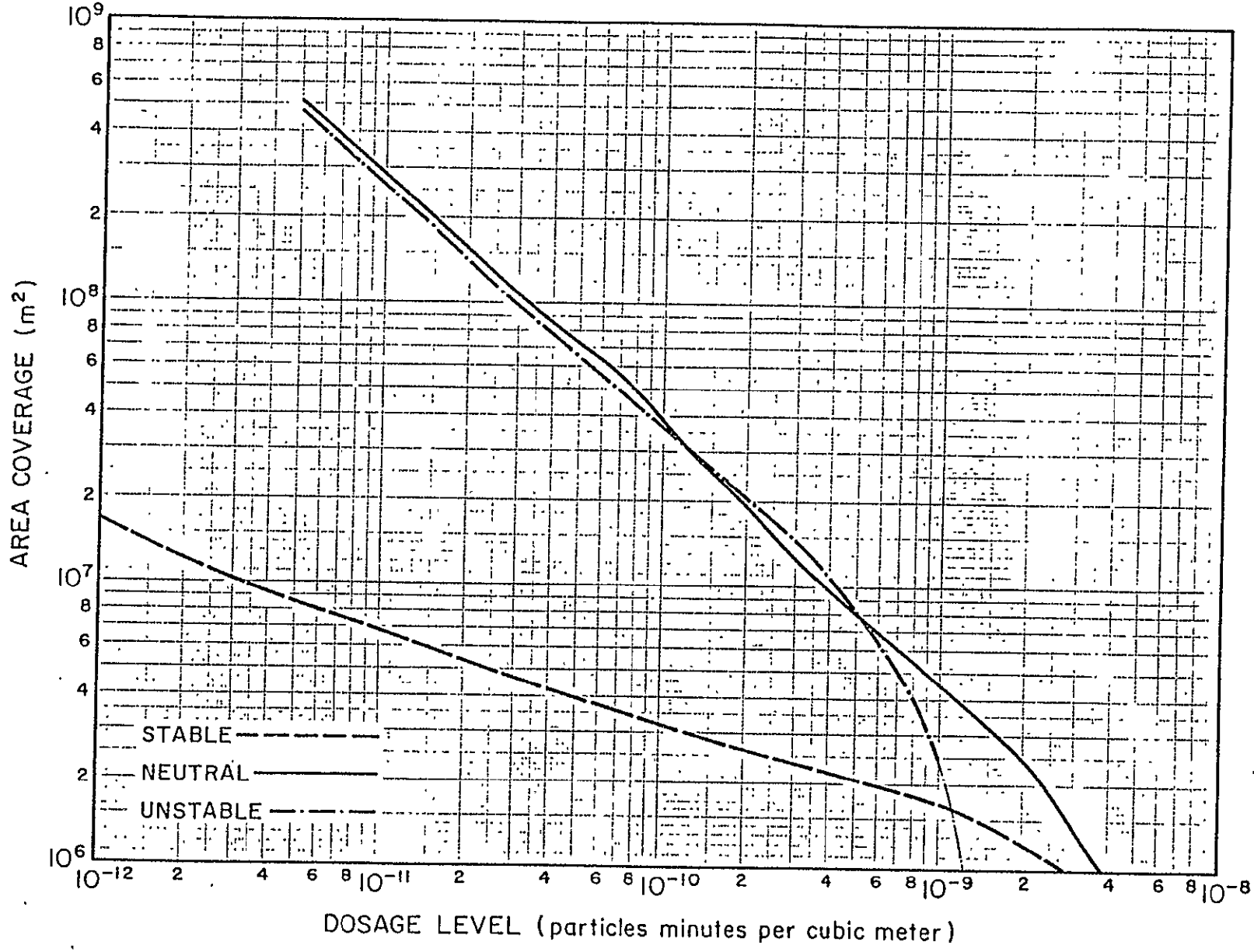

FIGURE 4-69. Area coverage versus dosage (exposure) level for a burn rate of 100 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second

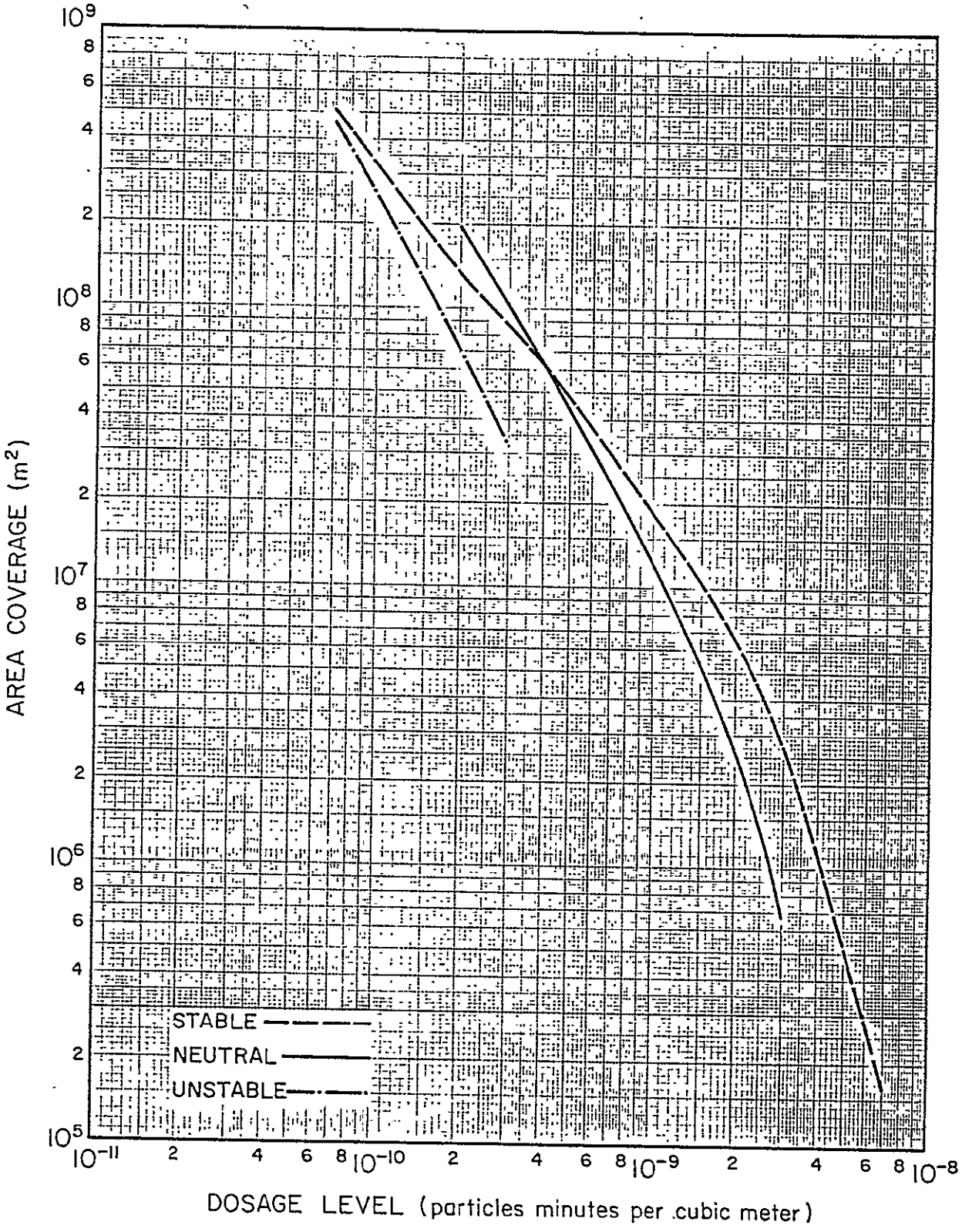

FIGURE 4-70. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 2 centimeters per second.

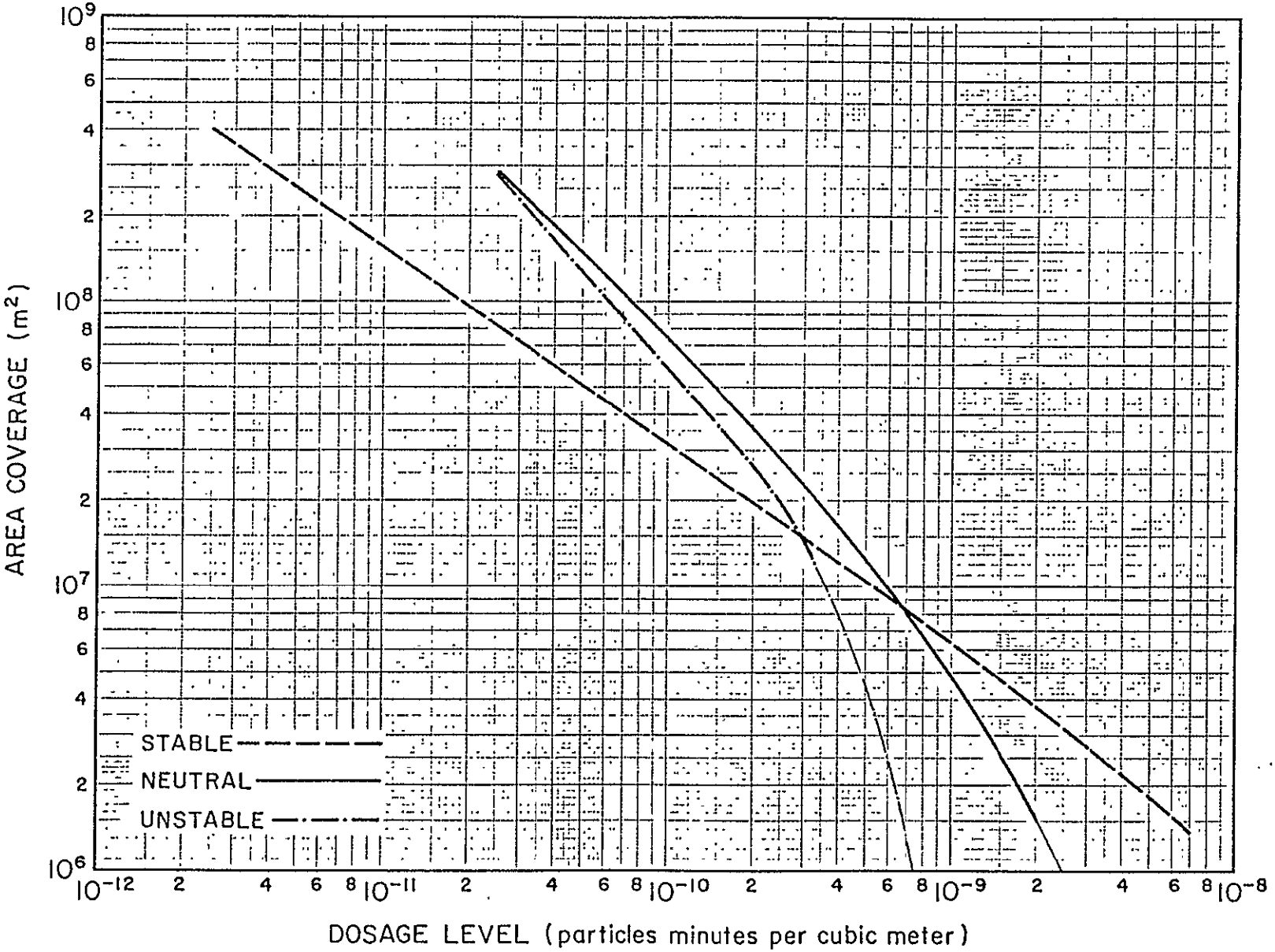

FIGURE 4-71. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 50 centimeters per second.

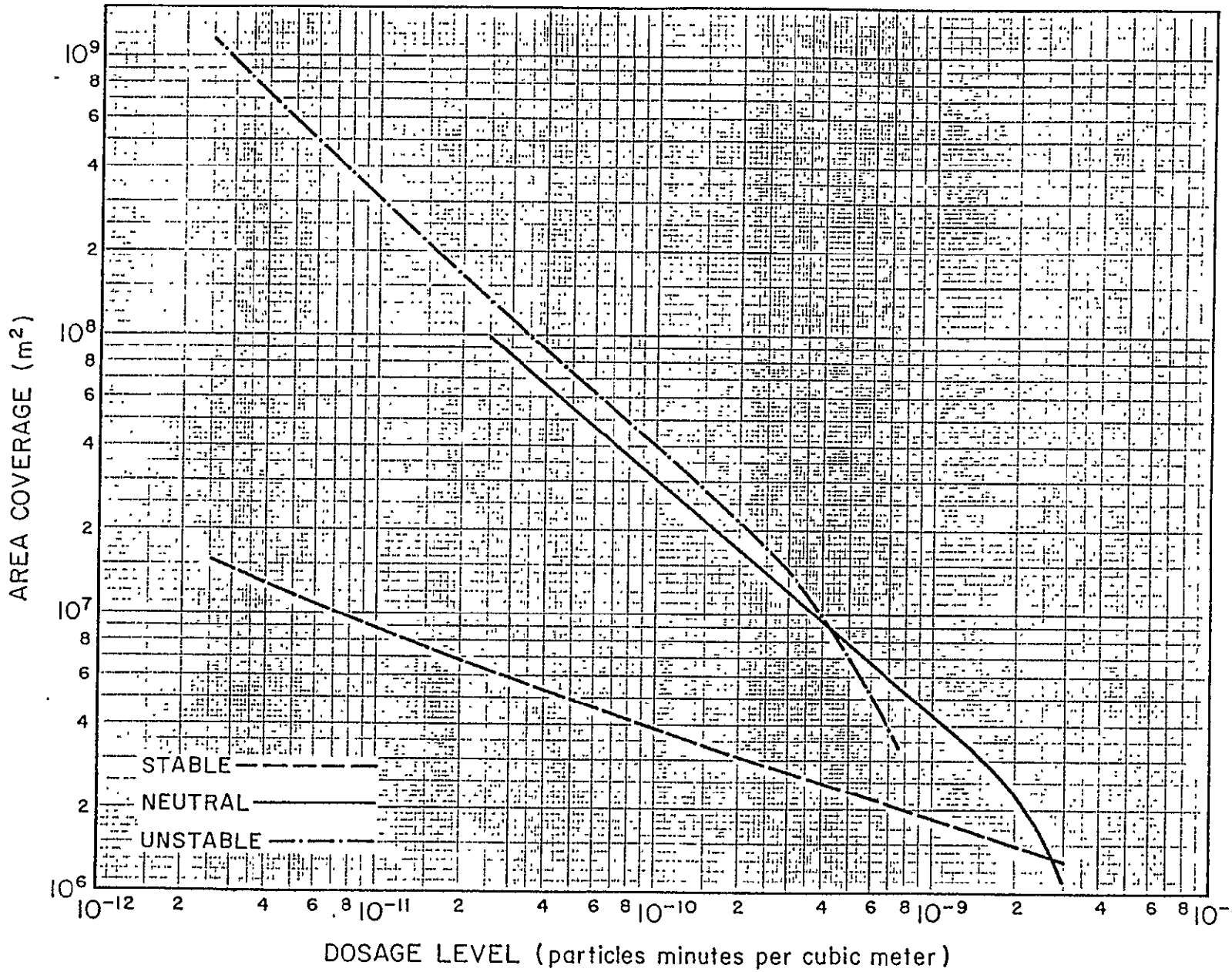

FIGURE 4-72. Area coverage versus dosage (exposure) level for a burn rate of 200 gallons per minute, total burn of 2000 gallons, and gravitational settling velocity of 1 meter per second.

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