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RISØ-M-2204

RECOMMENDATIONS ON DOSE BUILDUP FACTORS USED IN MODELS FOR CALCULATING GAMMA DOSES FROM A PLUME

Per Hedemann Jensen and Søren Thykier-Nielsen

Abstract. Calculations of *external γ-doses* from radioactivity released to the atmosphere have been made using different *dose buildup factor* formulas. Some of the dose buildup factor formulas are used by the Nordic countries in their respective γ-dose models. A comparison of calculated γ-doses using these dose buildup factors shows that the γ-doses can be significantly dependent on the buildup factor formula used in the calculation. Increasing differences occur for increasing plume height, crosswind distance, and atmospheric stability and also for decreasing downwind distance. It is concluded that the most accurate γ-dose can be calculated by use of *Capo's* polynomial buildup factor formula. Capo-coefficients have been calculated and shown in this report for γ-energies below the original lower limit given by Capo.

INIS descriptors: BUILDUP, DOSE RATES, EARTH ATMOSPHERE, EXTERNAL IRRADIATION, GAMMA RADIATION, MATHEMATICAL MODELS, METEOROLOGY, PLUMES, RADIATION DOSES, THEORETICAL DATA.

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CONTENTS

1. INTRODUCTION

In the calculation of external gamma doses from a radioactive plume the dose buildup factor accounts for the contribution of scattered gamma radiation to the total absorbed gamma dose at a given location.

It has been assumed (THY78, THY79, HE74, GO73, HEN69 and HOV69) that one of the reasons for observed differences in the calculated gamma doses from various dose models is caused by the use of different dose buildup factor formulas in the models.

To study this effect, calculations have been made using different dose buildup factor formulas. The study has been done as a part of the current work going on in the Nordic working group SNODAS *). The purpose of this work is to define recommendations concerning the Nordic dose models.

2. ASSUMPTIONS FOR THE CALCULATIONS

The gamma doses in this report are calculated from:

$$D_\gamma = \text{konst}\cdot E_\gamma \cdot \frac{\mu_{en}}{\rho} \cdot y \cdot \int_0^\infty \int_{-H}^\infty \int_{-\infty}^\infty \frac{B(E_\gamma,\mu r)}{4\pi r^2}\, e^{-\mu r} \chi\, dy\, dz\, dx \quad [\text{rad}\cdot\text{Ci}^{-1}] \qquad (1)$$

---

*) SNODAS is an abbreviation of: "Samordning af NOrdiske Dosisberegninger og Atmosfæriske Spredningsberegninger (Co-ordination of Nordic dose calculations and atmospheric dispersion calculations) and is a working group set up in May 1975 with participation from Sweden, Norway, Finland, and Denmark.

where the relative time-integrated concentration is given by:

$$\chi = \frac{\exp\left(-\frac{y^2}{2\sigma_y^2}\right)}{2\pi\sigma_y\sigma_z u} \cdot \left[\exp\left(-\frac{z^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \quad [s\cdot m^{-3}] \qquad (2)$$

and

σ_y, σ_z are the dispersion parameters [m]

E_γ is the photon energy [$MeV\cdot fot^{-1}$]

y is the photon yield [$fot\cdot dis^{-1}$]

μ is the linear attenuation coefficient for air [m^{-1}]

μ_{en}/ρ is the mass-energy absorption coefficient for air [$cm^2\cdot g^{-1}$]

$B(E_\gamma,\mu r)$ is the dose buildup factor for air for a point isotropic source

$r = [(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2]^{\frac{1}{2}}$ is the distance from a plume volume element to the detector point [m]

(x,y,z) are the coordinates of the volume element [m]

(x_1,y_1,z_1) are the coordinates of the detector point [m]

u is the wind velocity [$m\cdot s^{-1}$]

H is the effective release height [m]

Further details of the dose model can be found in (THY80).

2.2. Release situations

Gamma doses are calculated for a unit release under 3 different meteorological conditions:

I. Atmospheric stability: Pasquill A
Wind velocity: 1 m/s
Release height: 20 m and 100 m
No inversion layer
No deposition

II. Atmospheric stability: Pasquill C
Wind velocity: 1 m/s
Release height: 20 m and 100 m
No inversion layer
No deposition

III. Atmospheric stability: Pasquill F
Wind velocity: 1 m/s
Release height: 20 m and 100 m
No inversion layer
No deposition

The duration of the release is assumed to be 1800 seconds, and releases of 1 Ci of 4 different "fictive" isotopes are considered. The isotope data and the attenuation/energy absorption data for air used in the calculations are shown in Table 1.

Table 1. Isotope data and attenuation/energy absorption data for air.

No.	E_γ [$MeV \cdot fot^{-1}$]	y [$fot \cdot dis^{-1}$]	μ [m^{-1}]	μ_{en}/ρ [$cm^2 \cdot g^{-1}$]
Isotope 1	0.04	1	0.0315	0.0657
Isotope 2	0.38	1	0.0128	0.0294
Isotope 3	1.09	1	0.0079	0.0273
Isotope 4	2.53	1	0.0050	0.0217

2.3. Dose buildup factors

The simple definition of the buildup factor is the ratio of any desired quantity characteristic of the total gamma ray flux (e.g. gamma dose) to the same quantity characteristic of the unscattered flux.

Applying the above definition, the dose buildup factor is the ratio of the total dose or dose rate at a given point in a given medium to the dose or dose rate at that point due to unscattered flux.

The buildup factors are very useful since calculations making use of them are relatively simple and yield fairly accurate results. Different functions are used to estimate dose buildup factors, and in this study five different forms have been used.

- Linear form
- Quadratic form
- Berger form
- Capo form
- Jülich form.

2.3.1. Linear form

One of the formulas used earliest for the buildup factor was the linear form given by

$$B(E,\mu R) = 1 + K(E)\mu R$$

where

E is the photon energy	[MeV fot^{-1}]
μ is the linear attenuation coefficient	[m^{-1}]
R is the distance to the source	[m]

In this report K(E) for air is calculated from

$$K(E) = \frac{\mu(E) - \mu_{en}(E)}{\mu_{en}(E)} \qquad (4)$$

where μ_{en} is the linear energy absorption coefficient. The values for μ and μ_{en} are taken from Table 1.

2.3.2. Quadratic form

The quadratic formula for the buildup factor is given by

$$B(E,\mu R) = 1+A_1(E)\mu R + A_2(E)\ (\mu R)^2 \tag{5}$$

The values of A_1 and A_2 are given by *Trubey* (TRU66) for water at photon energies above 0.255 MeV. As the effective atomic number for water is approximately identical to the effective atomic number for air, the buildup factors for water and air will be nearly identical.

2.3.3. Berger form

The formula for the buildup factor introduced by *Berger* is given by

$$B(E,\mu R) = 1+C(E)\mu R\ e^{D(E)\mu R} \tag{6}$$

The value of C and D are given by *Trubey* (TRU66) for water at photon energies above 0.255 MeV and by *Vrubel* (VRU73) for air at photon energies from 0.020 MeV to 6 MeV.

In this report values from Trubey are used for energies above 0.255 MeV and values from Vrubel below 0.255 MeV.

2.3.4. Capo form

The *Capo* formula for the buildup factor is a bivariant polynomial given by

$$B(E,\mu R) = \sum_{i=0}^{3} \sum_{j=0}^{4} C_{ij}\ E^{-j}\ (\mu R)^{i} \tag{7}$$

which can be re-written as a 4-term polynomial

$$B(E,\mu R) = \sum_{i=0}^{3} \beta_i (\mu R)^i \tag{8}$$

where

$$\beta_i = \sum_{j=0}^{4} C_{ij} \; E^{-j} \tag{9}$$

Capo (CA58) has published a rather complete set of coefficients, C_{ij}, for many materials including water. For water the coefficients are given for energies above 0.255 MeV.

Unlike all other formulations of the buildup factor, Capo's coefficients result in an expression which does not reduce exactly to one for $\mu R = 0$. However, the Capo formula has the advantage that one may generate a set of β-values for any energy.

The Capo-coefficients were derived by the method of least squares fit to the basic data for dose buildup factors given by Goldstein and Wilkins (GO54).

2.3.5. Jülich form

Vogt (VO70) derived a formula for the dose buildup factor for air based on the data given by *Goldstein* and *Wilkins* (GO54). For two energy ranges the buildup factor is given by

$E \leq 0.5$ MeV:

$$B(E,\mu R) = 1 + 1.1\ \mu R + (\mu R)^2 \tag{10}$$

0.5 MeV $< E <$ 2 MeV:

$$B(E,\mu R) = 1 + \mu R + \frac{(\mu R)^2}{7 \cdot E^{2.4}} \tag{11}$$

3. DISCUSSION OF RESULTS

Calculated γ-doses using the 5 different buildup factor formulas are shown in Figs. 5-28 as a function of downwind distance and in Figs. 29-100 as a function of crosswind distance.

The different buildup factors used deviate from each other particularly at low energies, especially the linear and Jülich forms. At higher energies they all converge more or less to the same value.

In Figs. 1-4 the different buildup factors are shown as a function of the number of mean free paths, μR, for photon energies in the range 0.04 - 2.53 MeV.

When γ-doses from a plume are calculated by use of two different buildup factor forms B_1 and B_2, then the difference between the two sets of γ-doses will increase as the distance from the detector point to the plume, R, increases, if

$$\frac{B_1(\mu R_1)}{B_2(\mu R_1)} > 1 \ \wedge \ \frac{B_1(\mu R_2)}{B_2(\mu R_2)} > 1 \ : R_1 < R_2 \Rightarrow \frac{B_1(\mu R_1)}{B_2(\mu R_1)} < \frac{B_1(\mu R_2)}{B_2(\mu R_2)}$$

If the downwind distance is called x, the crosswind distance y, and the plume height h, this can be expressed as

$$x_2 > x_1 \Rightarrow \left(\frac{D_\gamma(B_1)}{D_\gamma(B_2)}\right)_{x_1} > \left(\frac{D_\gamma(B_1)}{D_\gamma(B_2)}\right)_{x_2} \tag{12}$$

$$y_2 > y_1 \Rightarrow \left(\frac{D_\gamma(B_1)}{D_\gamma(B_2)}\right)_{y_2} > \left(\frac{D_\gamma(B_1)}{D_\gamma(B_2)}\right)_{y_1} \tag{13}$$

$$h_2 > h_1 \Rightarrow \left(\frac{D_\gamma(B_1)}{D_\gamma(B_2)}\right)_{h_2} > \left(\frac{D_\gamma(B_1)}{D_\gamma(B_2)}\right)_{h_1} \tag{14}$$

or more generally

$$\lim_{r\to\infty} \left(\frac{D_\gamma(B_1(\mu r))}{D_\gamma(B_2(\mu r))}\right) = \frac{B_1(\mu r)}{B_2(\mu r)} \tag{15}$$

Looking at the calculated doses in Figs. 6, 8, and 10, and Figs. 44, 45, and 46, successively, the effect expressed in (12) is clearly demonstrated as would be expected from the appearance of the buildup factors shown in Fig. 1. The effect is even more marked for increasing stability, because - for a given downwind distance - the distance from the plume to the detector point then increases. This is illustrated by looking at Figs. 32, 38, and 44, successively.

Looking at the calculated doses at Figs. 47 and 53 the effect expressed in (13) appears. It is noticed - as seen from the buildup factors shown in Fig. 2 - that the calculated γ-dose using the linear buildup factor deviates by an increasing amount, as the crosswind distance increases. The effect expressed in (14) is apparent by looking at the doses at Figs. 9 and 10, successively.

For increasing photon energy the calculated doses using the different buildup factors converge as expected, which is illustrated by looking at Figs. 10, 16, and 22, successively, and at Figs. 44, 62, and 80, successively.

4. CONCLUSION

Most of the buildup factors in current use are based on the fundamental work of Goldstein and Wilkins (GO54). Trubey (TRU66) concludes that the Capo-polynomial buildup factor function gives the very best fit of these basic data.

Besides, the Capo formula has the advantage that buildup factors may be generated at any energy from the matrix of coefficients. At a given energy, a repeated calculation of the buildup factor for a numerical integration in a computer is as fast as using the linear buildup factor, when the calculations are performed with $B = \beta_0+\mu R(\beta_1+\mu R(\beta_2+\beta_3\mu R))$.

Furthermore, it has been shown from the calculations that the linear and the Jülich buildup factors forms should be used with some care, and not at low photon energies in any case.

It is therefore recommended that for calculating γ-doses from a plume as well as from deposited activity on the ground, the bivariant Capo-form should be used, given by

$$B(E,\mu R) = \sum_{i=0}^{3} \sum_{j=0}^{4} C_{ij} \, (\mu R)^{i} \cdot E^{-j} \qquad (16)$$

and valid in the following ranges

$0.255 \text{ MeV} \leq E \leq 10 \text{ MeV}$

$0 \leq \mu R \leq 20$

The coefficients C_{ij} are shown in Table 2.

However, it is necessary also to calculate γ-doses at photon energies below 0.255 MeV. For this purpose a least-square fit has been made to the buildup data for air as given by Vrubel (VRU73). A 5-term polynomial was used:

$$B(E,\mu R) = \sum_{i=0}^{4} \beta_i \, (\mu R)^i \qquad (17)$$

and fitted for the range

$$0 \leq \mu R \leq 7$$

The fit was made at seven photon energies below 0.255 MeV, and the coefficients β_i are shown in Table 3. To make a better fit the degree of the polynomial has been raised by one compared with the original Capo polynomial.

It is recommended that these β-values are used for calculation of γ-doses at photon energies below 0.255 MeV.

Table 2. Capo coefficients for dose buildup factors in water.

Polynomial Coefficients, C_{ij}				
j/i	0	1	2	3
0	1.01094 E+0	1.16772 E-1	-7.65869 E-3	1.67068 E-4
1	-6.00394 E-2	2.32125 E+0	-1.79023 E-2	5.69295 E-4
2	7.20778 E-2	-2.12801 E+0	2.41735 E-1	-7.96332 E-3
3	-3.01498 E-2	7.67783 E-1	-4.34443 E-2	7.23758 E-3
4	3.94733 E-3	-9.08139 E-2	-1.34203 E-3	-9.87237 E-4

Table 3. β-coefficients for dose buildup factors in air.

E[MeV]	β_0	β_1	β_2	β_3	β_4
0.04	9.999769E-1	2.189205E+0	1.631374E-1	5.579626E-3	2.090830E-4
0.06	1.010677E+0	3.119120E+0	6.896355E-1	2.376420E-2	8.212706E-3
0.08	1.038852E+0	2.785472E+0	1.077117E+0	-2.146634E-2	2.352953E-2
0.10	1.054717E+0	2.338676E+0	1.182395E+0	-5.917086E-2	3.052626E-2
0.12	1.057473E+0	2.098229E+0	1.161661E+0	-6.951280E-2	3.133146E-2
0.15	1.053050E+0	1.900506E+0	1.065865E+0	-6.525791E-2	2.892497E-2
0.20	1.040584E+0	1.655762E+0	8.583238E-1	-4.527632E-2	2.244595E-2

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6. LIST OF FIGURES

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Stability class: Pasquill A
Photon energy: 0.04 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 35–40: Gamma doses as a function of crosswind distance
Stability class: Pasquill C
Photon energy: 0.04 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 41–46: Gamma doses as a function of crosswind distance
Stability class: Pasquill F
Photon energy: 0.04 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 47–52: Gamma doses as a function of crosswind distance
Stability class: Pasquill A
Photon energy: 0.38 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 53–58: Gamma doses as a function of crosswind distance
Stability class: Pasquill C
Photon energy: 0.38 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 59–64: Gamma doses as a function of crosswind distance
Stability class: Pasquill F
Photon energy: 0.38 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 65-70: Gamma doses as a function of crosswind distance
Stability class: Pasquill A
Photon energy: 1.09 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

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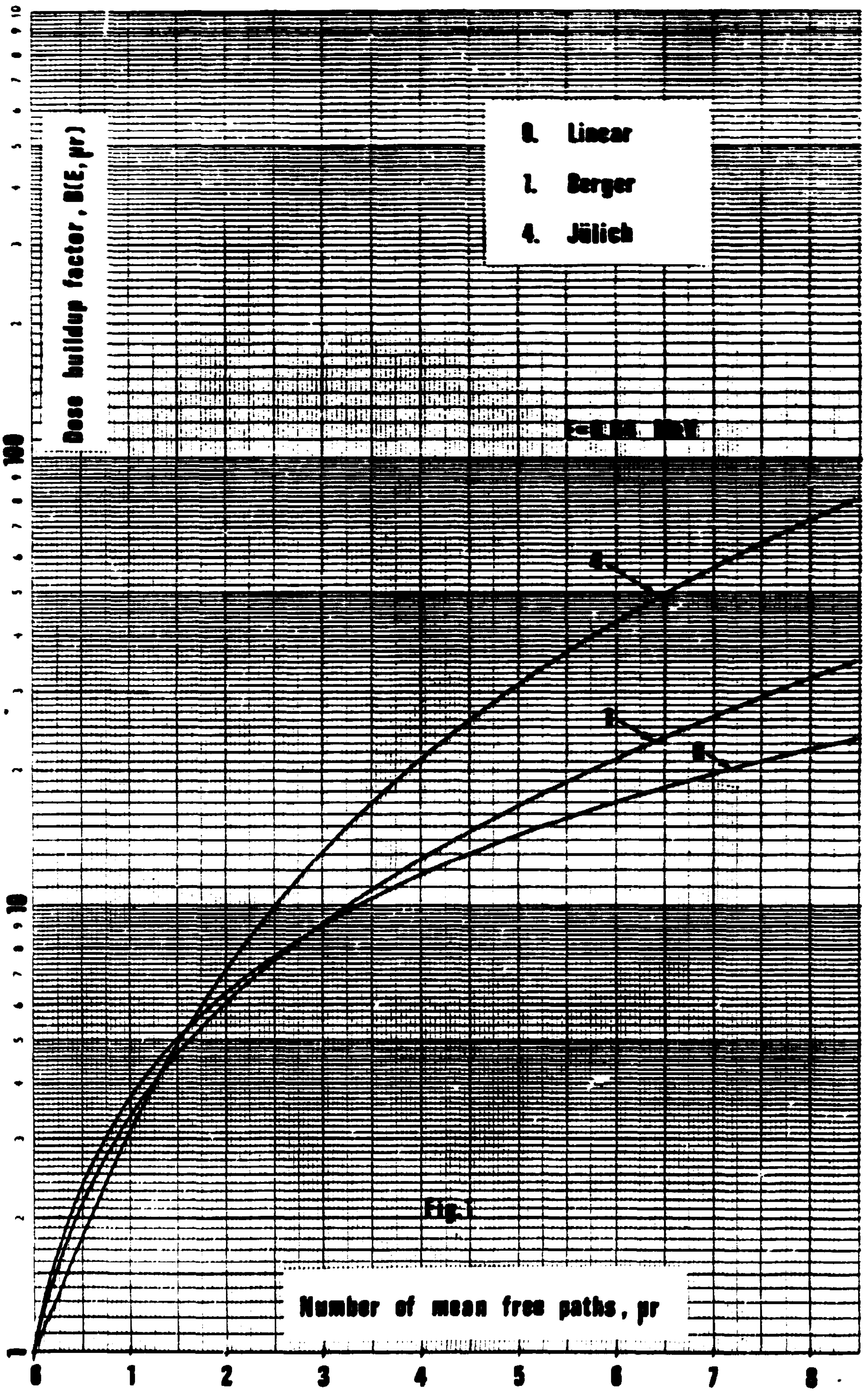
Stability class: Pasquill C
Photon energy: 1.09 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 77-82: Gamma doses as a function of crosswind distance
Stability class: Pasquill F
Phothon energy: 1.09 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 83-88: Gamma doses as a function of crosswind distance
Stability class: Pasquill A
Photon energy: 2.53 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 89-94: Gamma doses as a function of crosswind distance
Stability class: Pasquill C
Photon energy: 2.53 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km

Figures 95-100: Gamma doses as a function of crosswind distance
Stability class: Pasquill F
Photon energy: 2.53 MeV
Release heights: 20 m and 100 m
Downwind distances: 1 km, 10 km, and 50 km



Dose buildup factor, B(E, μr)
0. Linear
1. Berger
4. Jülich
Fig.1
Number of mean free paths, μr

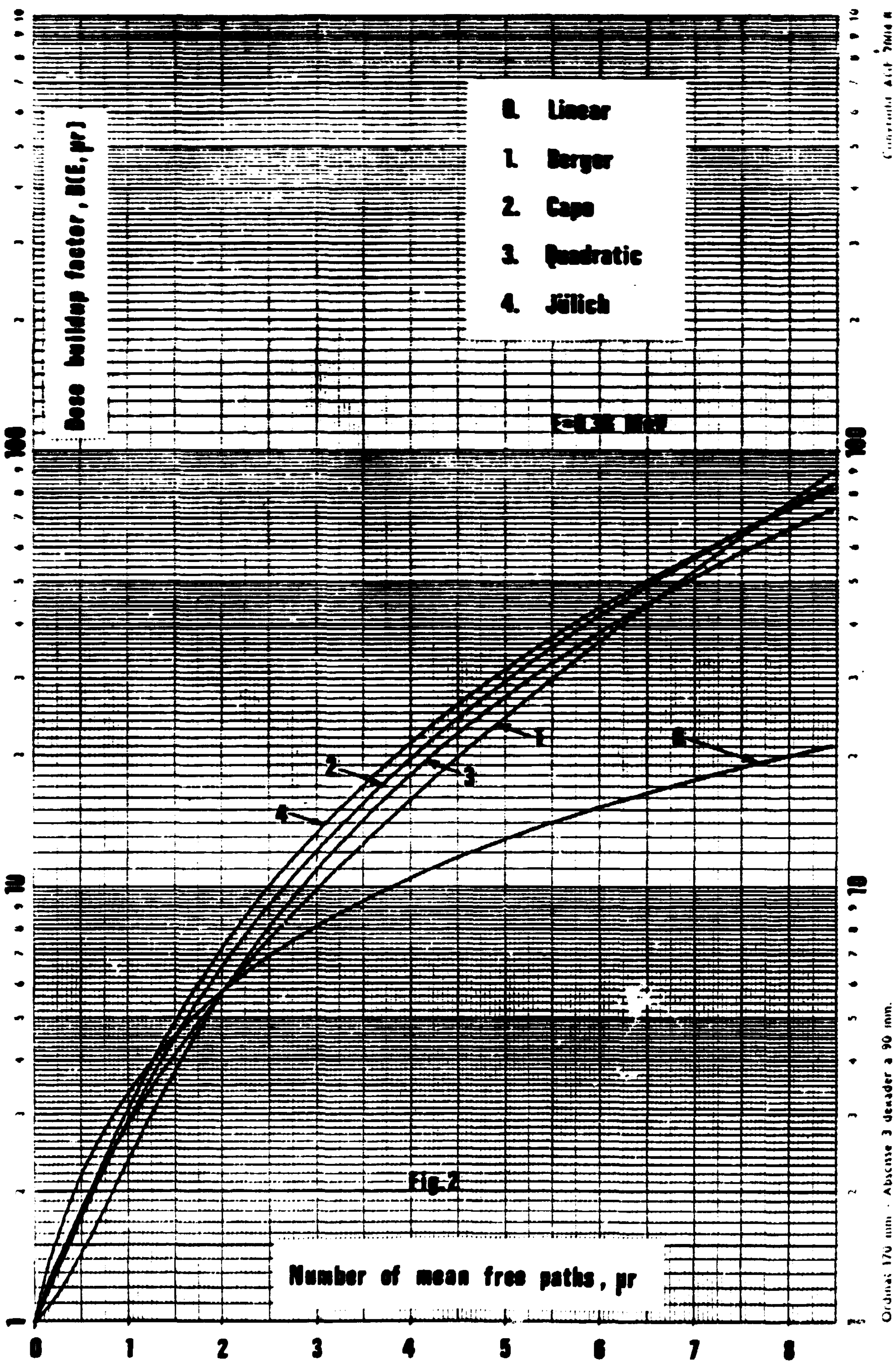

0. Linear
1. Berger
2. Cape
3. Quadratic
4. Jülich
Dose buildup factor, B(E, pr)
Number of mean free paths, pr
Ordinat 170 mm · Abscisse 3 dekader a 90 mm.

Fig.2

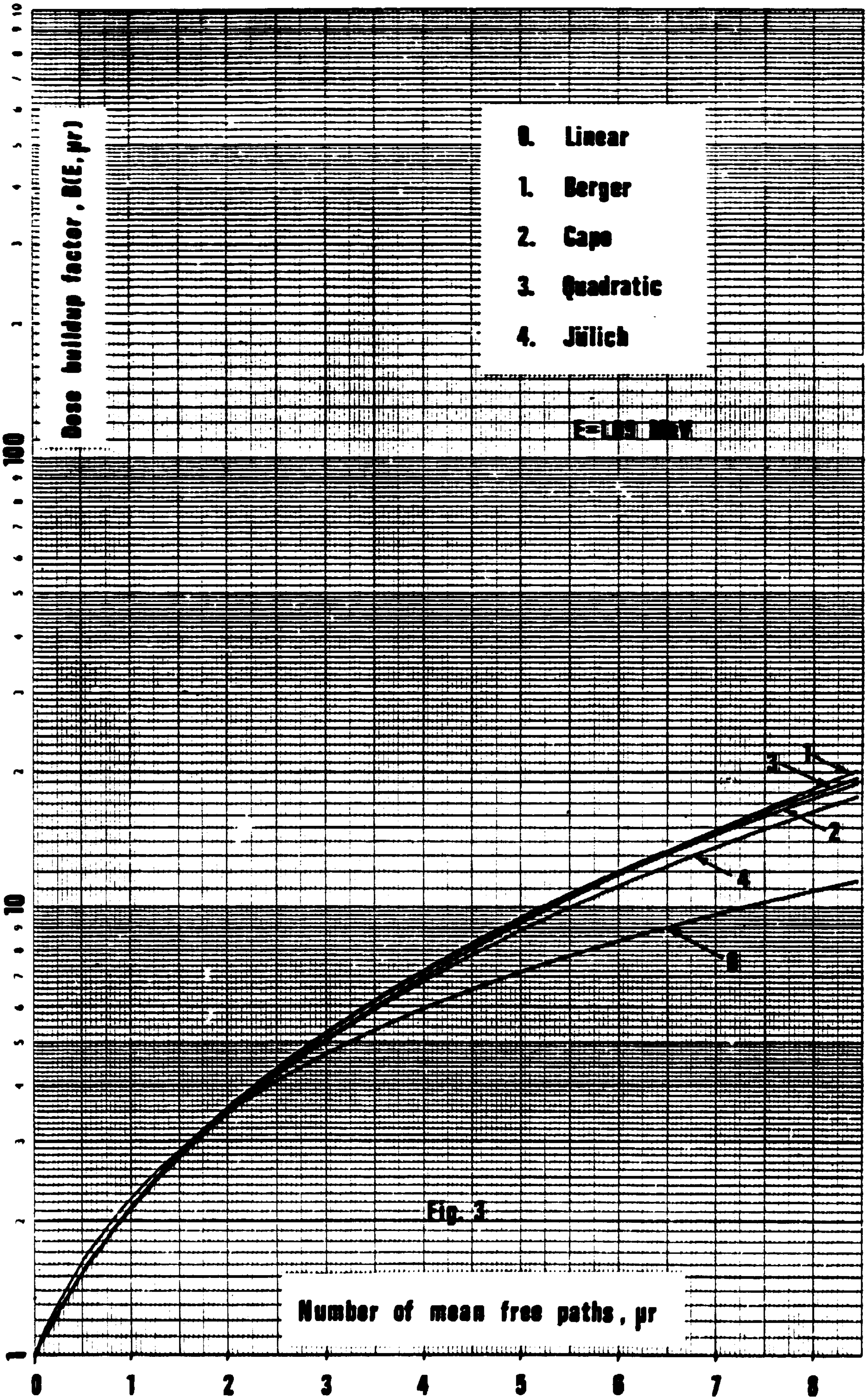
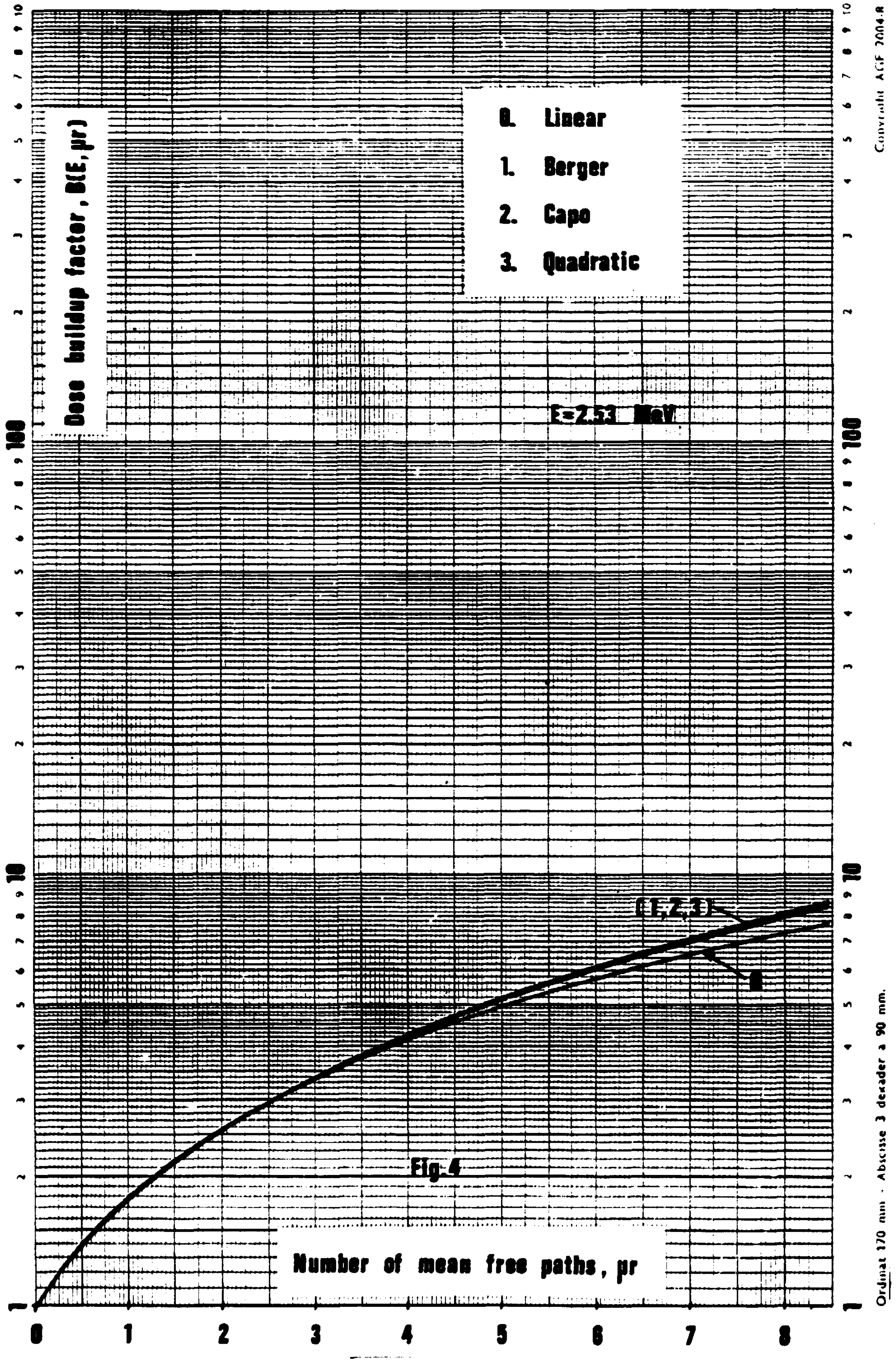

Dose buildup factor, B(E, μr)
0. Linear
1. Berger
2. Cape
3. Quadratic
4. Jülich
Number of mean free paths, μr
0
1
2
3
4
5
6
7
8
1
10
100

Fig. 3



0. Linear
1. Berger
2. Capo
3. Quadratic
E=2.53 MeV
Dose buildup factor, B(E, μr)
(1,2,3)
0
Fig. 4
Number of mean free paths, μr
0 1 2 3 4 5 6 7 8
10
100
Ordinat 170 mm · Abscisse 3 dekader à 90 mm.
Copyright AGF 2004-R

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

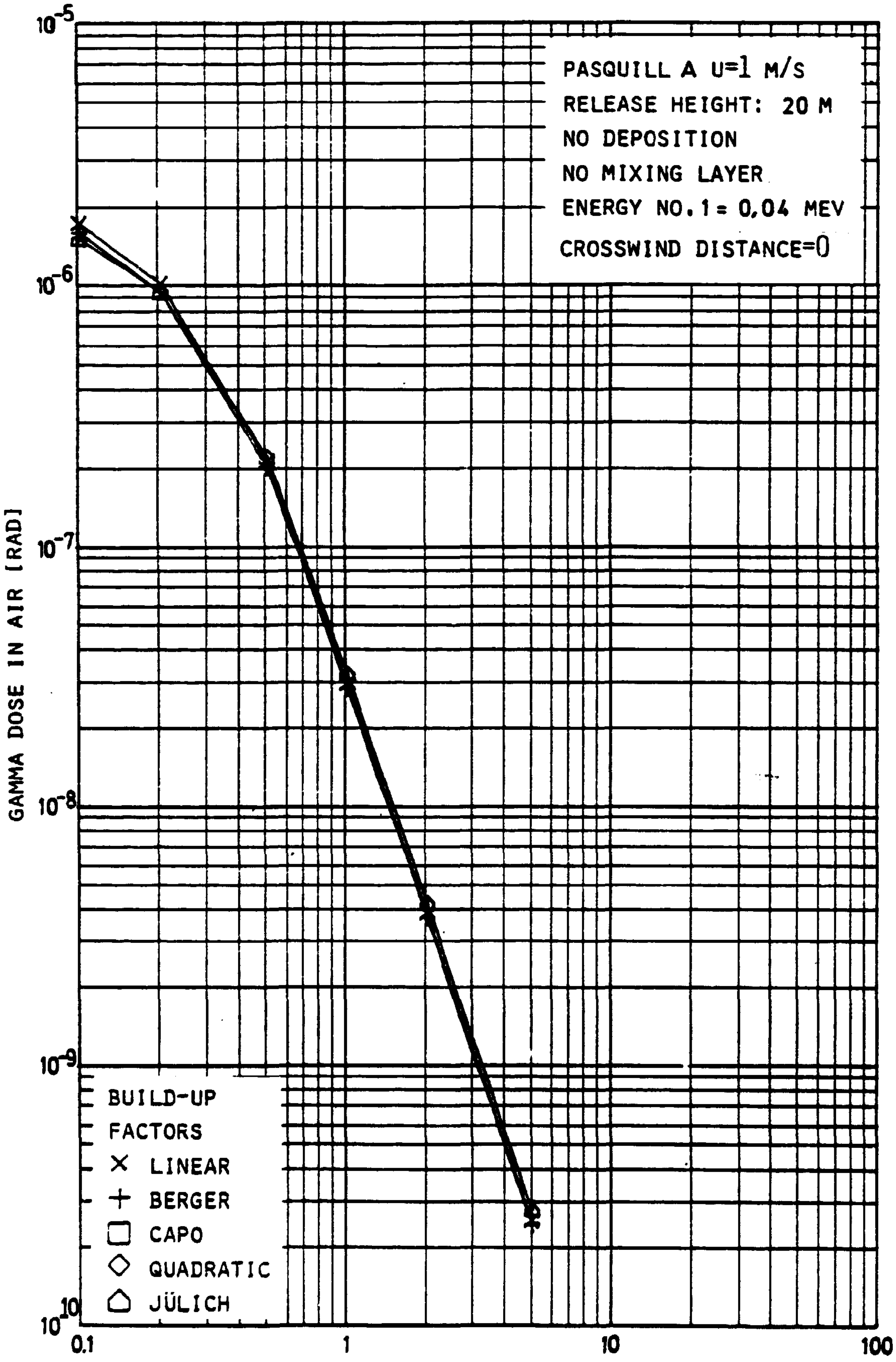


FIG. 5

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

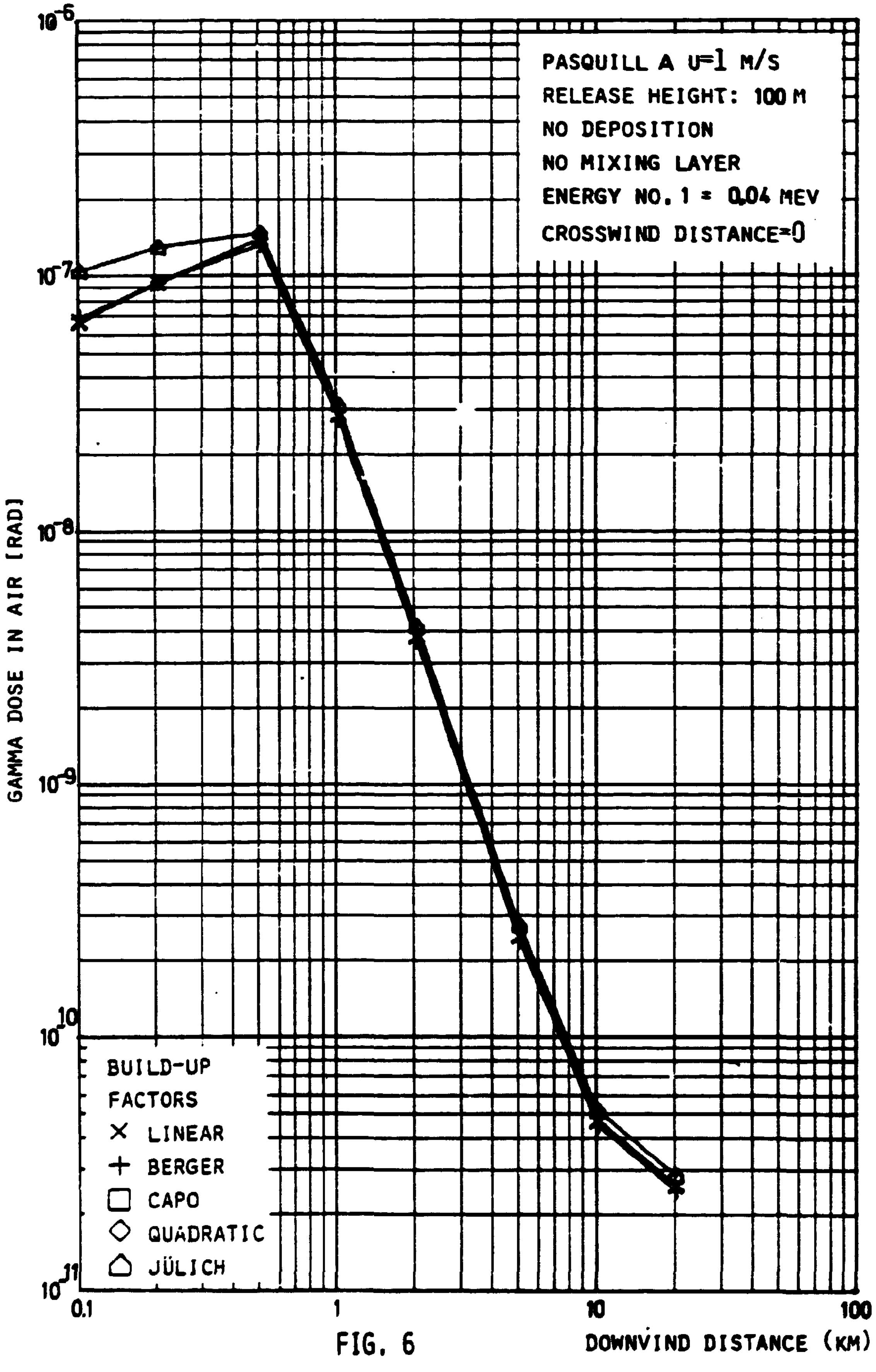


FIG. 6

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

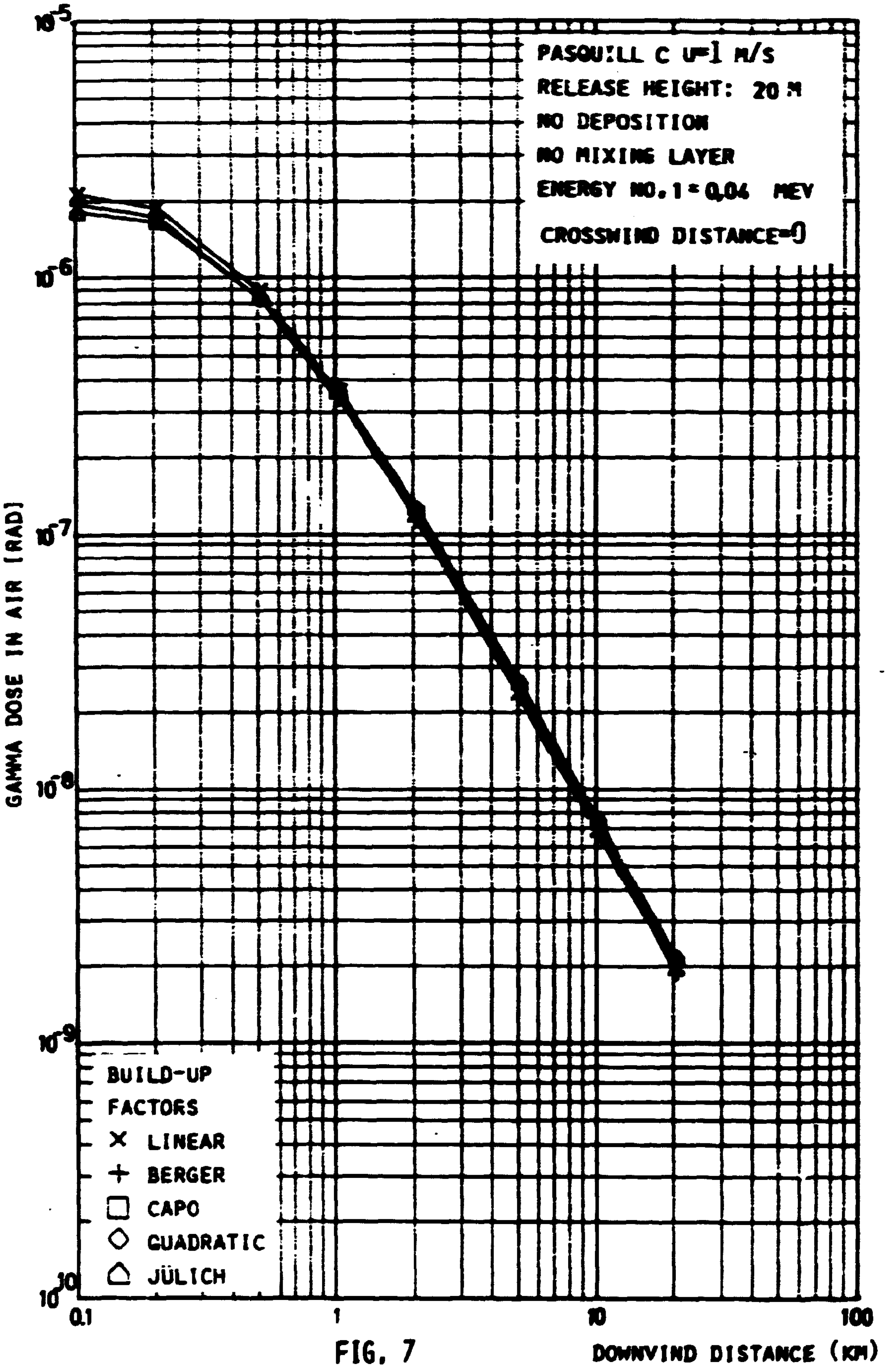


FIG. 7

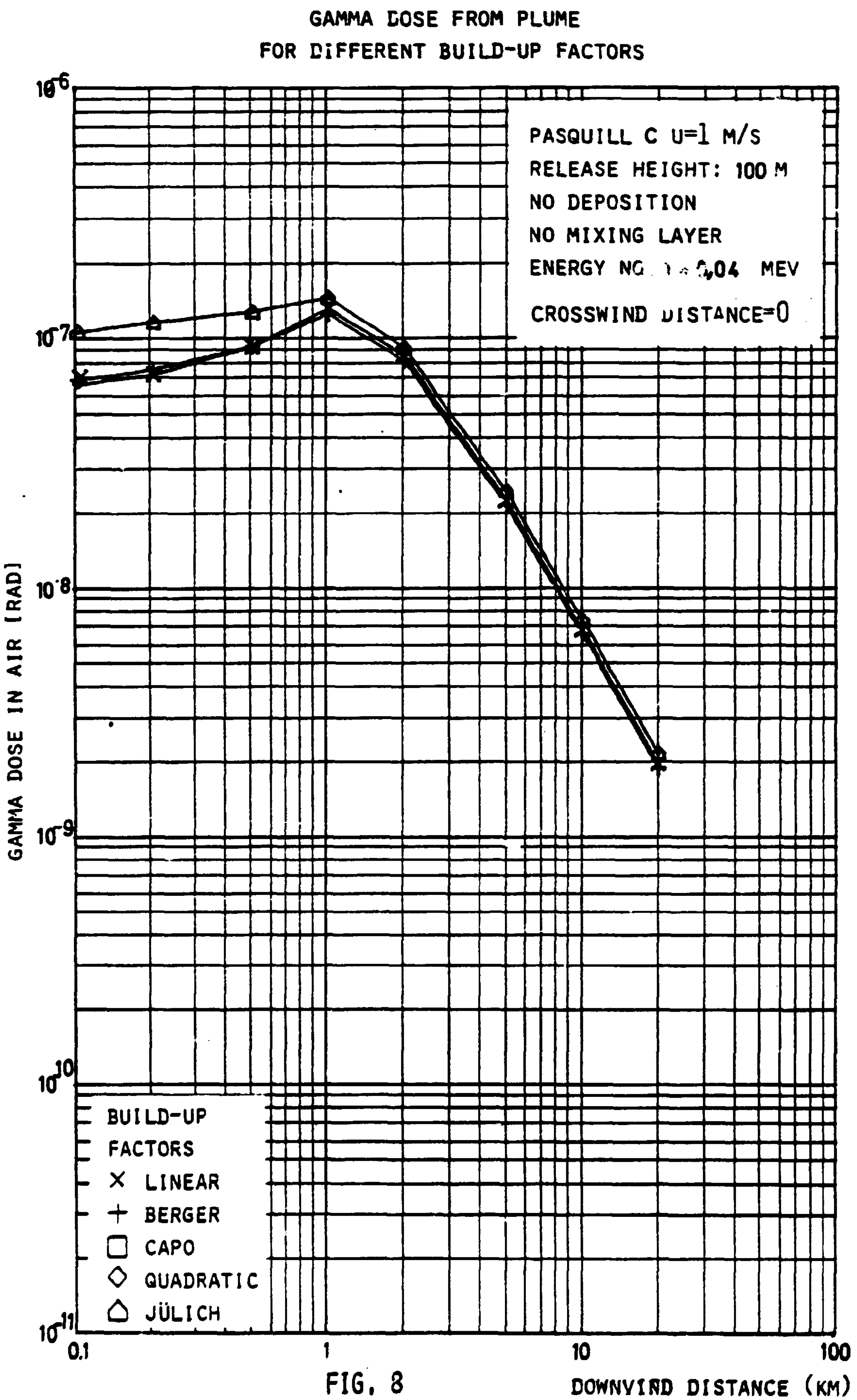

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
CROSSWIND DISTANCE=0
BUILD-UP
FACTORS
LINEAR
BERGER
CAPO
QUADRATIC
JÜLICH
GAMMA DOSE IN AIR [RAD]
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
0.1
1
10
100
DOWNVIRD DISTANCE (KM)

FIG. 8

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

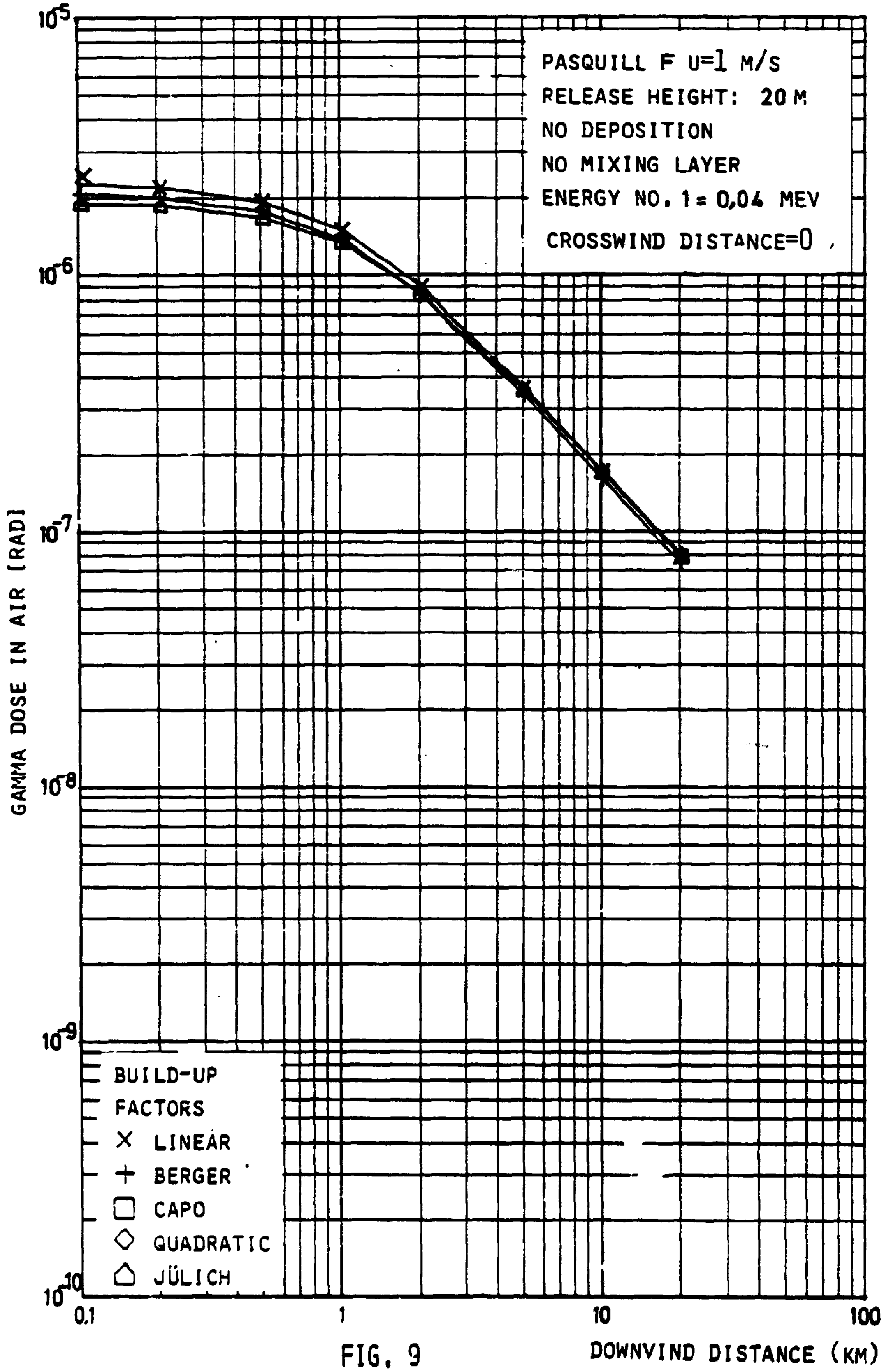


FIG. 9

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

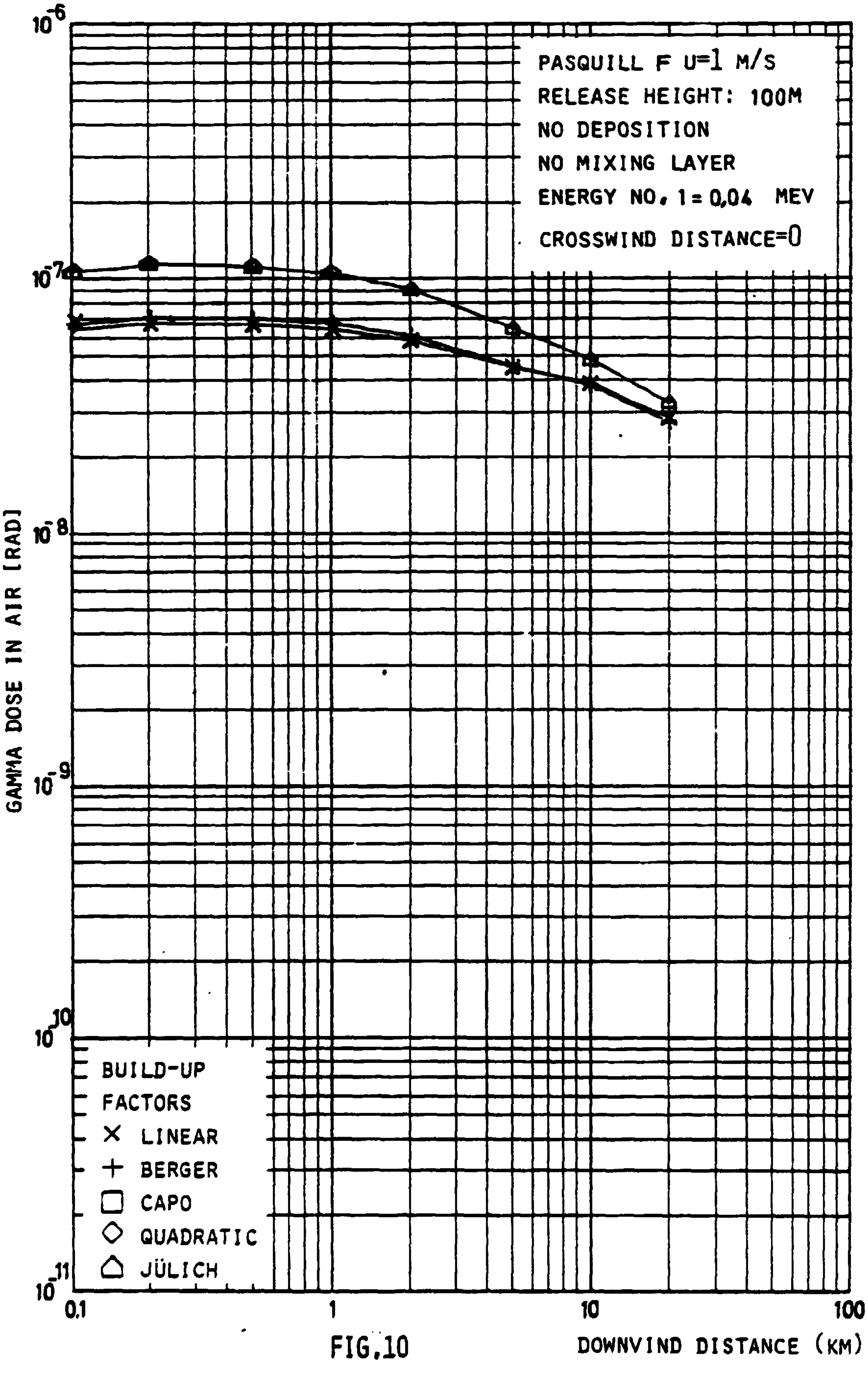


FIG.10

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

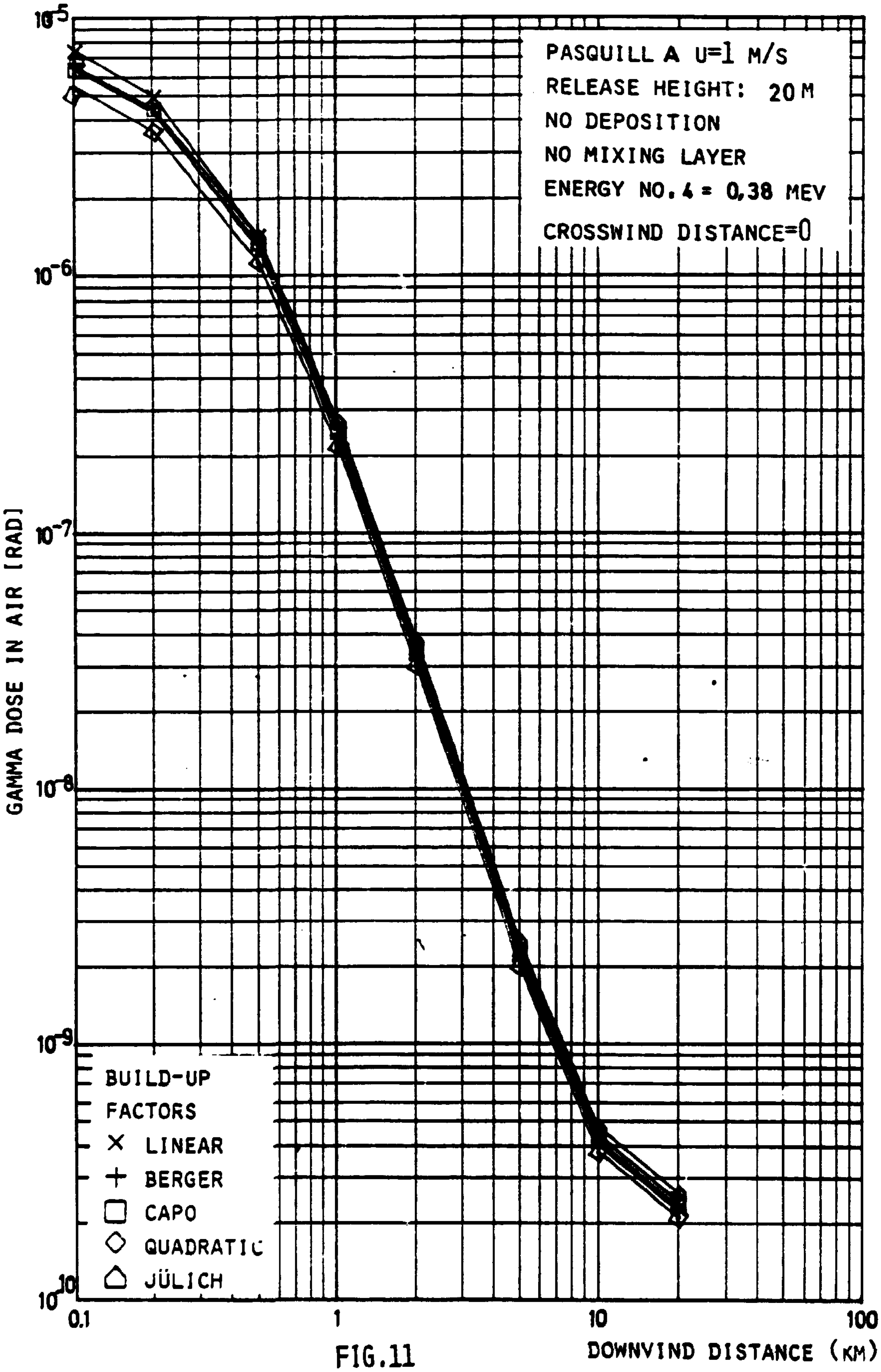
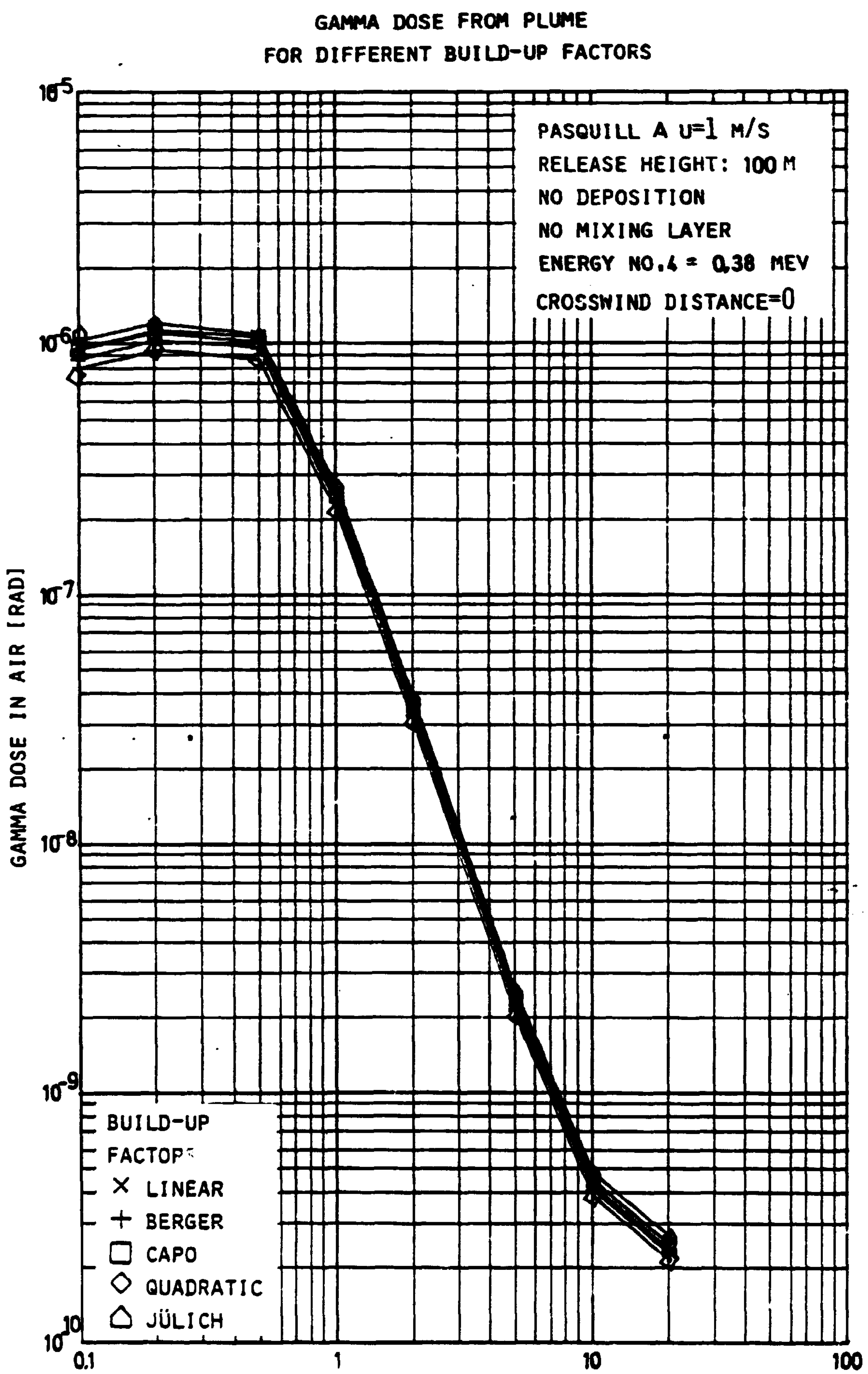


FIG.11



GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL A U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.4 = 0.38 MEV
CROSSWIND DISTANCE=0
GAMMA DOSE IN AIR [RAD]
BUILD-UP
FACTORS
LINEAR
BERGER
CAPO
QUADRATIC
JÜLICH
0.1
1
10
100
DOWNVIND DISTANCE (KM)

FIG.12

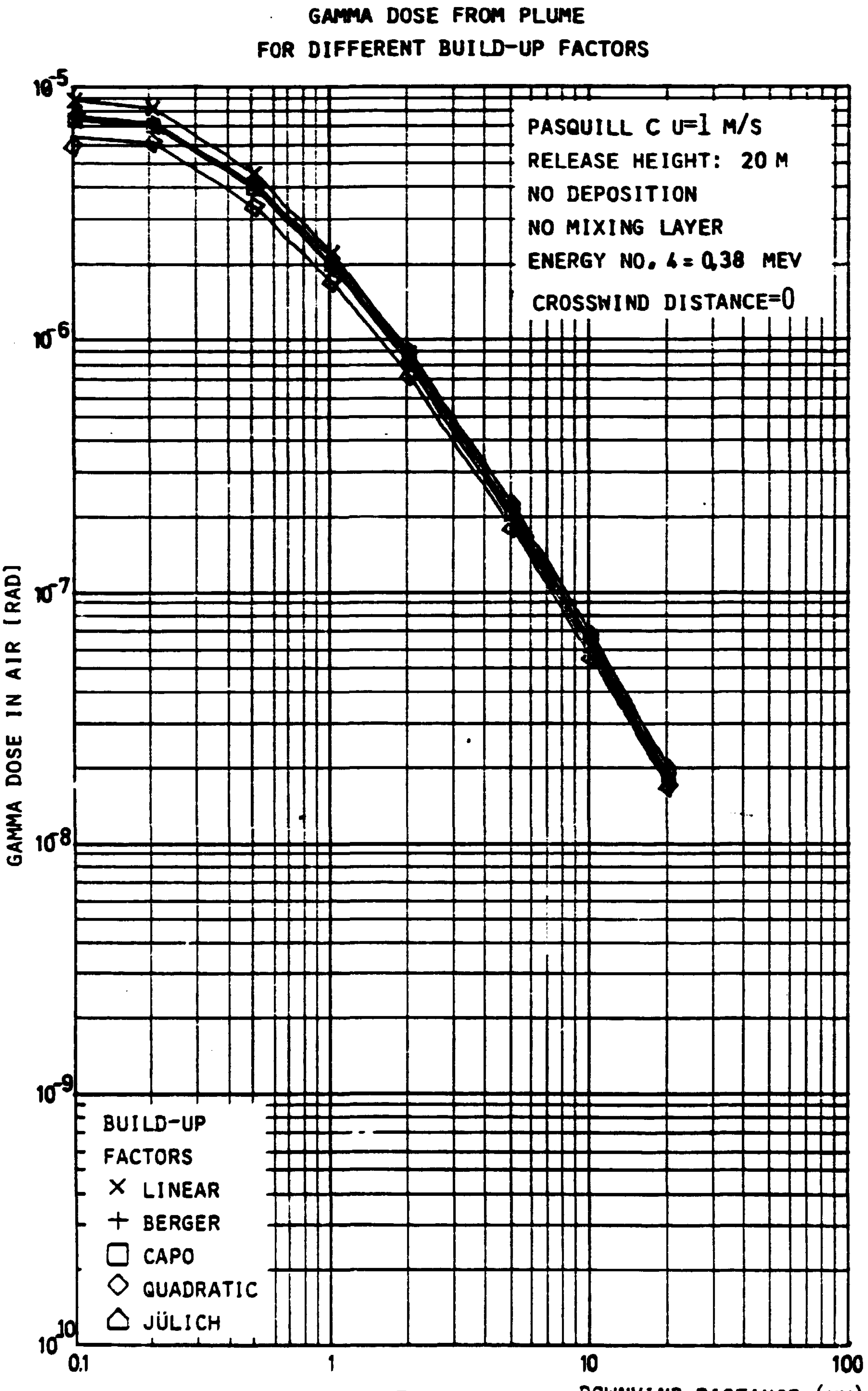

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 20 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO. 4 = 0.38 MEV
CROSSWIND DISTANCE=0
GAMMA DOSE IN AIR [RAD]
10-5
10-6
10-7
10-8
10-9
10-10
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
0.1
1
10
100
DOWNVIND DISTANCE (KM)

FIG.13

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

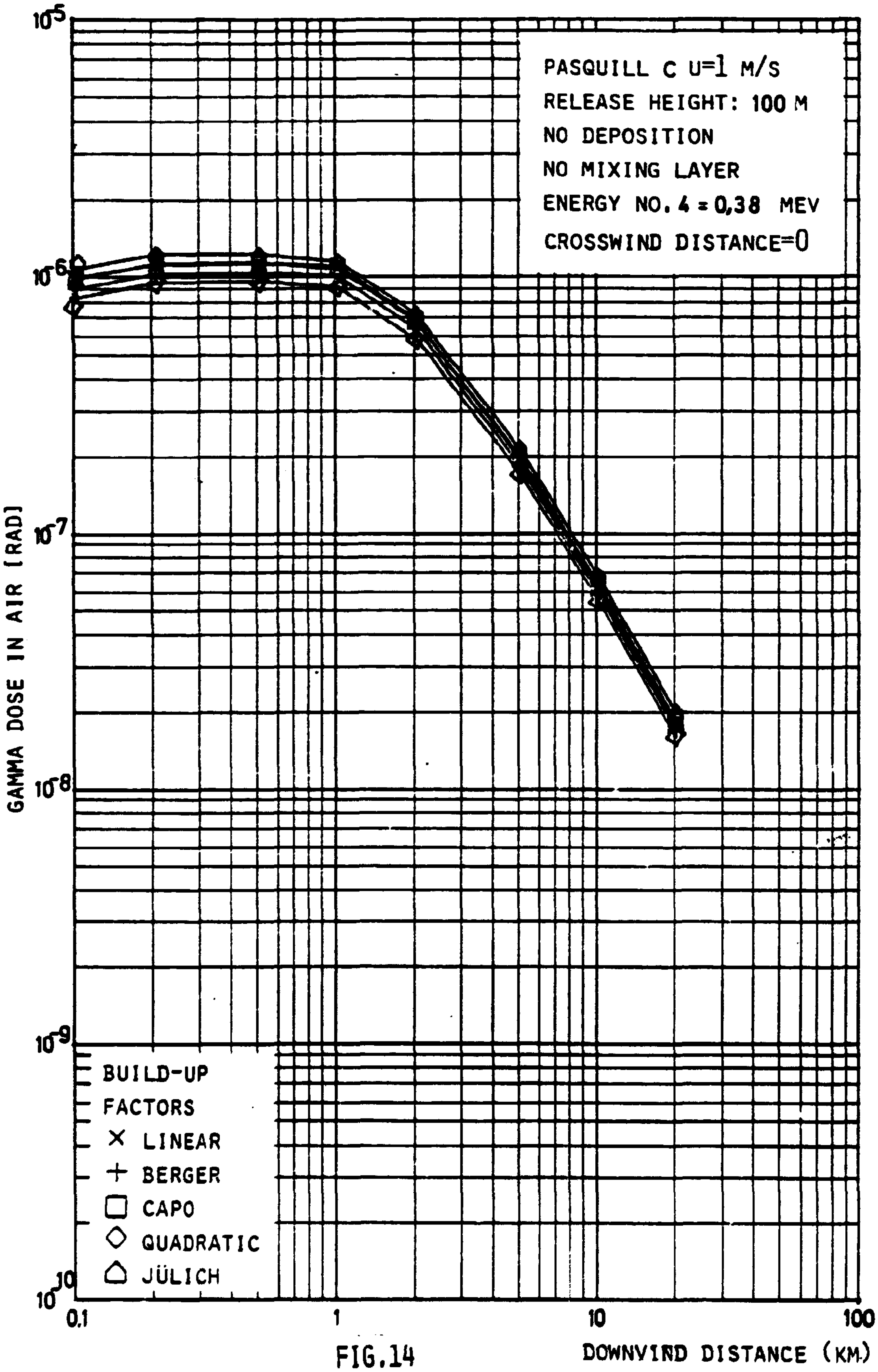


FIG.14

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

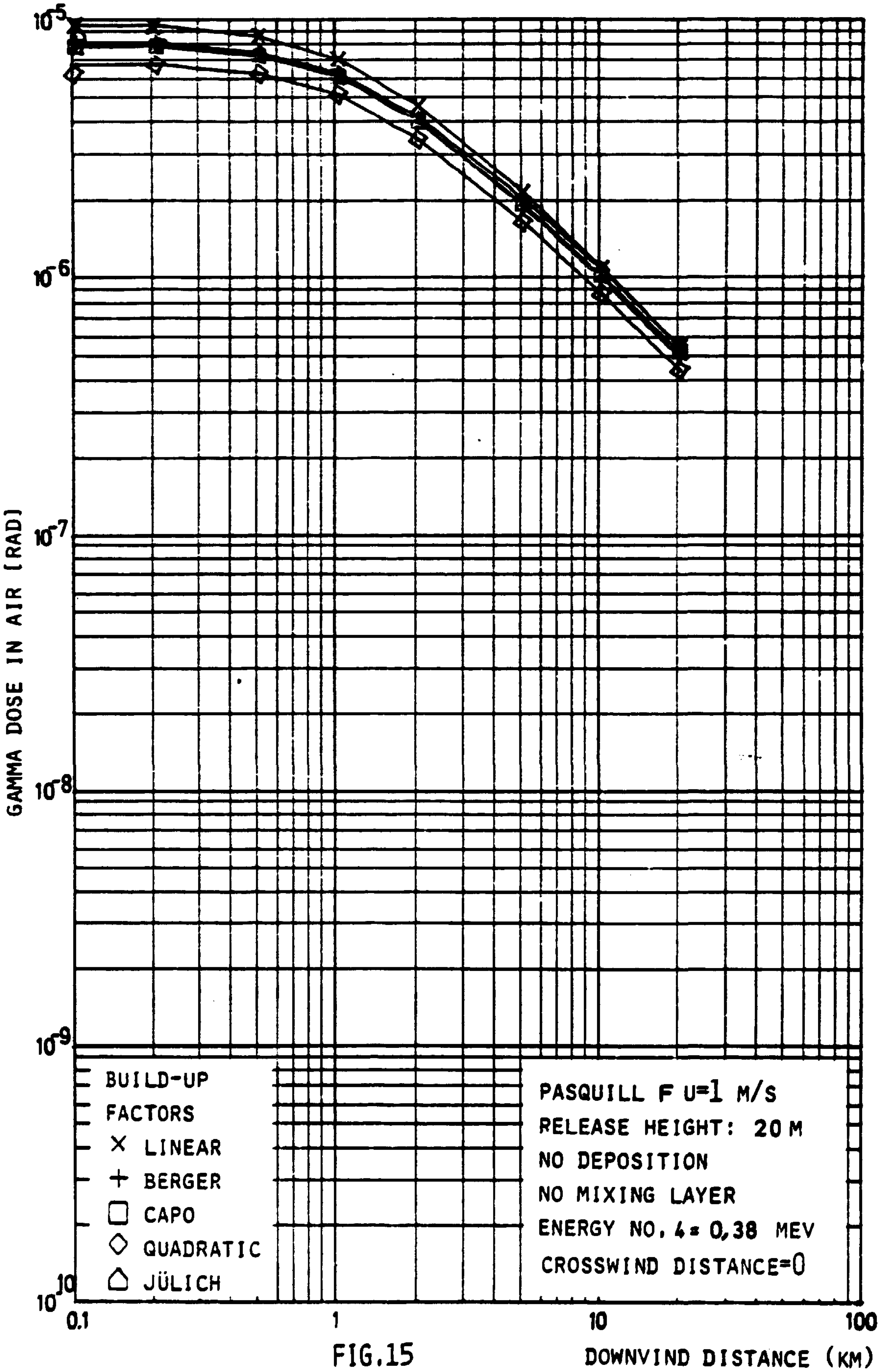


FIG.15

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

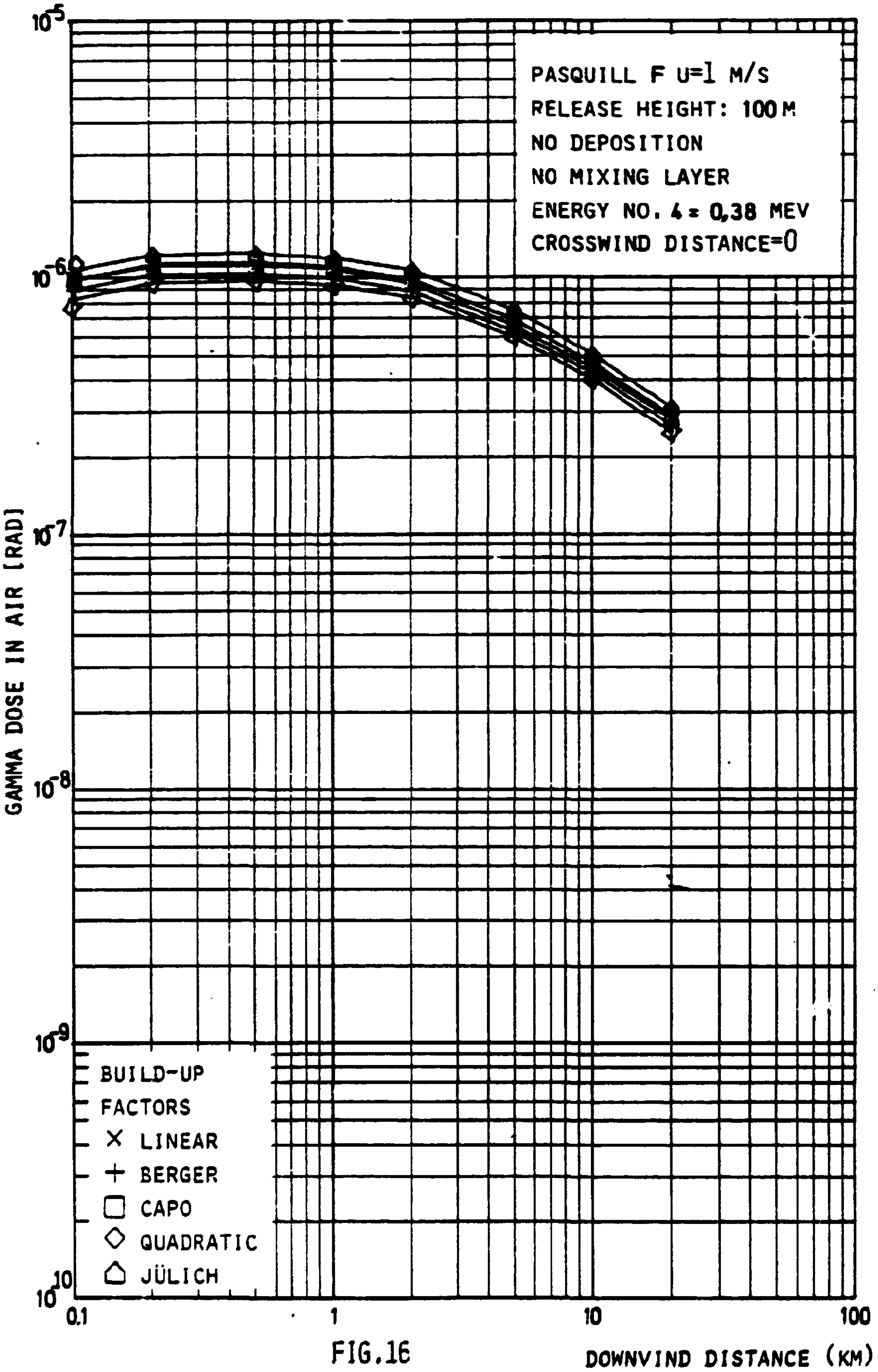


FIG.16

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

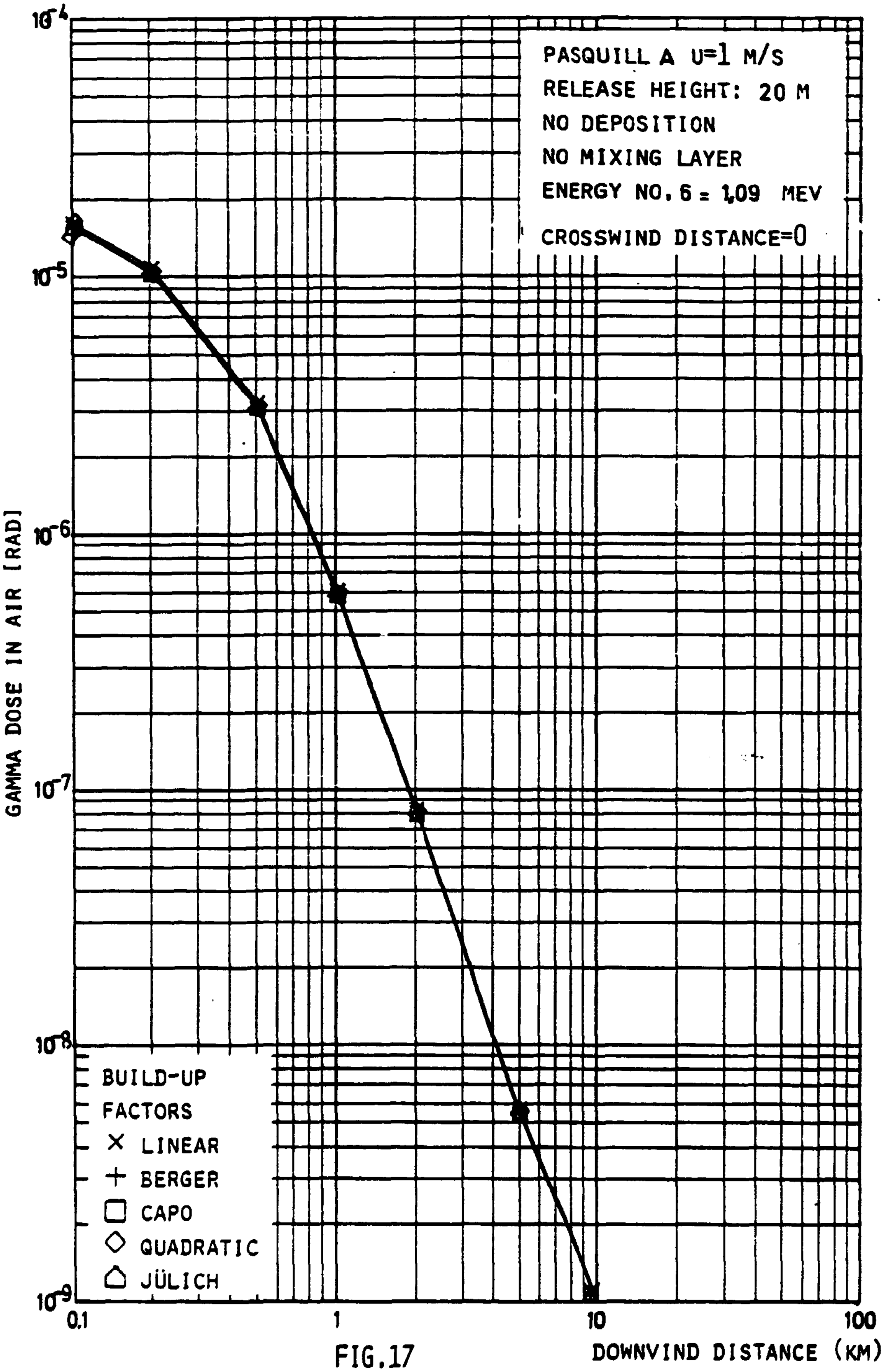


FIG.17

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

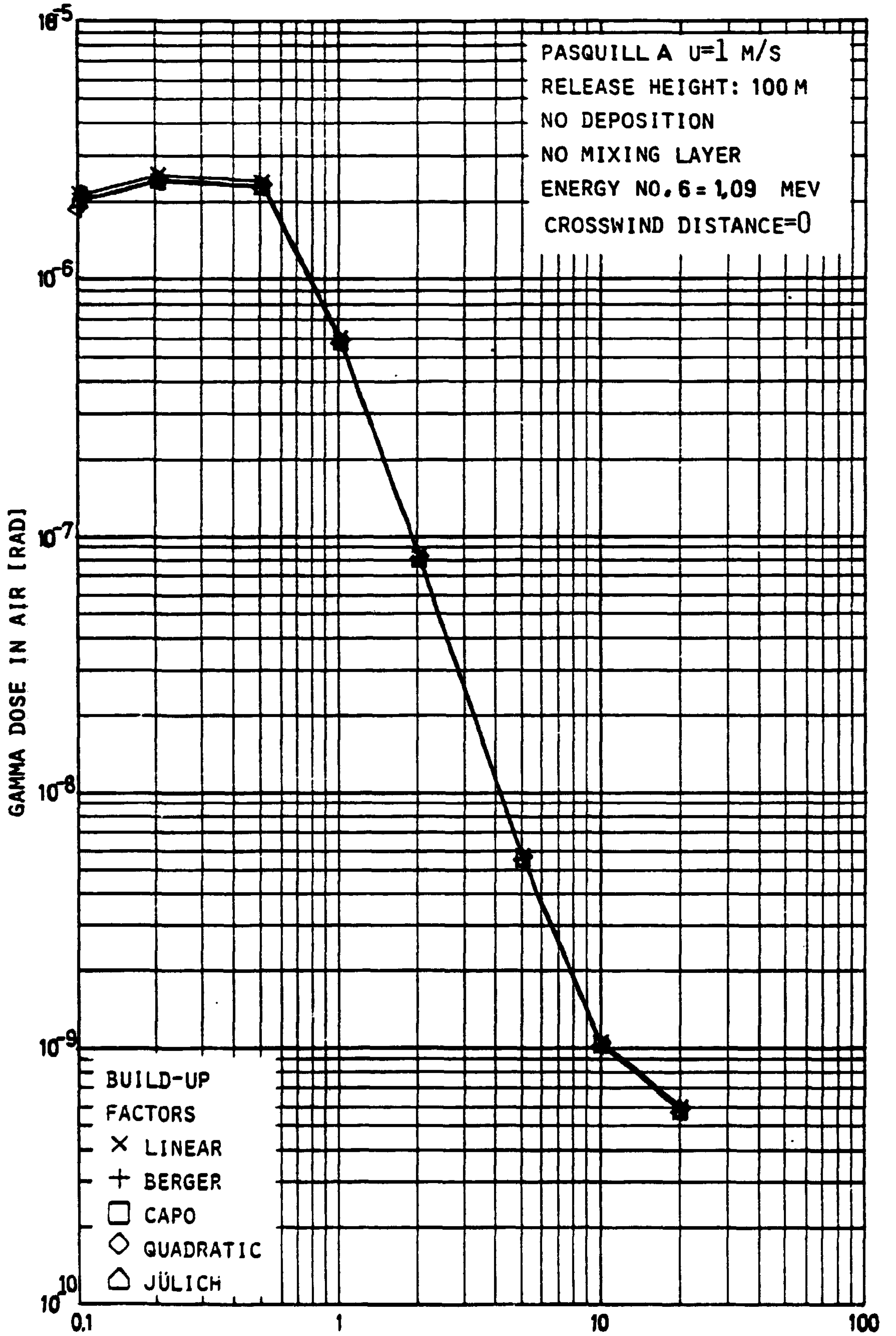


FIG.18

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

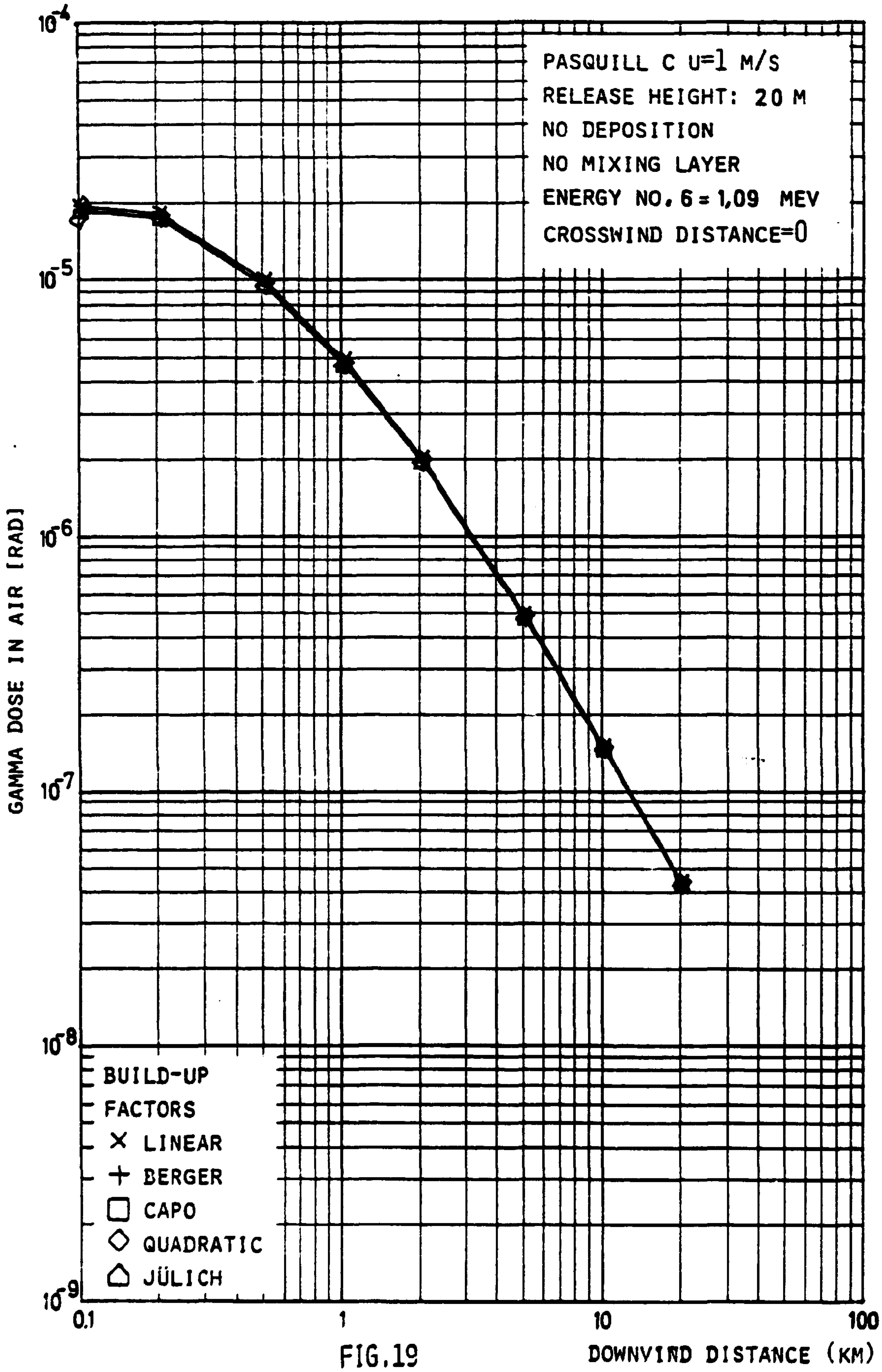


FIG.19

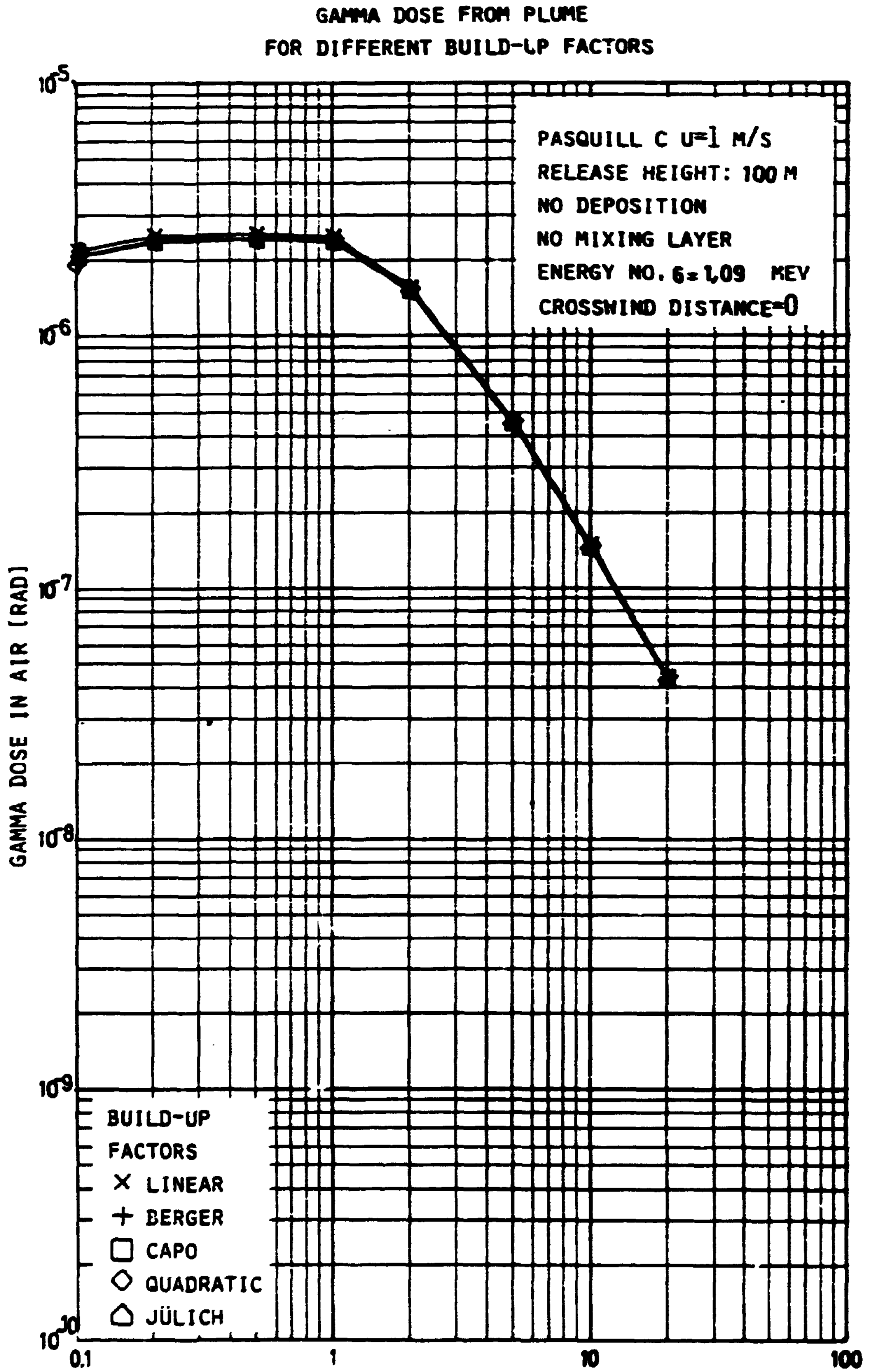

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO. 6=1,09 MEV
CROSSWIND DISTANCE=0
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
GAMMA DOSE IN AIR [RAD]
10-5
10-6
10-7
10-8
10-9
10-10
0.1
1
10
100
DOWNVIND DISTANCE (KM)

FIG.20

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

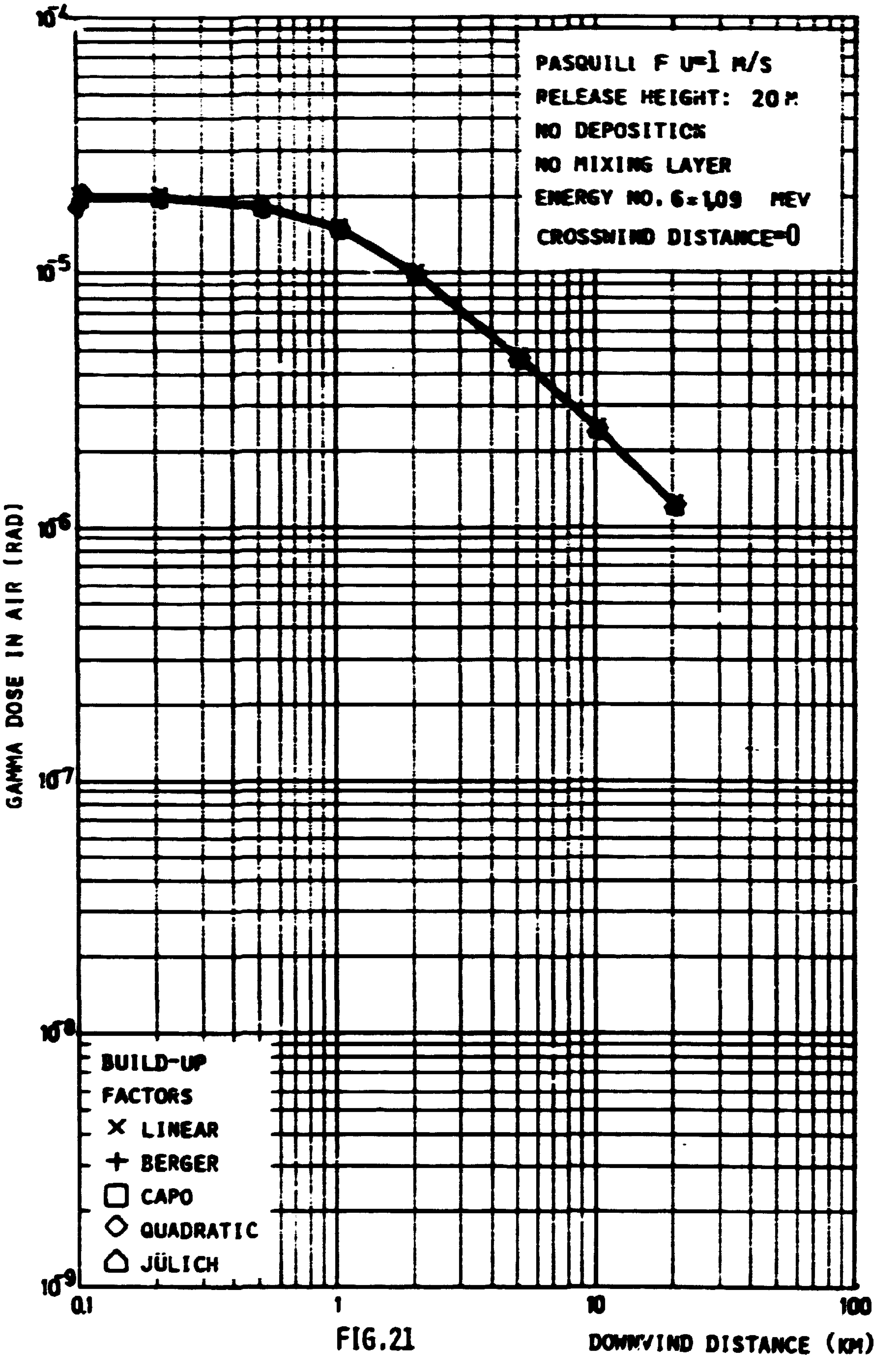


FIG.21

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

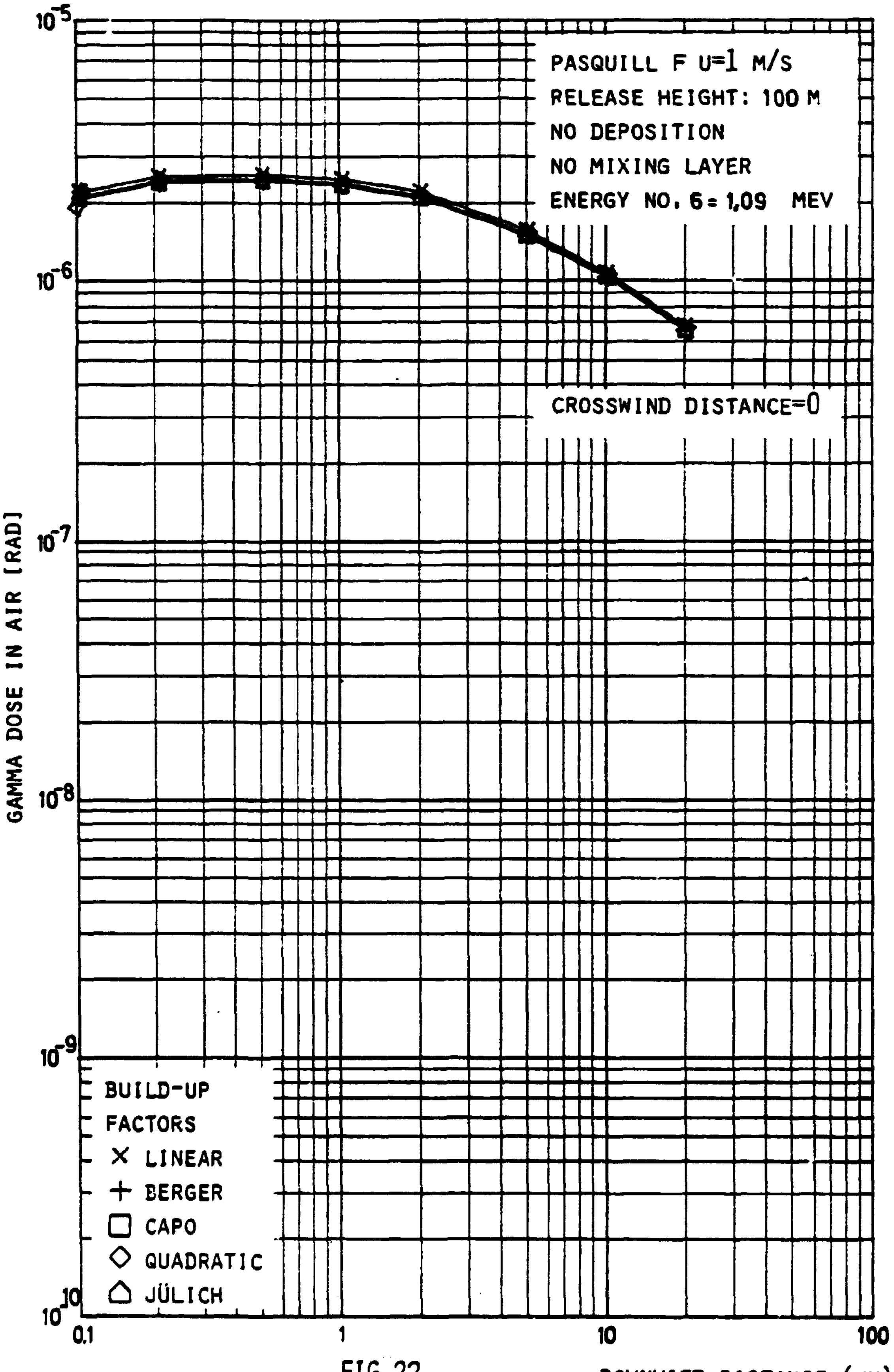


FIG.22

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

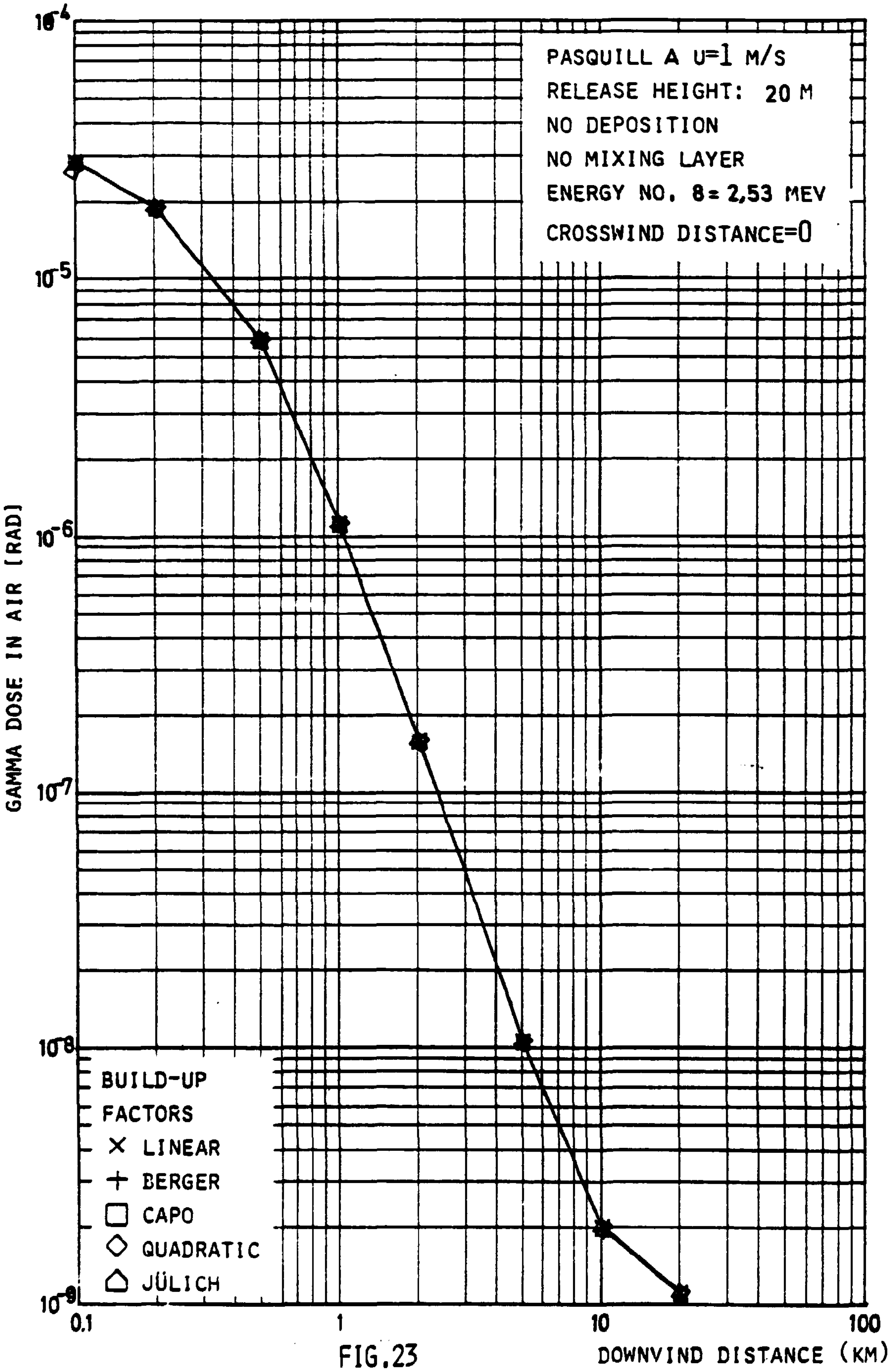


FIG.23

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

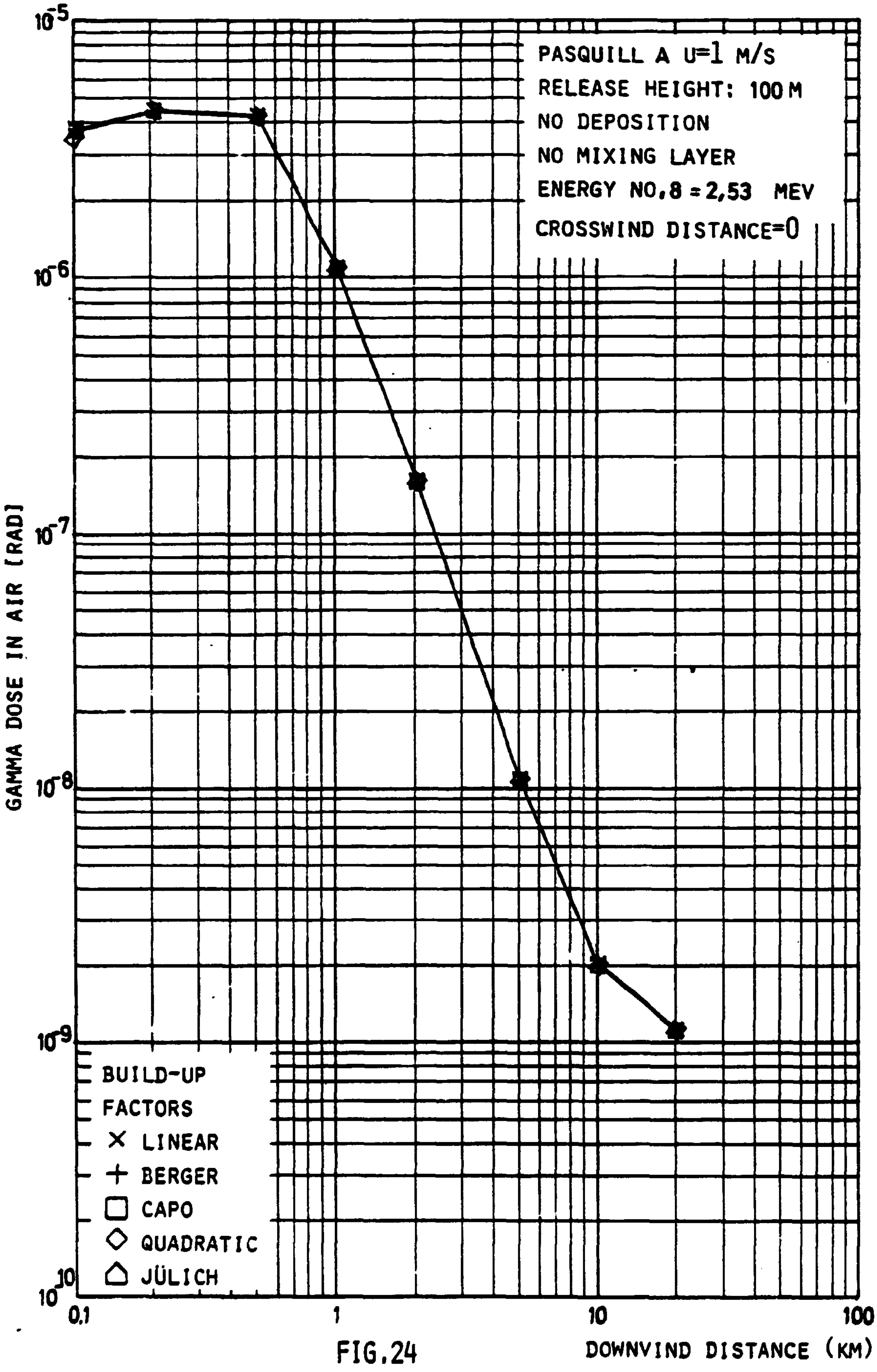


FIG.24

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

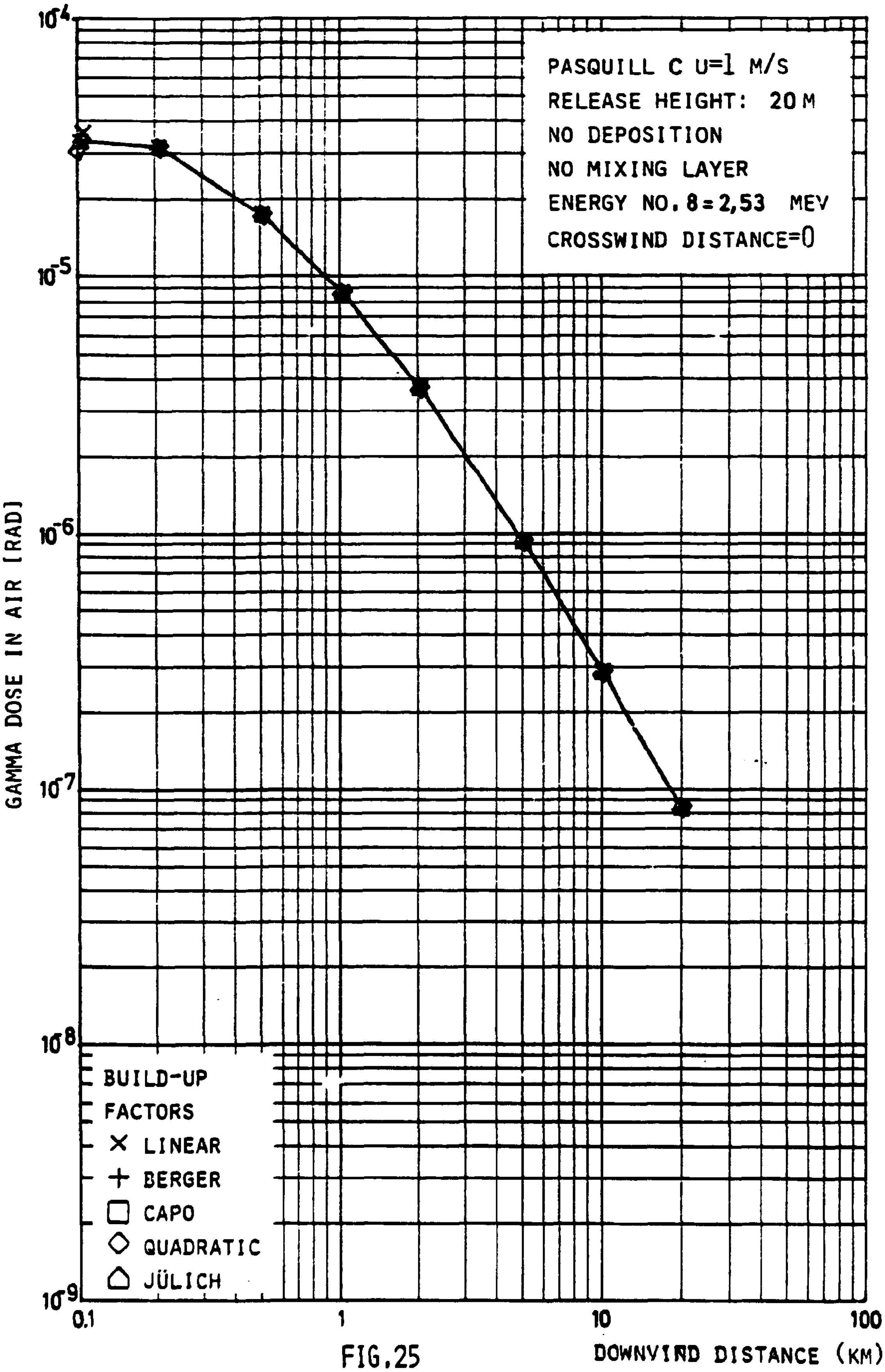


FIG. 25

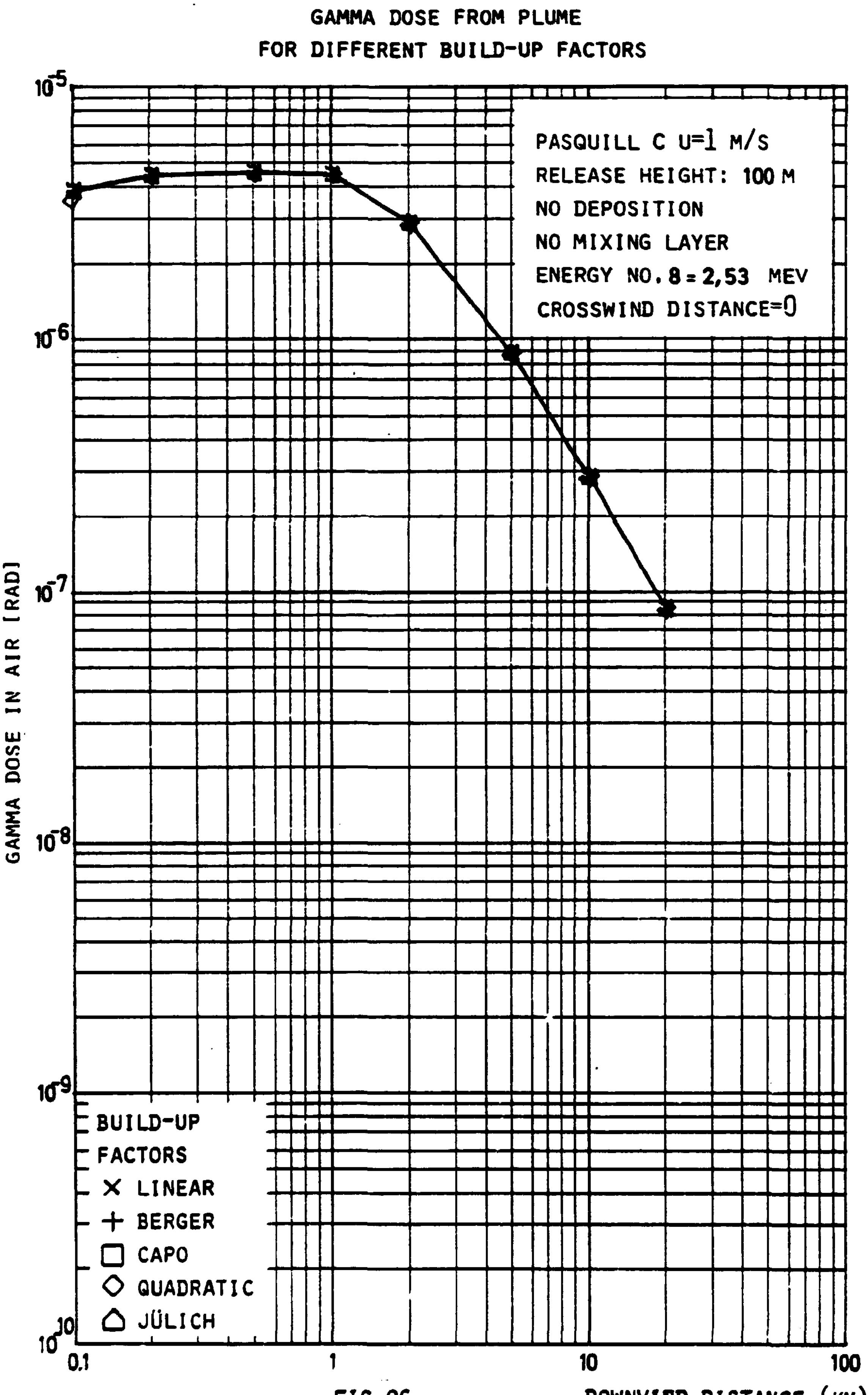

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO. 8 = 2,53 MEV
CROSSWIND DISTANCE=0
GAMMA DOSE IN AIR [RAD]
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
0.1
1
10
100
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
DOWNVIND DISTANCE (KM)

FIG.26

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

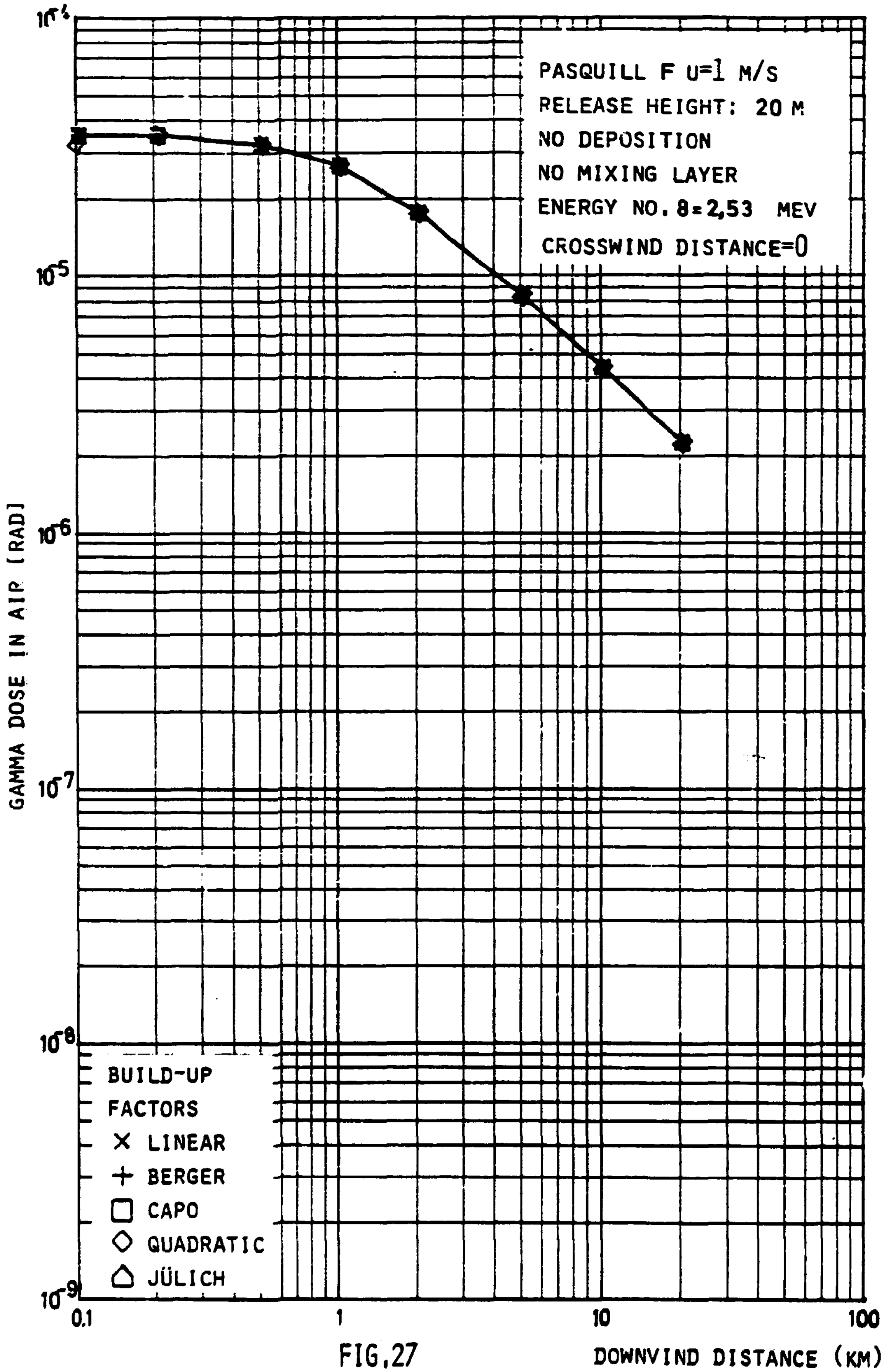


FIG.27

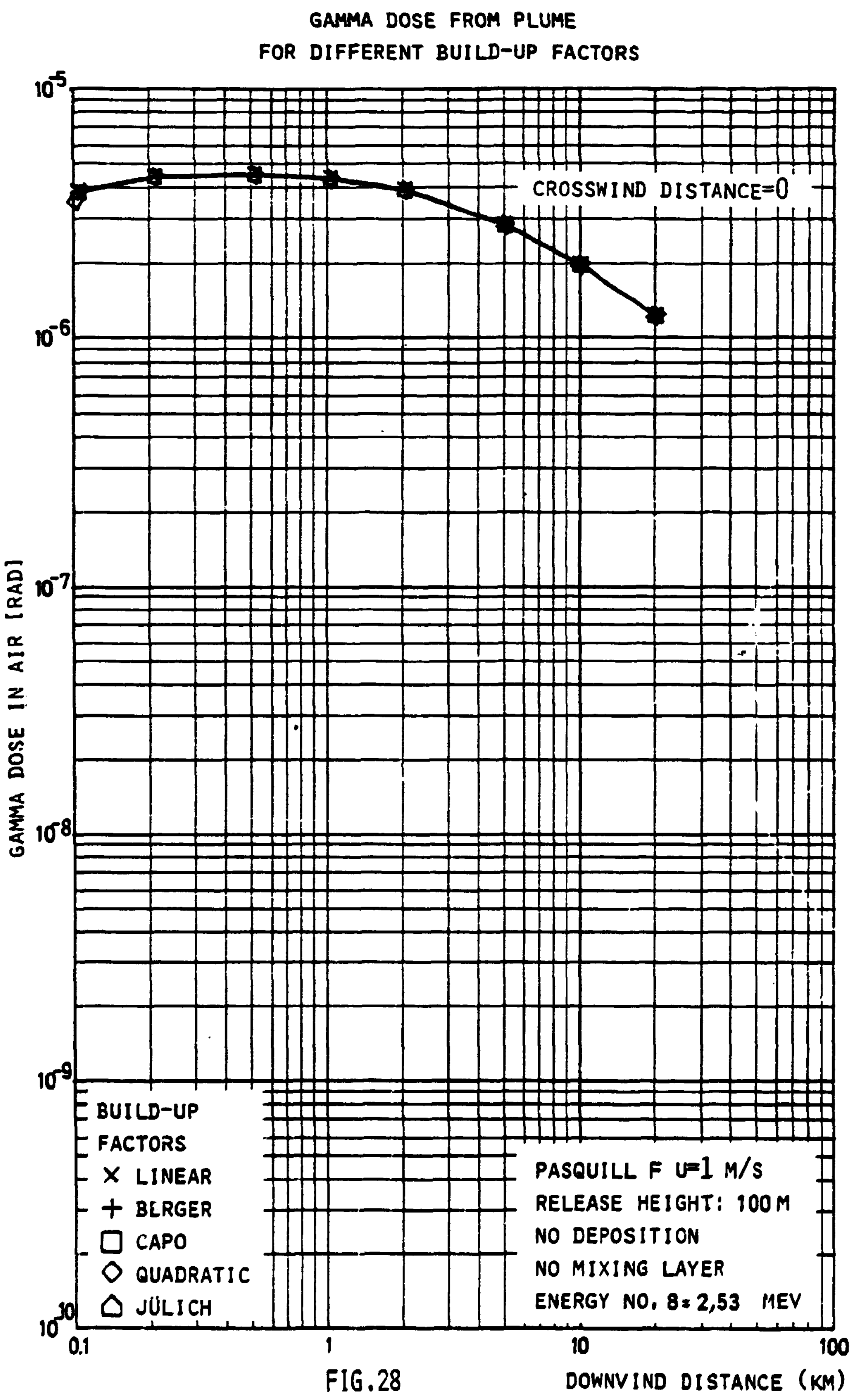

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
CROSSWIND DISTANCE=0
GAMMA DOSE IN AIR [RAD]
10-5
10-6
10-7
10-8
10-9
10-10
BUILD-UP
FACTORS
X LINEAR
+ BERGER
CAPO
QUADRATIC
JÜLICH
PASQUILL F U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO. 8= 2,53 MEV
0.1
1
10
100
DOWNVIND DISTANCE (KM)

FIG.28

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

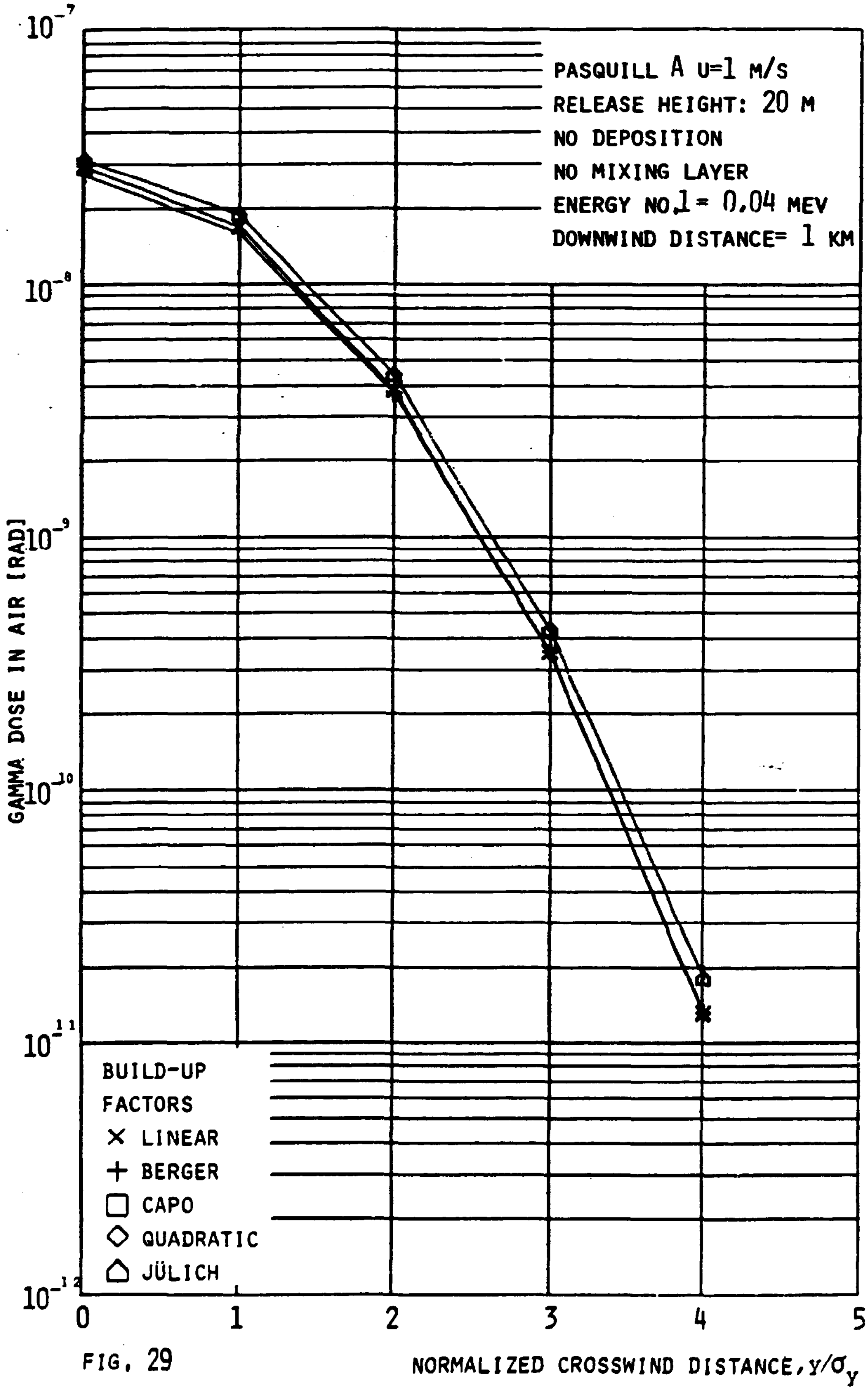


FIG. 29

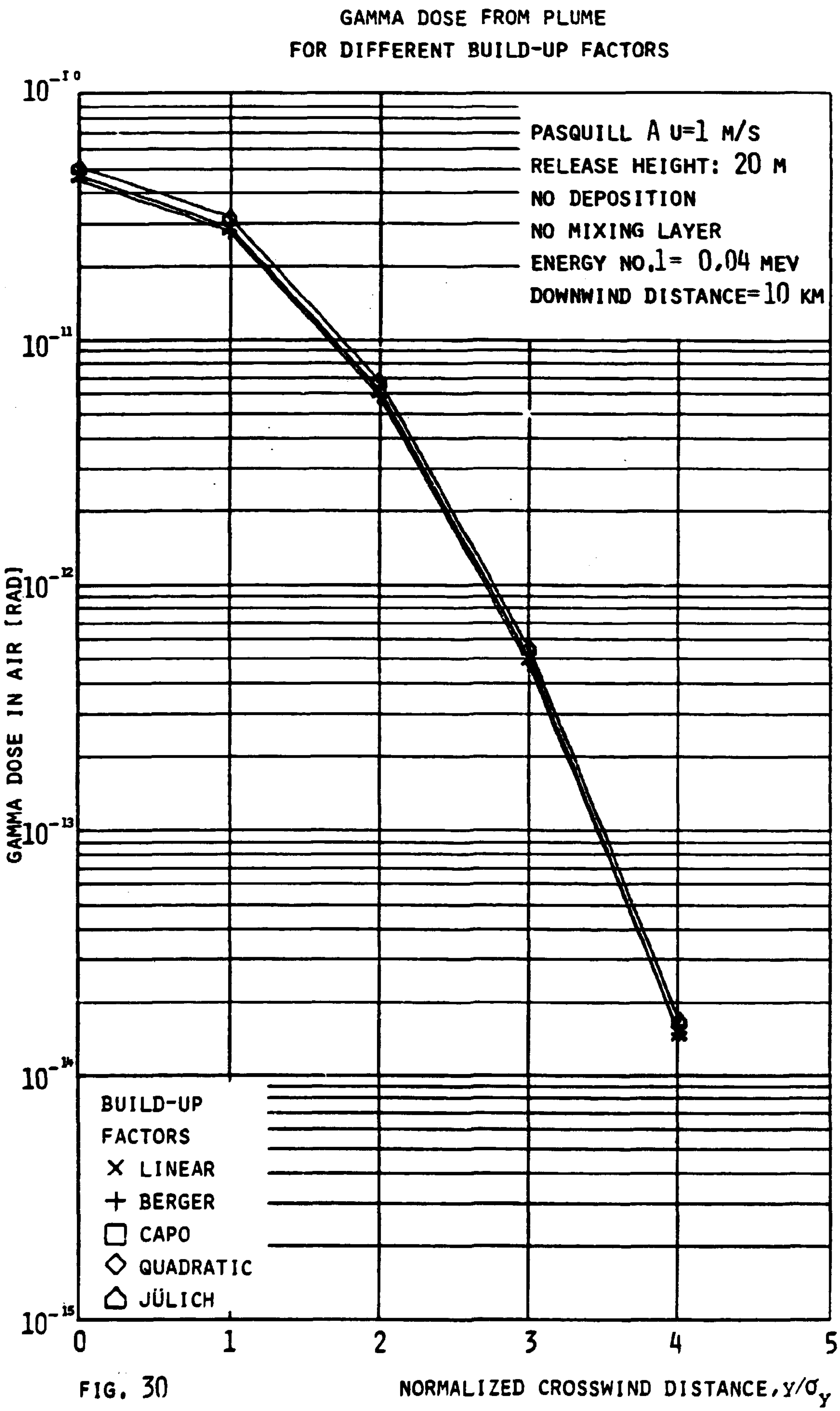

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL A U=1 M/S
RELEASE HEIGHT: 20 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.1= 0.04 MEV
DOWNWIND DISTANCE=10 KM
GAMMA DOSE IN AIR [RAD]
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
BUILD-UP FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
⌂ JÜLICH
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σ_y

FIG. 30

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

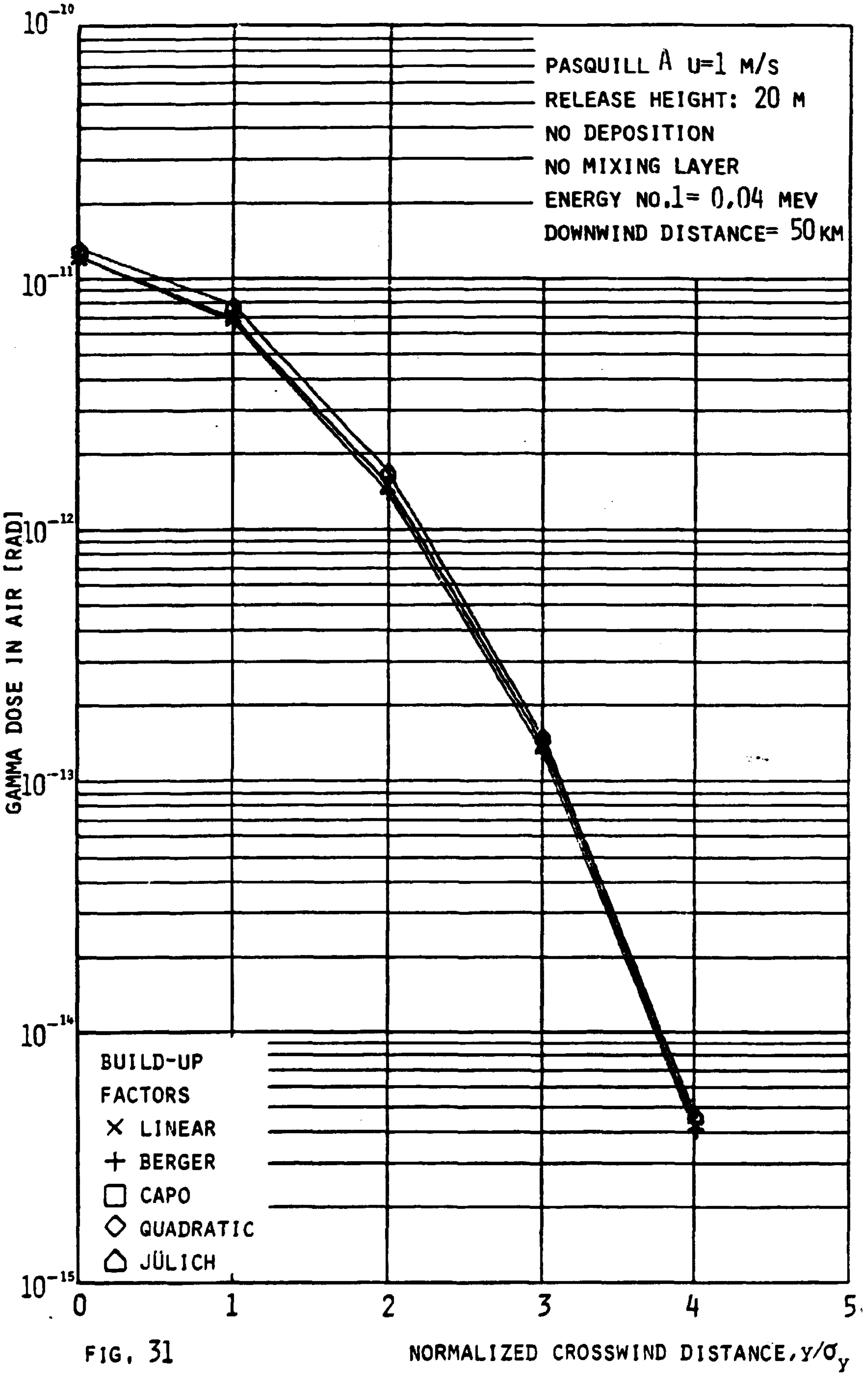


FIG. 31

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

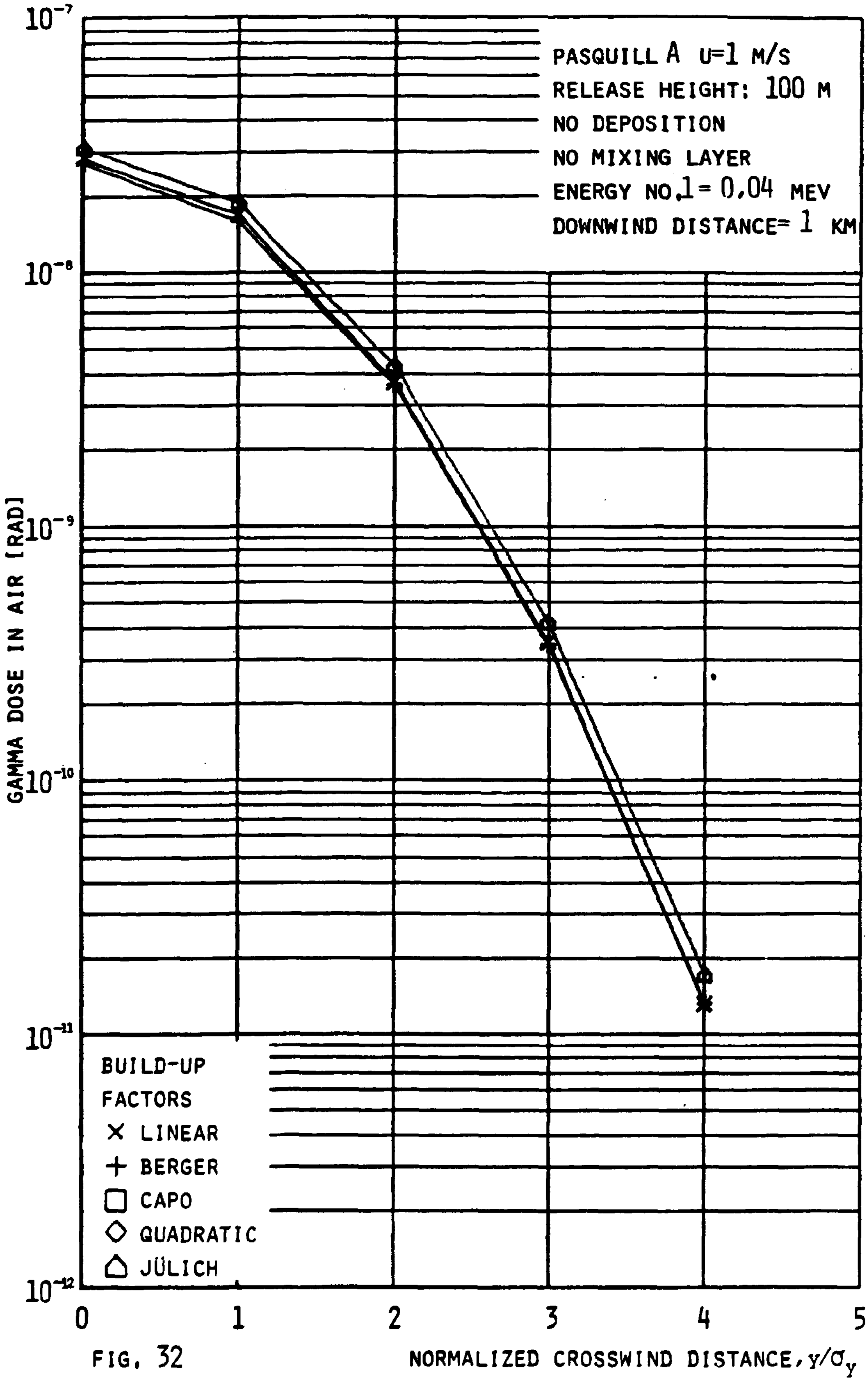


FIG. 32

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

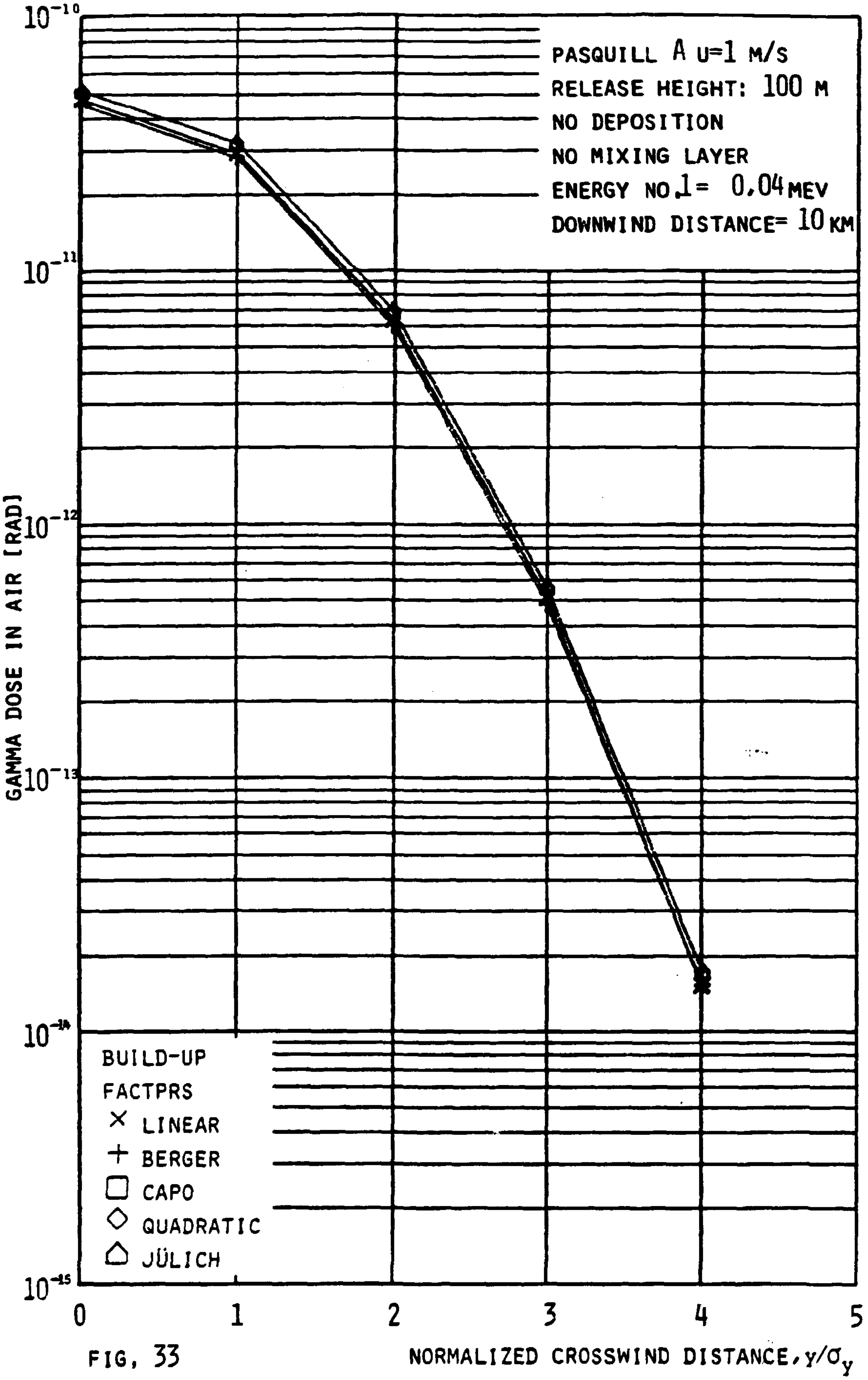


FIG. 33

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

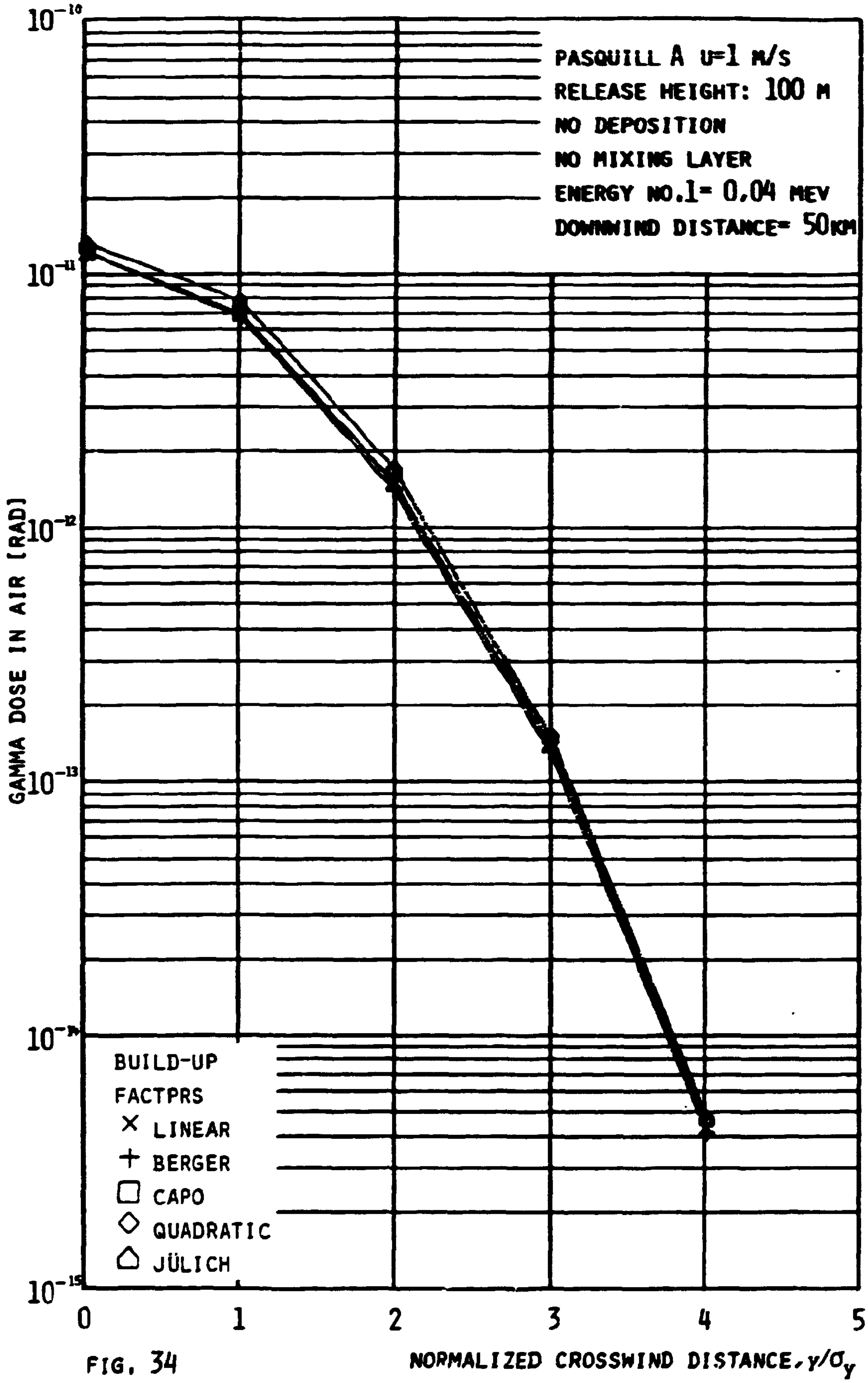


FIG. 34

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

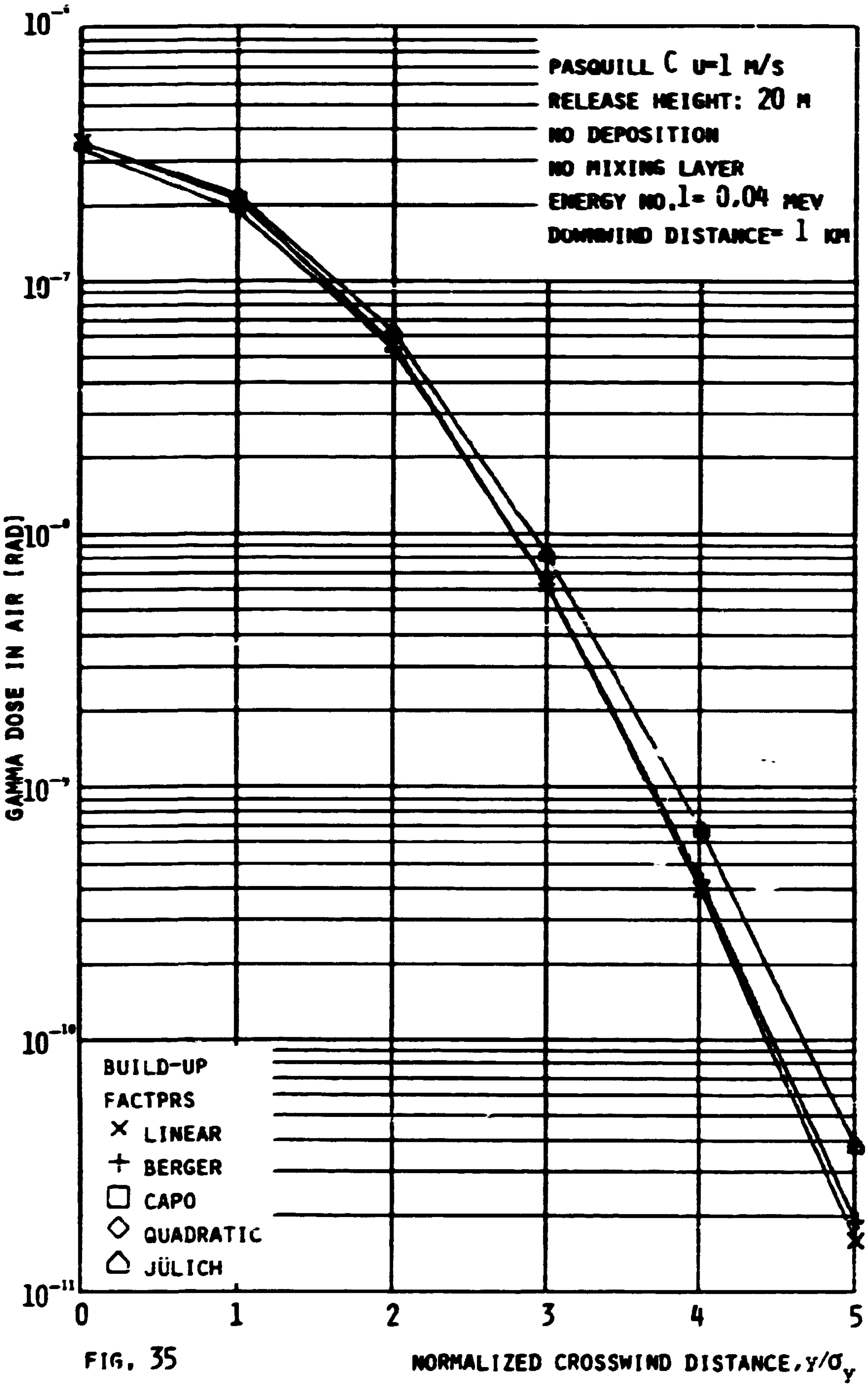


FIG. 35

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

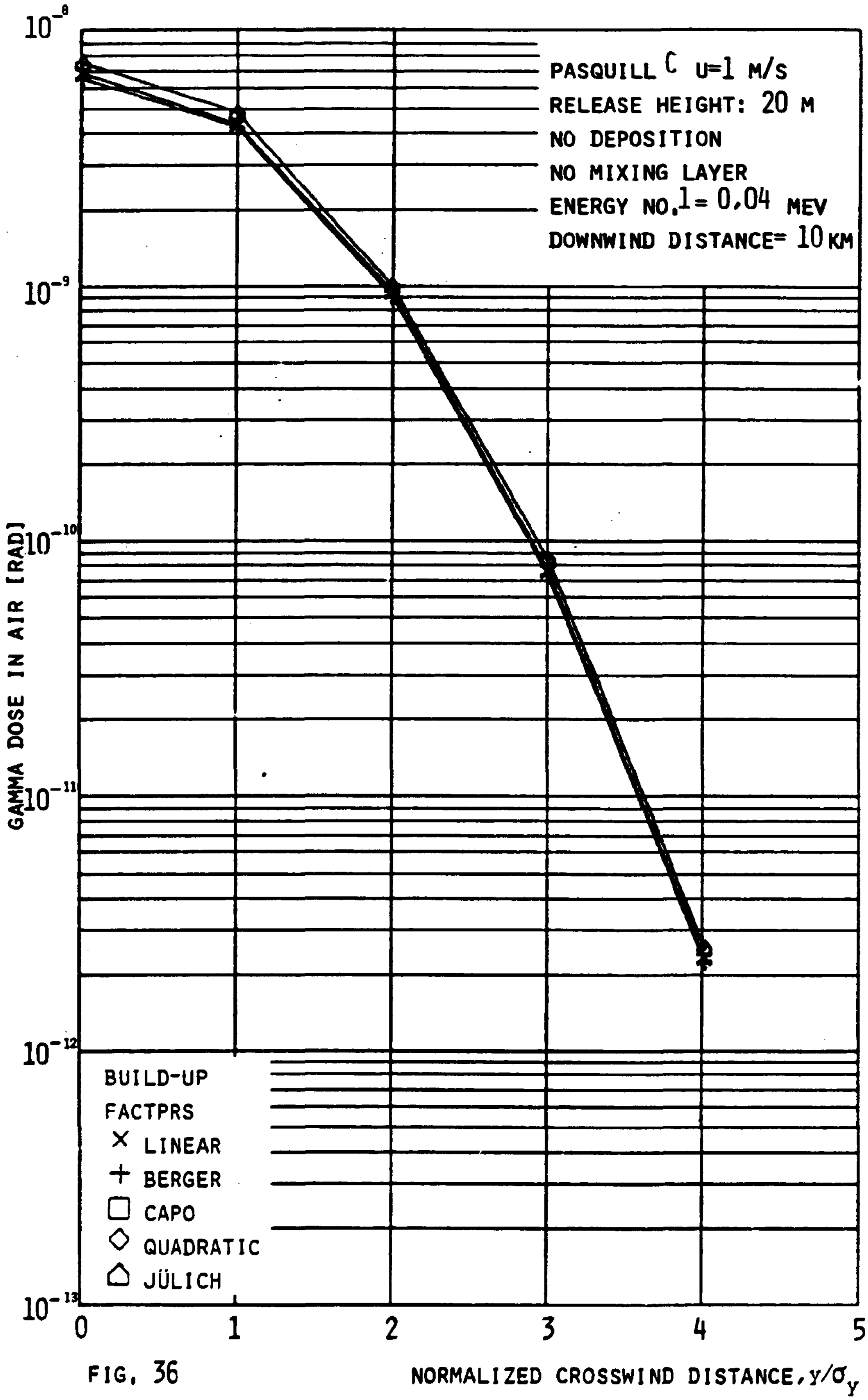


FIG. 36

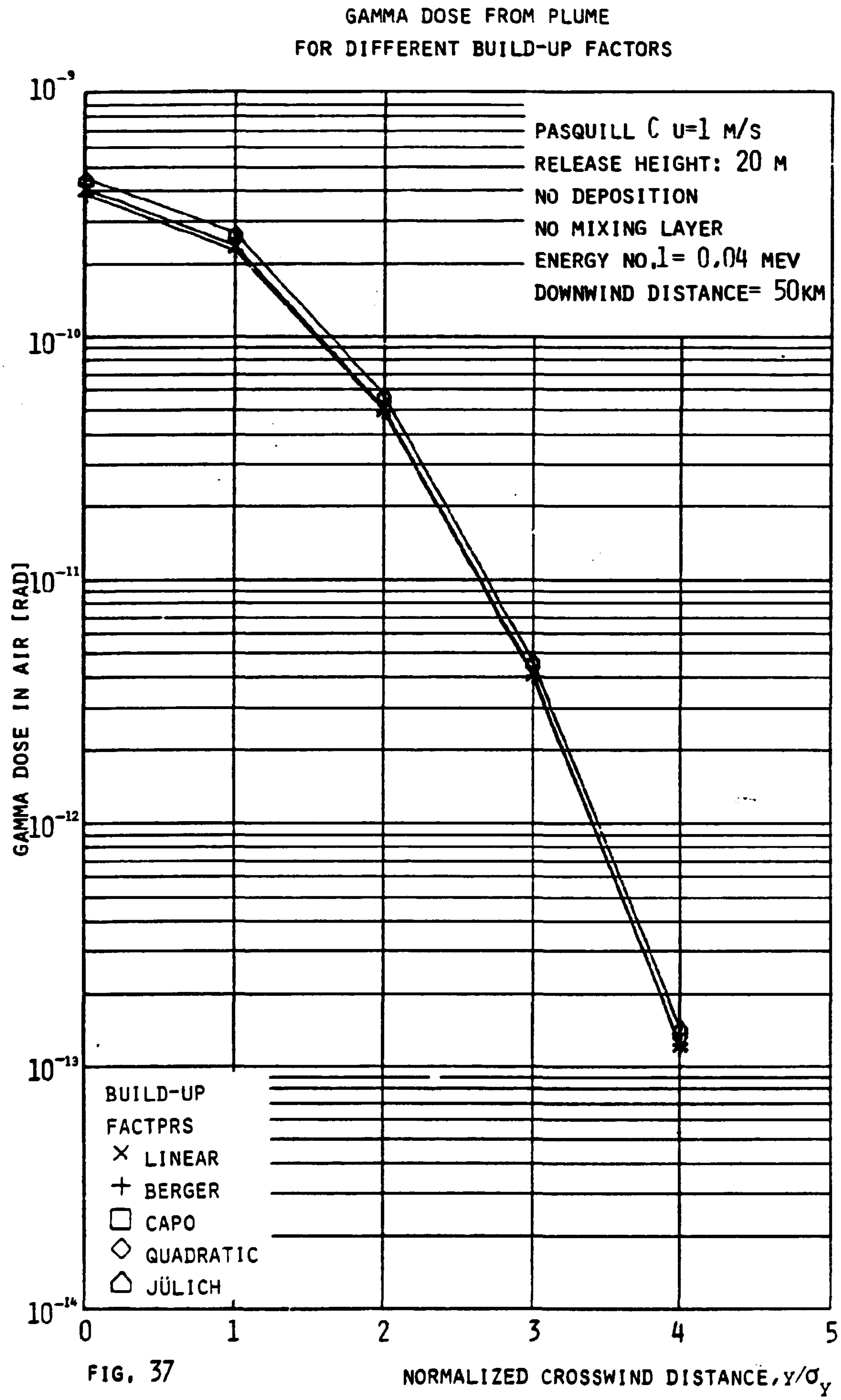

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 20 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.1= 0.04 MEV
DOWNWIND DISTANCE= 50KM
GAMMA DOSE IN AIR [RAD]
BUILD-UP
FACTPRS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
⌂ JÜLICH
NORMALIZED CROSSWIND DISTANCE, y/σ_Y

FIG. 37

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

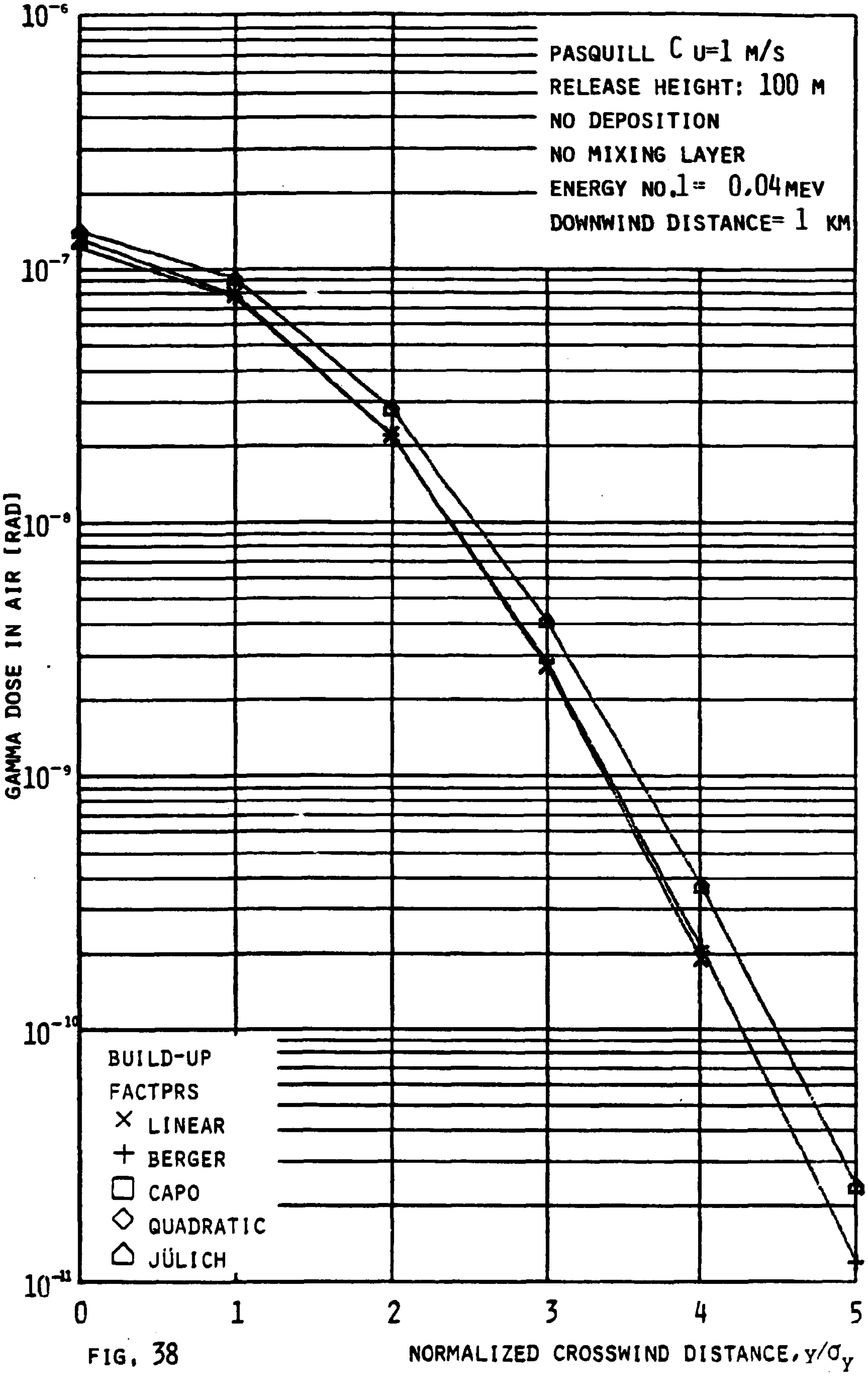


FIG. 38

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

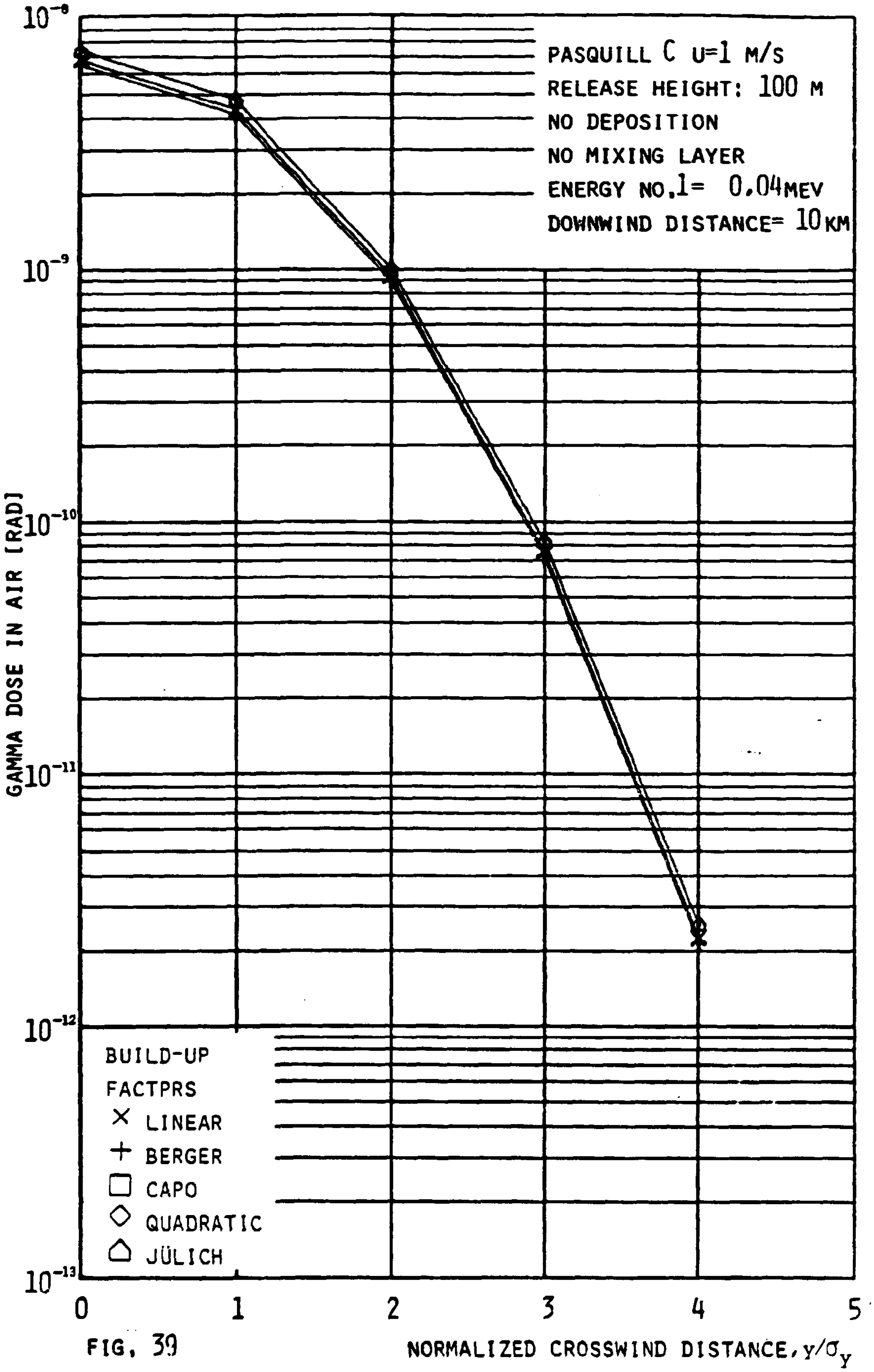


FIG. 39

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

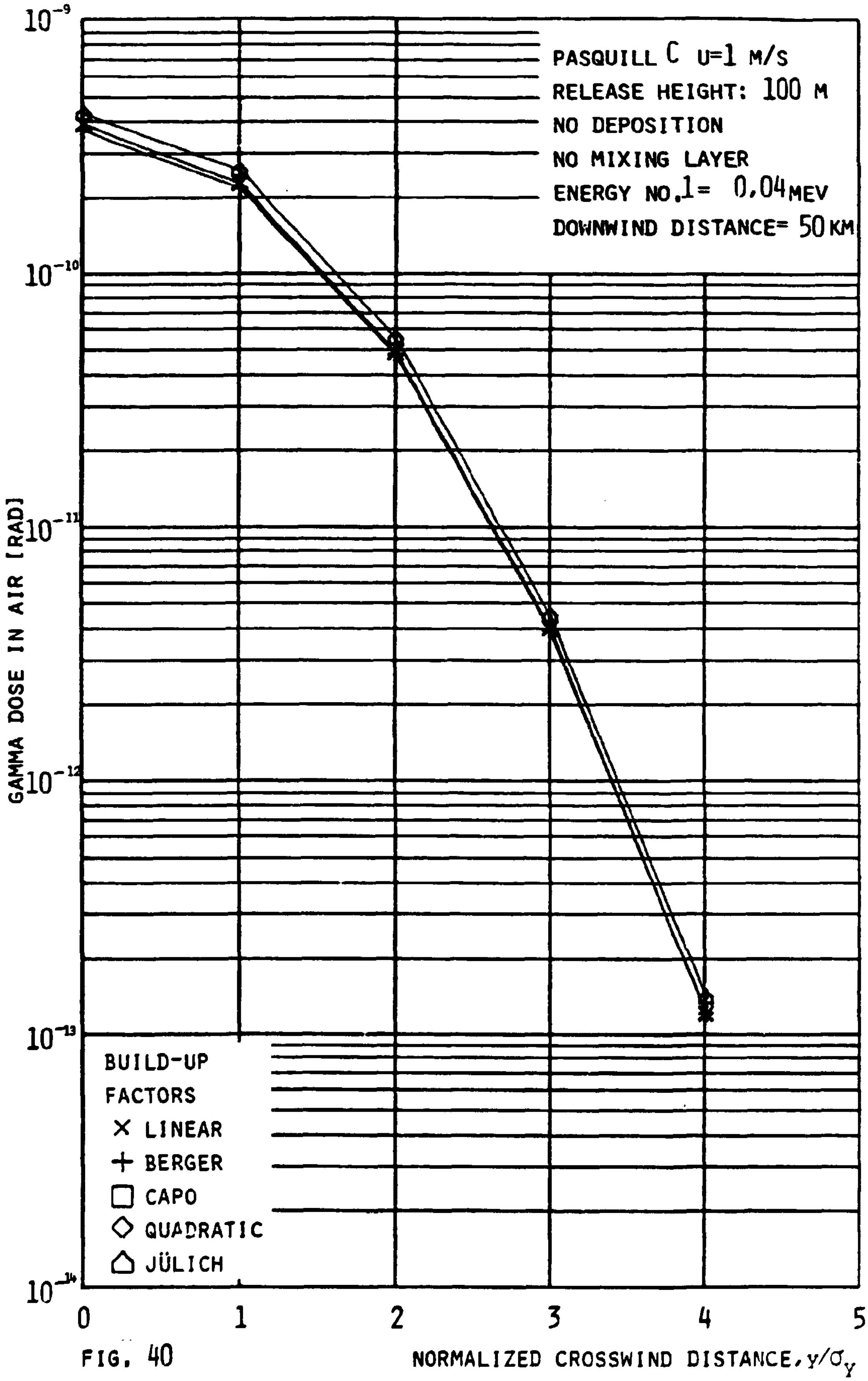


FIG. 40

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

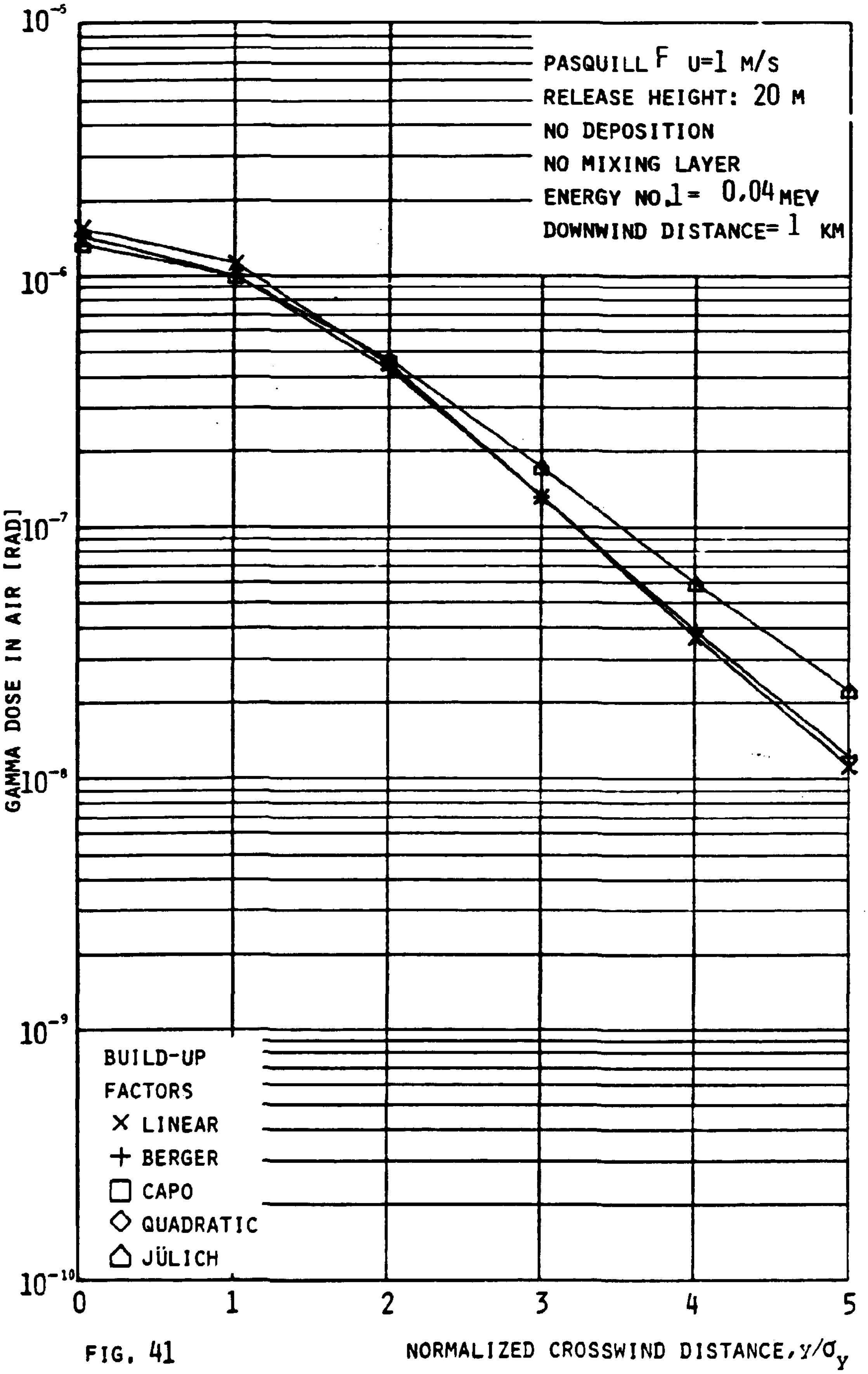


FIG. 41

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

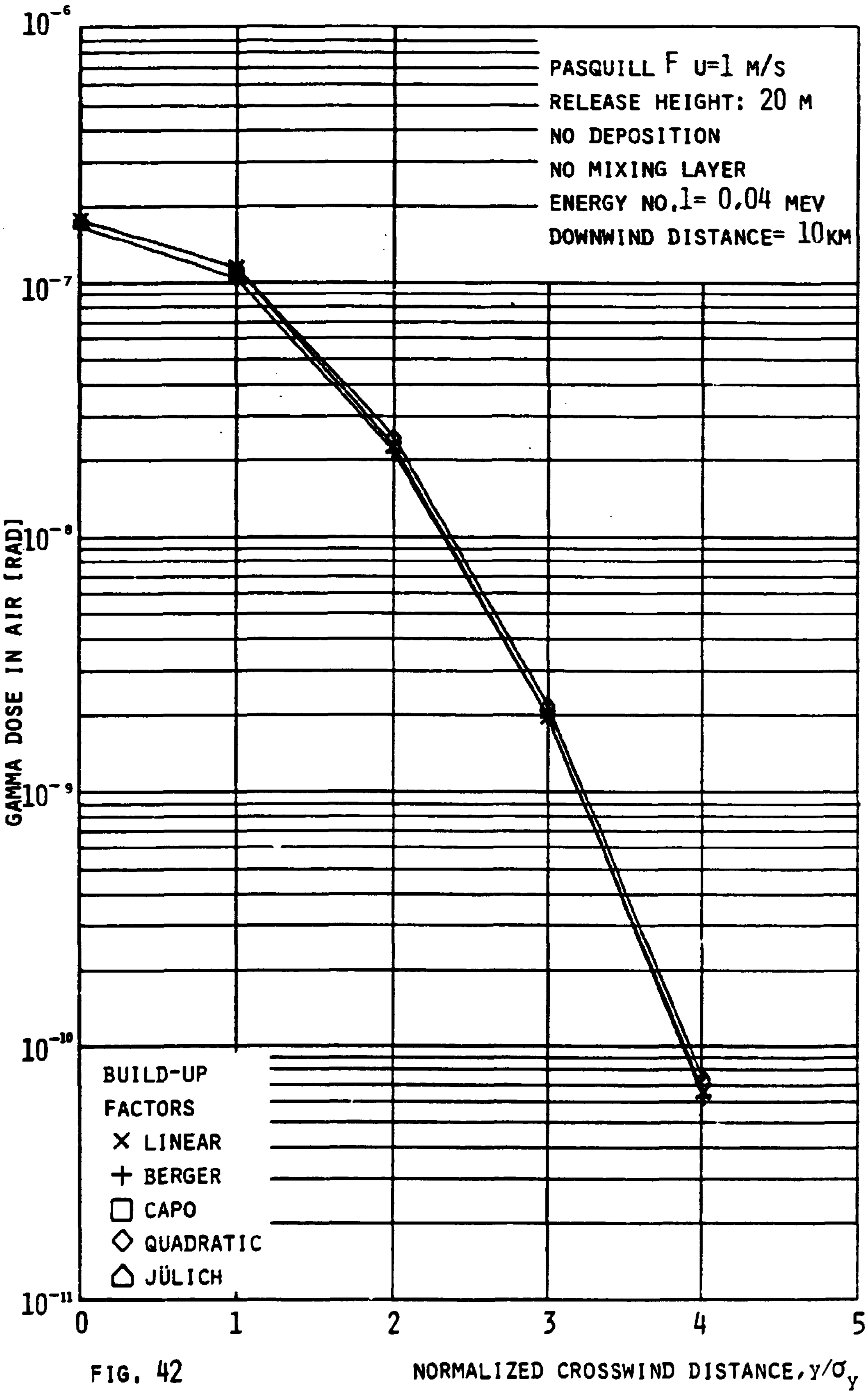


FIG. 42

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

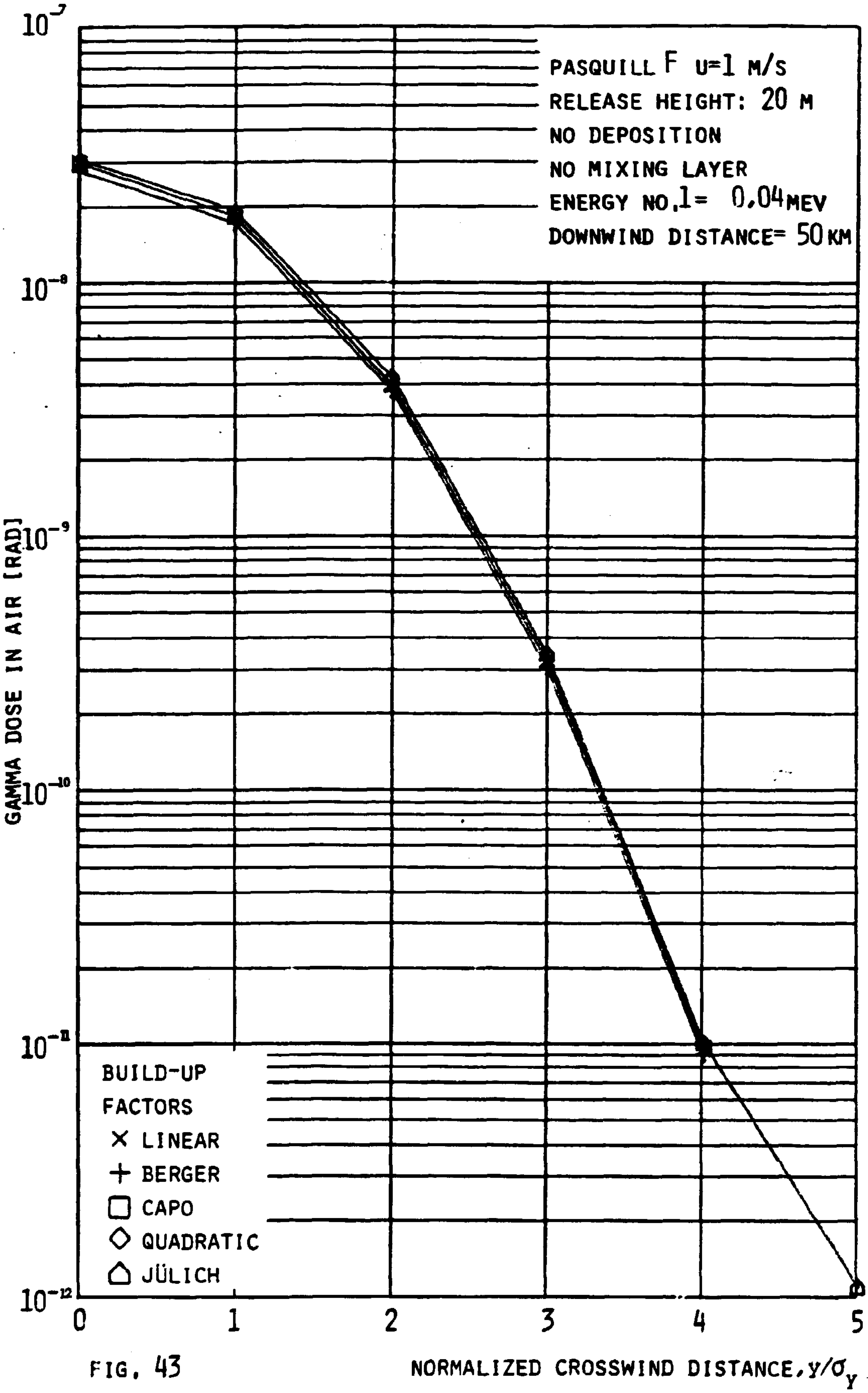


FIG. 43

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

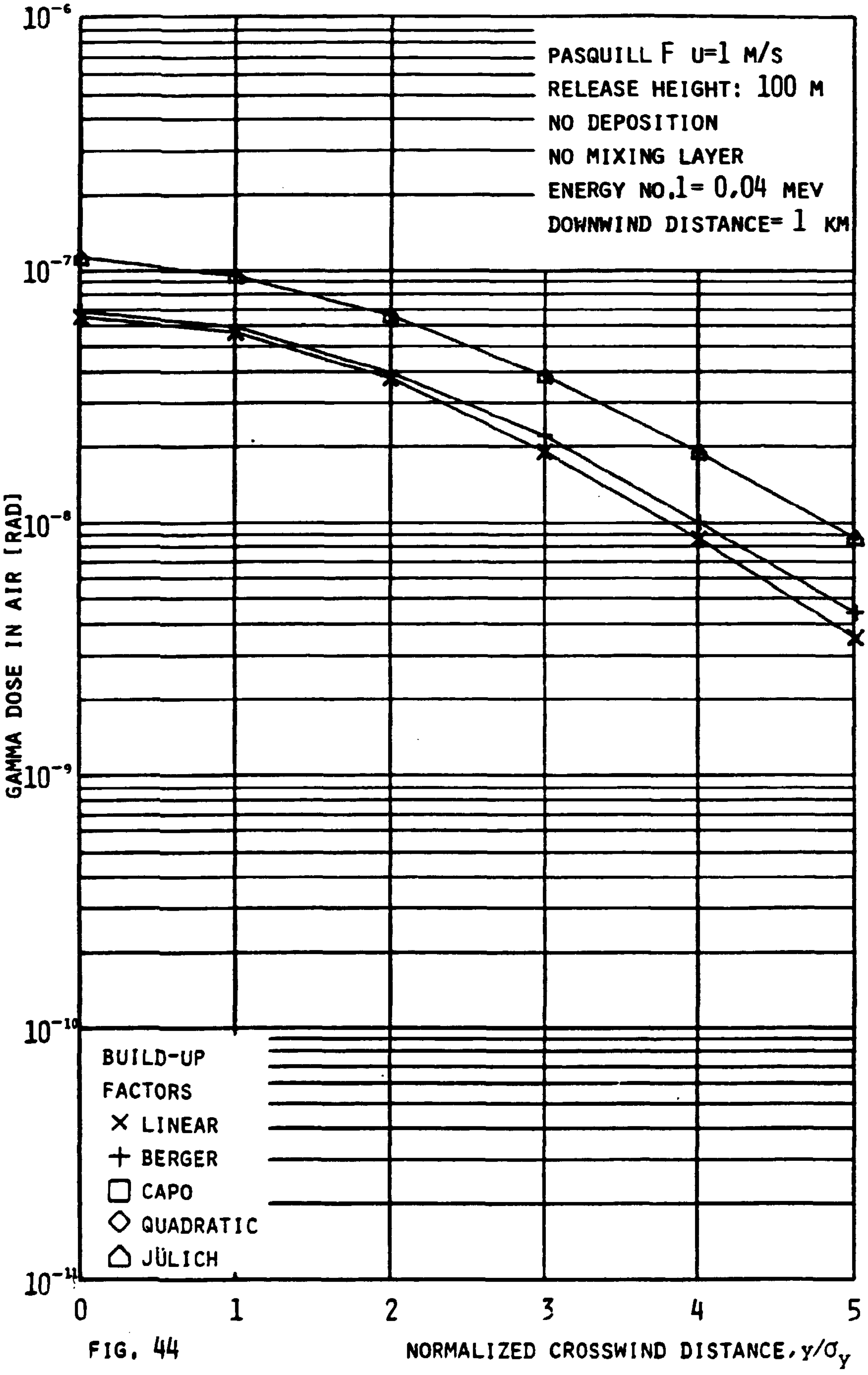


FIG. 44

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

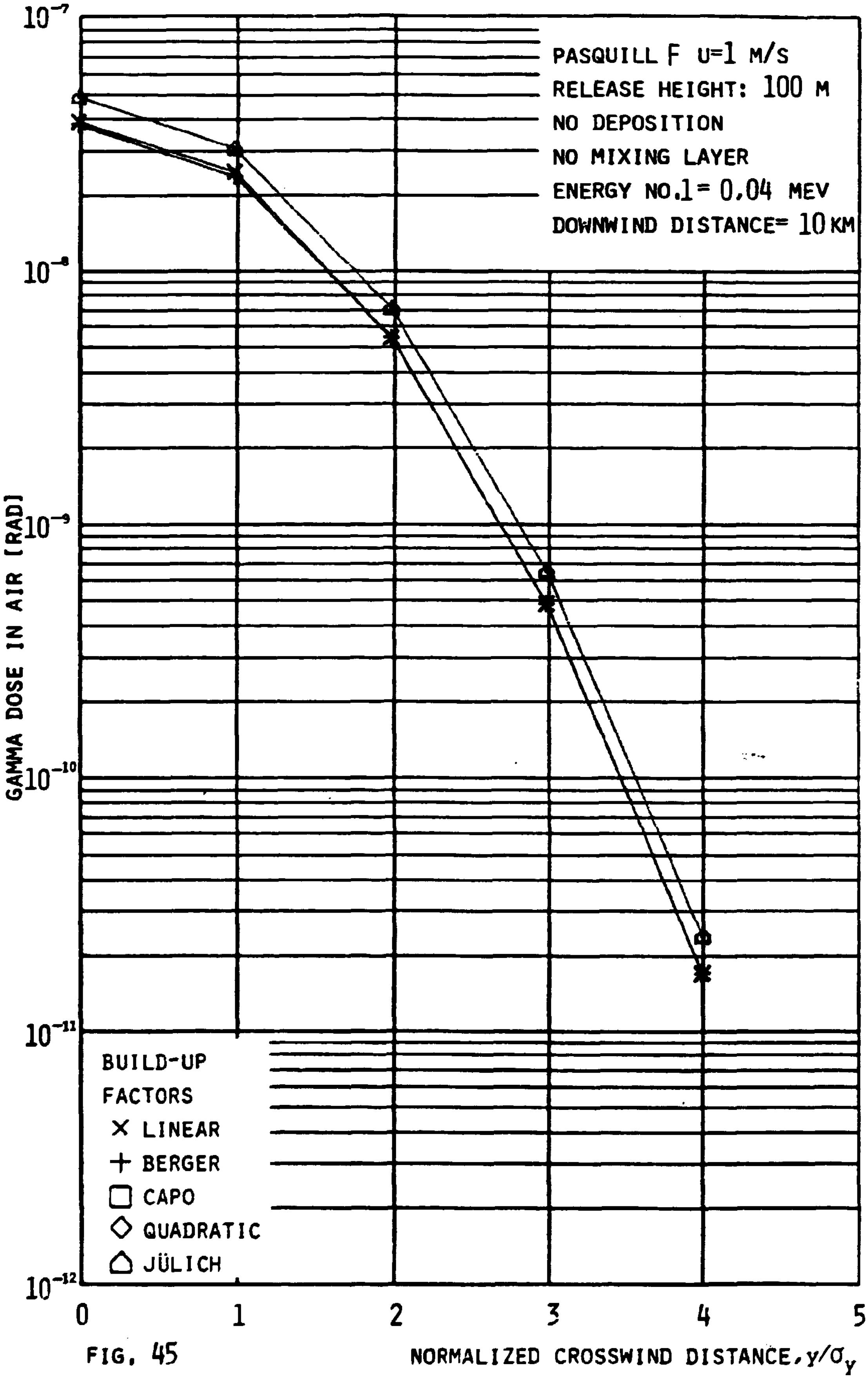


FIG. 45

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

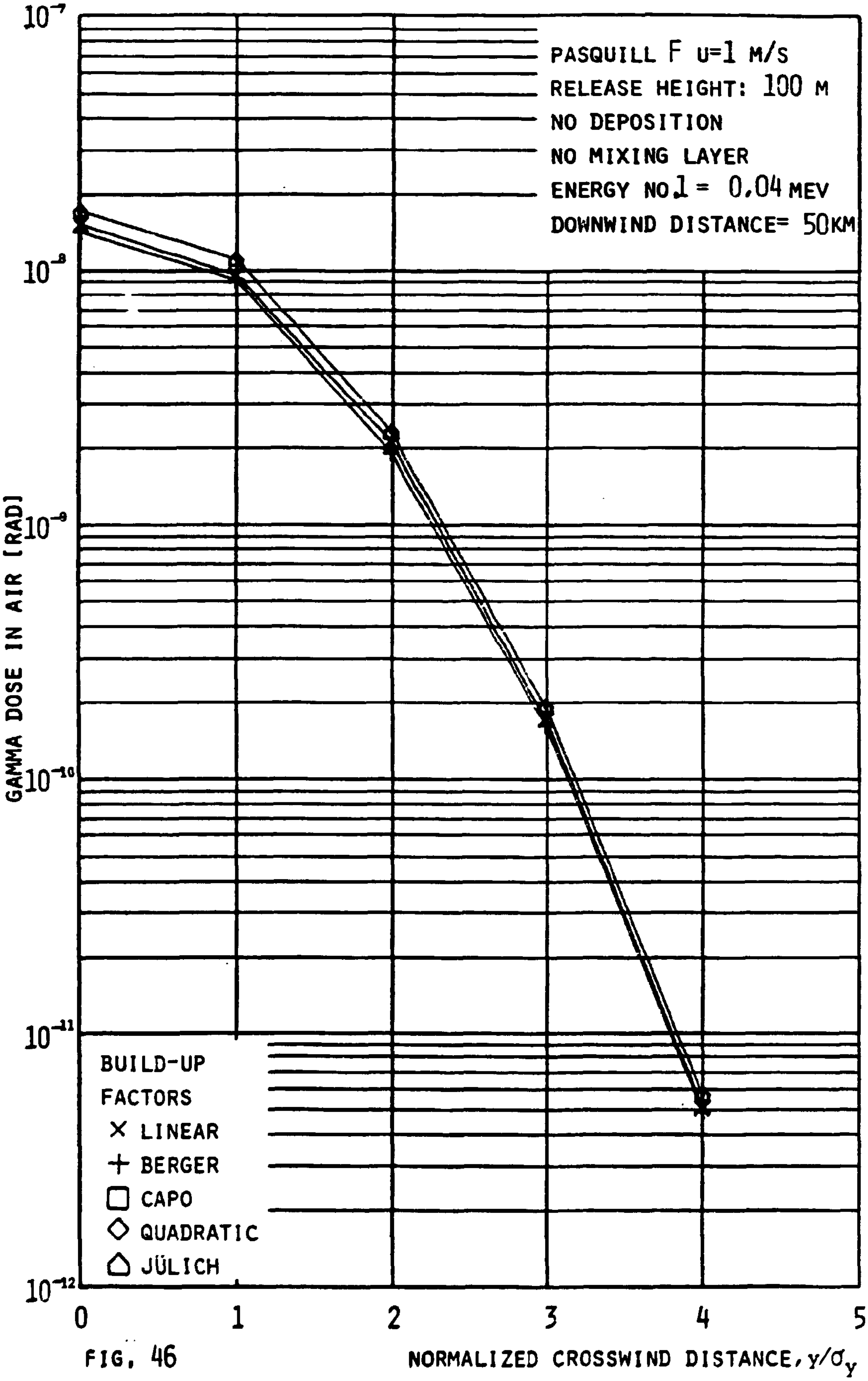


FIG. 46

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

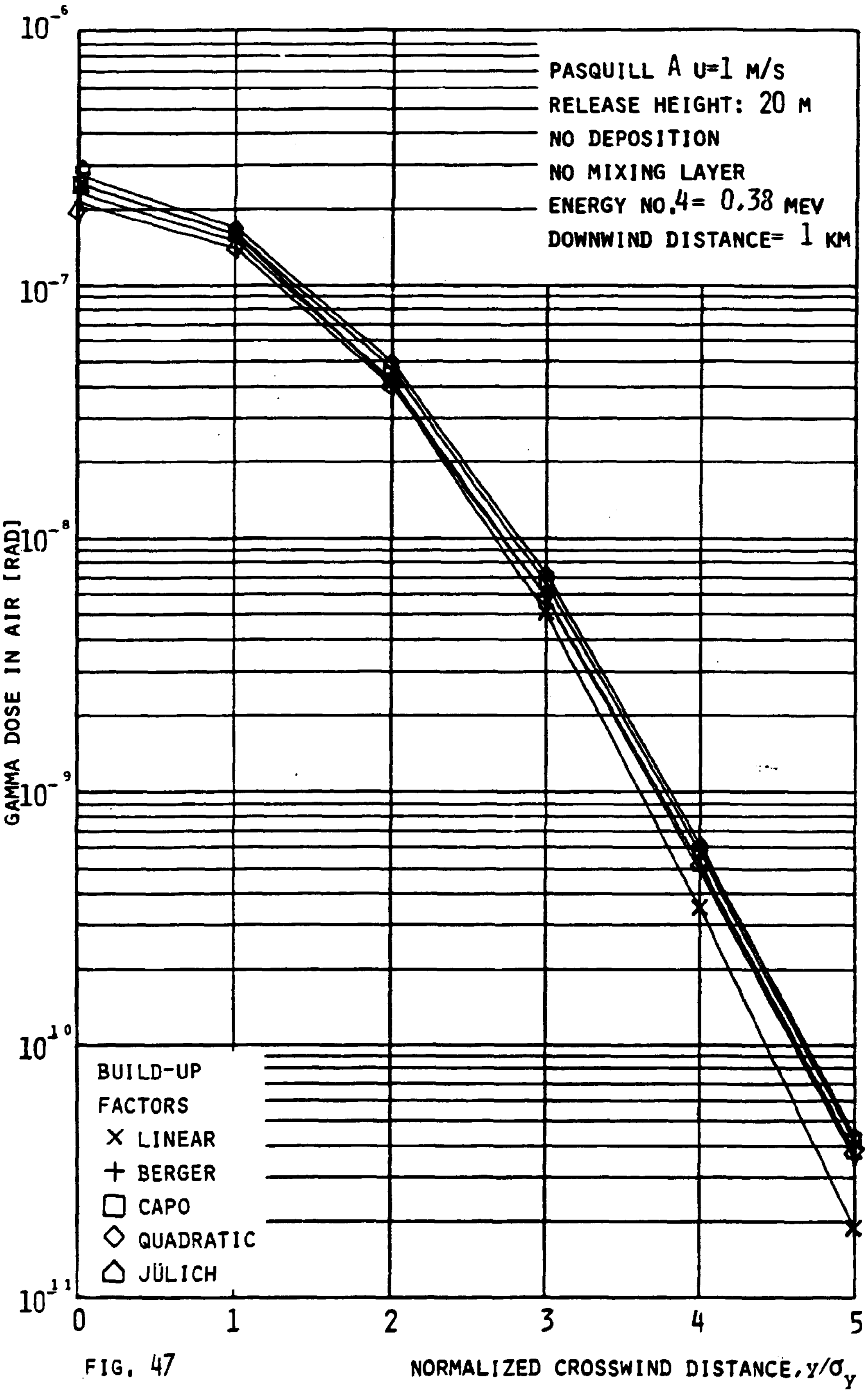


FIG. 47

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

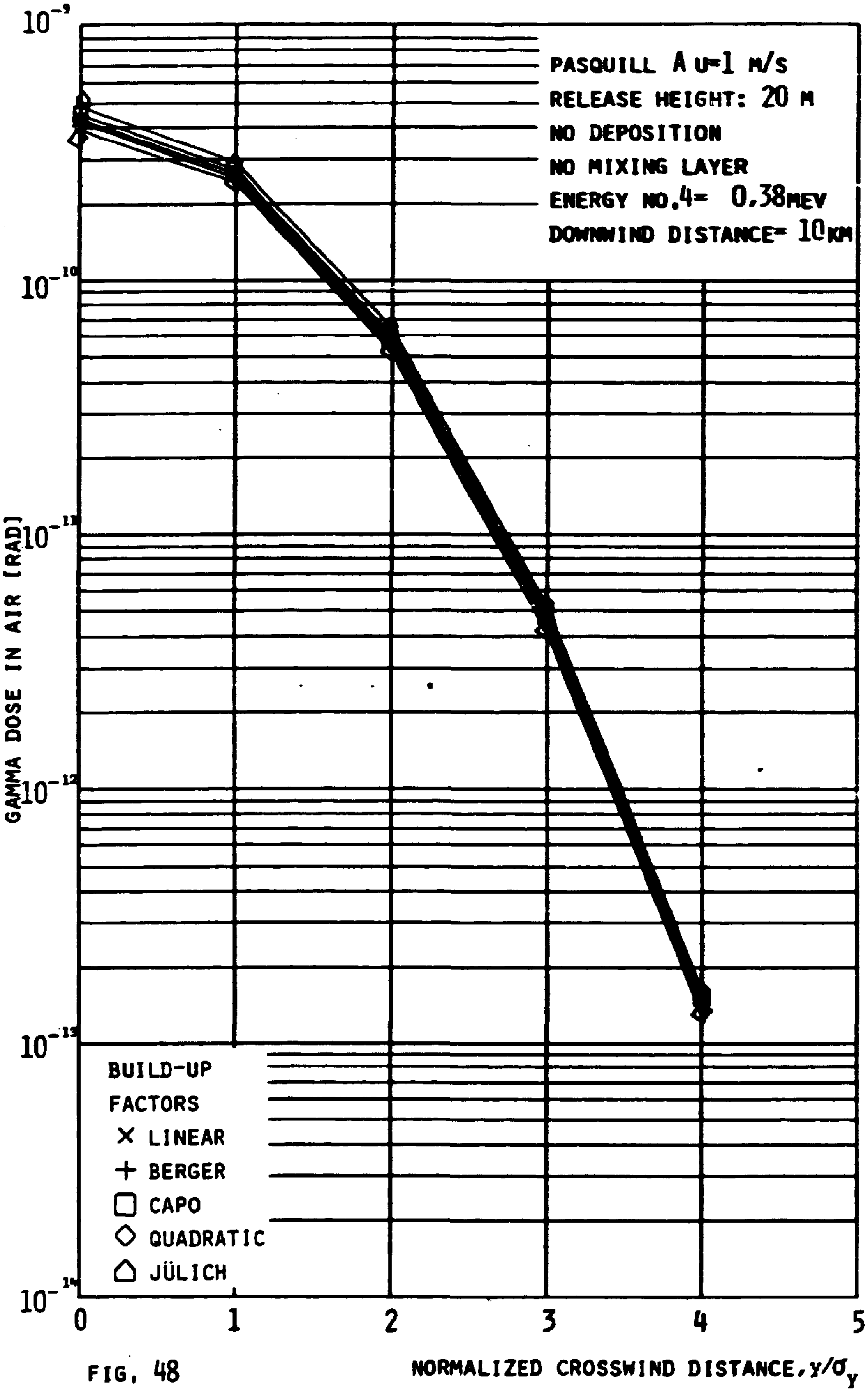


FIG. 48

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

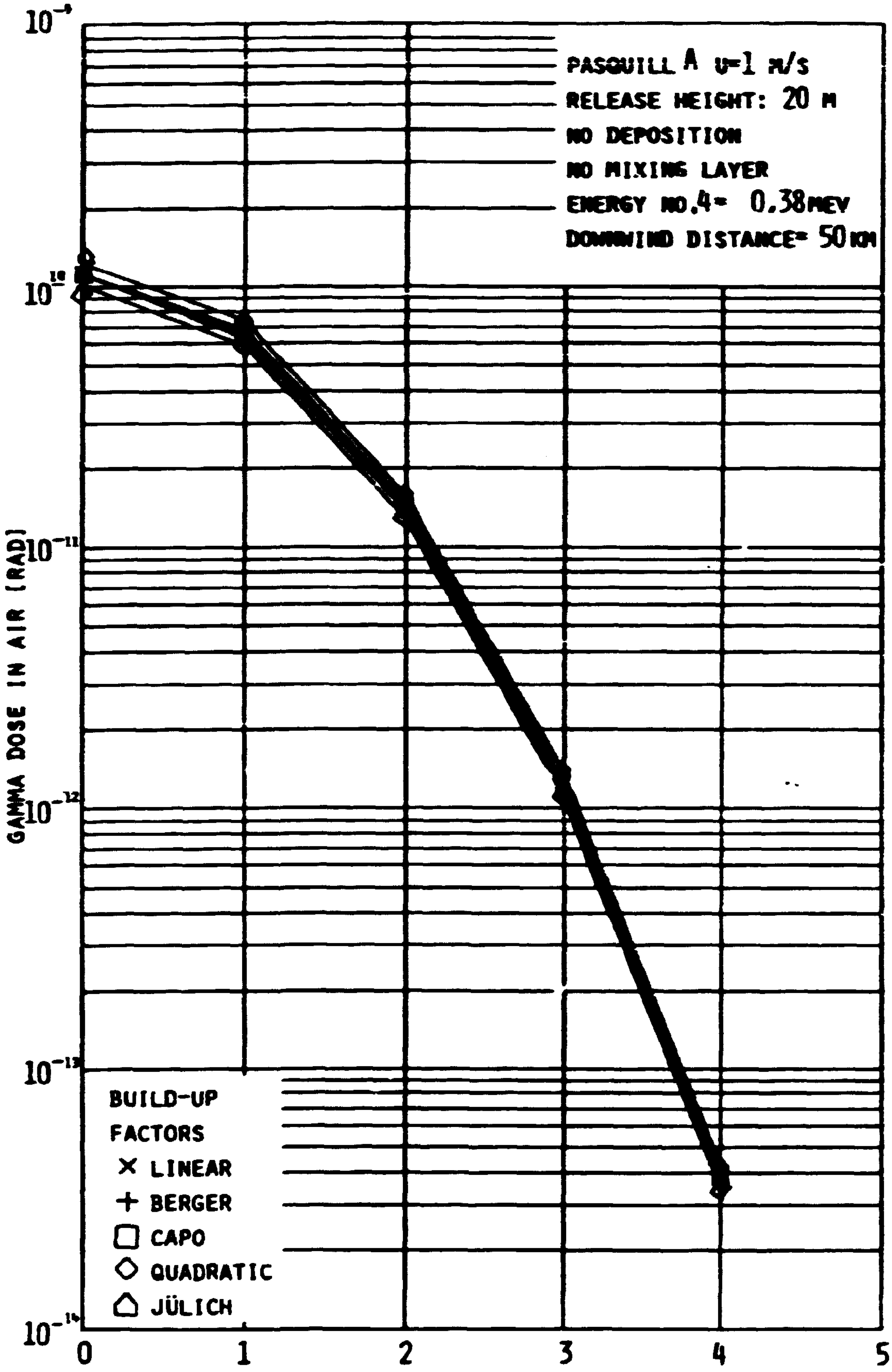


FIG. 49 NORMALIZED CROSSWIND DISTANCE, y/σ_y

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

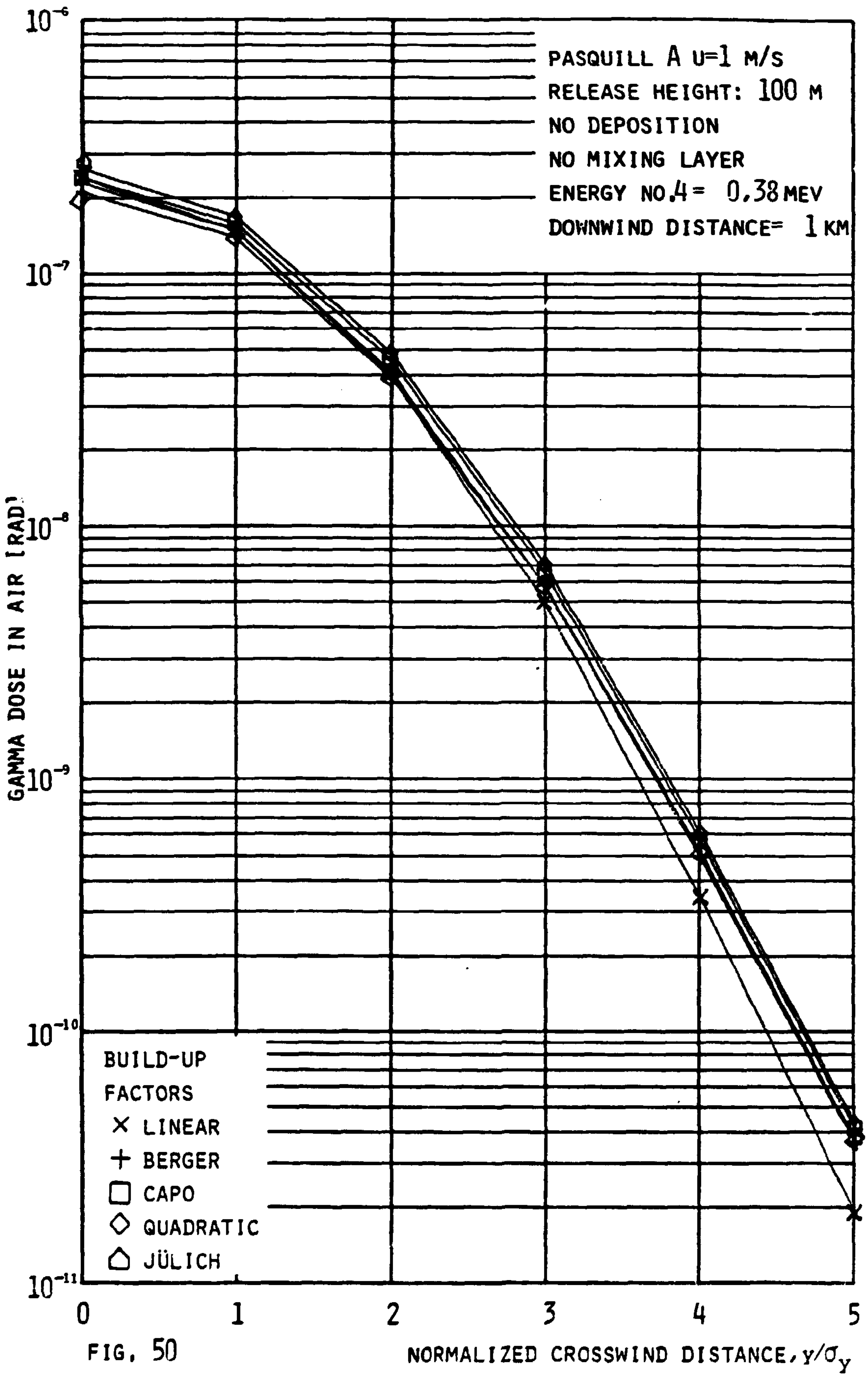


FIG. 50

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

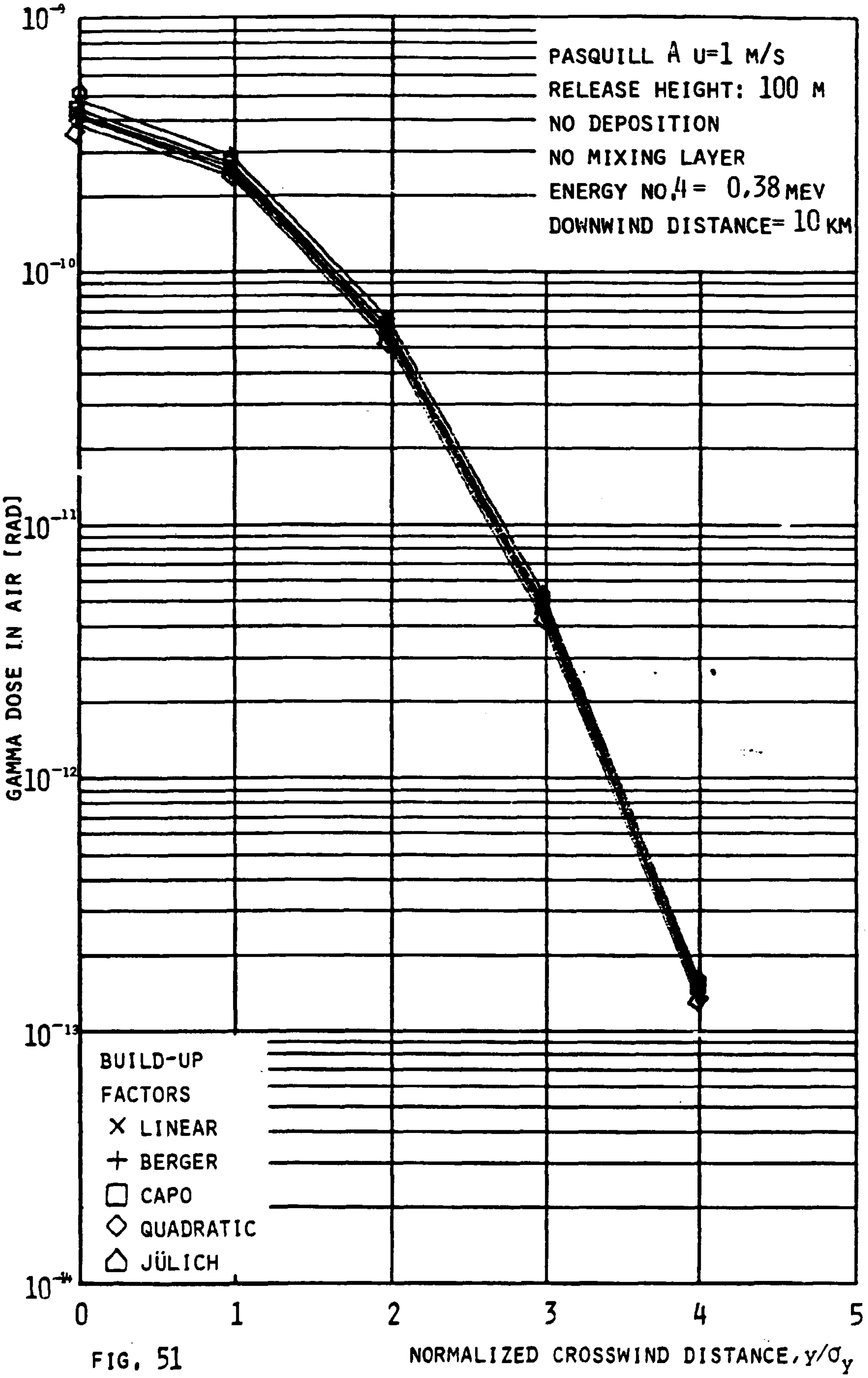


FIG. 51

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

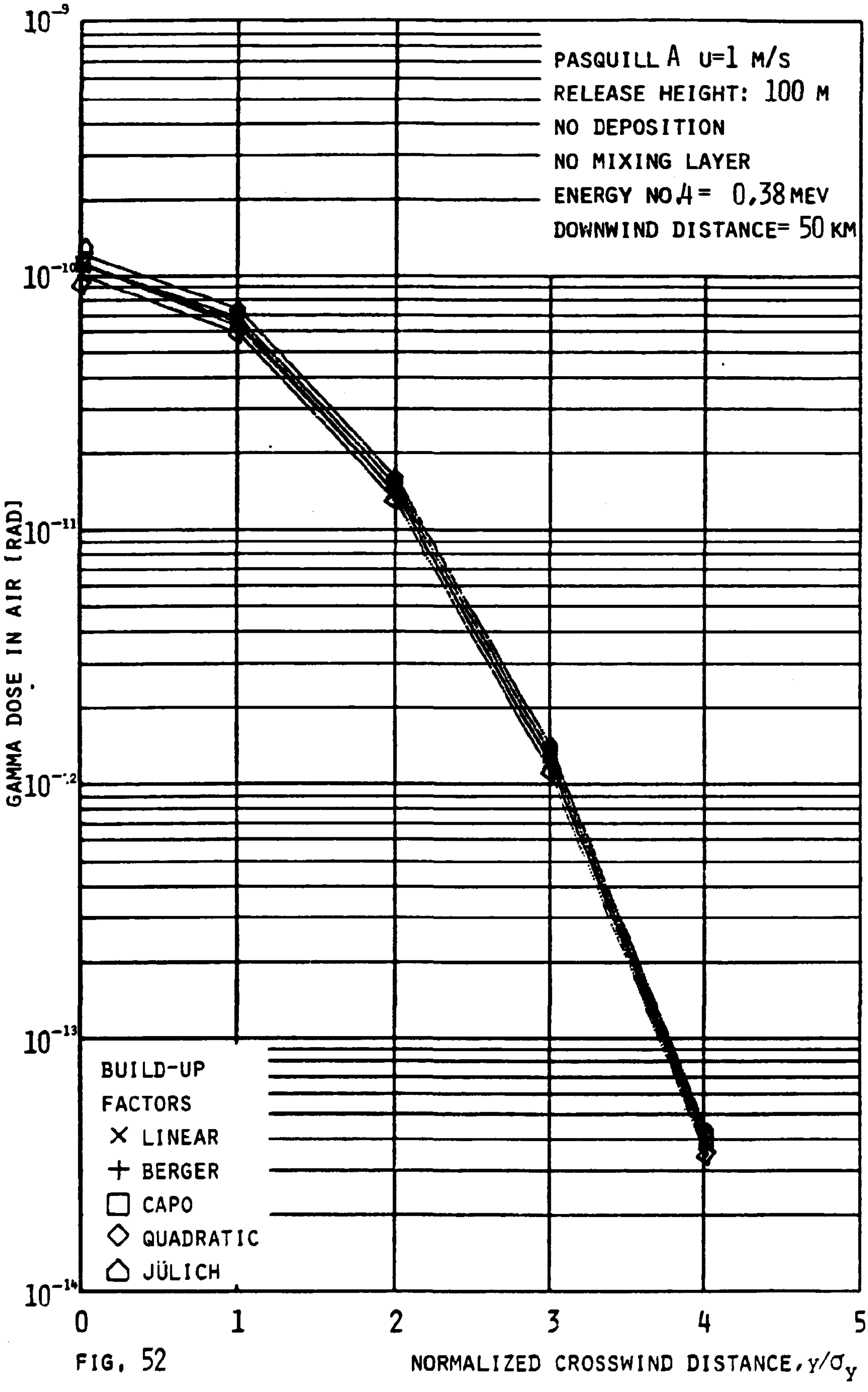


FIG. 52

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

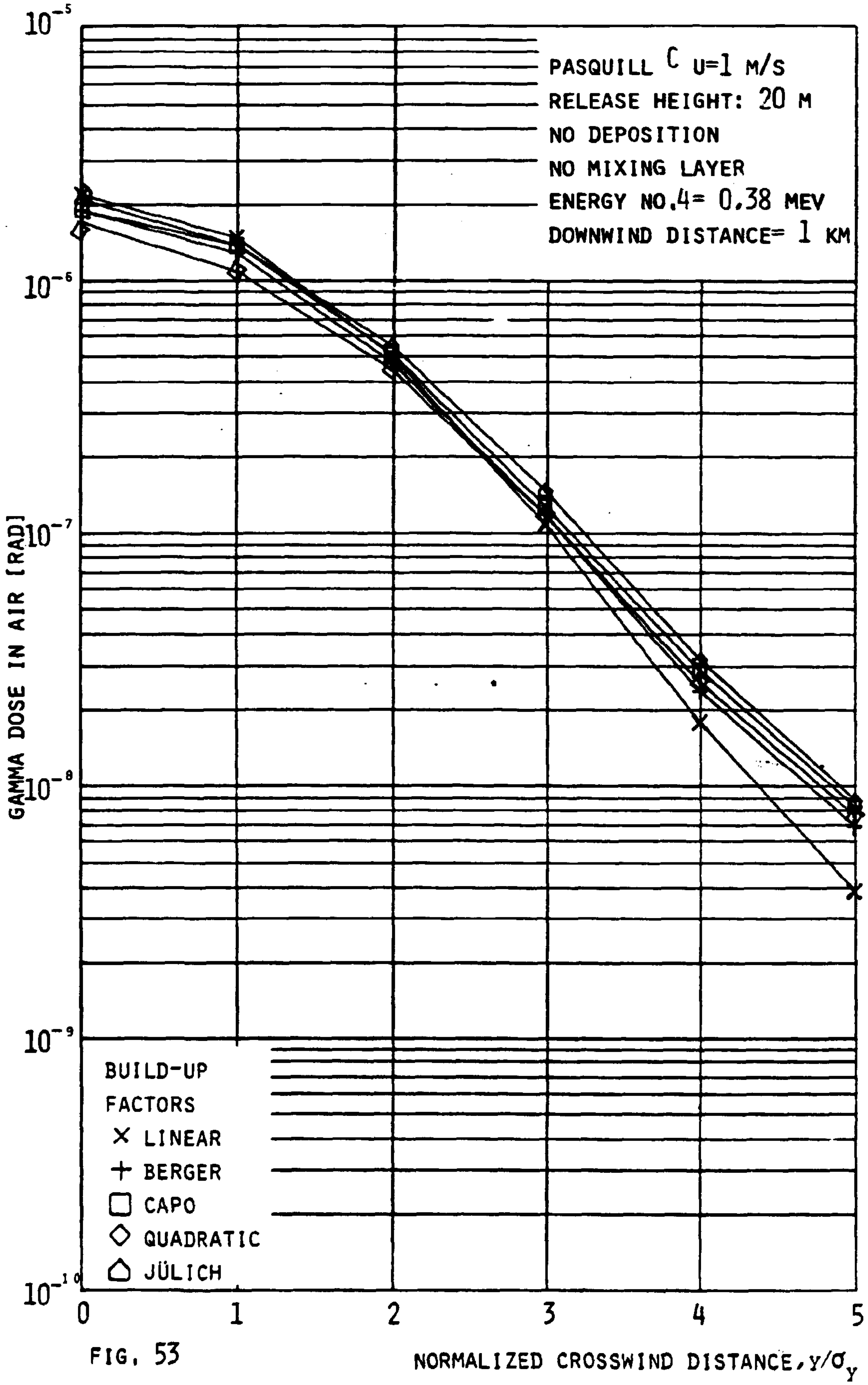


FIG. 53

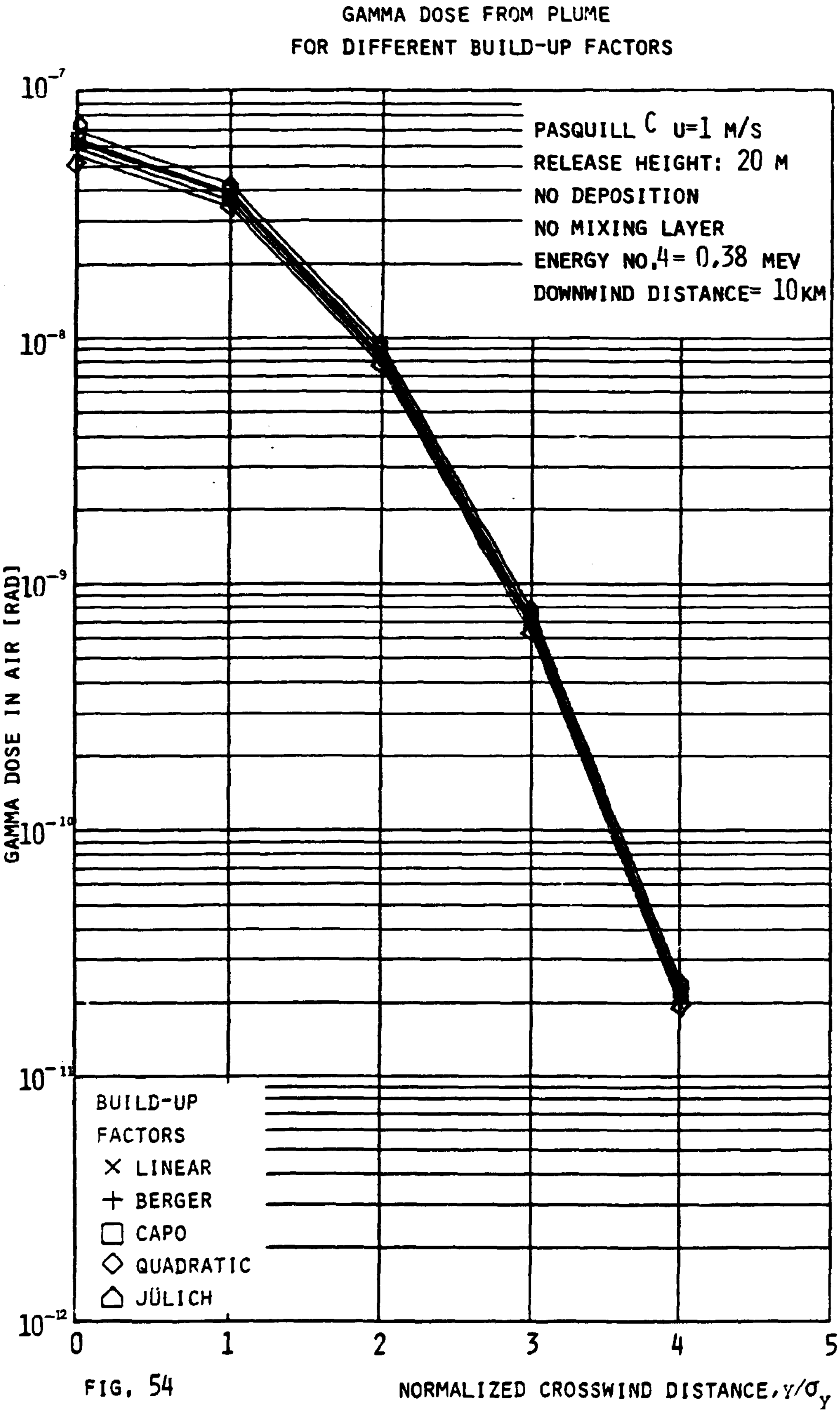

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 20 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.4= 0,38 MEV
DOWNWIND DISTANCE= 10KM
GAMMA DOSE IN AIR [RAD]
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σy

FIG. 54

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

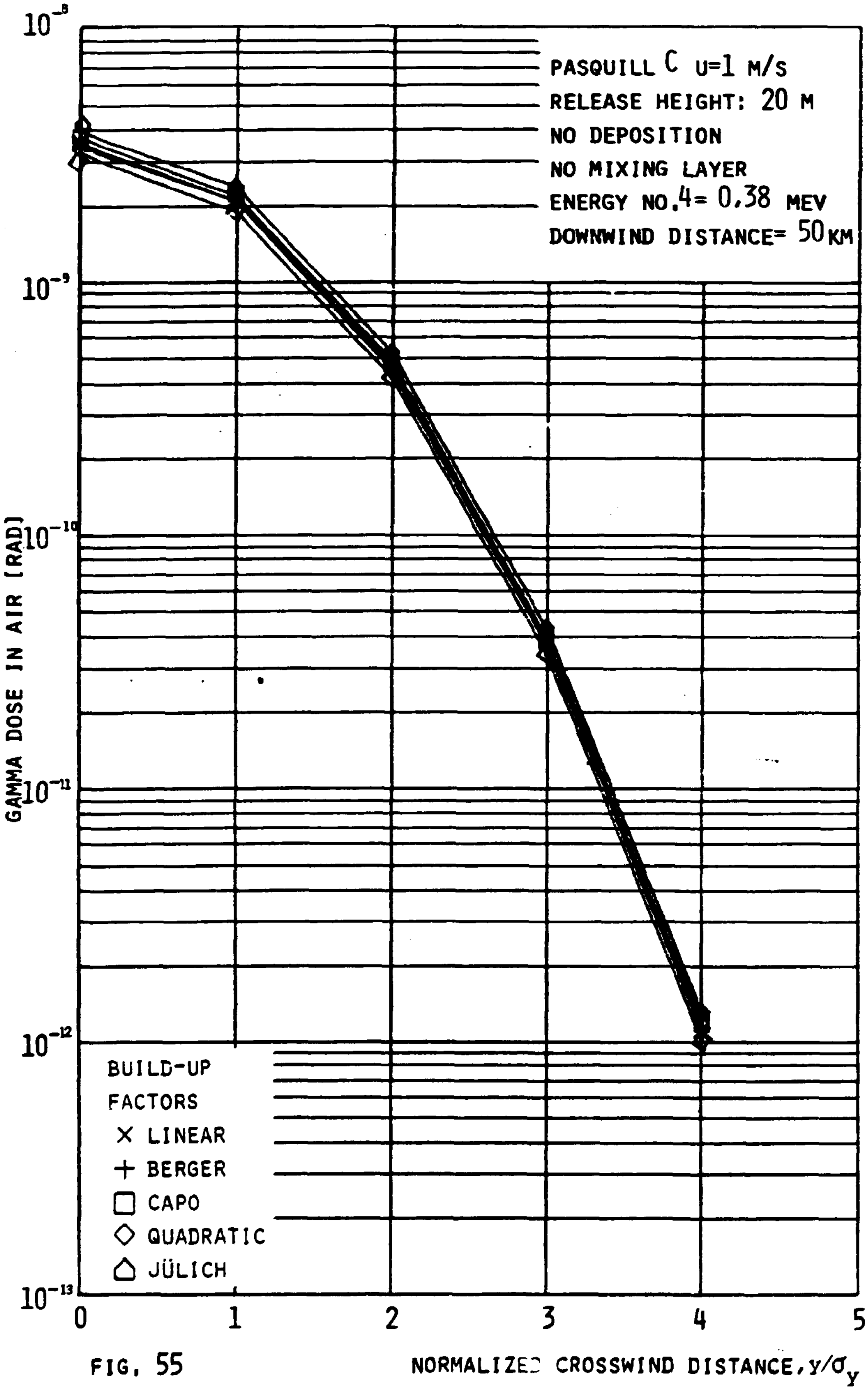


FIG. 55

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

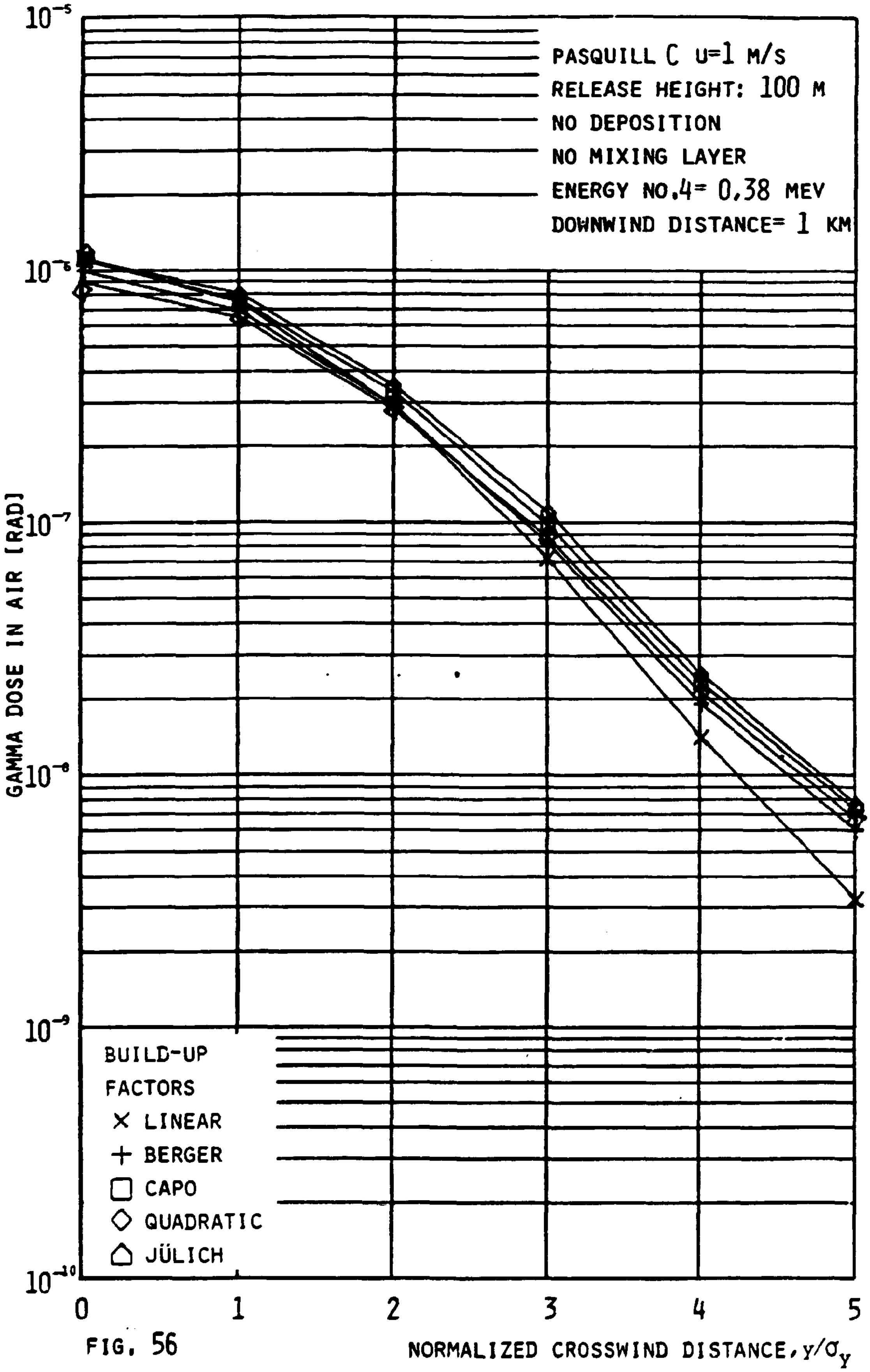


FIG. 56

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

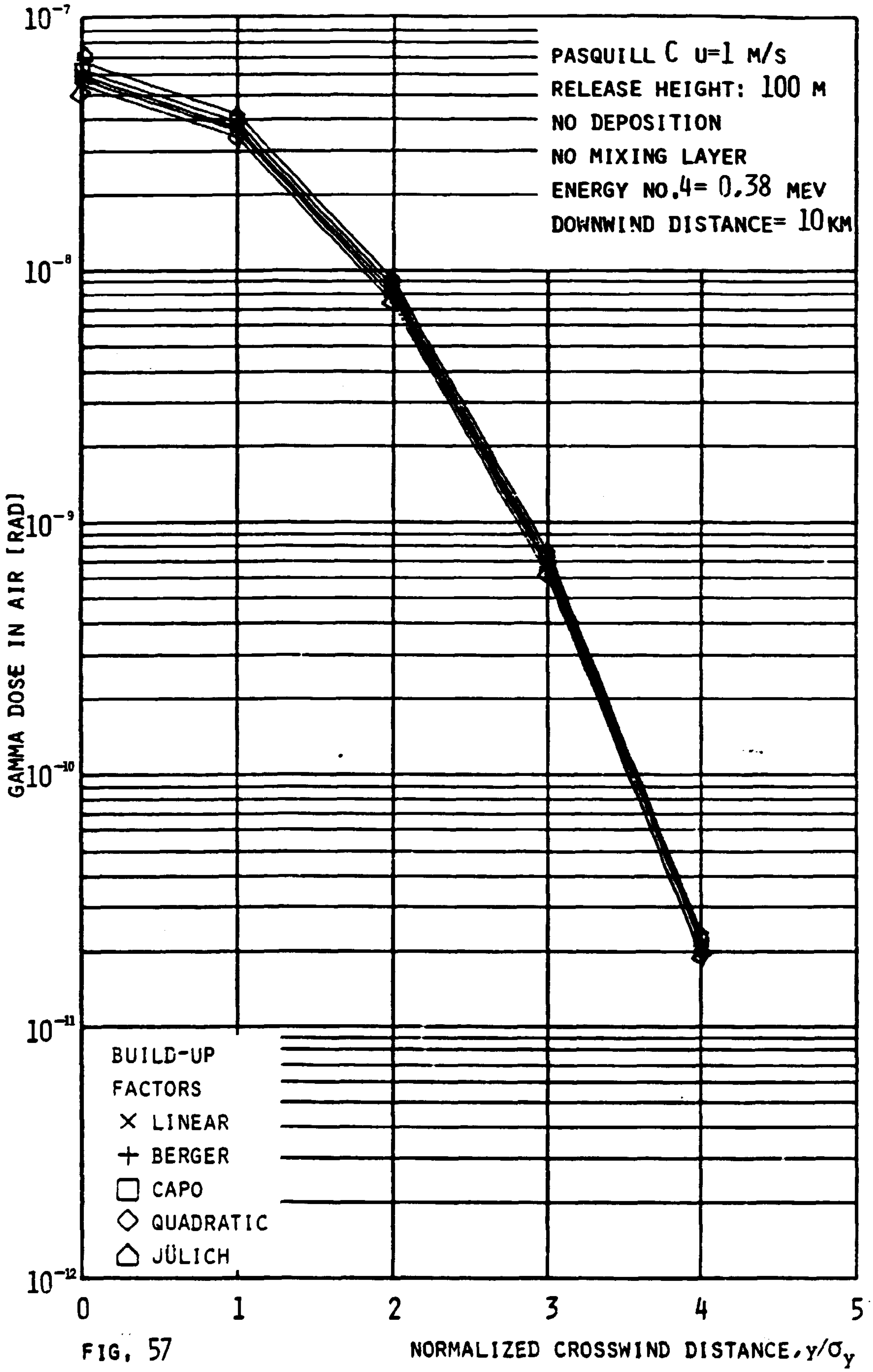


FIG. 57

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

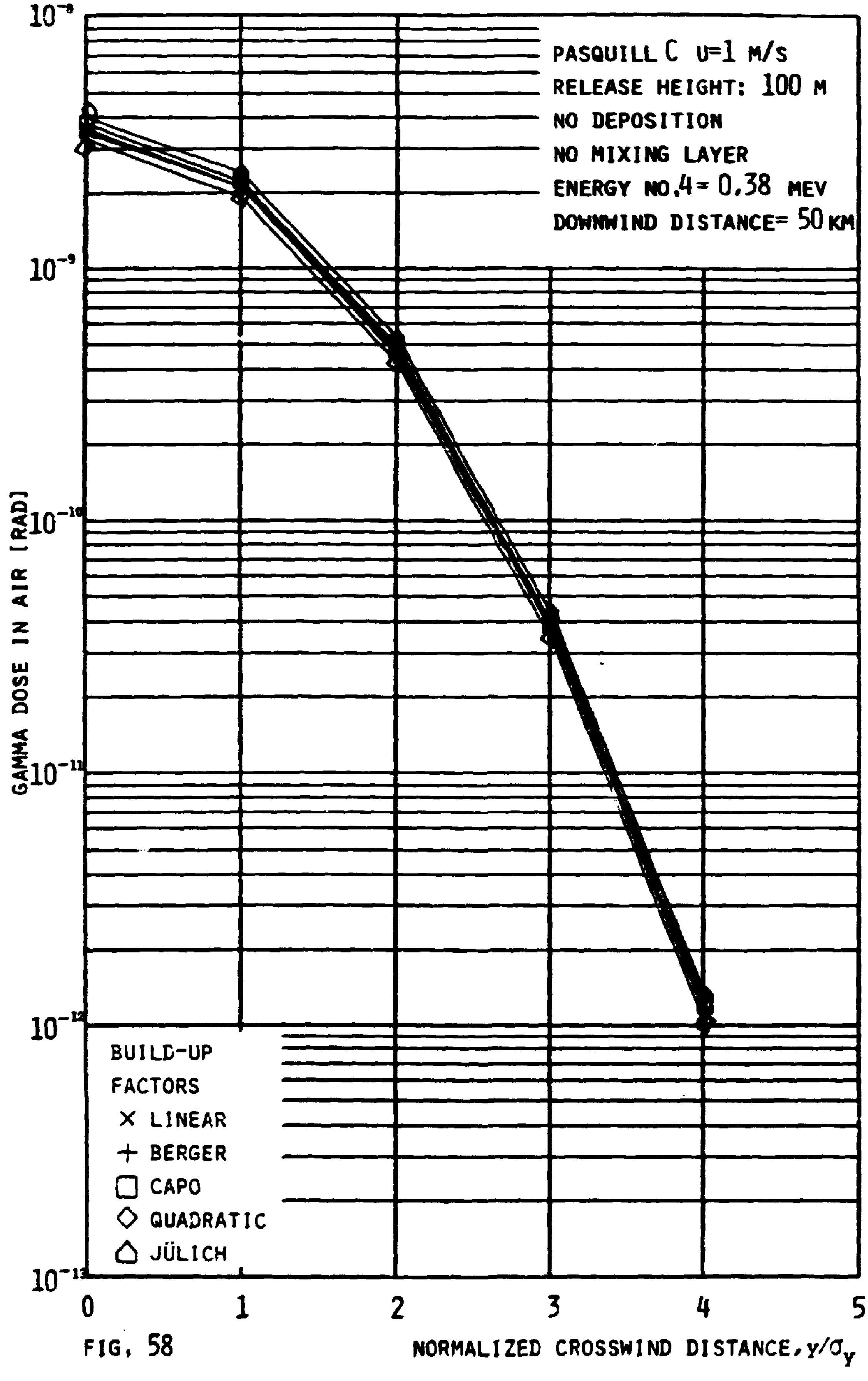


FIG. 58

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

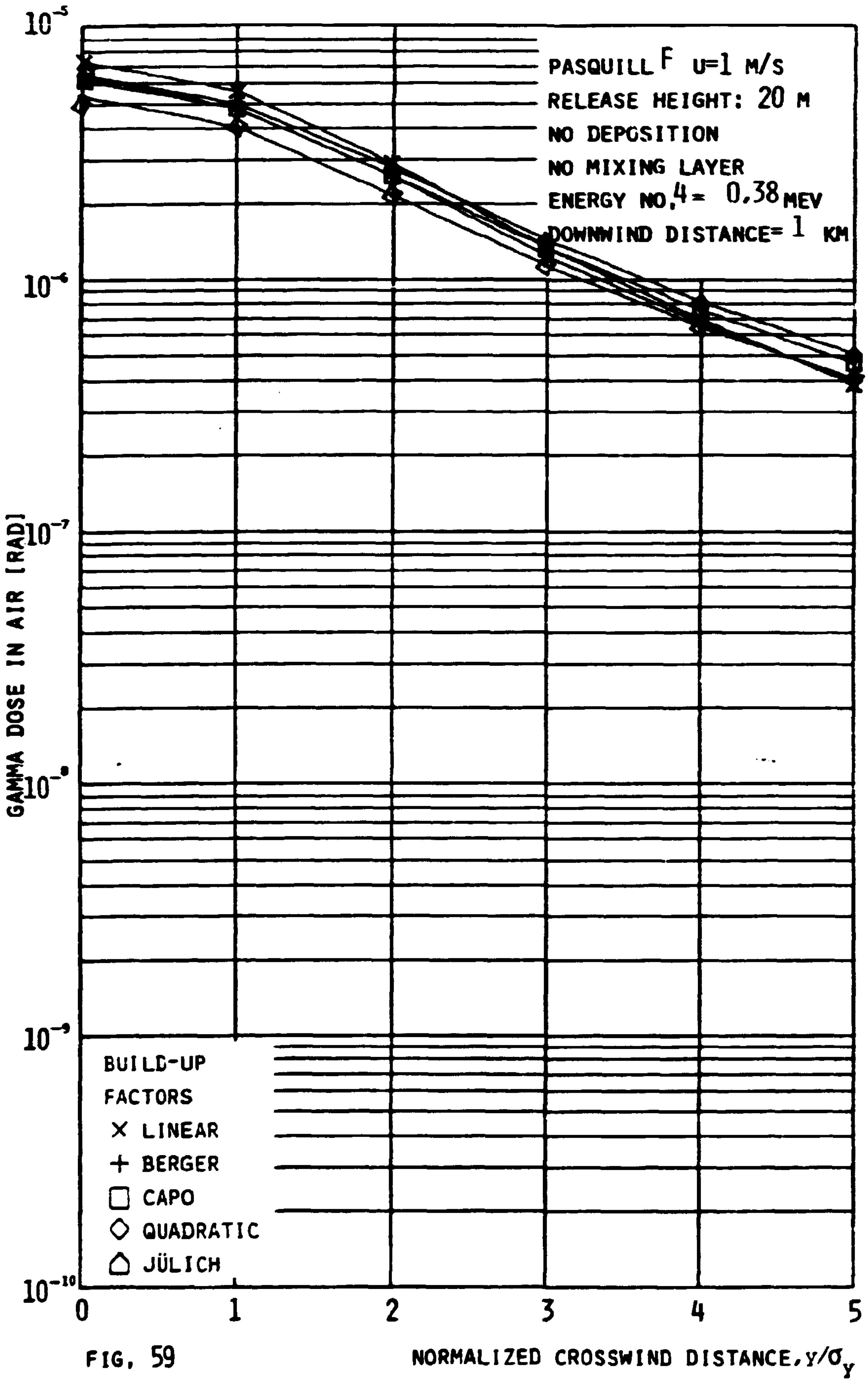


FIG. 59

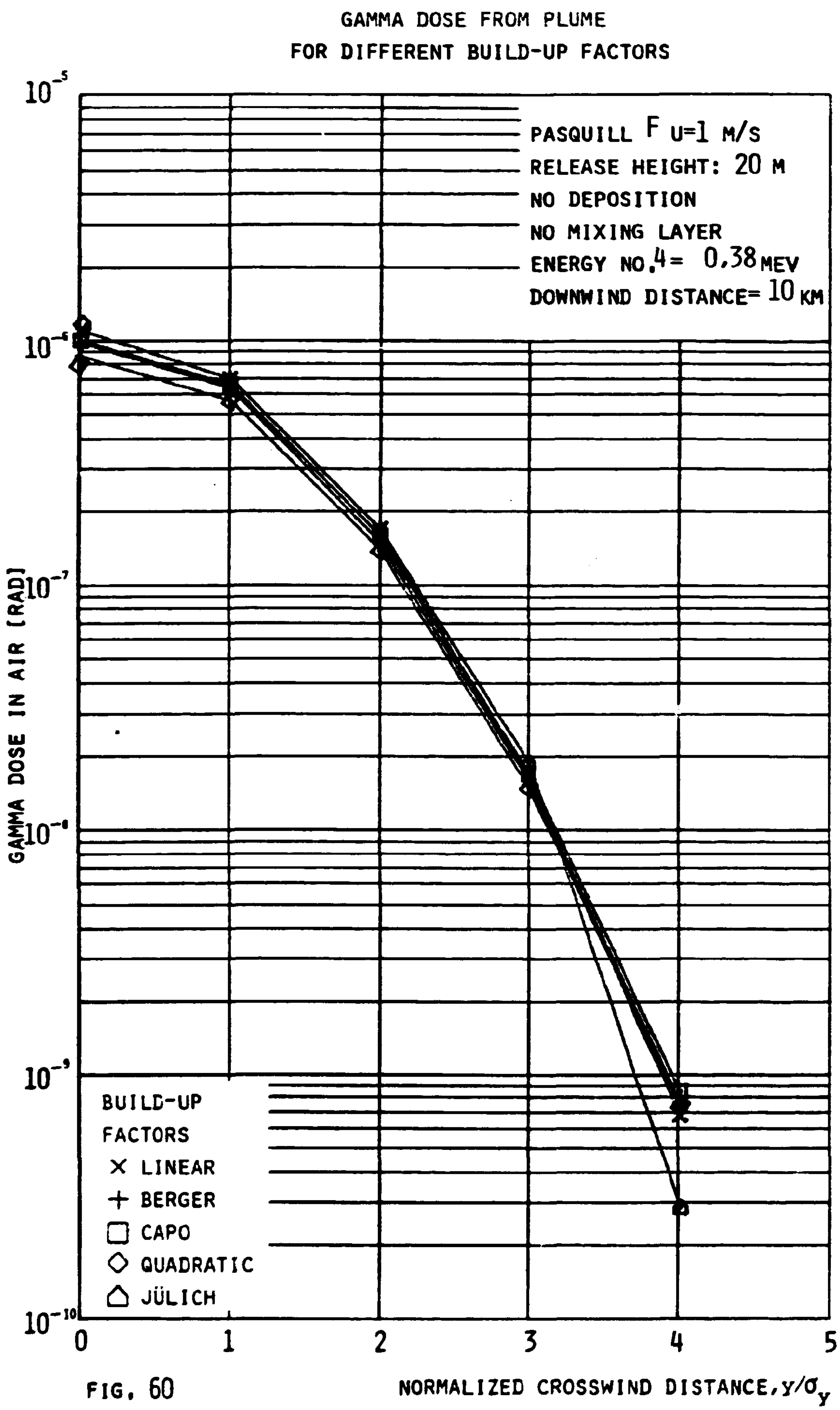

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL F U=1 M/S
RELEASE HEIGHT: 20 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.4= 0,38 MEV
DOWNWIND DISTANCE= 10 KM
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
GAMMA DOSE IN AIR [RAD]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σ_y

FIG. 60

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

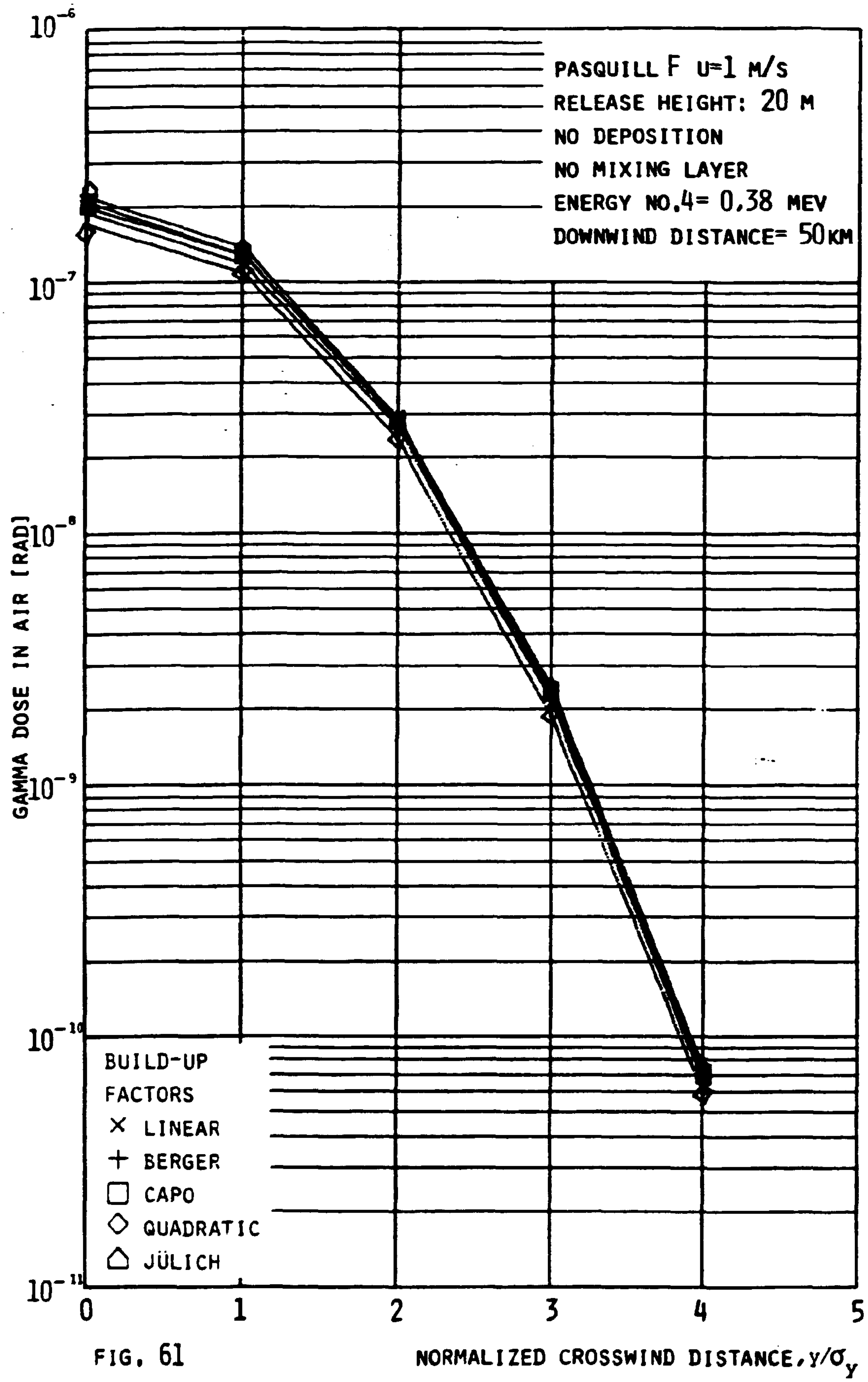


FIG. 61

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

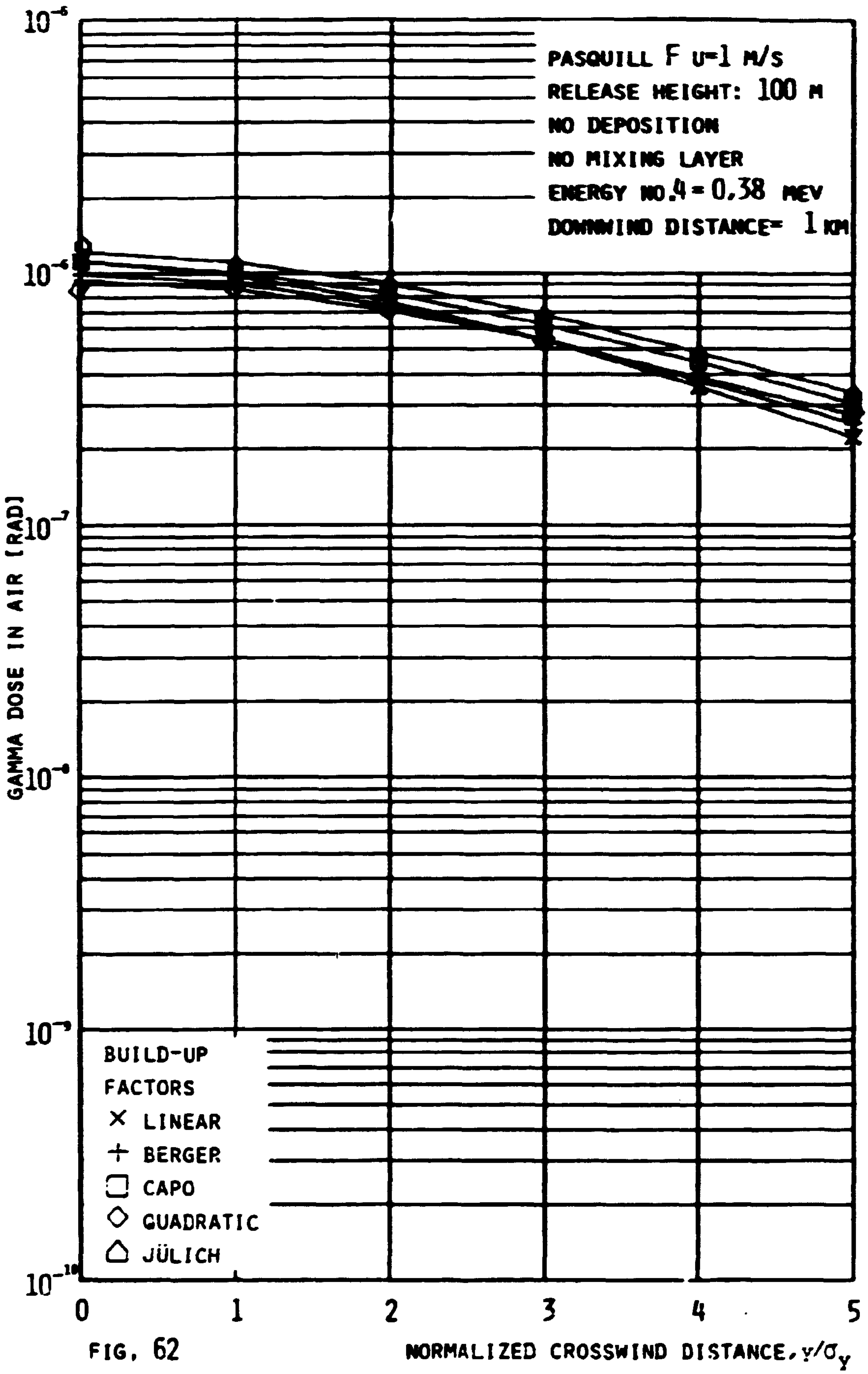


FIG. 62

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

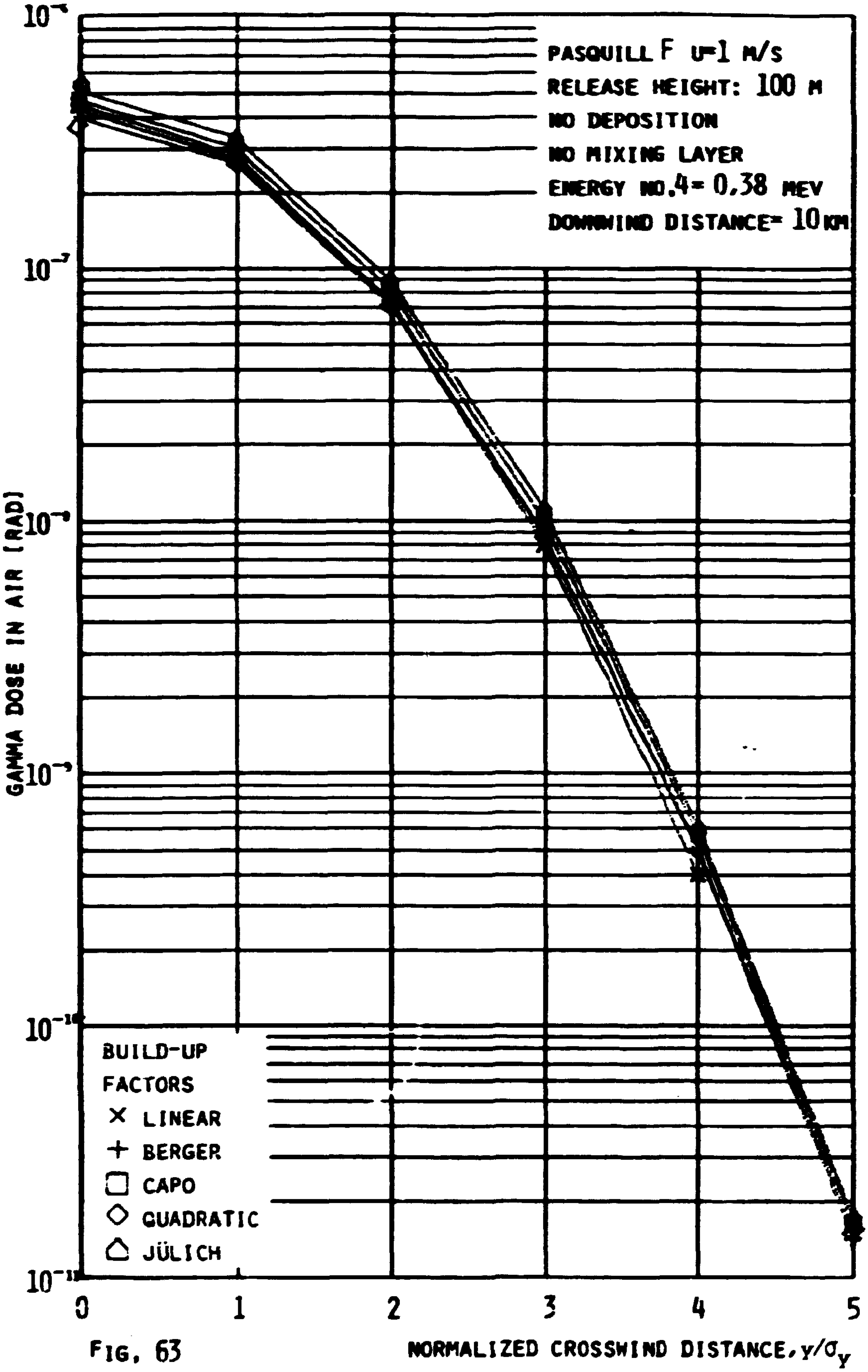


FIG. 63

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

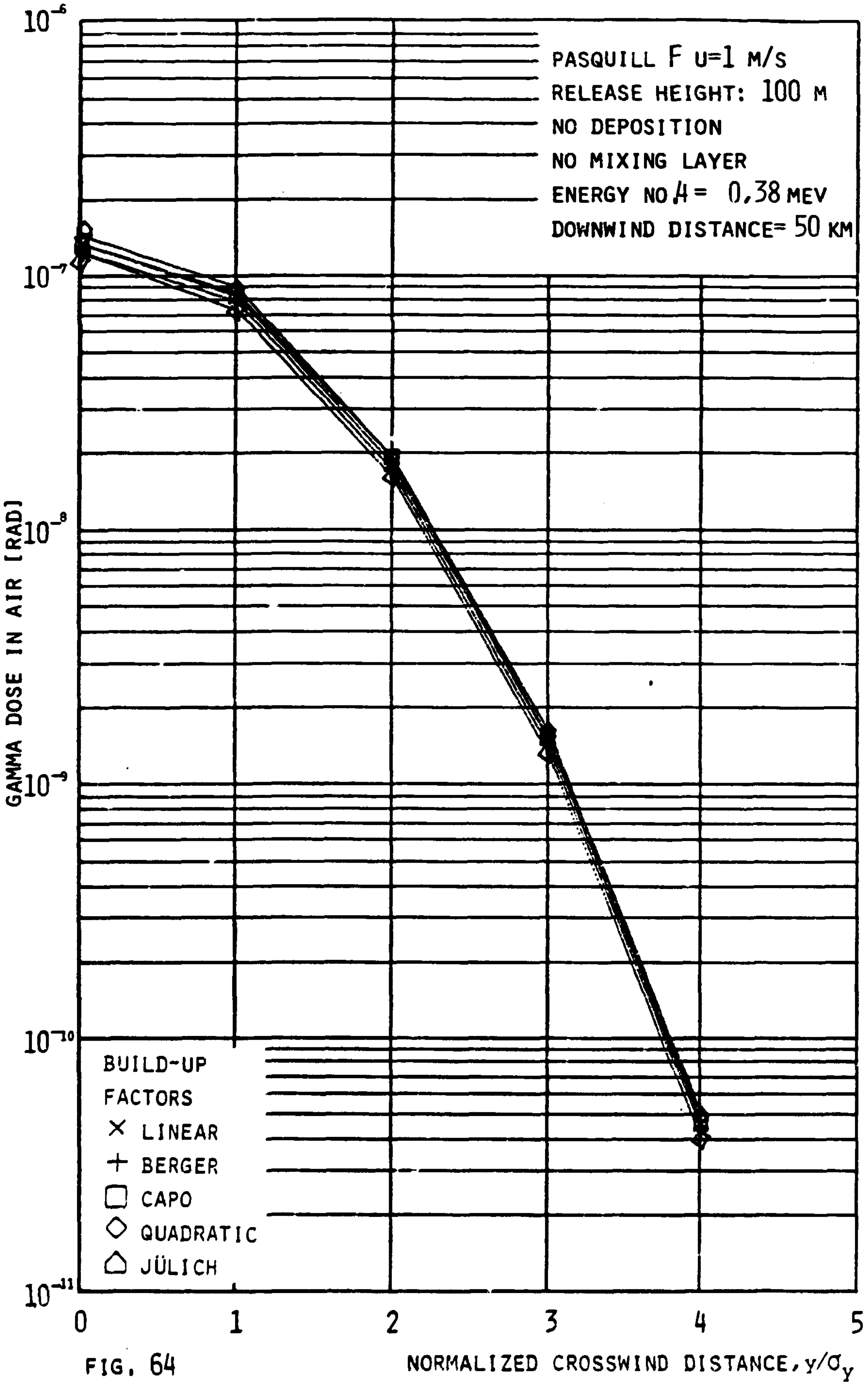


FIG. 64

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

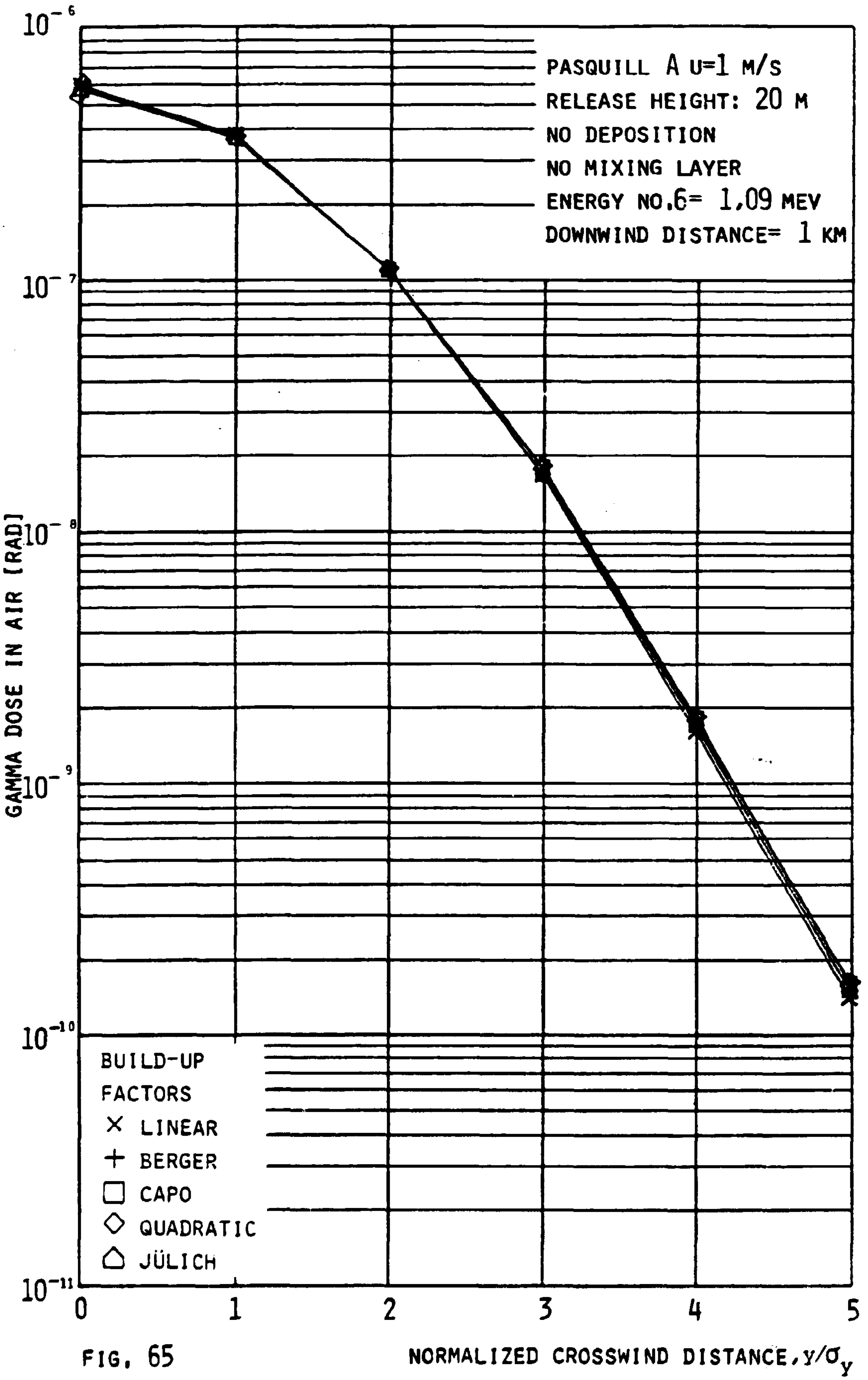


FIG. 65

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

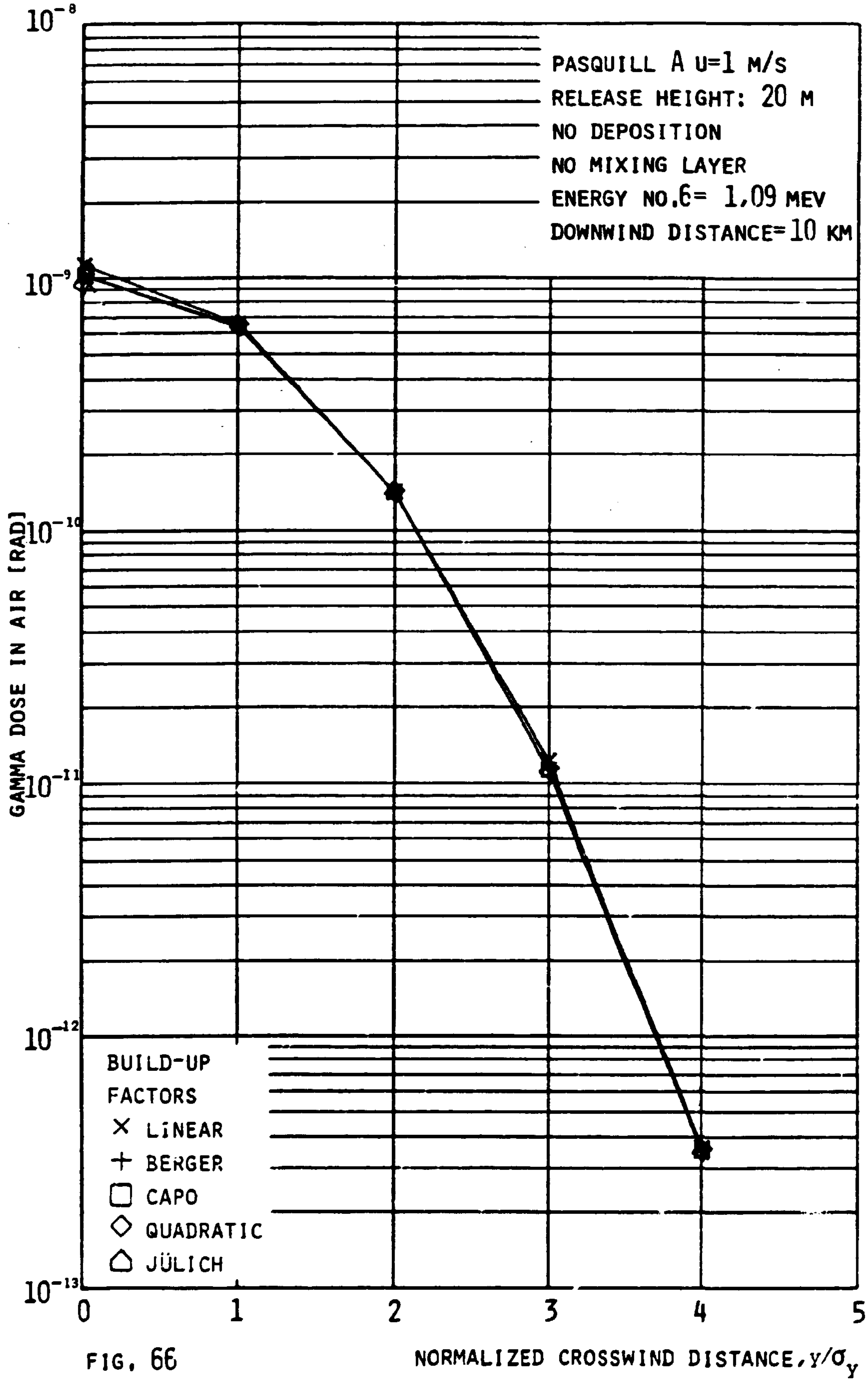
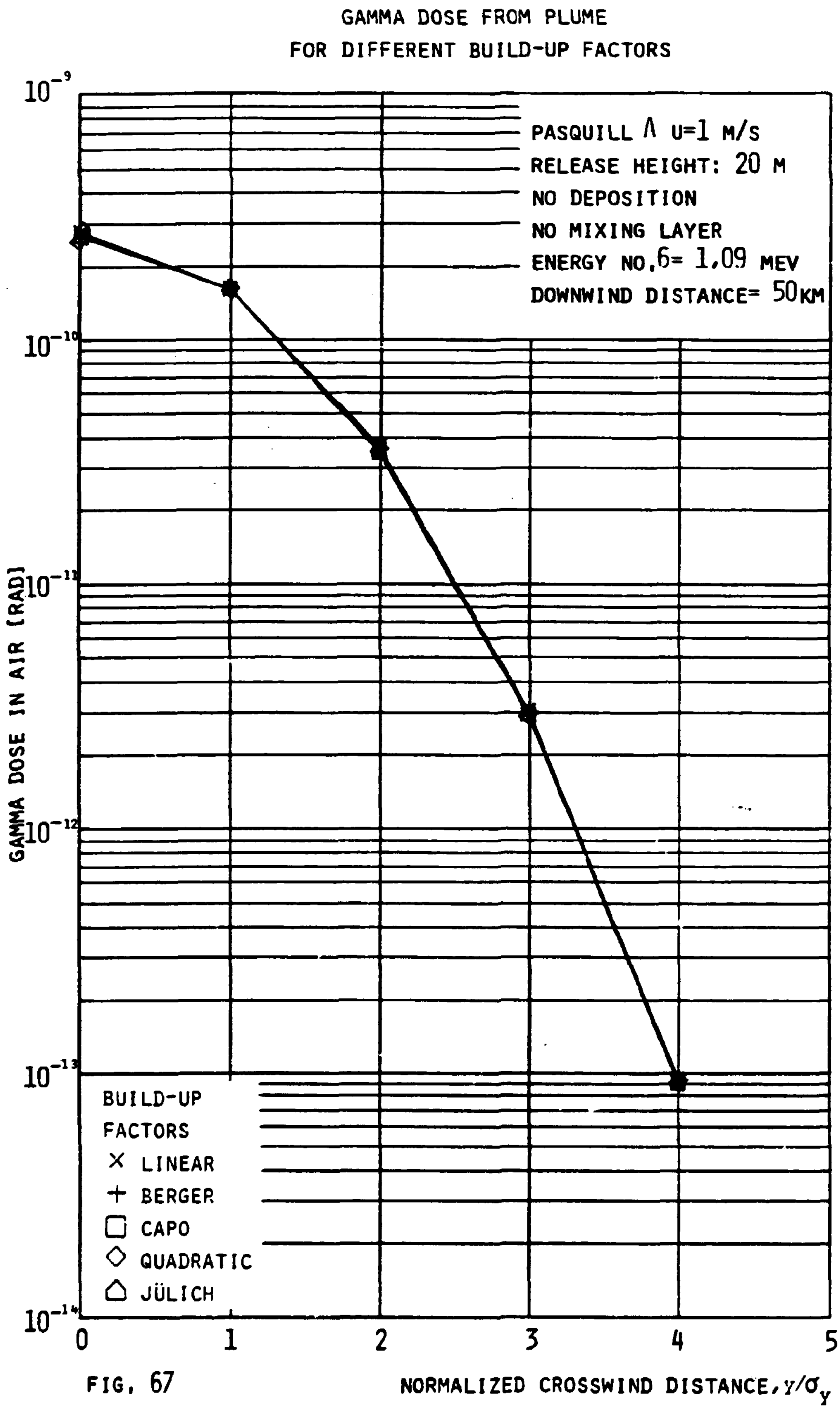


FIG. 66



GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL A U=1 M/S
RELEASE HEIGHT: 20 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.6= 1.09 MEV
DOWNWIND DISTANCE= 50KM
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
GAMMA DOSE IN AIR [RAD]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σ_y

FIG. 67

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

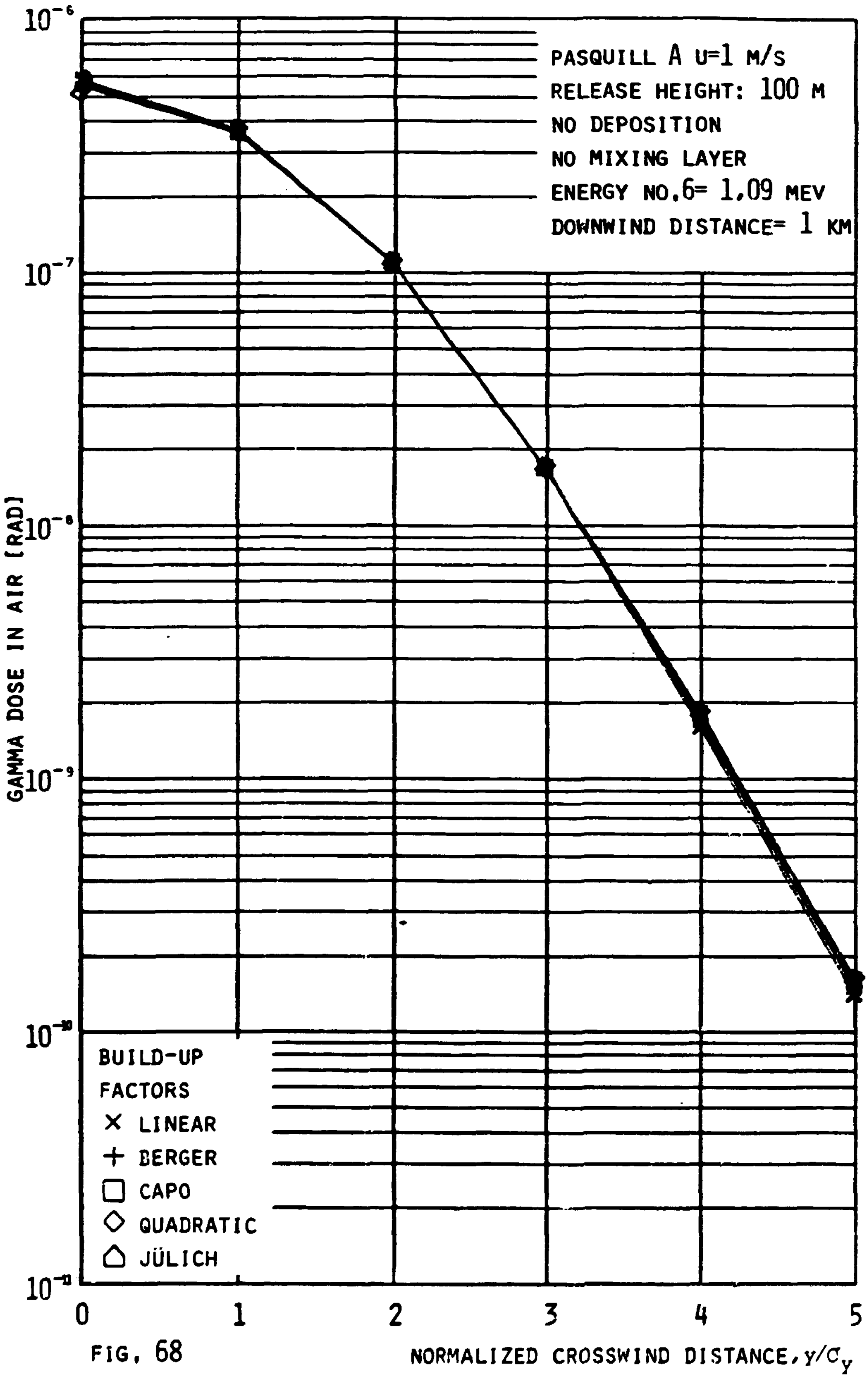


FIG. 68

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

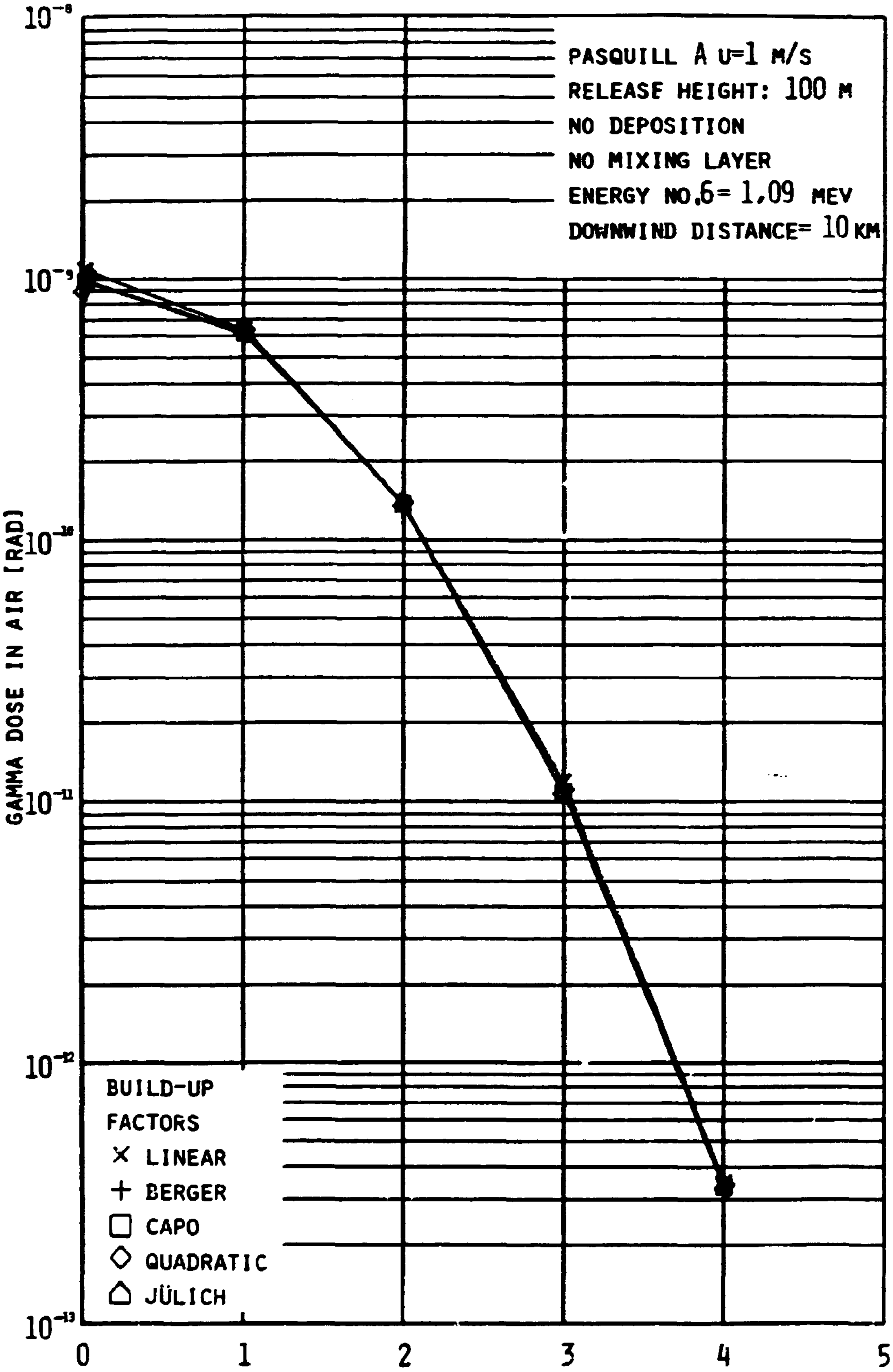


FIG. 69 NORMALIZED CROSSWIND DISTANCE, y/σ_Y

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

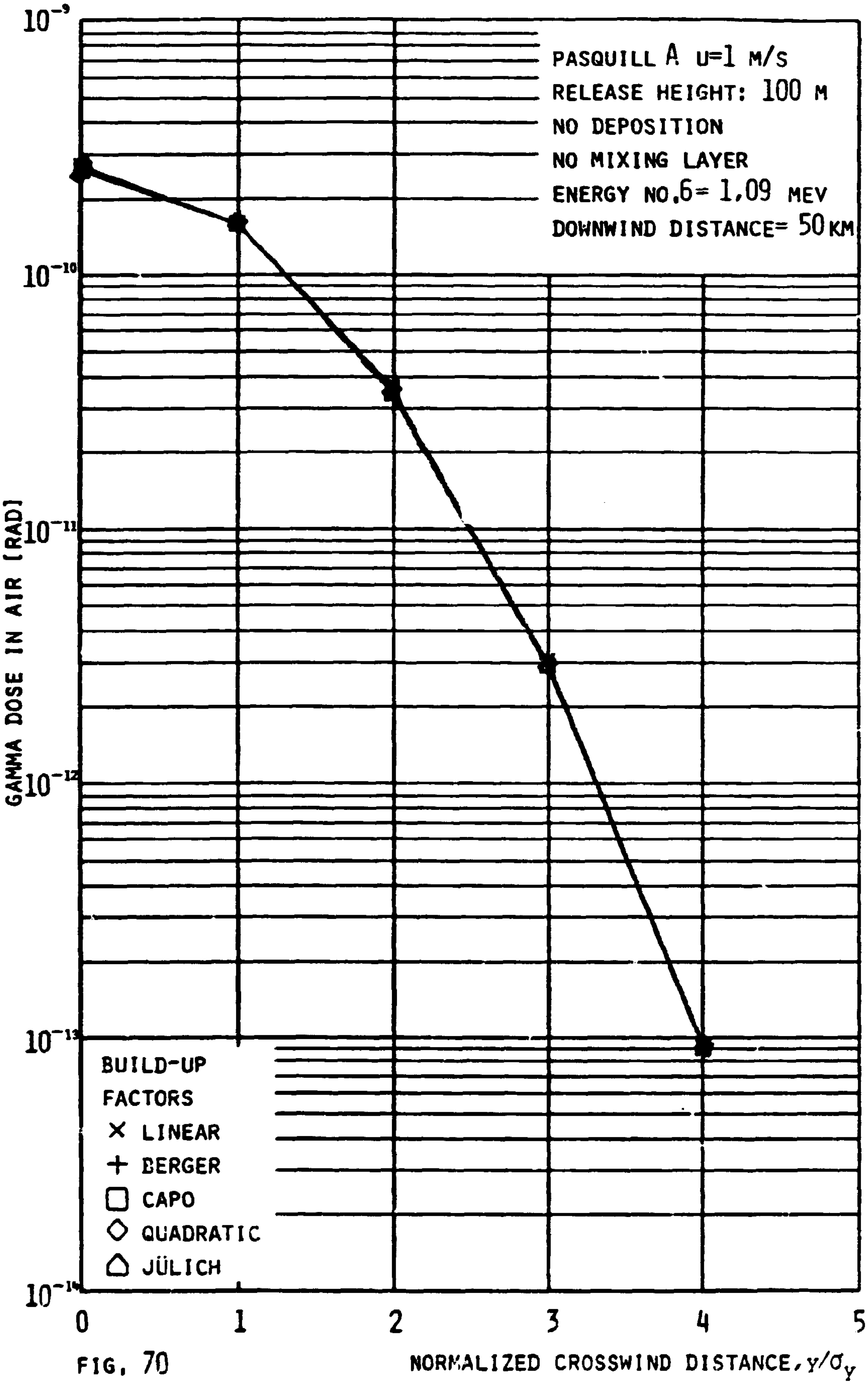


FIG. 70

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

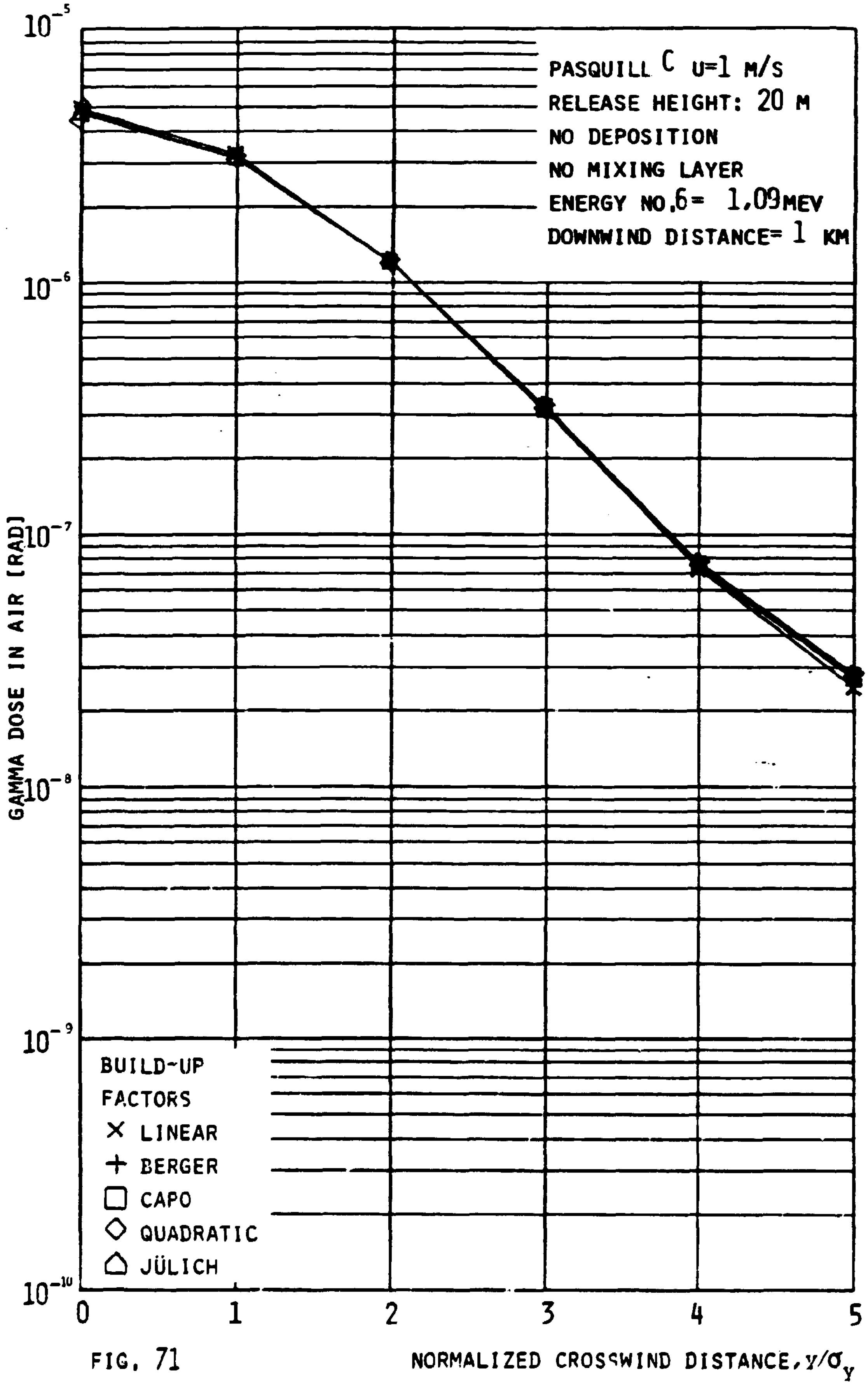


FIG. 71

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

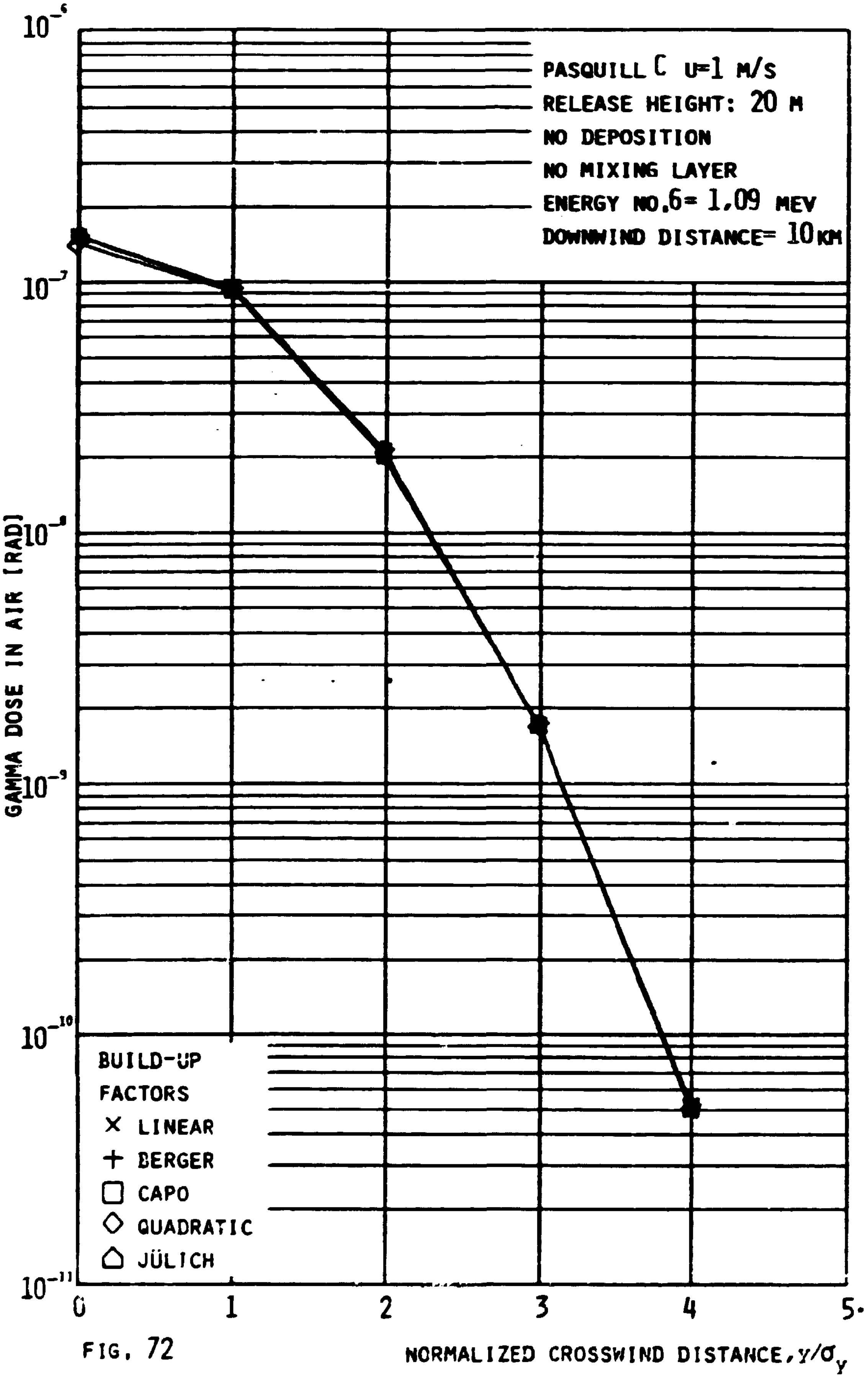
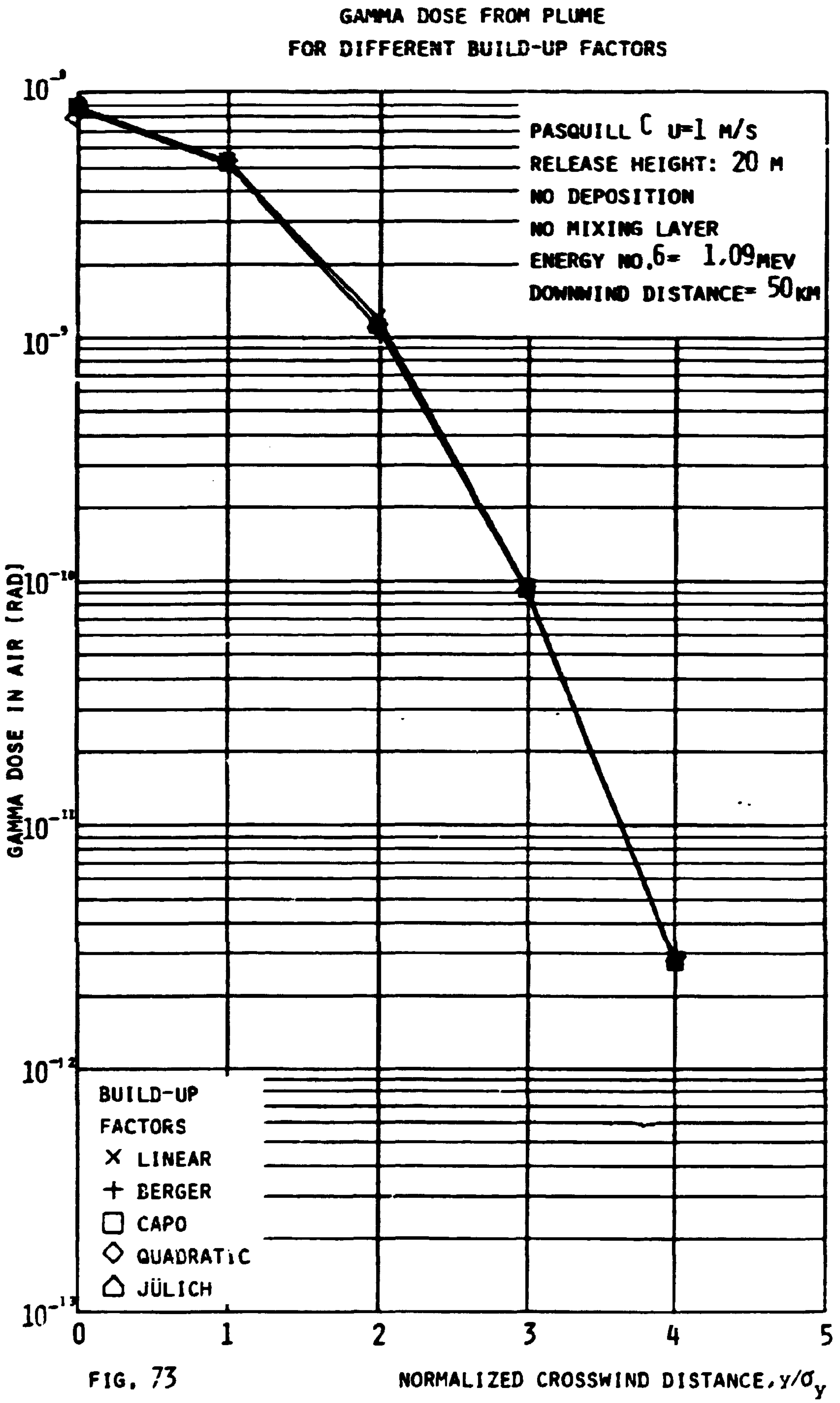


FIG. 72



GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 20 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.6= 1.09MEV
DOWNWIND DISTANCE= 50KM
GAMMA DOSE IN AIR (RAD)
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σ_y

FIG. 73

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

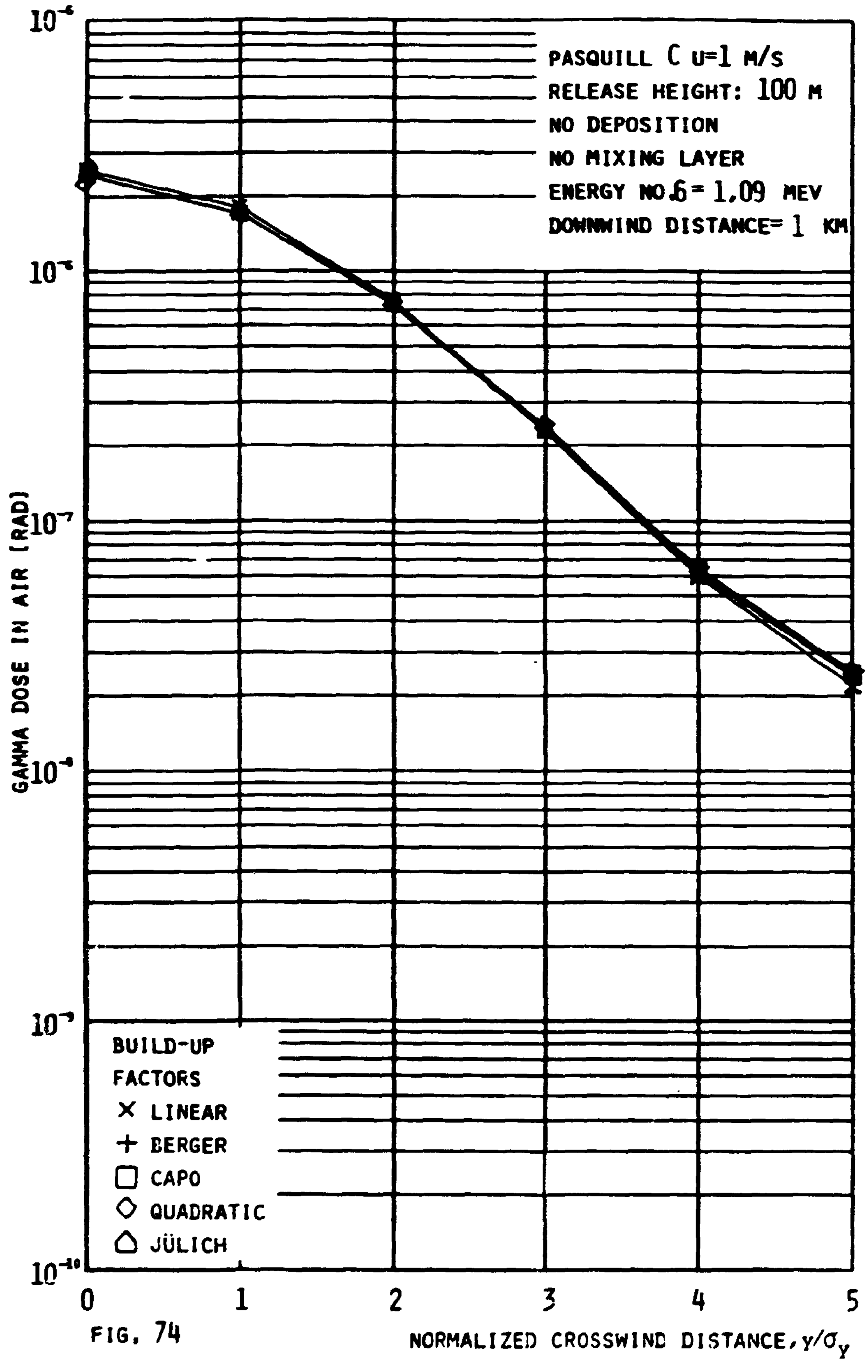


FIG. 74

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

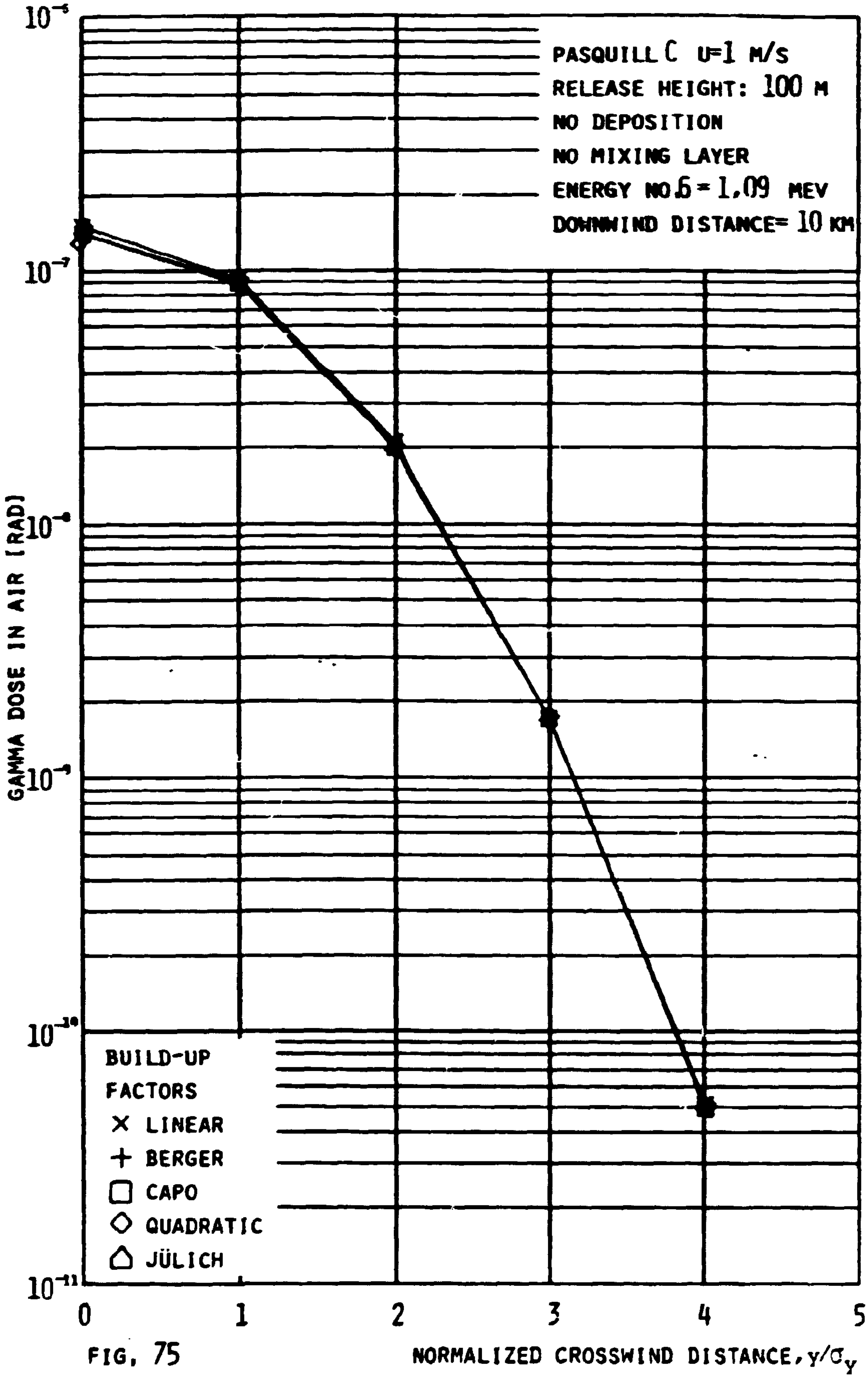


FIG. 75

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

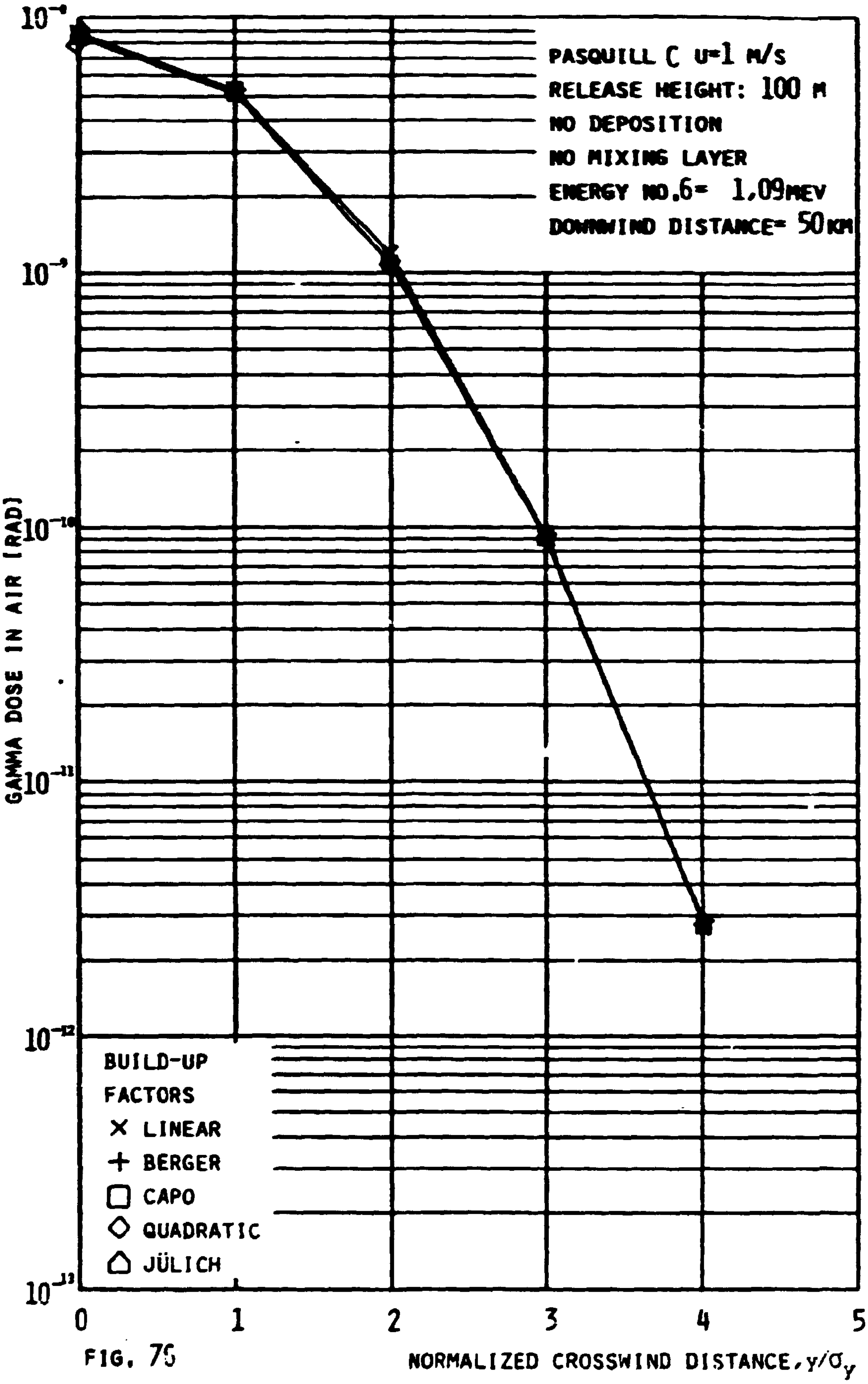


FIG. 75

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

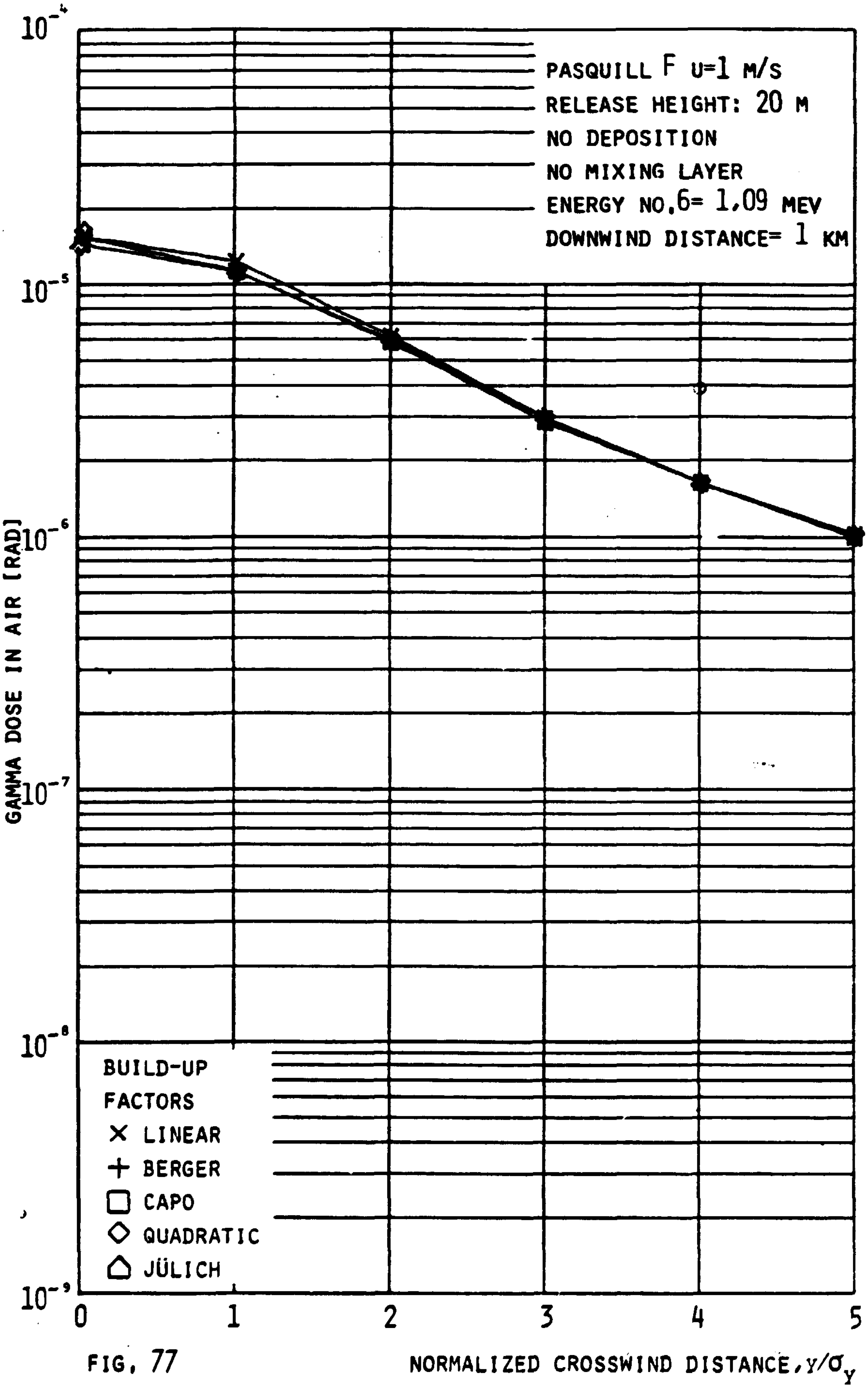


FIG. 77

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

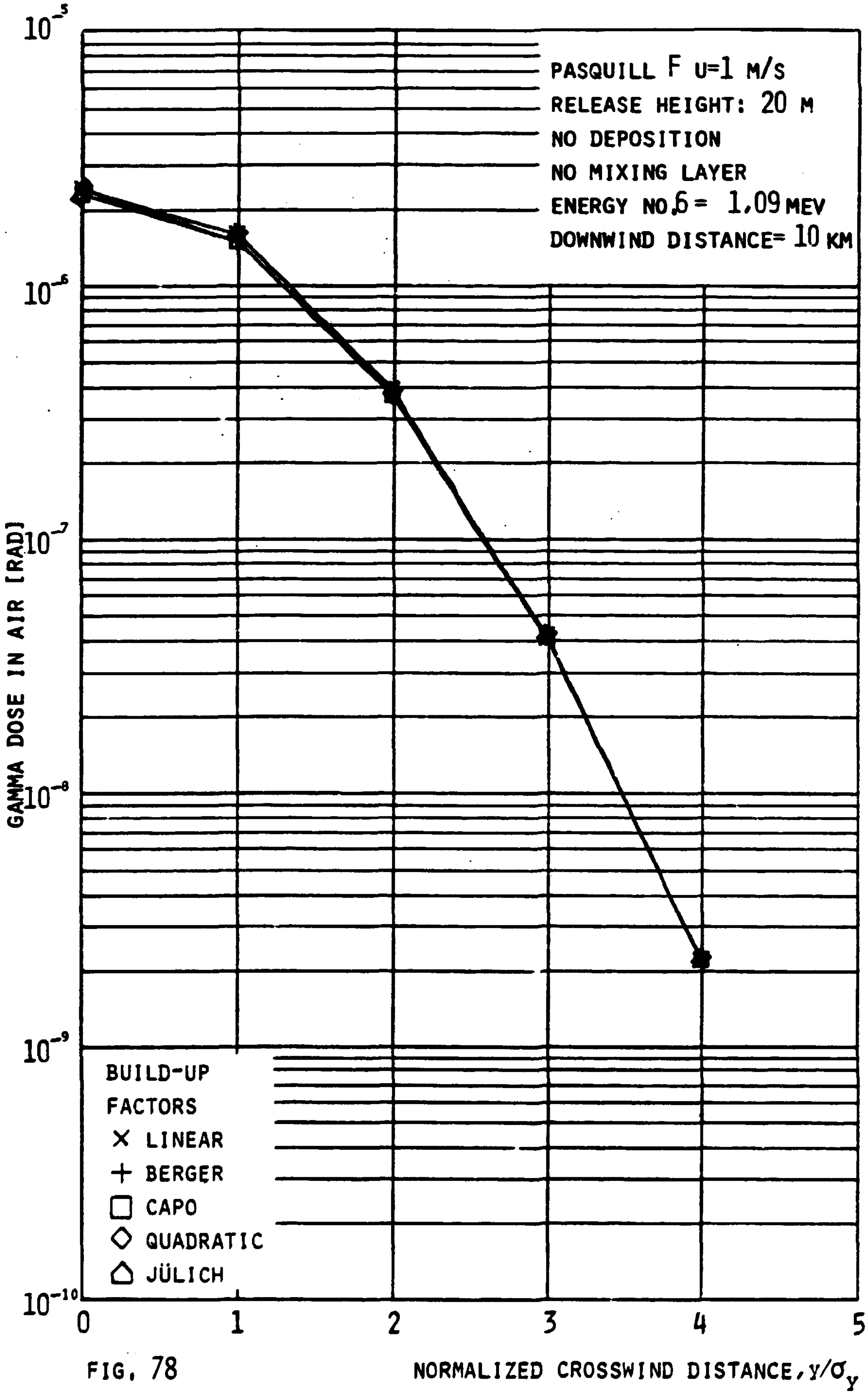


FIG. 78

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

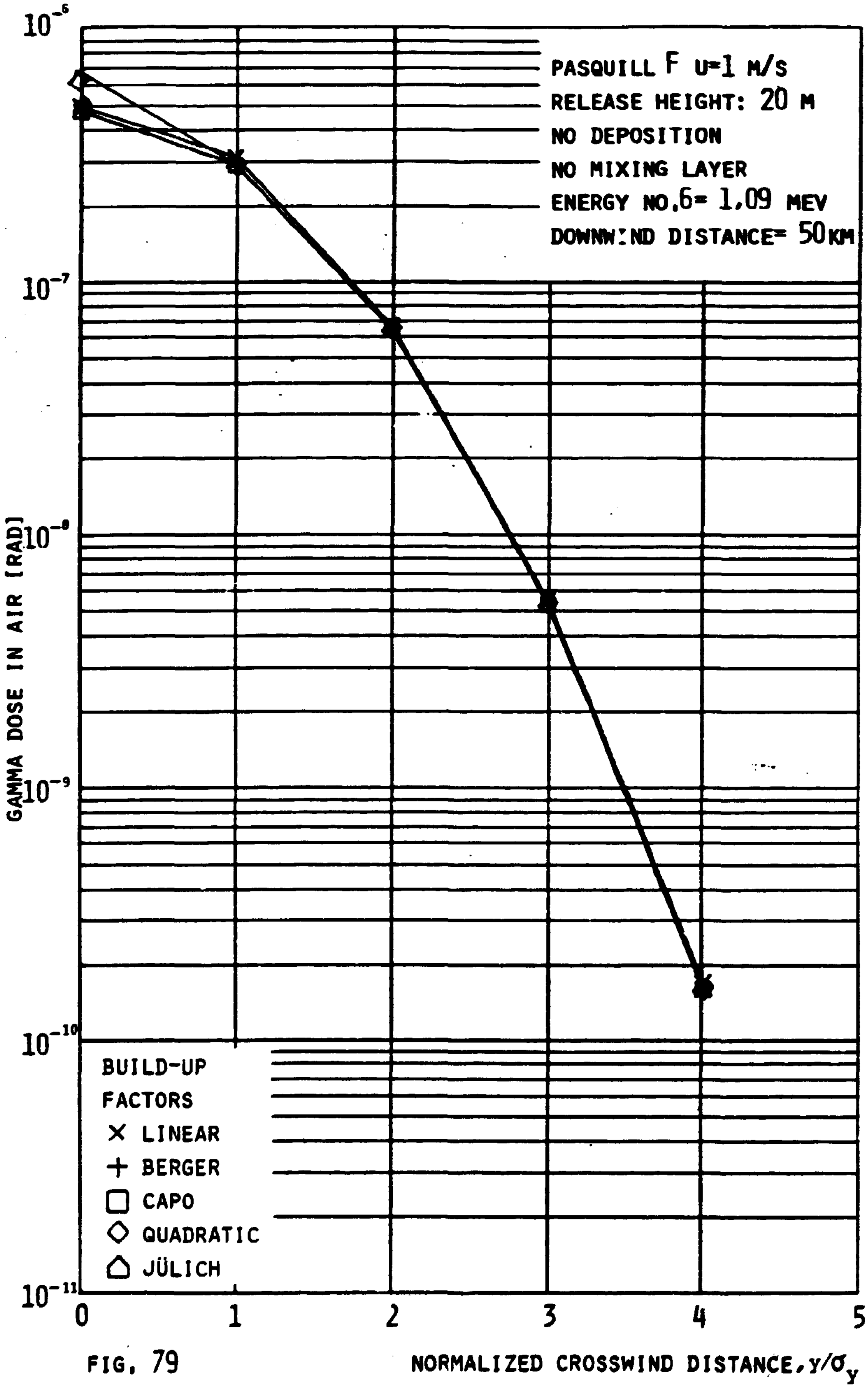
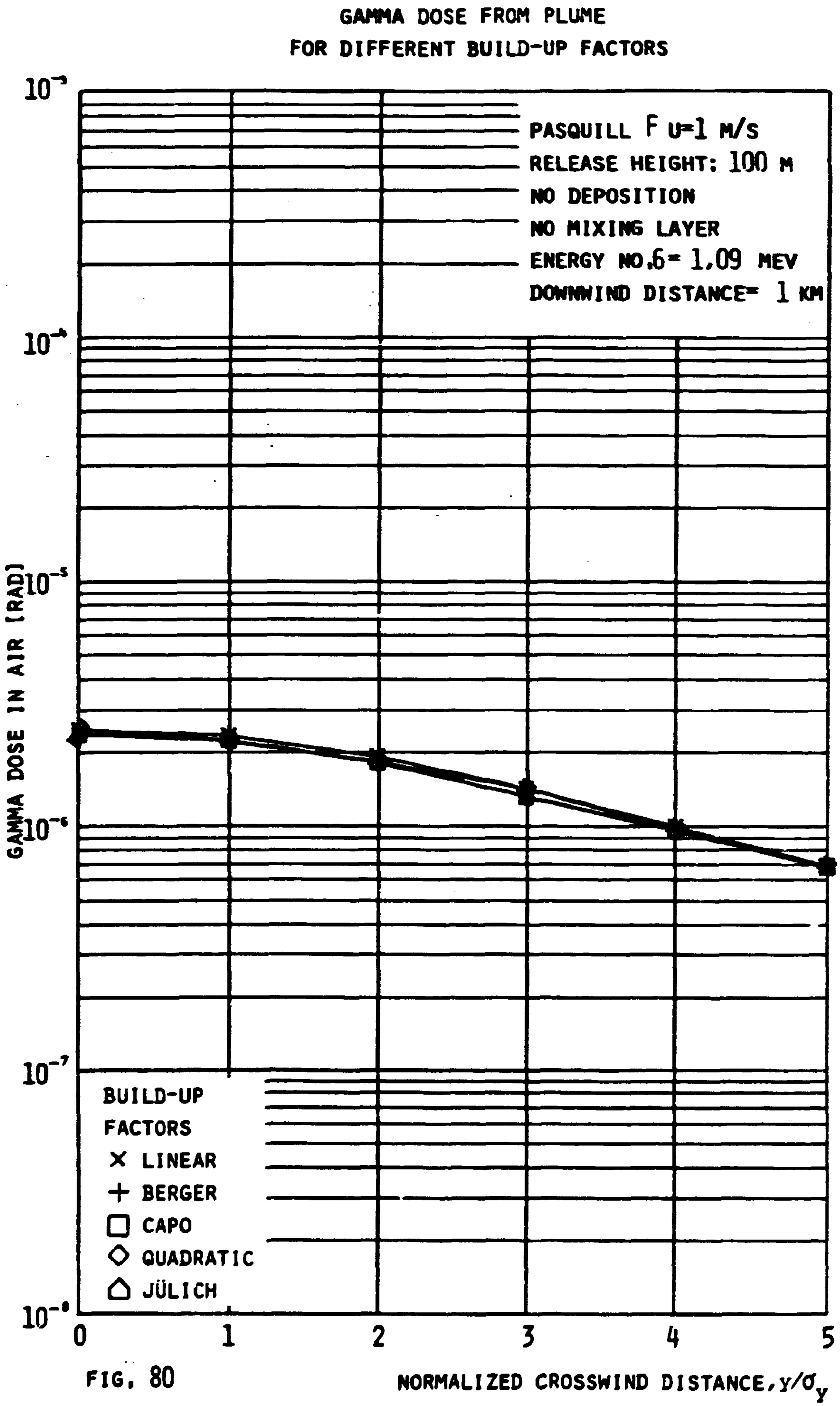


FIG. 79



GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL F U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.6= 1,09 MEV
DOWNWIND DISTANCE= 1 KM
GAMMA DOSE IN AIR [RAD]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σ_y

FIG. 80

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

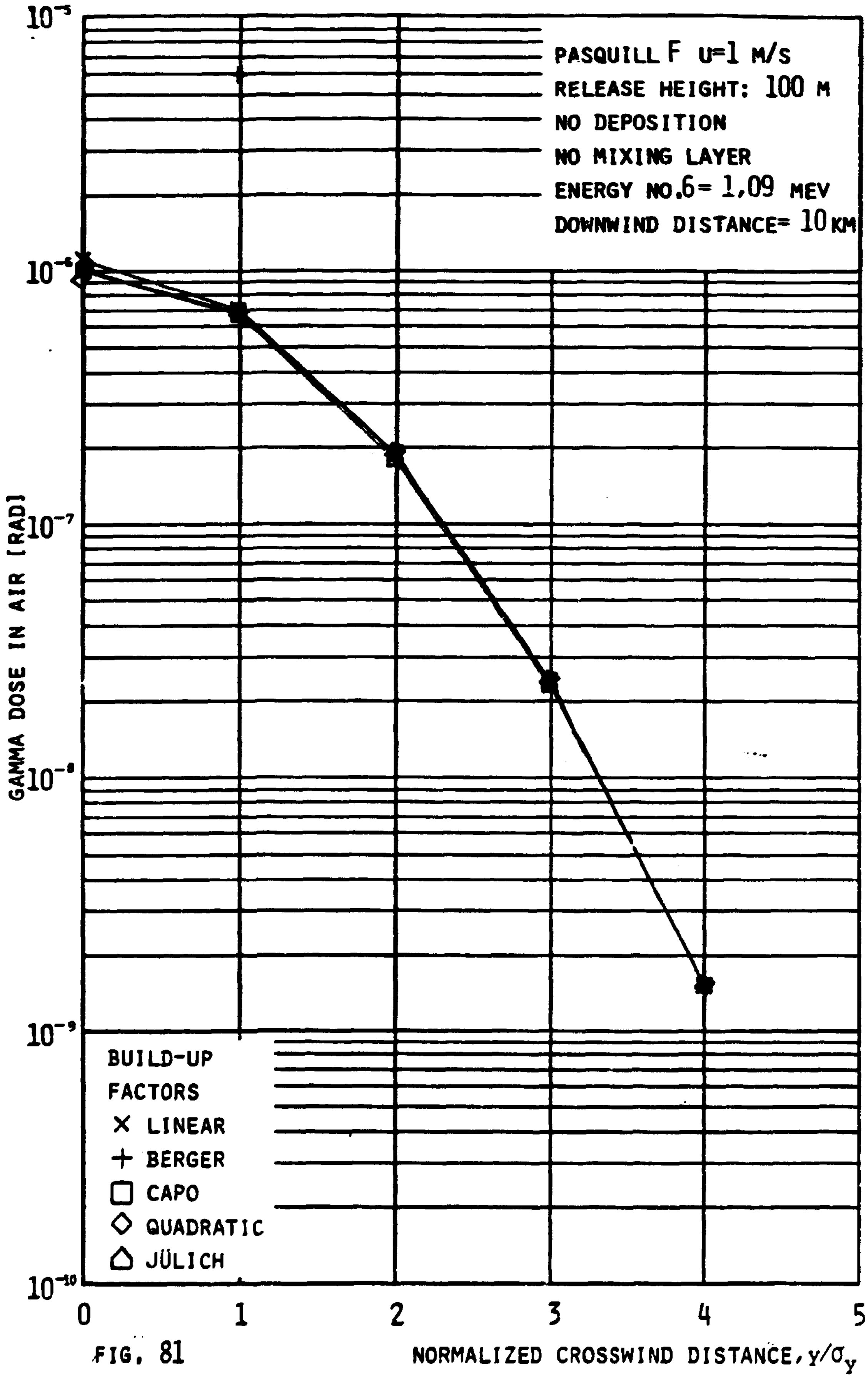


FIG. 81

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

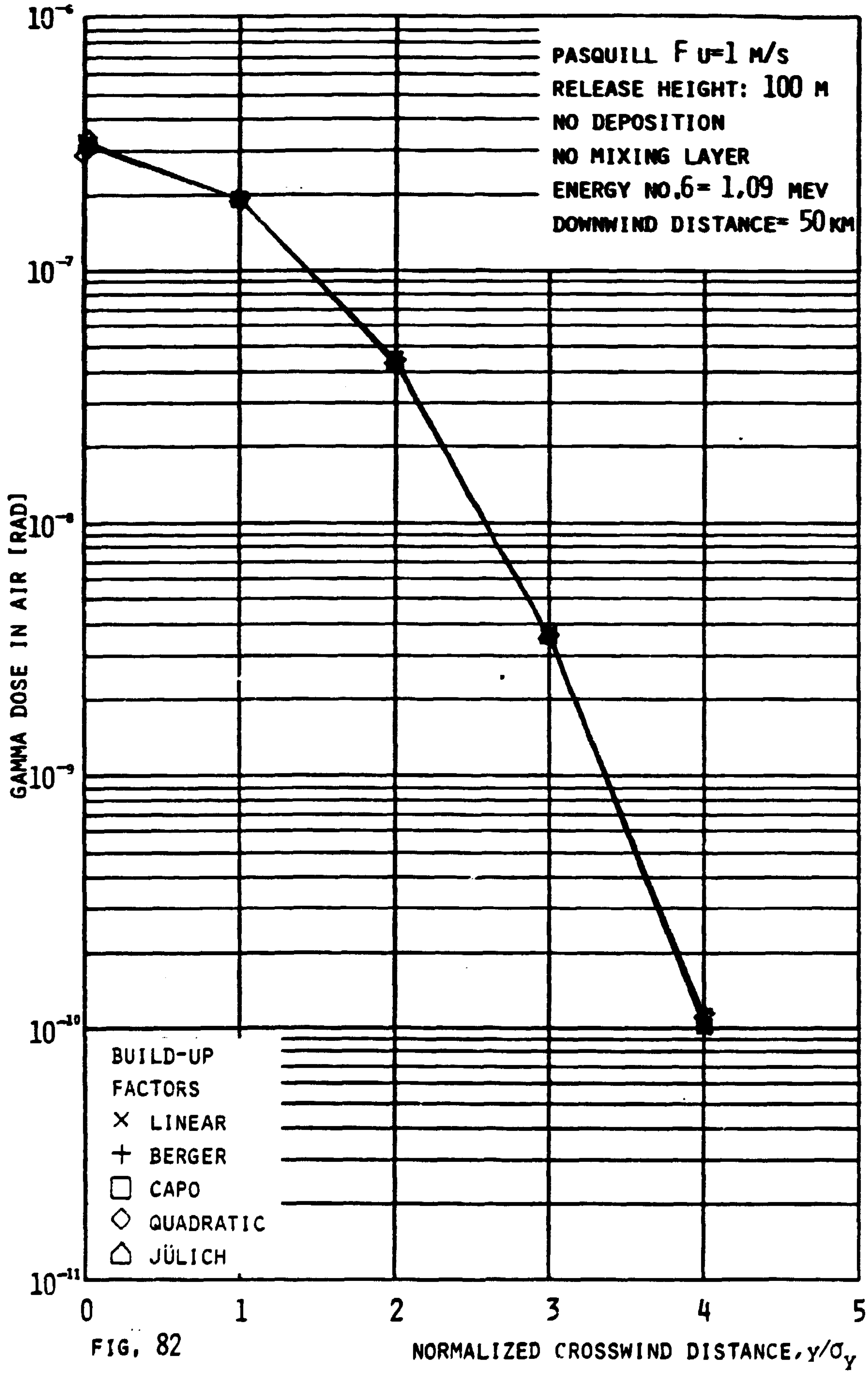


FIG. 82

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

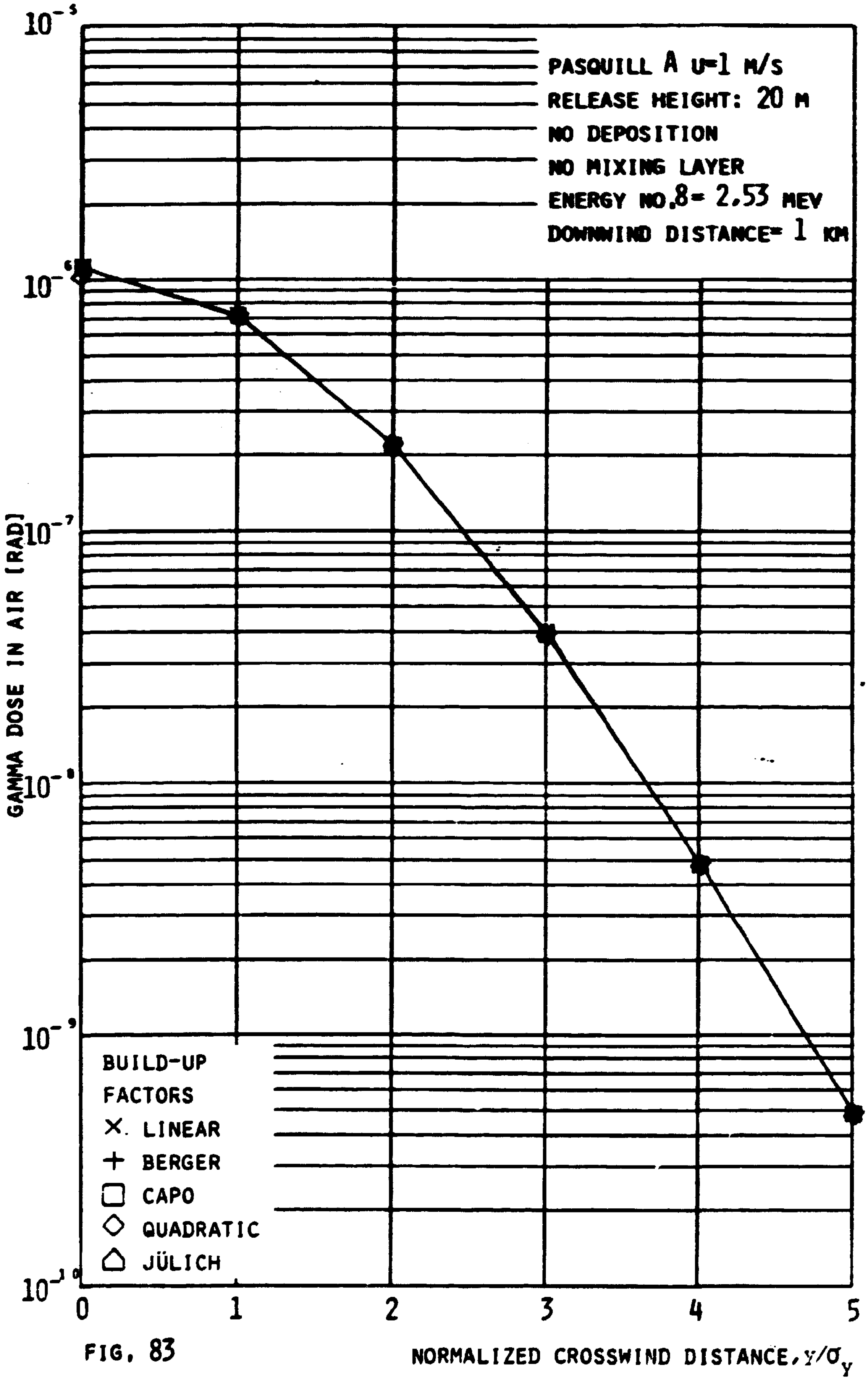


FIG. 83

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

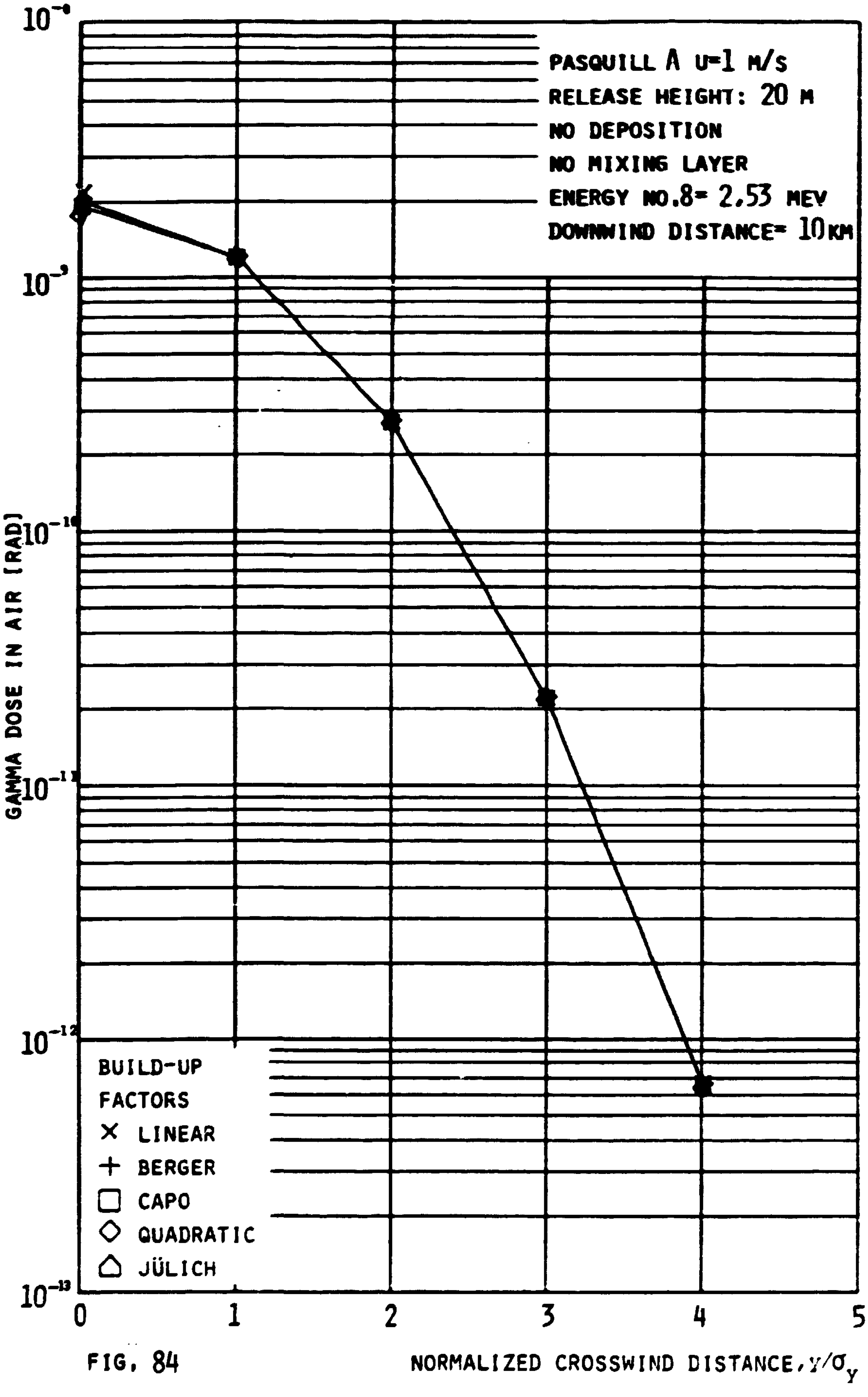


FIG. 84

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

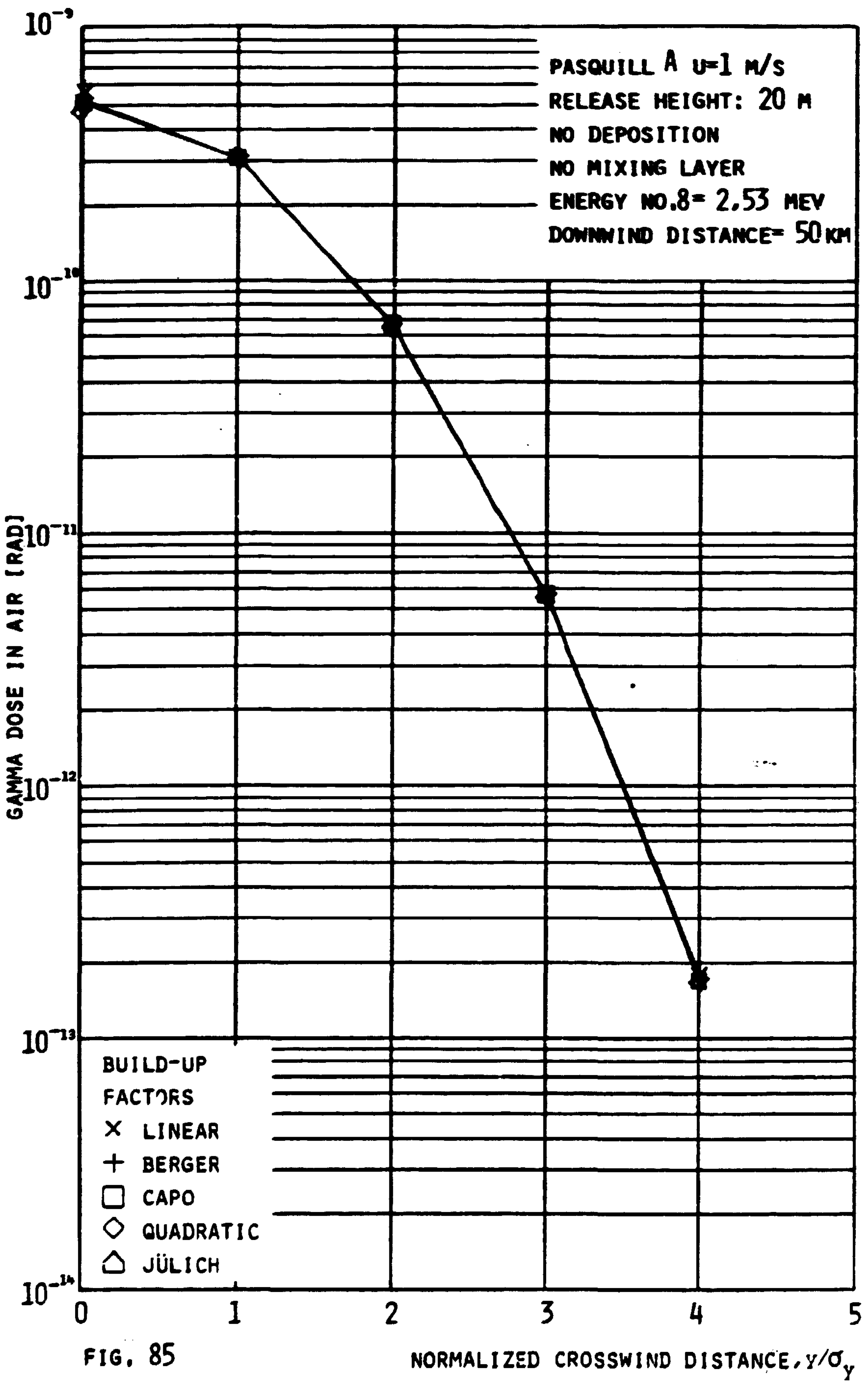


FIG. 85

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

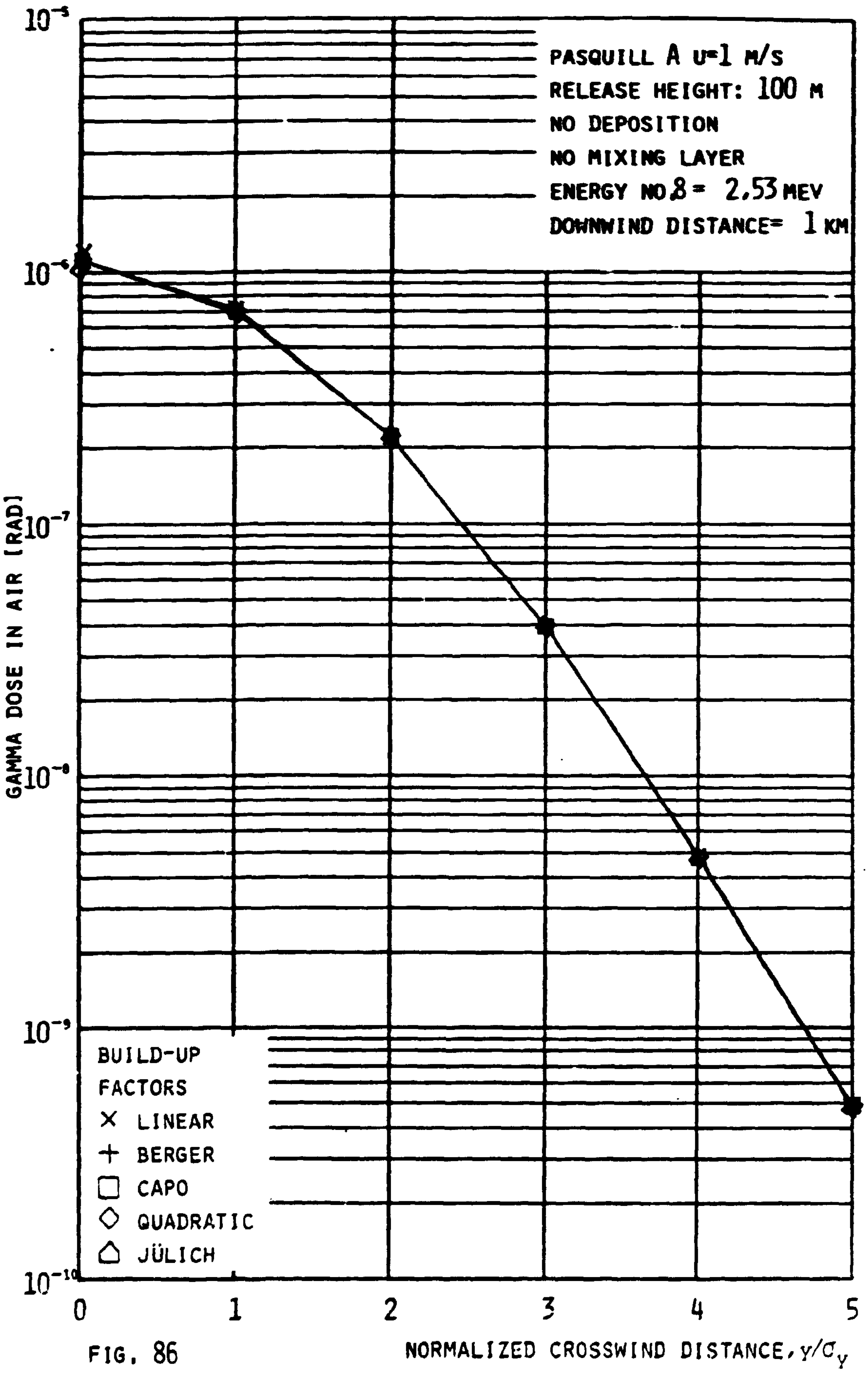


FIG. 86

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

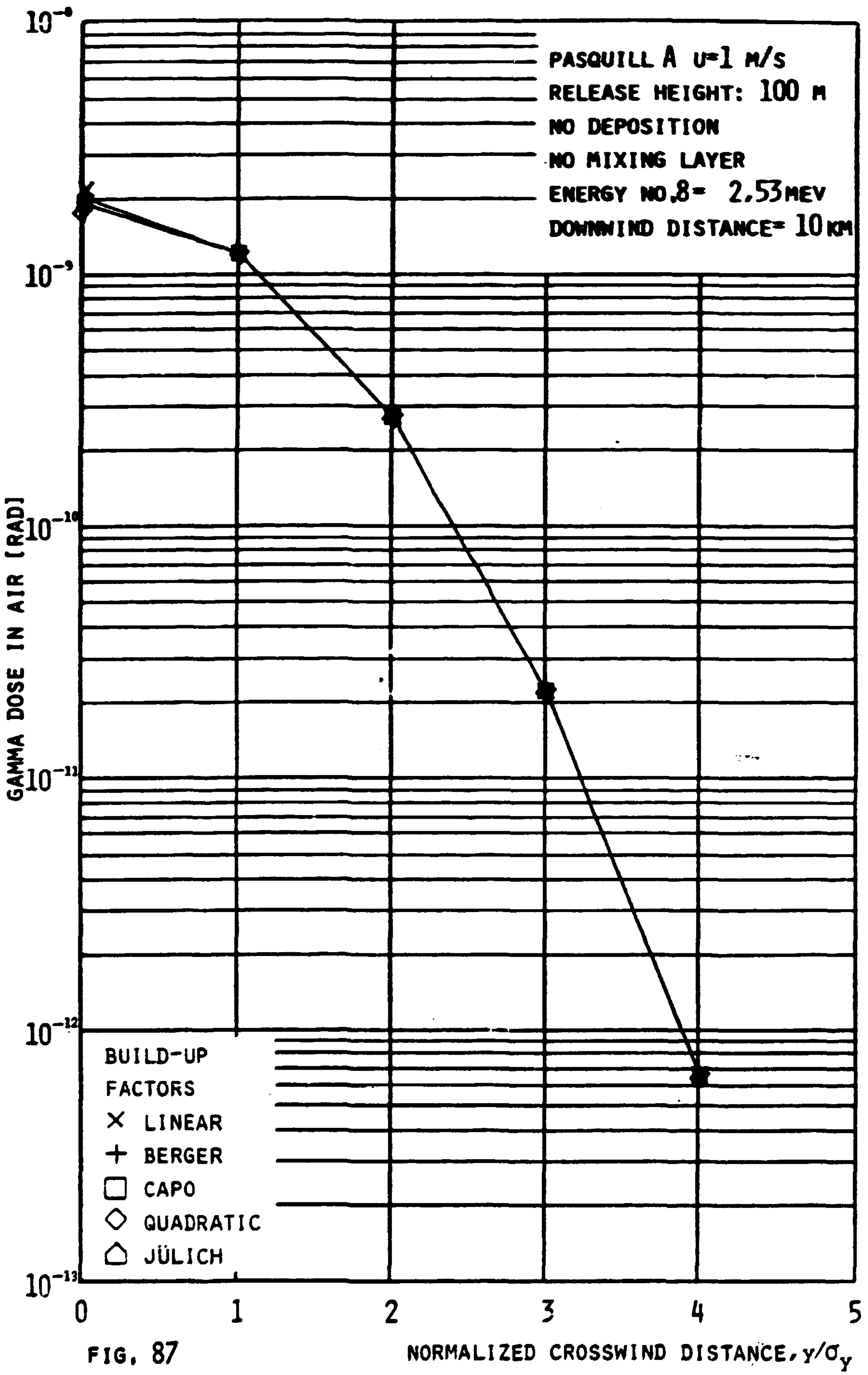


FIG. 87

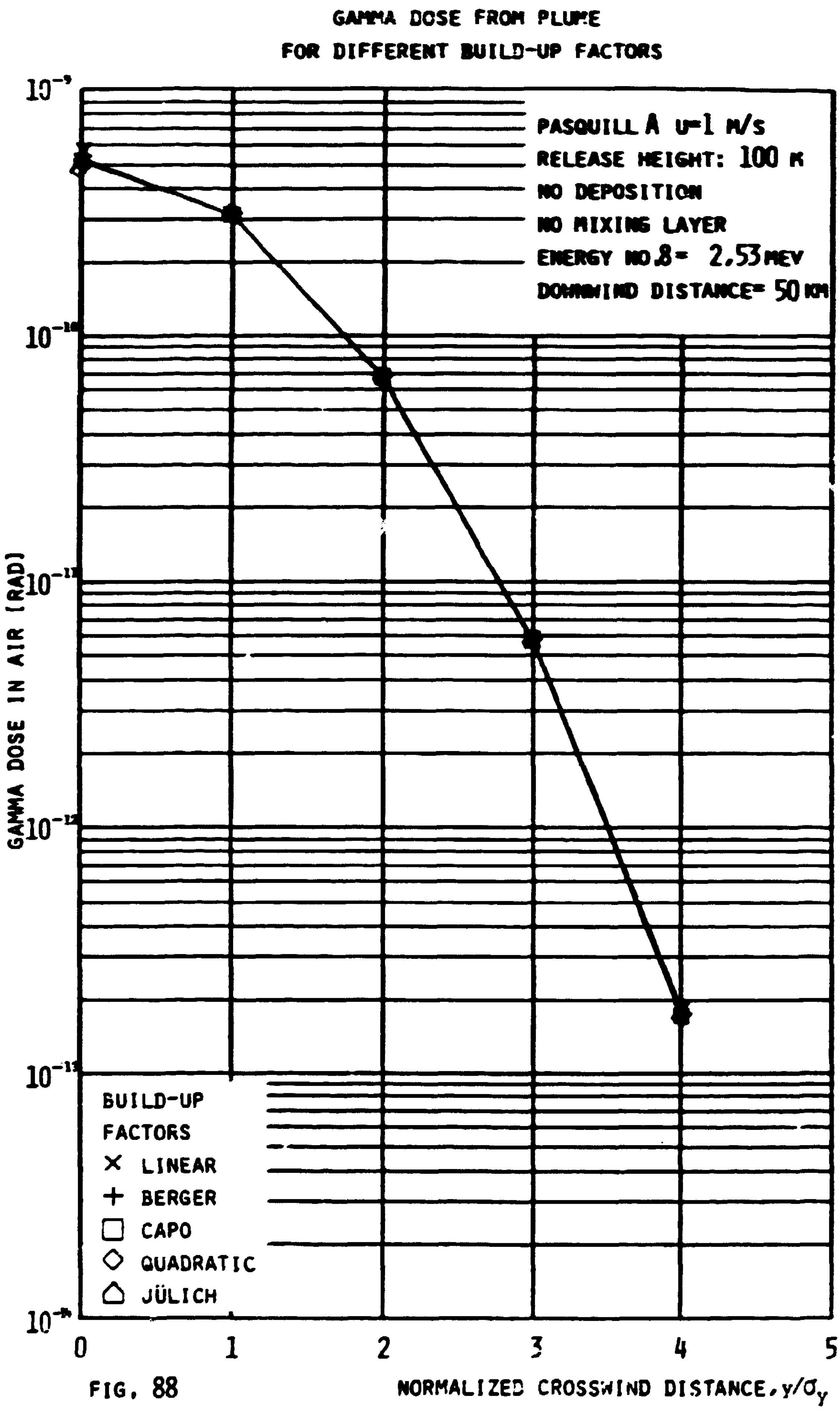

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL A u=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.8= 2.53 MEV
DOWNWIND DISTANCE= 50 KM
GAMMA DOSE IN AIR [RAD]
NORMALIZED CROSSWIND DISTANCE, y/σy
BUILD-UP
FACTORS
LINEAR
BERGER
CAPO
QUADRATIC
JÜLICH

FIG. 88

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

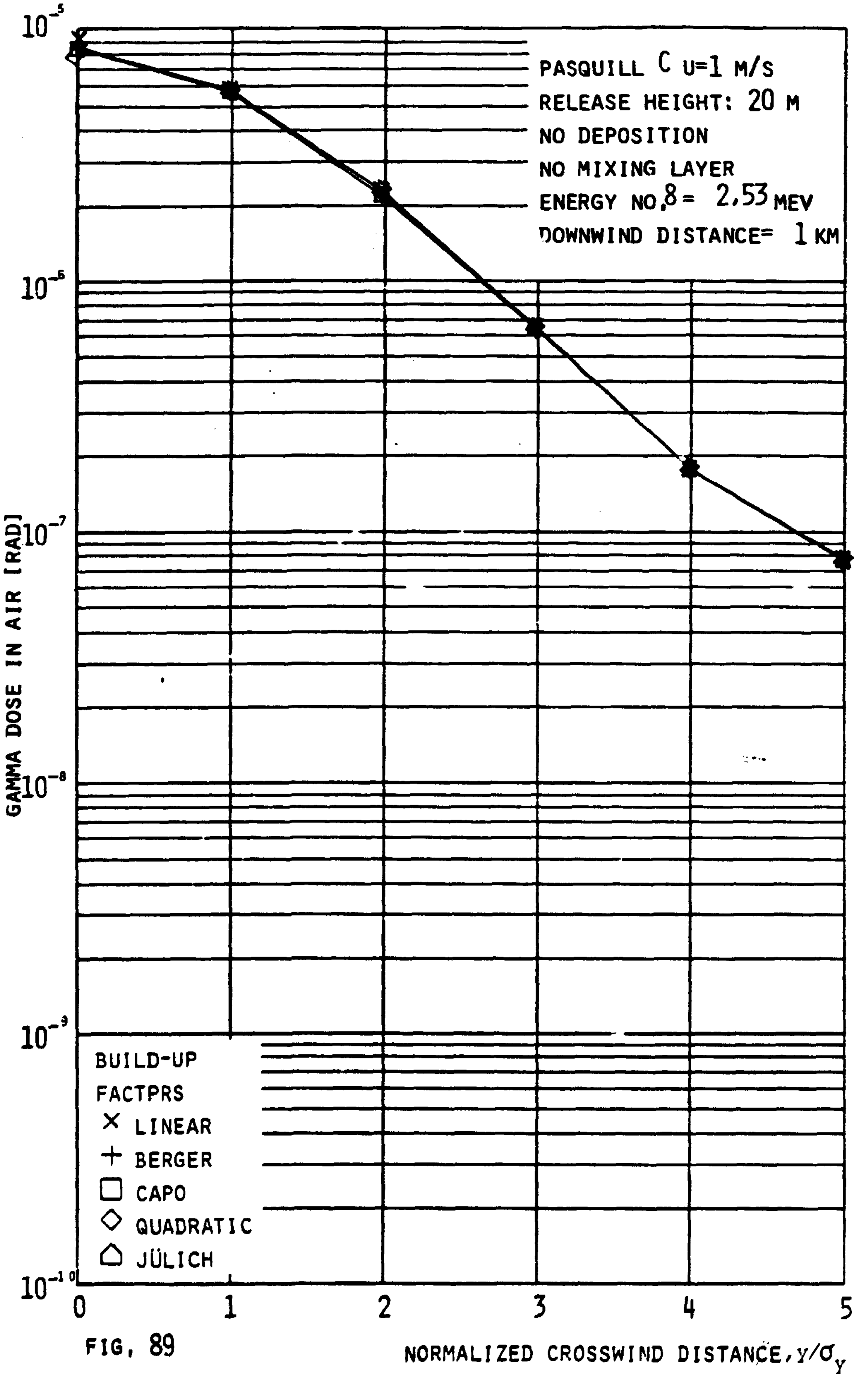


FIG. 89

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

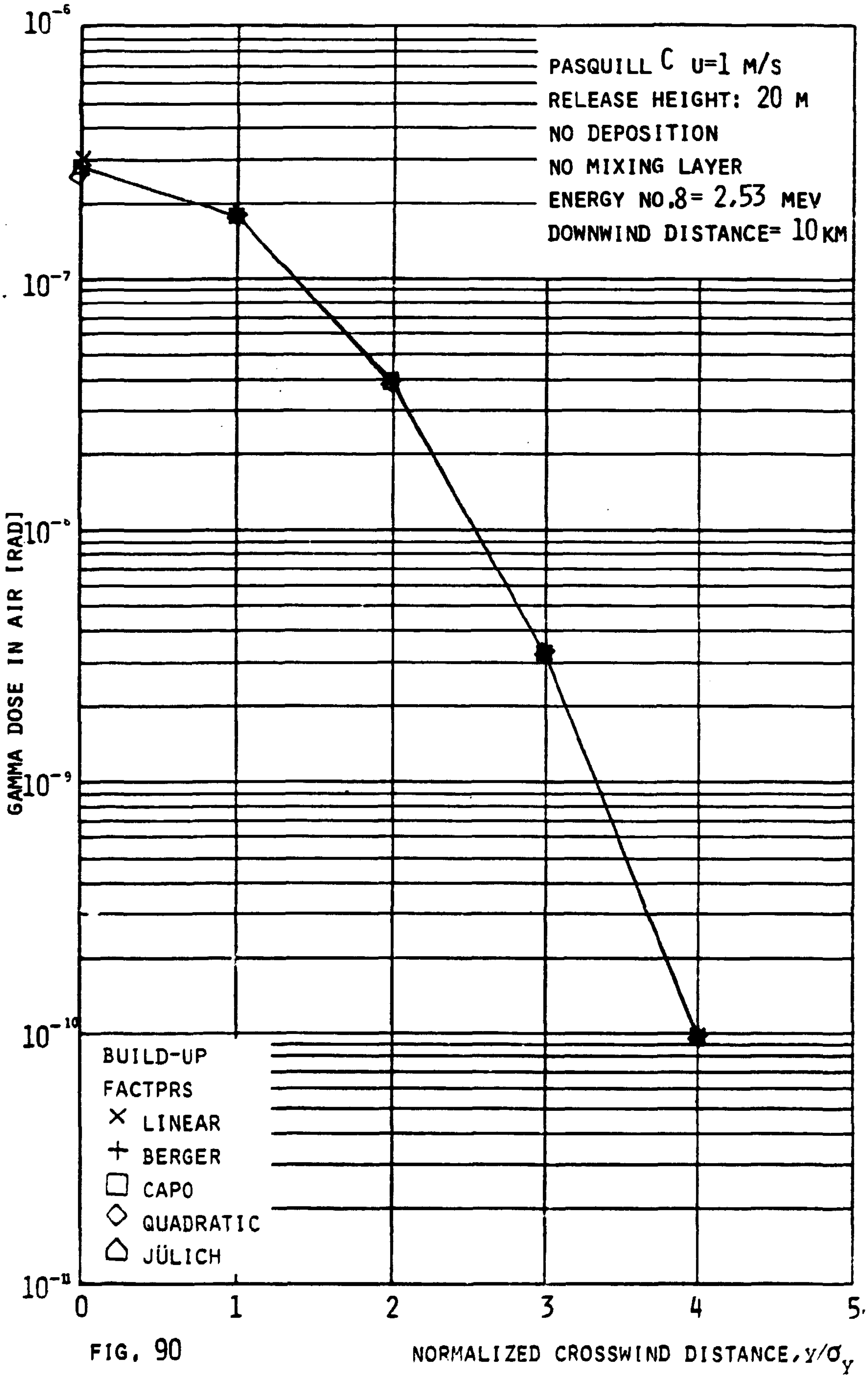
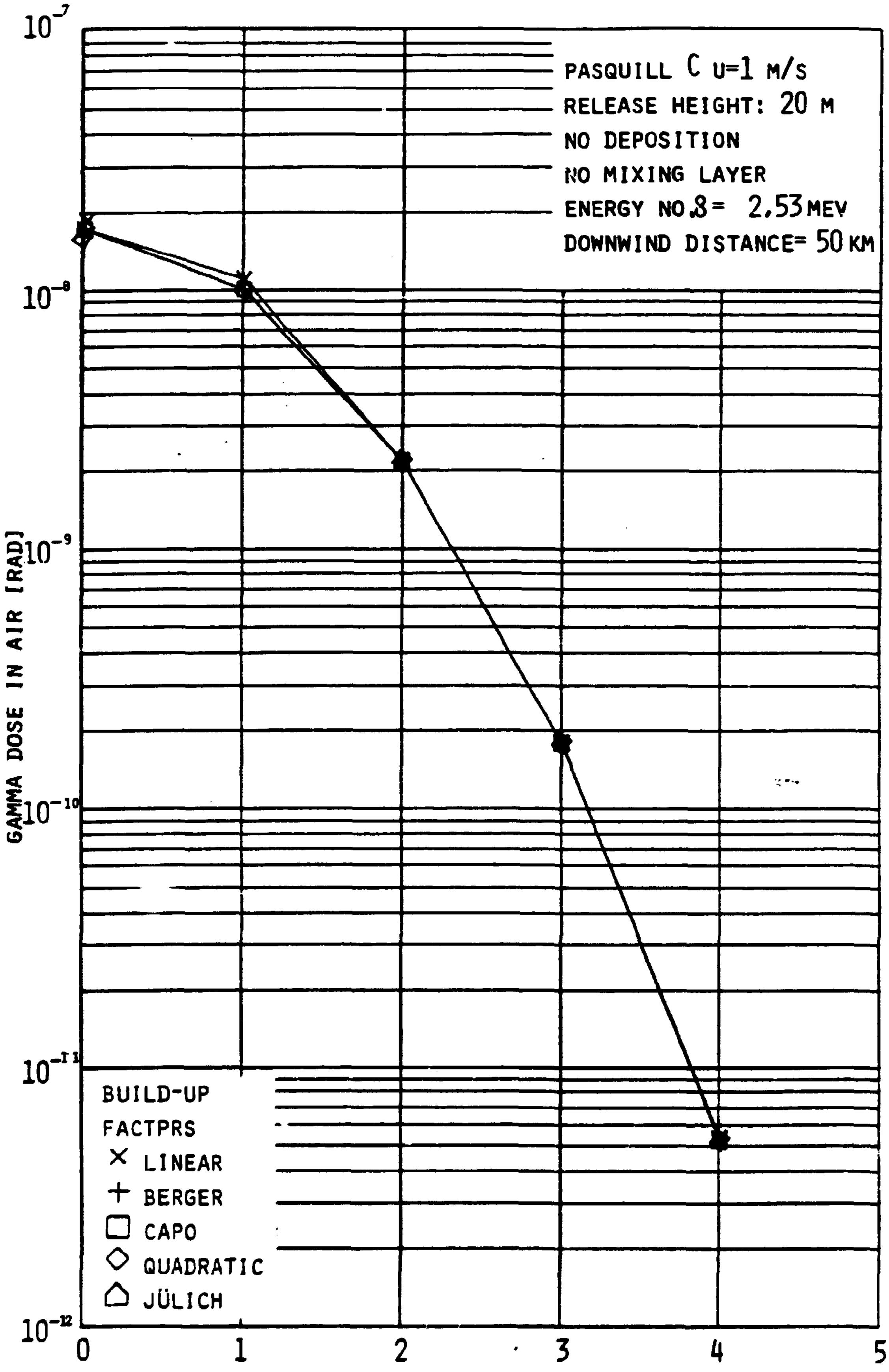


FIG. 90

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS



FIG, 91

NORMALIZED CROSSWIND DISTANCE, y/σ_Y

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

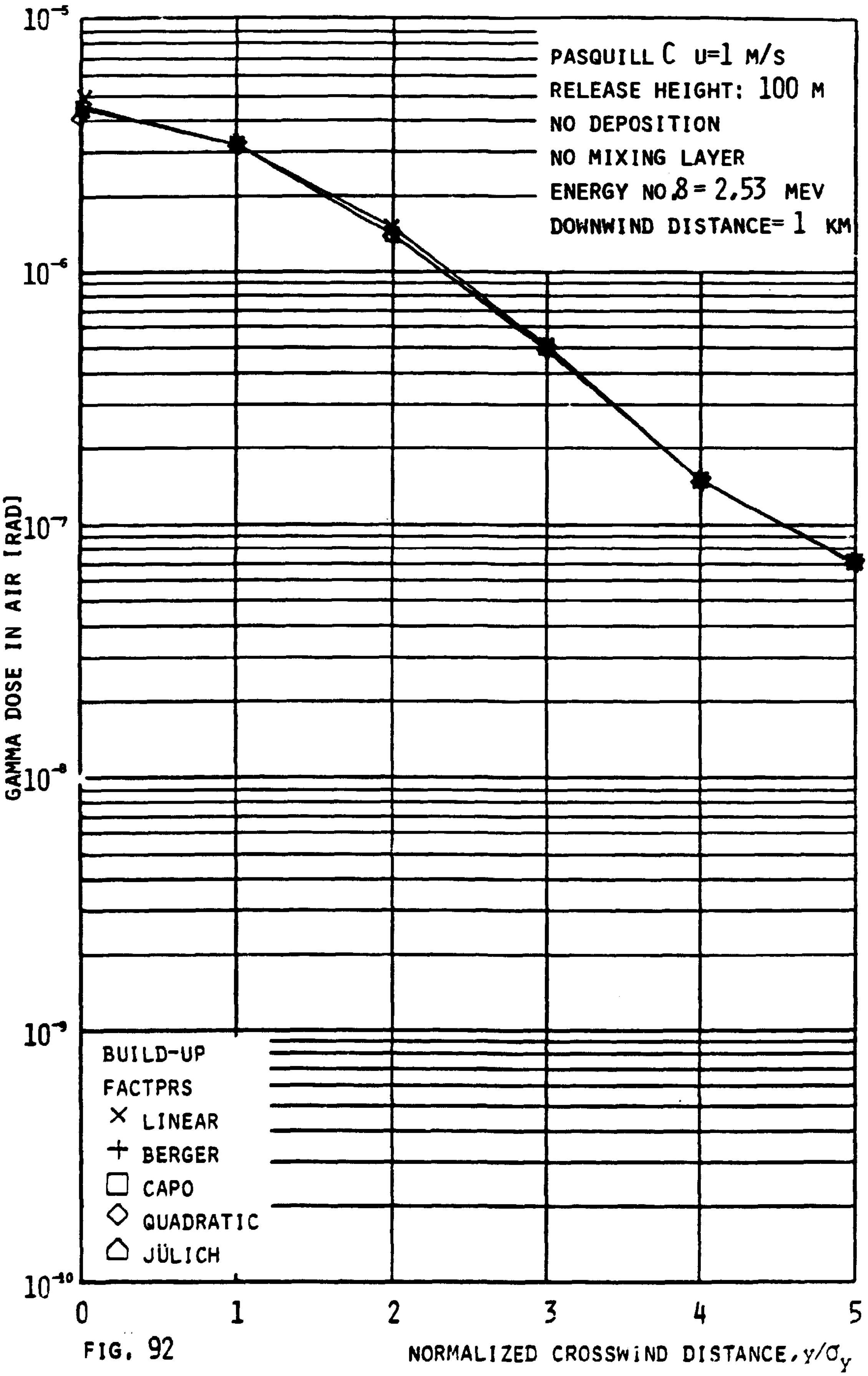


FIG. 92

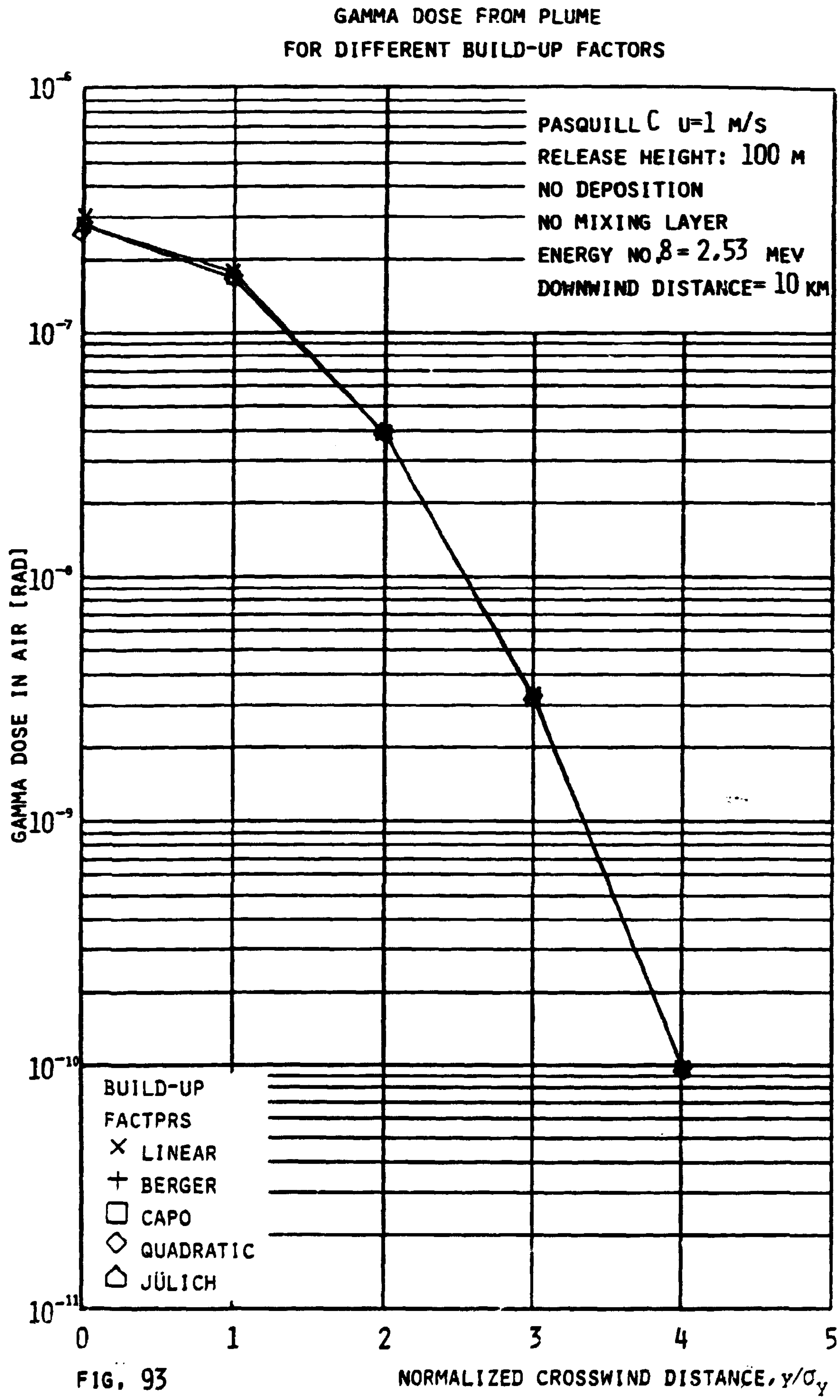

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL C U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.8 = 2.53 MEV
DOWNWIND DISTANCE= 10 KM
GAMMA DOSE IN AIR [RAD]
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
BUILD-UP
FACTPRS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
⌂ JÜLICH
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σY

FIG. 93

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

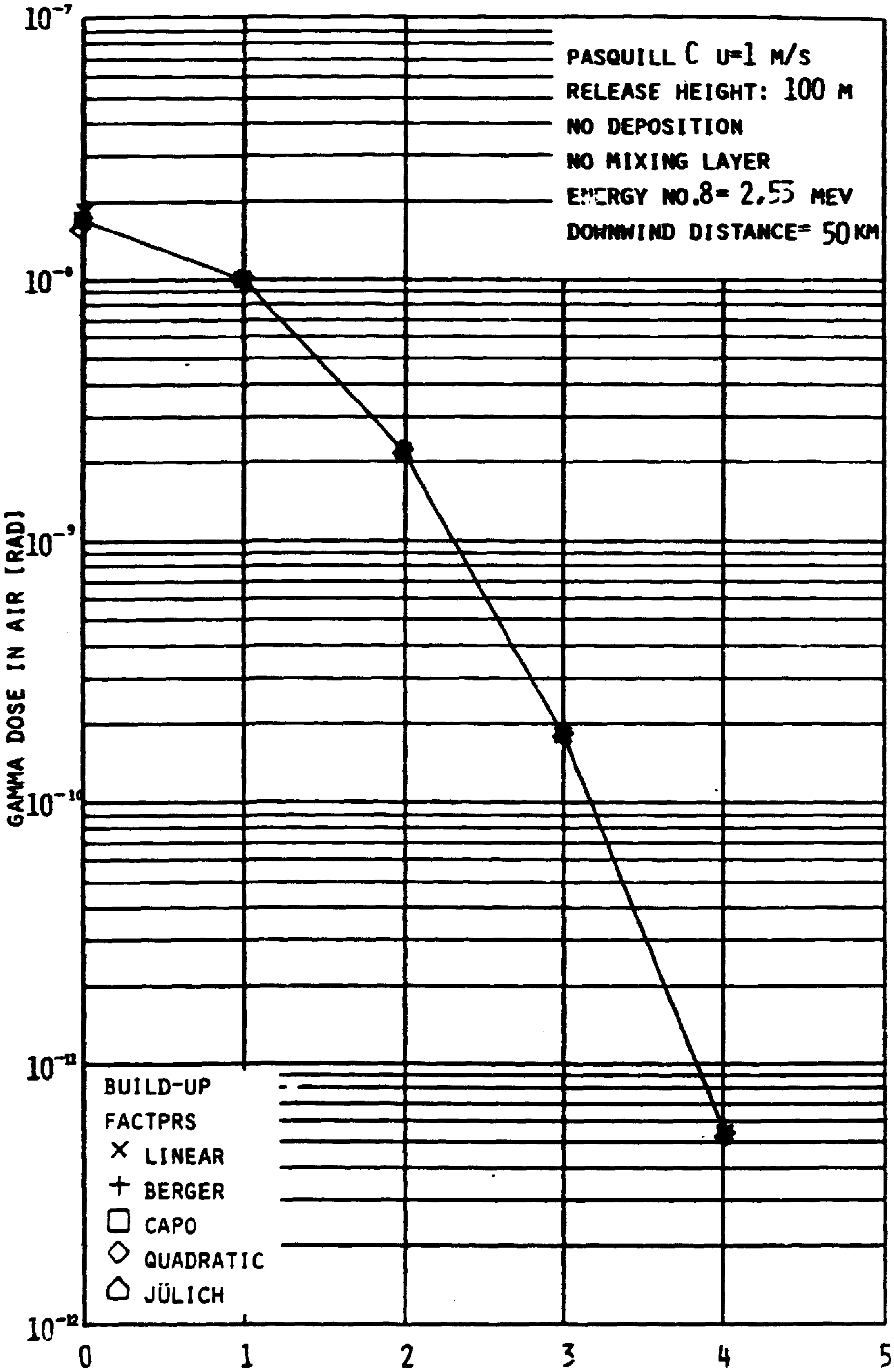


FIG. 94 NORMALIZED CROSSWIND DISTANCE, y/σ_y

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

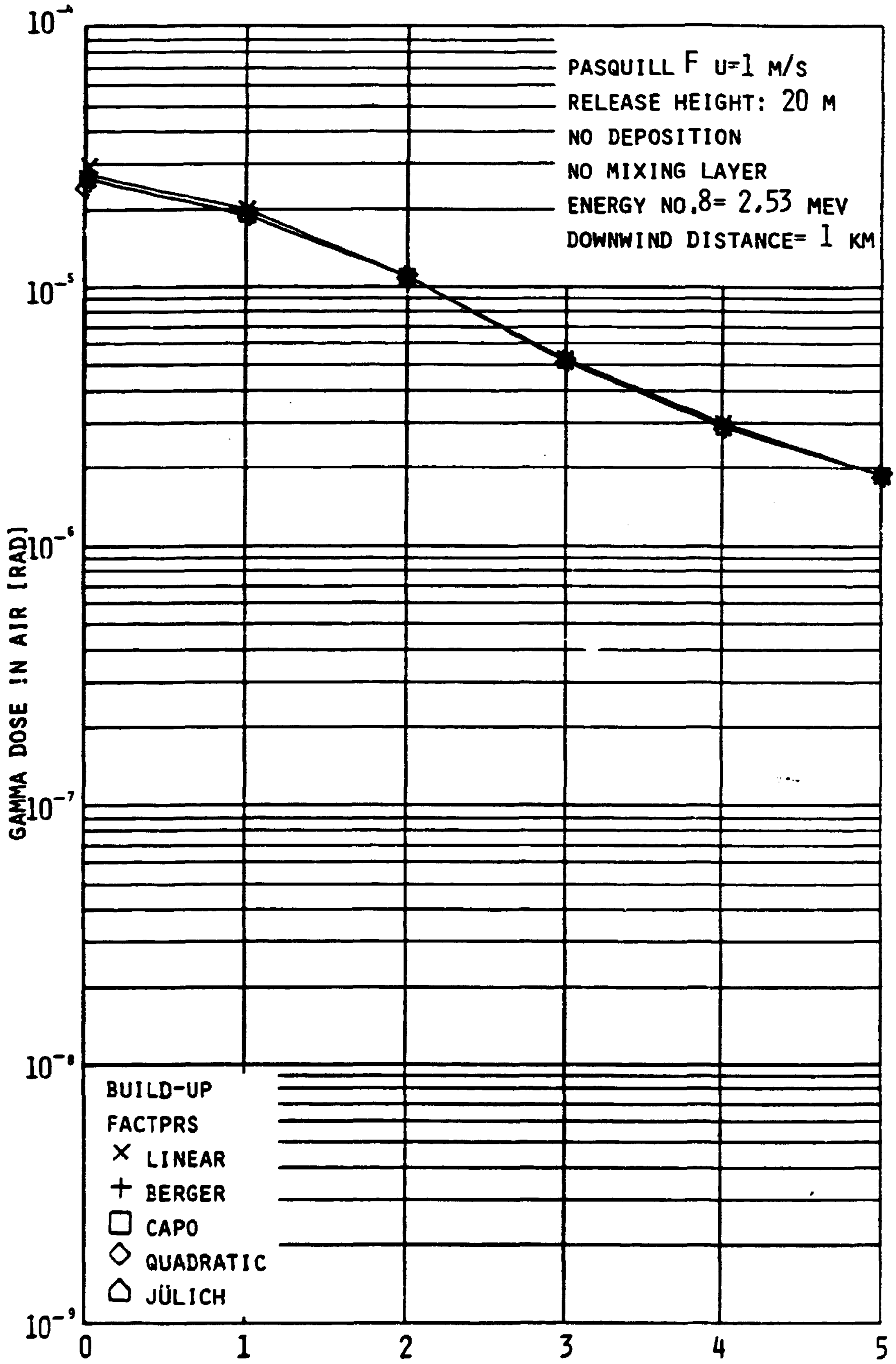


FIG. 95 NORMALIZED CROSSWIND DISTANCE, y/σ_y

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

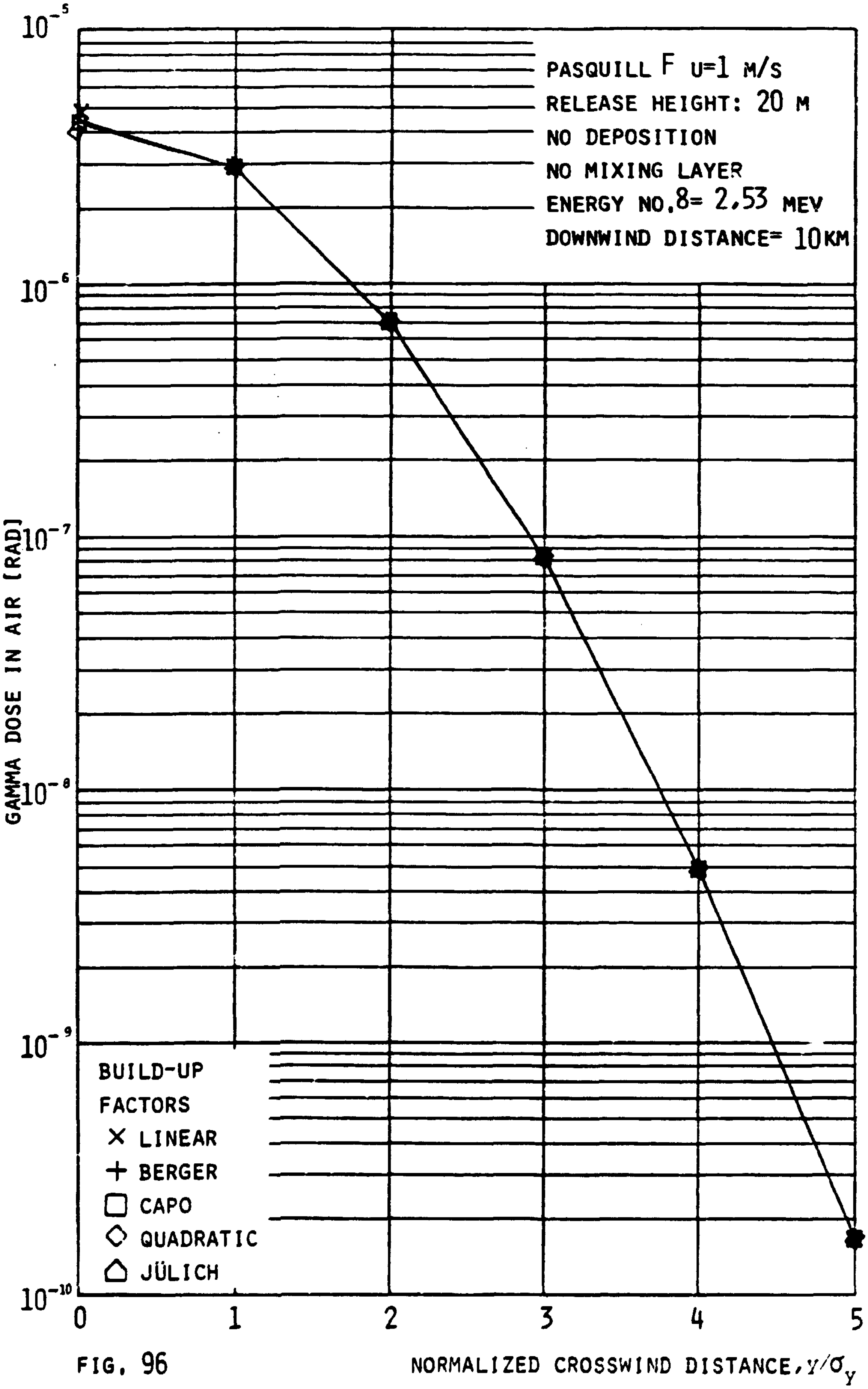


FIG. 96

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

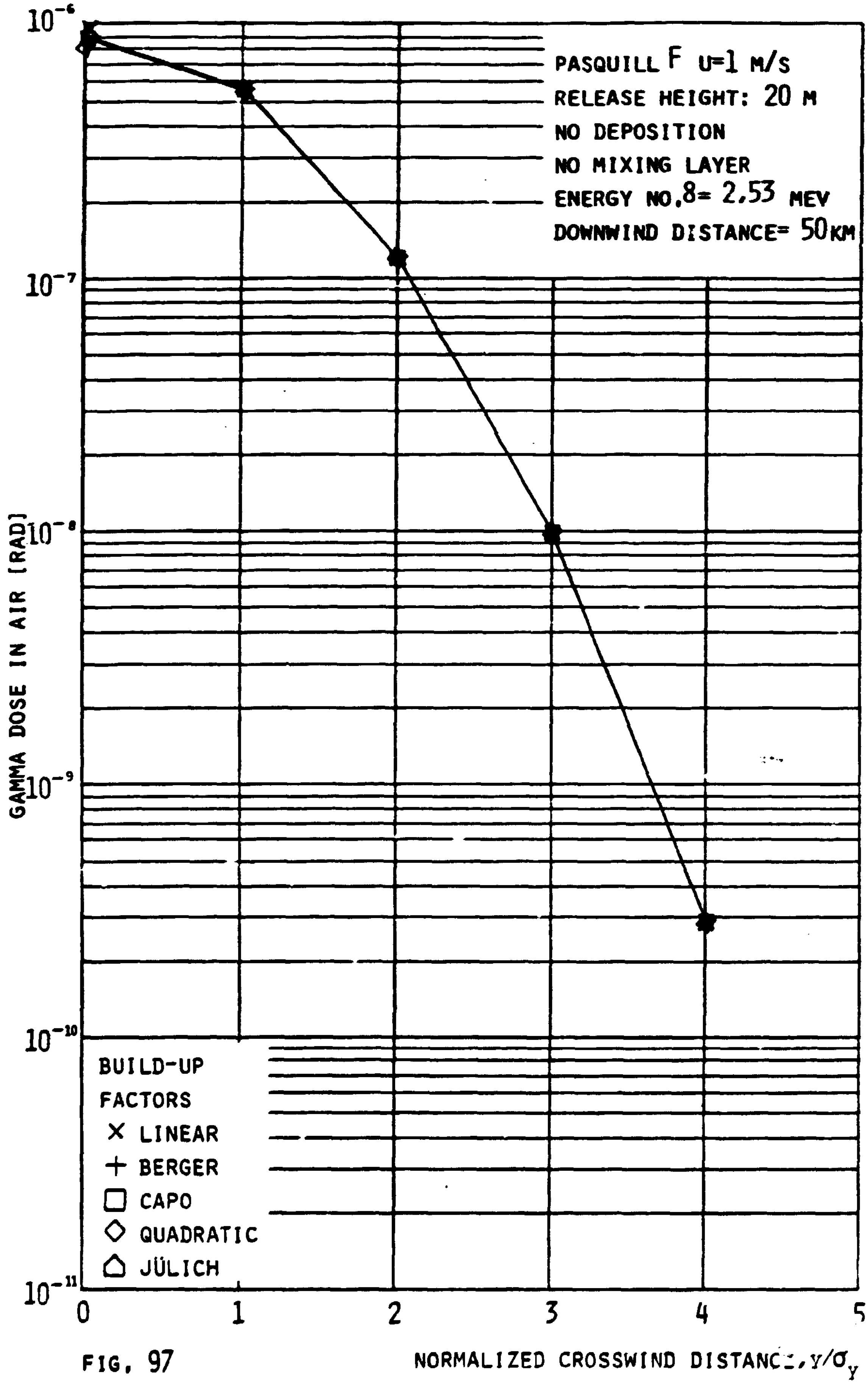


FIG. 97

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

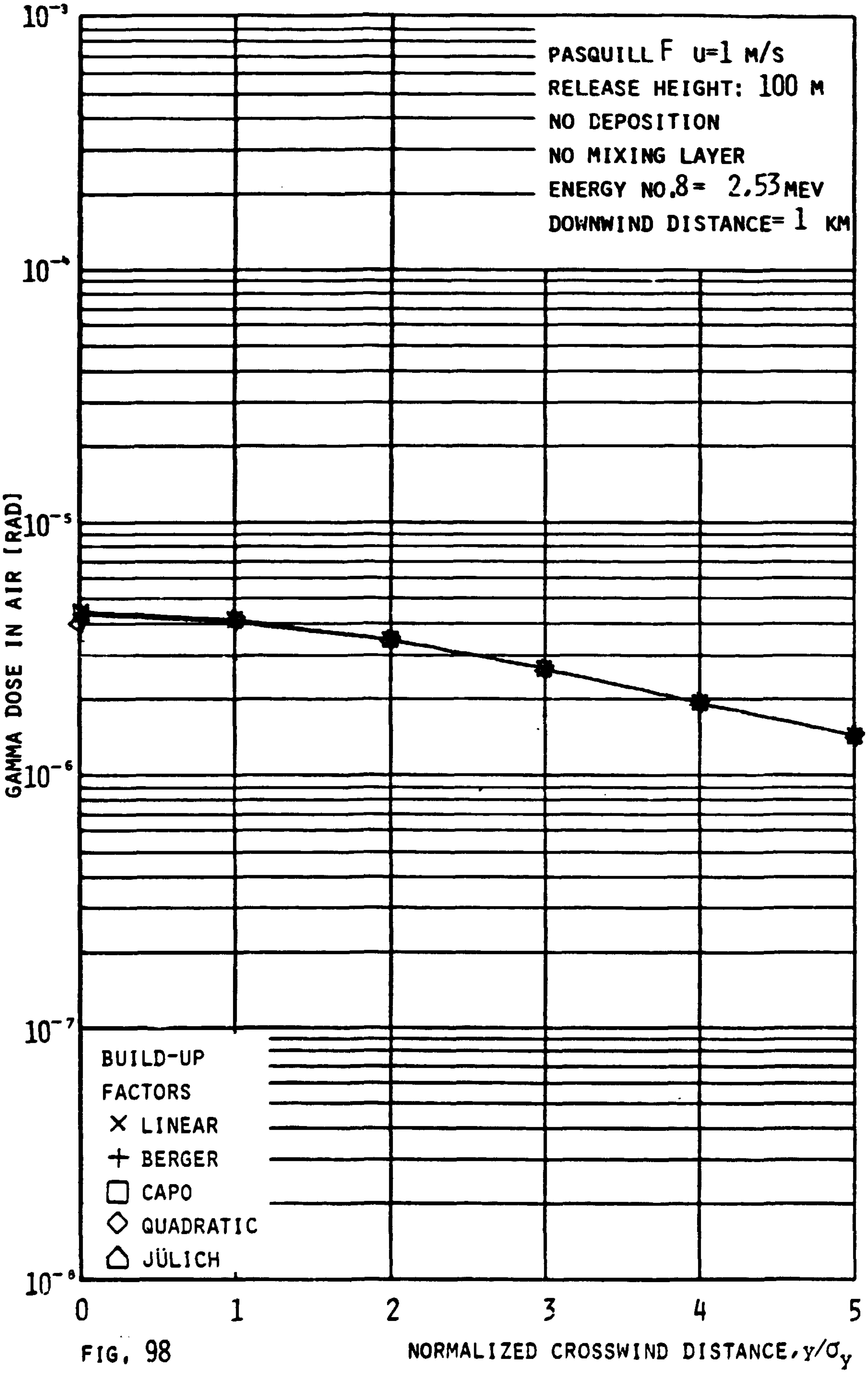
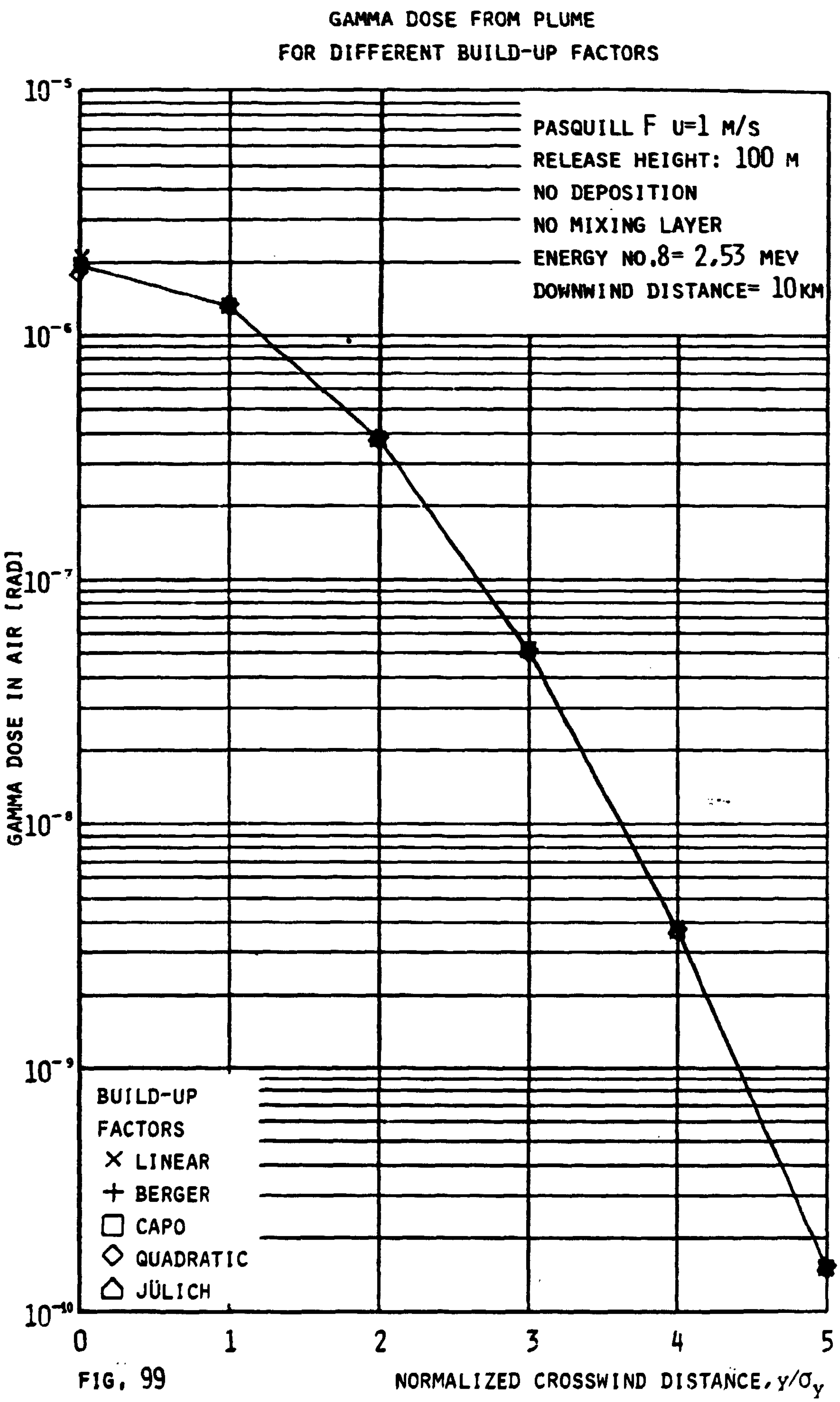


FIG. 98


GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS
PASQUILL F U=1 M/S
RELEASE HEIGHT: 100 M
NO DEPOSITION
NO MIXING LAYER
ENERGY NO.8= 2.53 MEV
DOWNWIND DISTANCE= 10KM
GAMMA DOSE IN AIR [RAD]
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
BUILD-UP
FACTORS
× LINEAR
+ BERGER
□ CAPO
◇ QUADRATIC
△ JÜLICH
0
1
2
3
4
5
NORMALIZED CROSSWIND DISTANCE, y/σy
FIG. 99

GAMMA DOSE FROM PLUME
FOR DIFFERENT BUILD-UP FACTORS

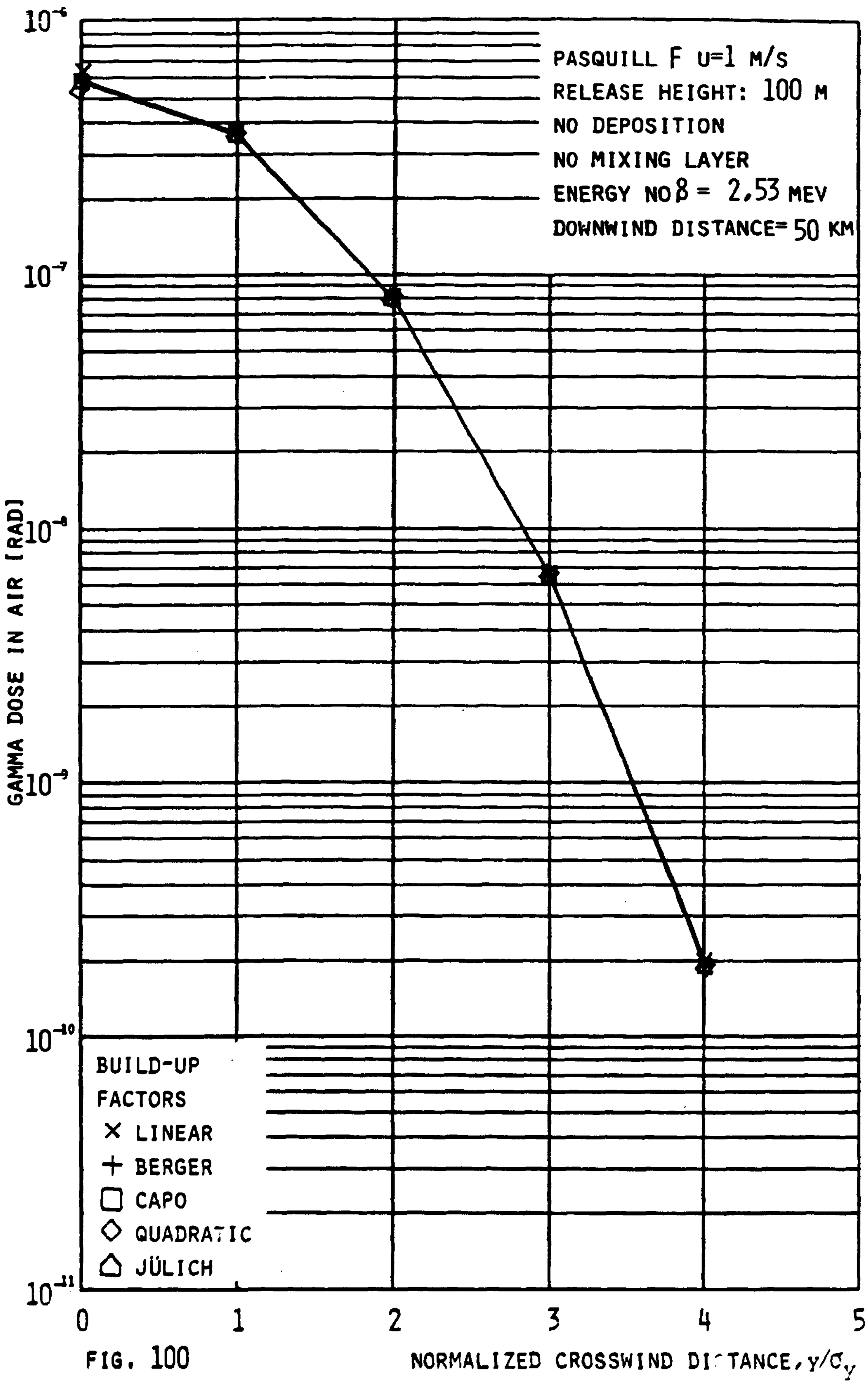


FIG. 100

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Title and author(s)	Date September 1980
RECOMMENDATIONS ON DOSE BUILDUP FACTORS USED IN MODELS FOR CALCULATING GAMMA DOSES FROM A PLUME Per Hedemann Jensen and Søren Thykier-Nielsen	Department or group
	Group's own registration number(s) H/TM 272
pages + tables + illustrations	

Abstract

Calculations of *external* γ-*doses* from radioactivity released to the atmosphere have been made using different *dose buildup factor* formulas. Some of the dose buildup factor formulas are used by the Nordic countries in their respective γ-dose models. A comparison of calculated γ-doses using these dose buildup factors shows that the γ-doses can be significantly dependent on the buildup factor formula used in the calculation. Increasing differences occur for increasing plume height, crosswind distance, and atmospheric stability and also for decreasing downwind distance. It is concluded that the most accurate γ-dose can be calculated by use of *Capo's* polynomial buildup factor formula. Capo-coefficients have been calculated and shown in this report for γ-energies below the original lower limit given by Capo.

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