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DIFFERENT TRACER GAS METHODS FOR ASSESSING AIR QUALITY

- Compilation of experimental data

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CONTENTS

(1)

PREFACE

In a recent article [1] is presented a theoretical framework which describes the use of moments of concentration histories as a means to assess air quality. (i.e. multiplying concentration readings by time of reading and then integrating with regard to time).
The article also presents the results from about 50 tests, using the described technique. The results are however presented in a very summarized form, mostly mean values are given.

The purpose of this report is to give a more detailed presentation of the test conditions and the results from each test, together with plots of concentration versus time graphs, since it is felt that this may be of general interest to others involved in tracer gas experiments.

TEST ARRANGEMENTS

Measurements were carried out in an indoor test chamber measuring (length · width · height) 2.4 · 1.8 · 1.8 m, see Figure 1. The chamber was mechanically ventilated by means of a fan in the exhaust air duct. The supply air was drawn from the surrounding laboratory without any additional heating or cooling. The exhaust air was dumped outdoors. The flow rate of the air entering the chamber via the supply air duct was measured by an orifice plate. The flow rate of the exhaust air was not measured since the leakage of the chamber, due to its construction with sealed joints, was expected to be very low.

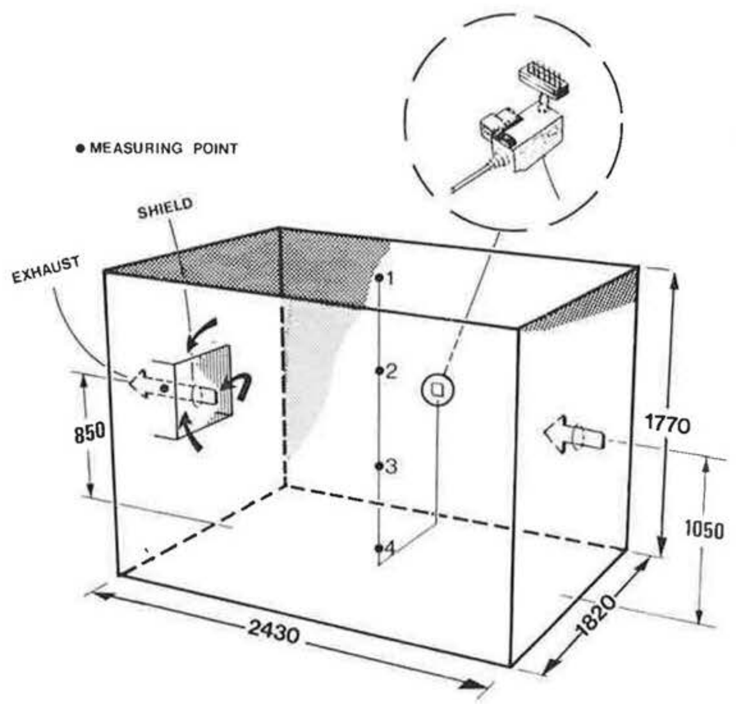


FIGURE 1. Test chamber. Dimensions in mm

Four measuring points were mounted at 0.1, 0.6, 1.15 and 1.7 m above floor level in the centre of the chamber, and a fifth measuring point in the exhaust duct. Thermocouples were used to measure air temperatures in the supply and exhaust ducts and at two levels in the chamber. From the measuring points air was pumped to an infrared gas analyzer via a manifold of 3-way solenoid valves. The gas analyzer output and the temperatures were monitored by a datalogger and recorded on cassette.
A microprocessor controller connected the measuring points one at a time to the gas analyzer and triggered the logger after sufficient purging. See Figure 2.

The solenoid valves were regulated so, that one line at the time was connected to the analyzer, while the remaining four were purged by an extra pump. The sample interval between two succesive lines was 20 seconds.
The chamber was also equipped with two mixing fans, controllable from the outside, and a 'contaminant source' consisting of a multiconnector through which tracer gas could be released into the chamber, (see Figure 1).

A series of tests were carried out using three different methods; step-up, step-down (decay) or pulse. In order to study any differences between different tracers the following gases were used:

Sulphur hexafluoride, SF_6 (density 6.41 kg/m^3)

Nitrous oxide, N_2O (density 1.83 kg/m^3)

Carbon dioxide, CO_2 (density 1.83 kg/m^3)

N_2O and SF_6 were used throughout the whole series of tests, while CO_2 was not used for the step-up method because of the lack of a satisfactorally accurate pressure reducing valve.

Fan speed and damper position were kept constant throughout the test series, giving an airflow of 4.25 litres/second in the supply air duct. This corresponds to a nominal time constant of 0.5 hours (n = 2 ac/h).

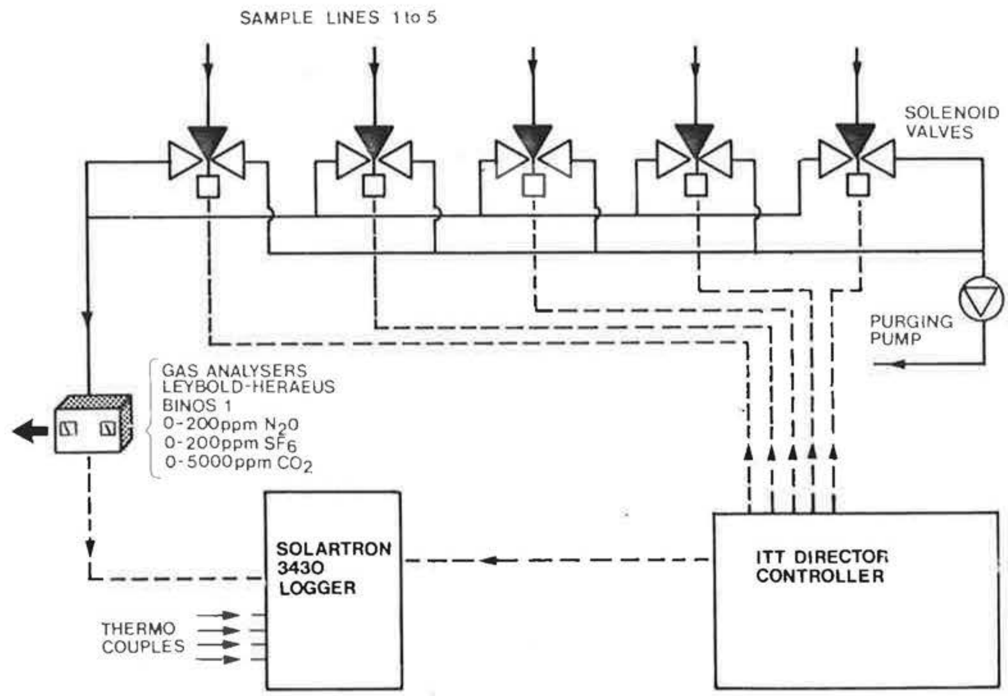


FIGURE 2. Measuring system

MOMENTS

For the recorded concentration histories from each test the 0:th to the 2:nd moments respectively were calculated, see Table 1. (The 0:th moment is the area under the curve). Furthermore, the slope of the exponential decay region of the ln concentration versus time curves were determined by a least square curve fitting to the actual part of the curve (step-down and pulse only).

TABLE 1. Definition of the moments and the calculation algorithms.

QUANTITY	CALCULATION PROCEDURE
0:th Moment: $\mu_c^{(o)} = \int_o^{\infty} c d\tau$	$\sum_{i=1}^{N} C_i \cdot \Delta\tau + (\frac{C_N}{\lambda})$
1:st Moment: $\mu_c^{(1)} = \int_o^{\infty} c\tau d\tau$	$\sum_{i=1}^{N} C_i \cdot \tau_i \cdot \Delta\tau + (\frac{C_N \cdot \tau_N}{\lambda} + \frac{1}{\lambda} (\frac{C_N}{\lambda}))$
2:nd Moment: $\mu_c^{(2)} = \int_o^{\infty} c\tau^2 d\tau$	$\sum_{i=1}^{N} C_i \cdot \tau_i^2 \cdot \Delta\tau + (\frac{C_N \cdot \tau_N^2}{\lambda} + \frac{2}{\lambda}(\frac{C_N \cdot \tau_N}{\lambda} + \frac{1}{\lambda}(\frac{C_N}{\lambda})))$

C_i = concentration reading number i

τ_i = time for concentration reading number i

$\Delta\tau$ = time interval between concentration readings

N = last reading

λ = slope of concentration decay curve

The values within parenthesis are the extrapolation terms, which take into account the remaining tail of the decay curve when the test is stopped.

THE STEP-DOWN METHOD

The step-down method was used to measure the spread of the supplied air within the chamber.

The mixing fans were first switched on and the chamber filled with gas to a suitable concentration level. After a period of mixing, the mixing fans were switched off and the sampling started. The concentration readings were then used to calculate the mean age of the air at each measuring point, p, using the following formula:

$$\mu_{\phi_p}^{(1)} = \frac{\mu_{c_p}^{(o)}}{C(o)}$$

where C(o) = concentration at start of test (τ = 0).

The results are shown in Table 2.

TABLE 2. The step-down method. Mean age of the air

Test no	Tracer	Mean age of air at point [h] 1	2	3	4	extract
21	SF_6	0.41	0.34	0.45	0.48	0.41
23	"	0.39	0.32	0.45	0.50	0.42
25	"	0.45	0.37	0.47	0.47	0.41
49	"	0.42	0.32	0.48	0.49	0.40
51	"	0.48	0.35	0.50	0.48	0.43
53	"	0.46	0.36	0.48	0.46	0.41
55	"	0.47	0.36	0.51	0.48	0.43
58	"	0.49	0.36	0.51	0.50	0.44
60	"	0.48	0.36	0.50	0.49	0.43
62	"	0.41	0.32	0.51	0.52	0.40
65S	"	0.46	0.36	0.50	0.48	0.43
39	N_2O	0.45	0.40	0.41	0.41	0.40
47	"	0.46	0.38	0.46	0.46	0.42
48	"	0.42	0.35	0.48	0.50	0.41
61	"	0.43	0.32	0.50	0.56	0.40
63	"	0.43	0.32	0.52	0.58	0.40
65N	"	0.44	0.33	0.48	0.46	0.40
29	CO_2	0.47	0.39	0.45	0.45	0.41
31	"	0.46	0.35	0.47	0.46	0.41
37	"	0.44	0.36	0.45	0.45	0.41
Mean		0.45	0.35	0.48	0.48	0.41
Std. dev.		±0.03	±0.02	±0.03	±0.04	±0.01

Because of gasanalyzer zero drift and other factors, some tests were unsuccesful and are not included in Table 2.

The mean age of the air in the exhaust duct, 0.41 h, was shorter than the nominal time constant. This shows that there was a leakage in the chamber and the volume flow of exhaust air larger than the expected 4.25 litres/second.

The plots of concentration versus time are not included in this report, since numerous examples of plots from 'step-down' experiments can be found in [2].

THE PULSE METHOD

The pulse method was used to simulate a 'contaminant source'. The 'source' was located at a distance of 0.1 m from the wall and at a level equal to half the height of the chamber (see Figure 1).

Before each test the tubing leading the gas to the 'contaminant source' was first flushed with gas to avoid any error being caused by air or gas from previous tests being left in the tube. This was done by activating a solenoid valve which bypassed the gas flow and diverted it to the exhaust air duct. After sufficient flushing, the gas flow rate was set to the desired level by means of a needle valve. The flowrate was measured by a rotameter.
The solenoid valve was then reset to 'injection mode' and the test started. The gas was allowed to flow into the chamber until the desired pulse volume had been achieved. The pulse flow rates varied between 0.3 and 1.8 litres/min and the injection times between 8.5 and 480 seconds. This corresponds to pulse volumes of 0.25 to 0.6 litres for SF_6 and N_2O and 3.6 to 7.3 litres for CO_2, for which the concentration level is much higher.
The following quantities were calculated:

- The mean age of the contaminant at each measuring point:

$$\mu^{(1)}_{\phi_p} = \frac{\mu^{(1)}_{c_p}}{\mu^{(o)}_{c_p}}$$

- The standard deviation:

$$\sigma = \left(\frac{\mu^{(2)}_c}{\mu^{(o)}_c} - \left(\frac{\mu^{(1)}_c}{\mu^{(o)}_c}\right)^2\right)^{0.5}$$

- Skewness:

$$S = \frac{1}{\sigma^3} \cdot \left(\frac{\sum_{i=1}^{\infty} (\tau_i - \mu^{(1)}_{\phi})^3 \cdot C_i}{\mu^{(o)}_c} \cdot \Delta\tau\right)$$

- Kurtosis:

$$K = \frac{1}{\sigma^4} \cdot \left(\frac{\sum_{i=1}^{\infty} (\tau_i - \mu_\phi^{(1)})^4 \cdot C_i}{\mu_c^{(o)}} \cdot \Delta\tau \right)$$

- The normalized maximum concentration occurring:

$$\hat{C}_{max} = C_{max} \cdot \frac{V}{m}$$

where

C = concentration in kg/m^3

m = amount of gas released, kg

V = volume of test chamber, m^3

- The normalized time instant for the maximum concentration:

$$\hat{\tau}_{max} = \frac{\tau_{max}}{\tau_n}$$

where

τ_n = nominal time constant of the ventilation system which has been set equal to the mean age of the air in the exhaust duct, see Table 1. Theoretically it holds:

$$\tau_n = \frac{V}{Q}$$

where

Q = volume flow of air

- The relationship between the amount of gas released in the pulse, m, and the amount passing the exhaust air duct, m_e:

$$\frac{m}{m_e} = \frac{m}{Q \cdot \int_o^{\infty} C_e(\tau) d\tau} = \frac{m}{\mu_{c_e}^{(o)} \cdot \frac{V}{\tau_n}}$$

At perfect conditions, this ratio should be 1. If the ratio differs much from 1, the gas has either leaked out or been absorbed, or the concentration readings have been incorrect. Since the sampling time interval in the exhaust duct was 100 seconds and the concentrations at some tests changed rapidly, the recorded concentration curve is an imperfect copy of the real curve.

Some tests have been omitted from the results because of this.

All parameters are presented in the Figures 3A to 18A together with plots, on a normal probability paper, of the remaining part of total area under the concentration curve versus time. Figures 3B to 18B and 3C to 18C are plots of concentration versus time and dosage versus time respectively. The dosage $D(\tau)$ is the time integral of the concentration up to time τ:

$$D(\tau) = \int_0^{\tau} C(\tau')d\tau'$$

The test conditions are summarized in Table 3.

Various statistical frequency distributions were fitted against the concentration versus time data and a log-normal distribution was found to best fit the data.
Appendix 1 contains plottings of a few curve-fittings using the log-normal distribution.

TABLE 3. The pulse method. Test conditions

Test no	Tracer	Amount of tracer [g]	Duration of tracer release (pulse) [s]
20	SF_6	3.654	60
22	"	1.923	60
24	"	1.923	60
26	"	1.843	30
27	"	1.843	30
28 1)	"	1.843	30
41	N_2O	0.915	30
42	"	0.954	17
45	"	0.4575	15
46	"	0.477	8.5
30	CO_2	13.46	240
32	"	12.81	360
33	"	12.81	480
34	"	6.730	120
35	"	6.405	180
36	"	6.405	240

1) continous sampling of measuring point no 3.

ID=PULS20

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	———	37.1	24.8	1.3	4.8	0.63	0.74	
2	-------	34.1	22.4	1.2	4.2	0.49	0.69	
3	------	34.5	25.0	1.4	5.0	0.92	0.58	
4	— — —	17.6	20.4	2.2	8.4	4.24	0.05	
5	-·-·-·-	35.3	23.9	1.3	4.8	0.57	0.67	1.04

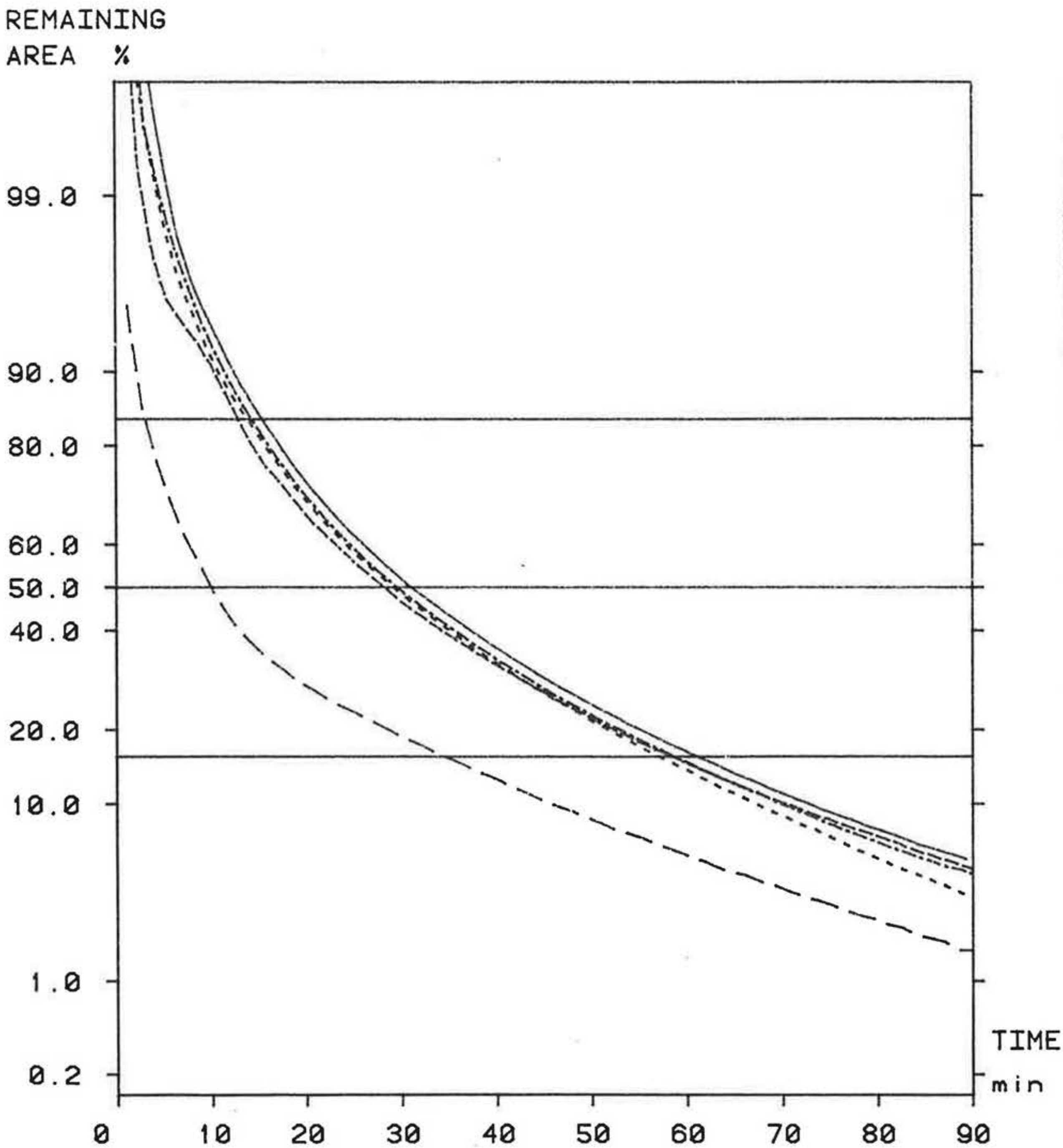


FIGURE 3A.

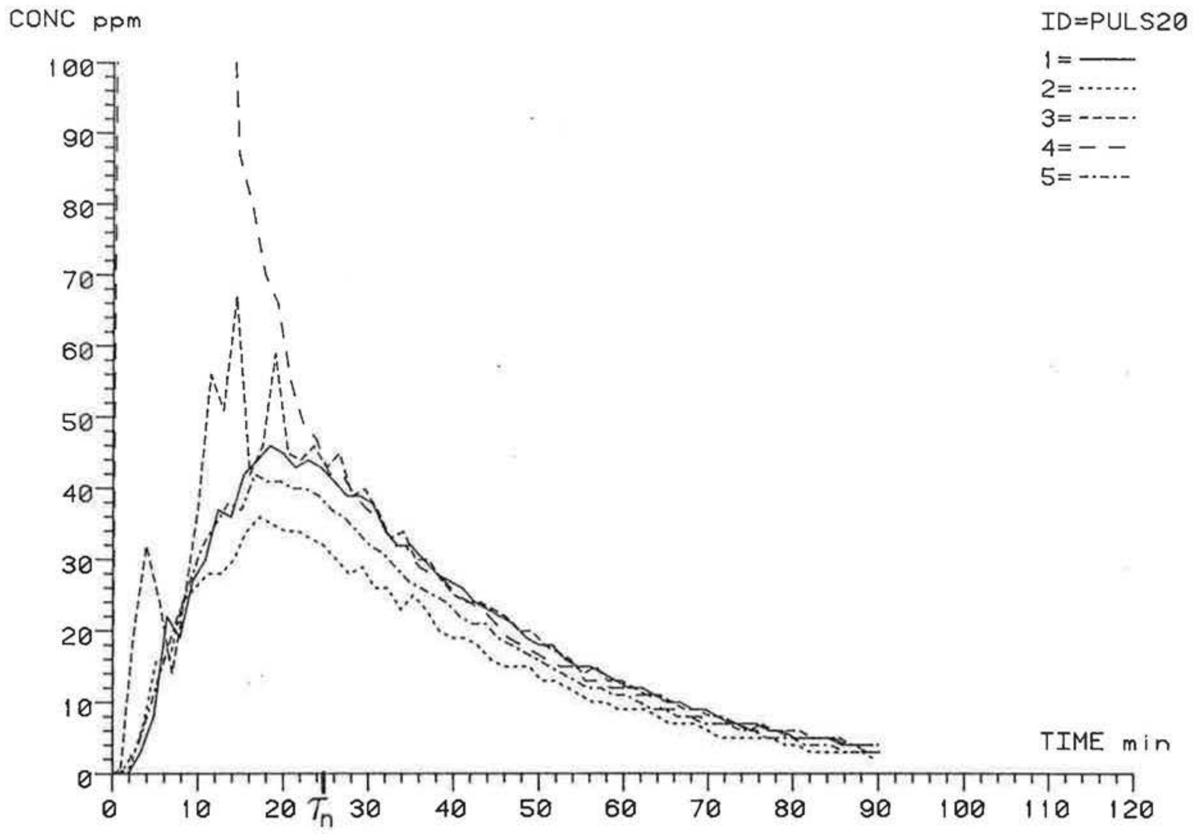


FIGURE 3B.

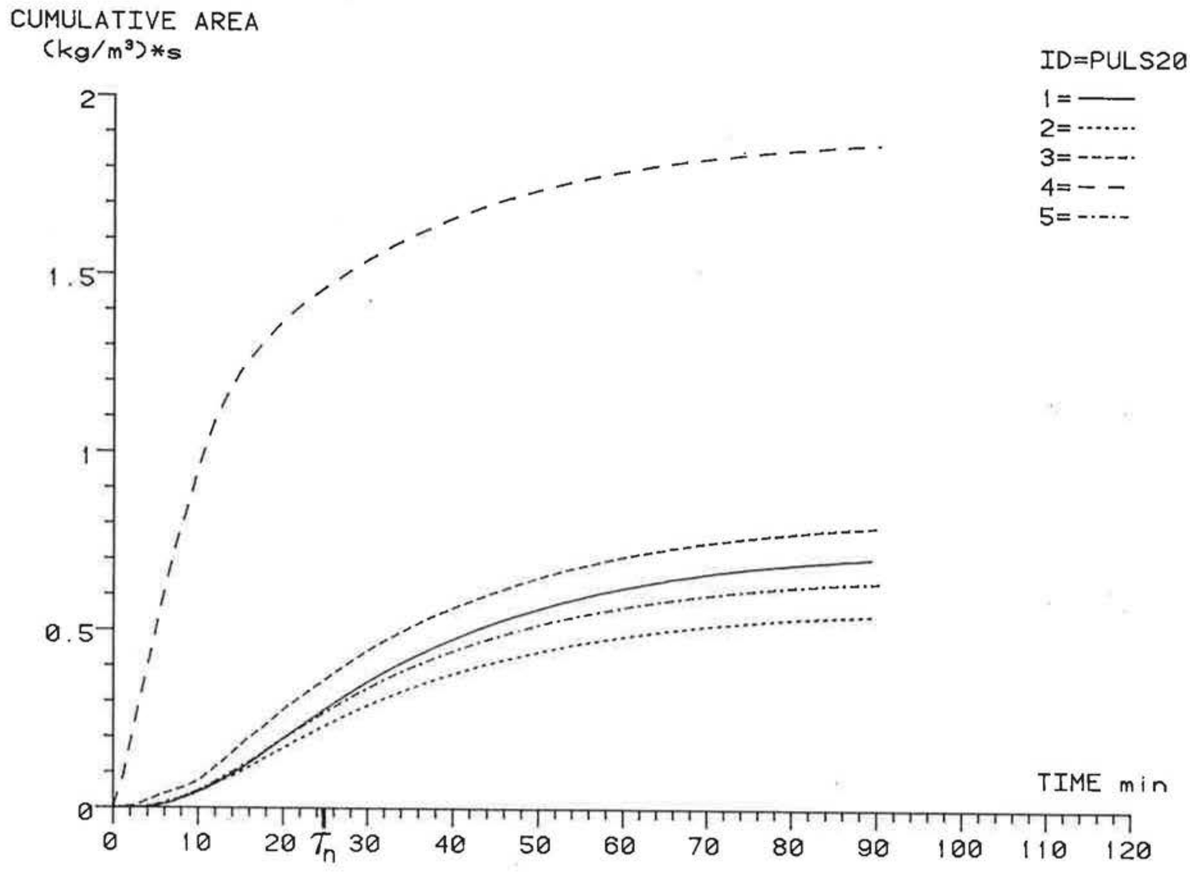


FIGURE 3C.

ID=PULS22

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	33.3	21.3	1.0	3.3	0.49	0.50	
2	- - - - - - -	33.9	21.5	1.1	3.5	0.36	0.69	
3	------	34.2	23.5	1.3	4.3	0.75	0.71	
4	— — —	19.3	21.1	2.1	7.9	5.84	0.05	
5	-·-·-·-	31.7	24.0	1.3	4.5	0.65	0.24	0.97

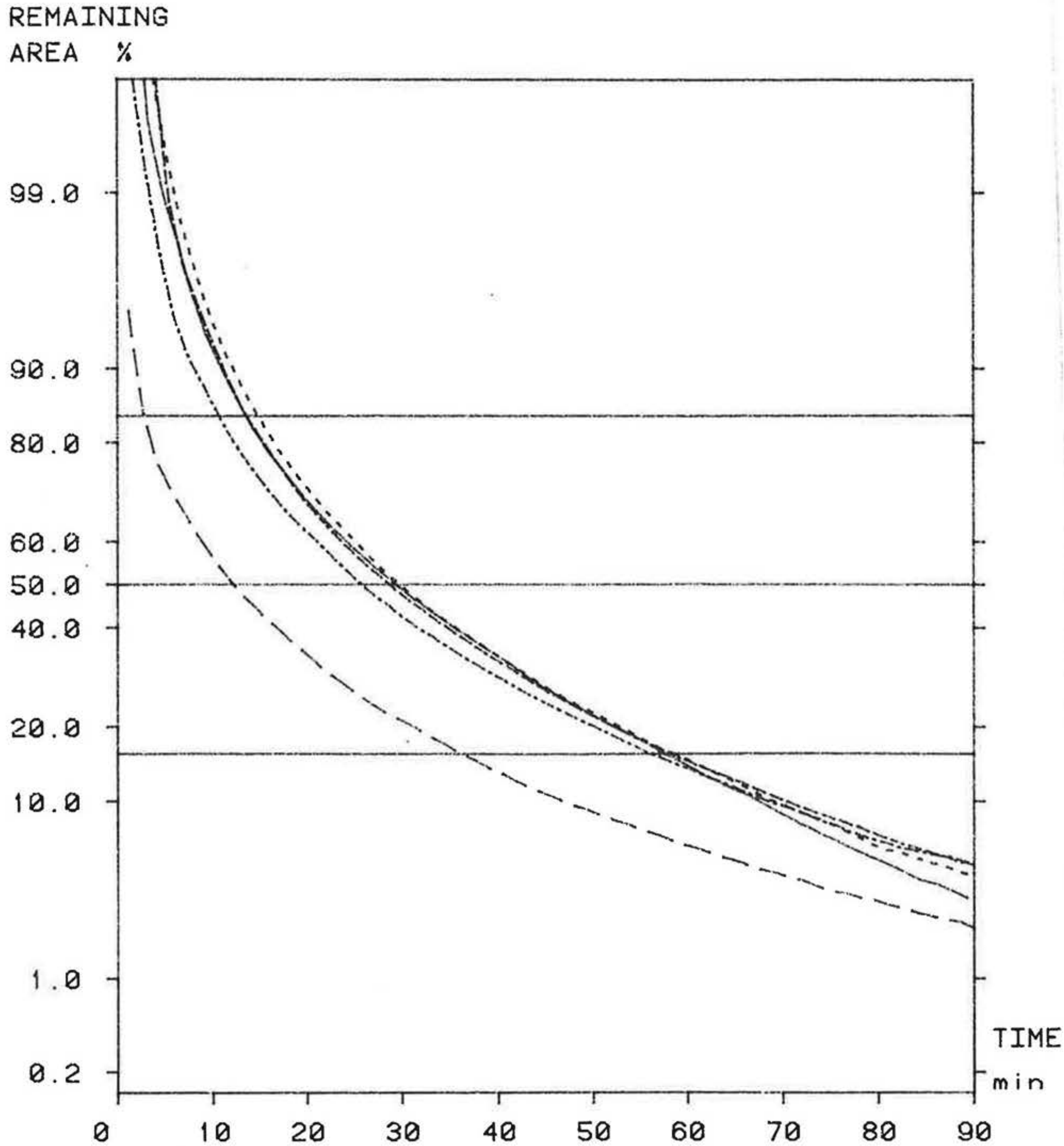


FIGURE 4A.

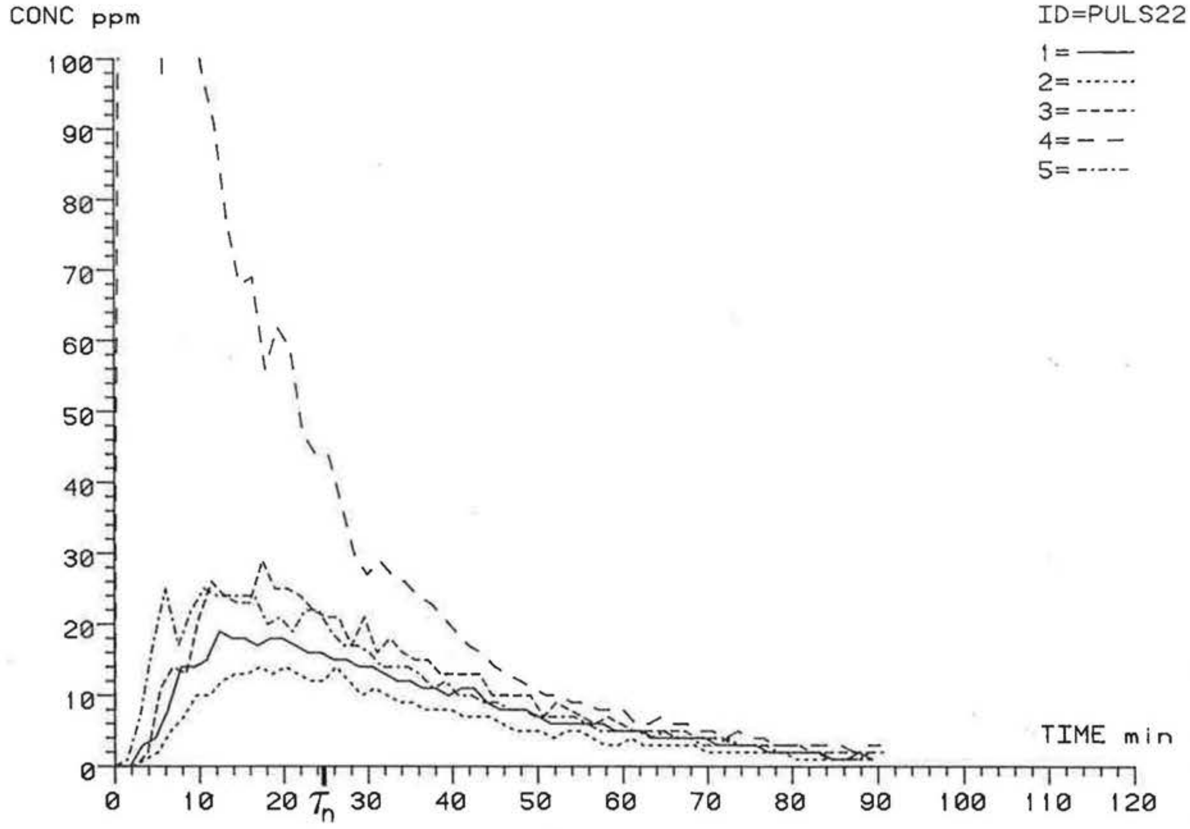


FIGURE 4B.

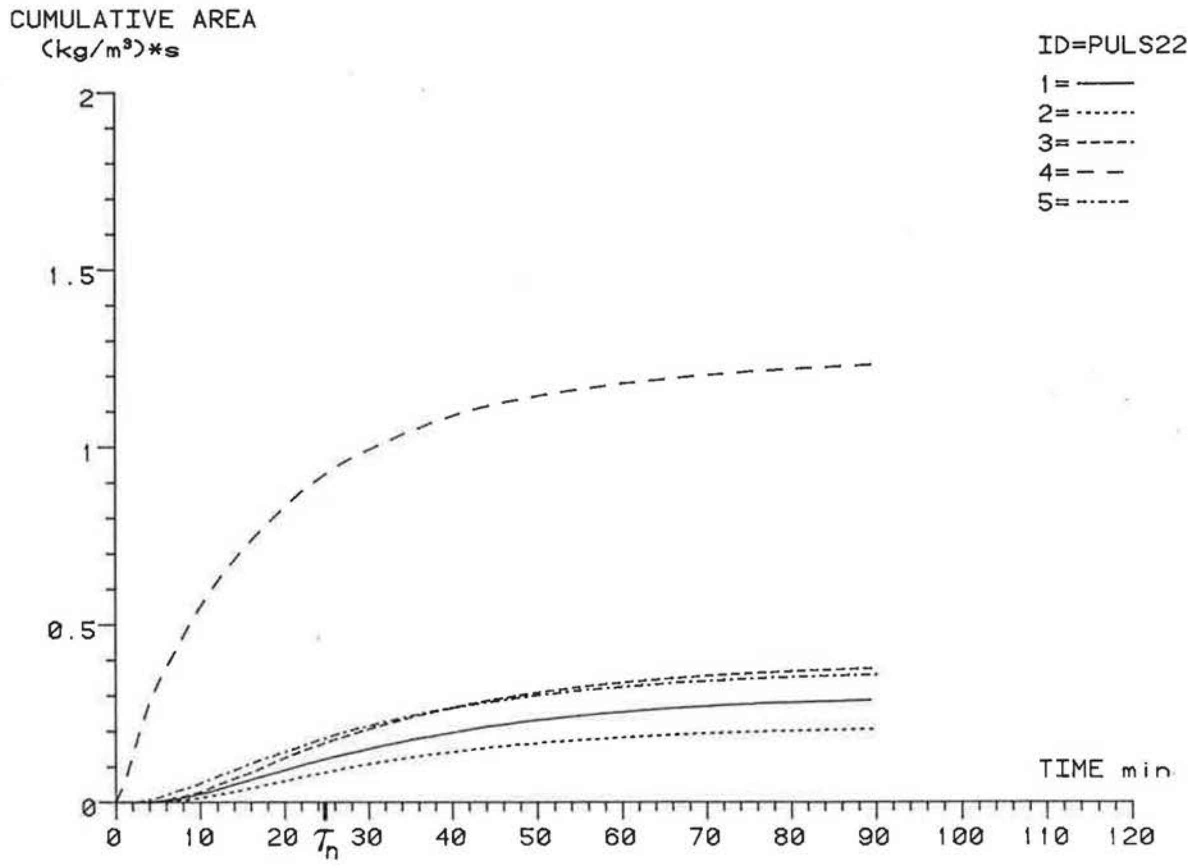


FIGURE 4C.

ID=PULS24

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	34.8	20.6	1.0	3.4	0.49	0.68	
2	- - - - - - -	34.4	21.1	1.1	3.5	0.41	0.69	
3	-·-·-·-·	31.1	23.6	1.4	4.7	0.96	0.46	
4	— — —	17.7	20.3	2.1	7.9	7.52	0.05	
5	-··-··-	31.9	21.4	1.1	3.6	0.57	0.67	1.09

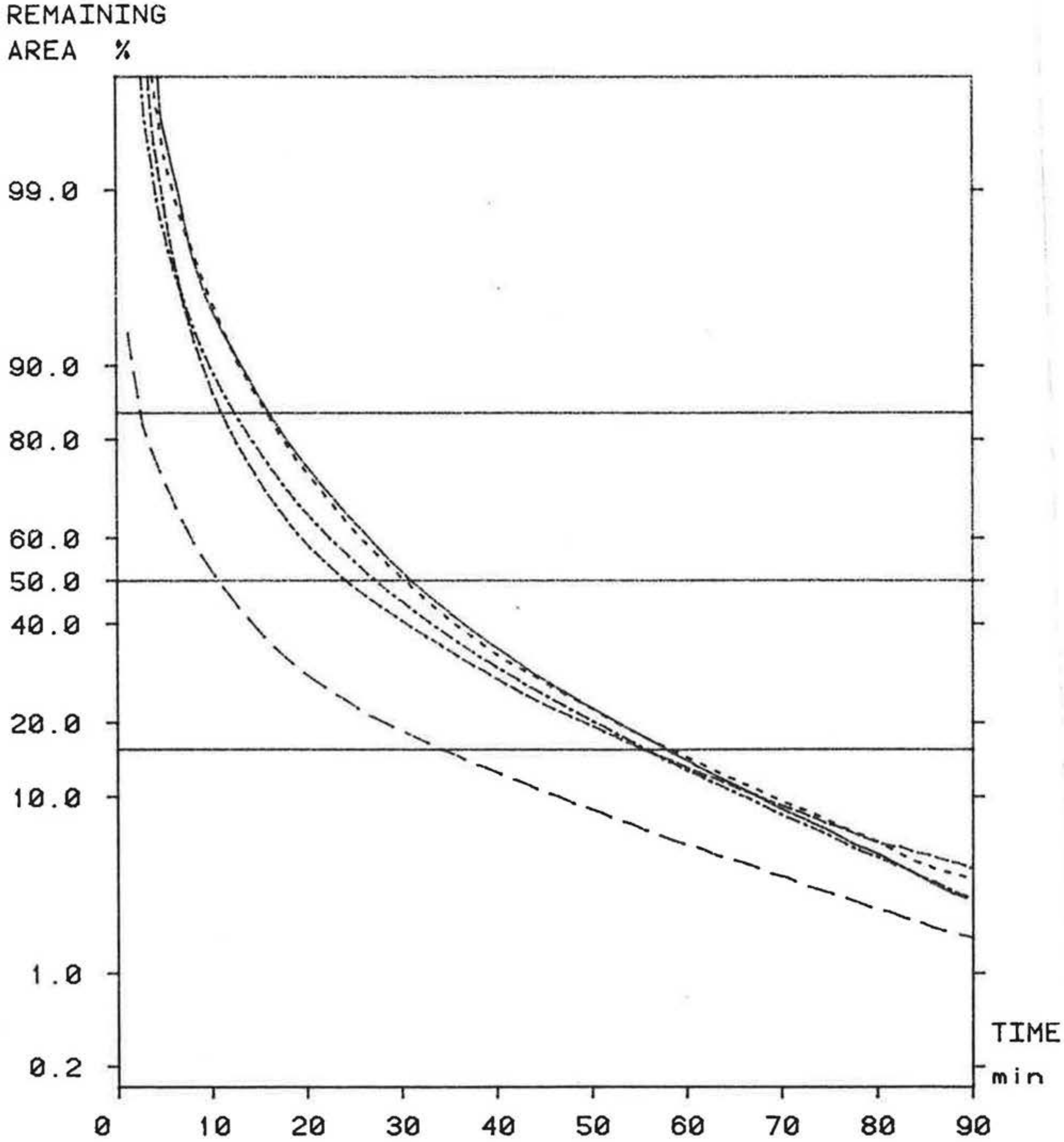


FIGURE 5A.

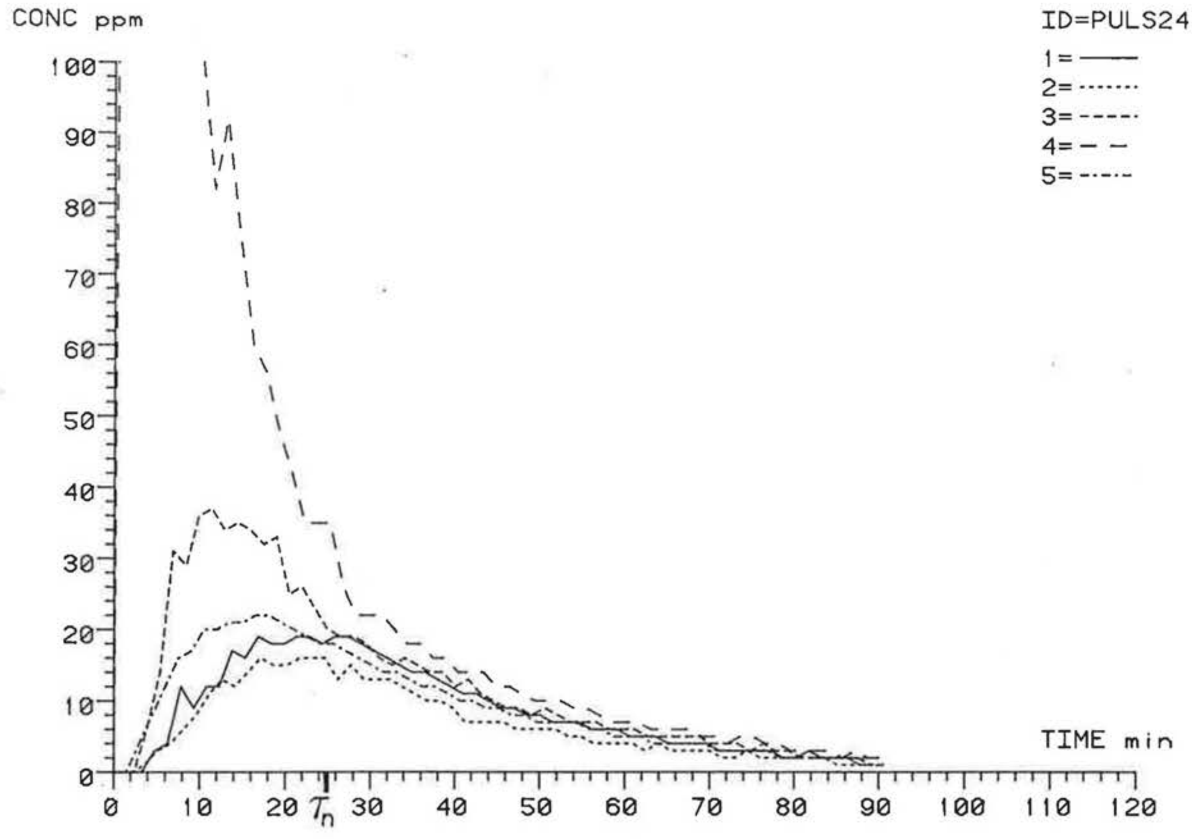


FIGURE 5B.

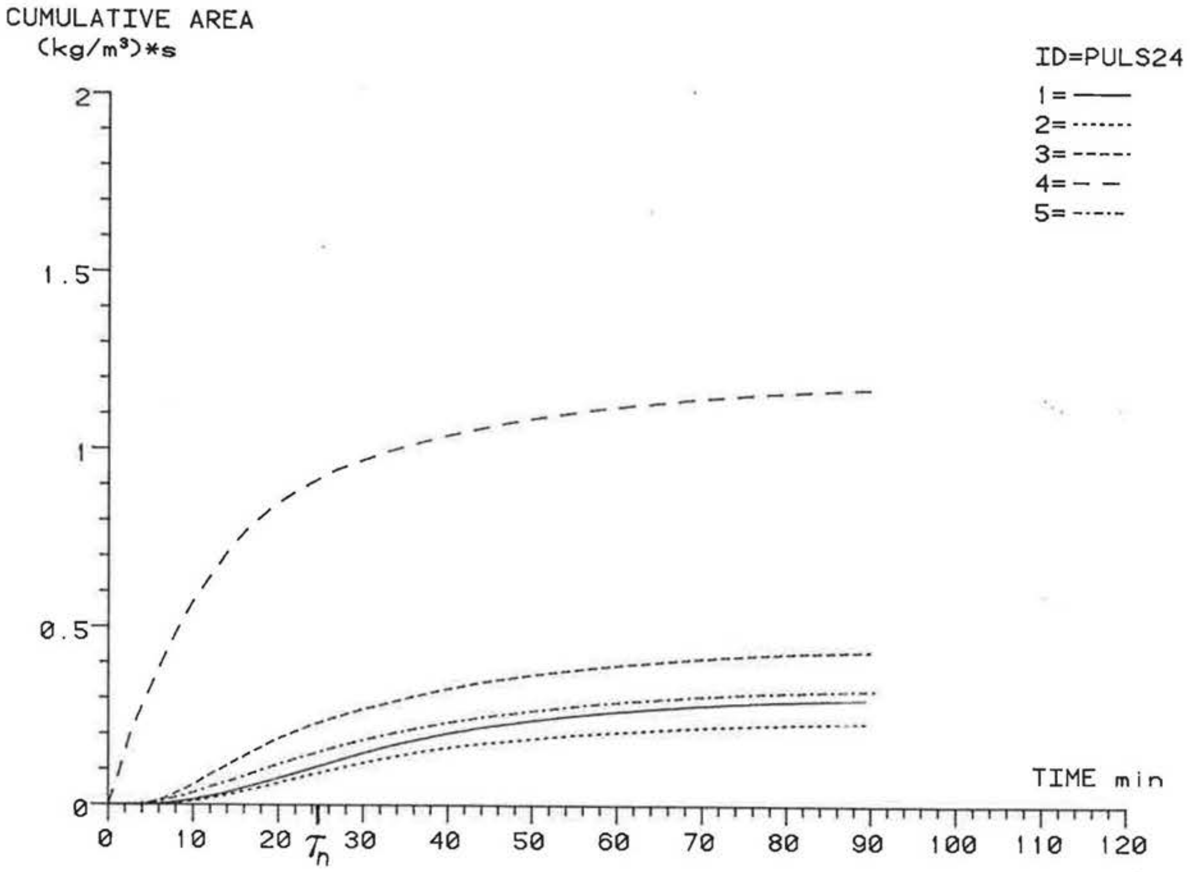


FIGURE 5C.

ID=PULS26

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	31.1	23.4	1.3	4.2	0.79	0.42	
2	-------	29.9	23.2	1.4	4.6	0.65	0.30	
3	-·-·-·-	31.1	22.7	1.3	4.2	0.84	0.45	
4	— — —	16.5	21.6	1.9	6.5	8.28	0.05	
5	-··-··-	30.6	23.5	1.3	4.2	0.73	0.48	0.97

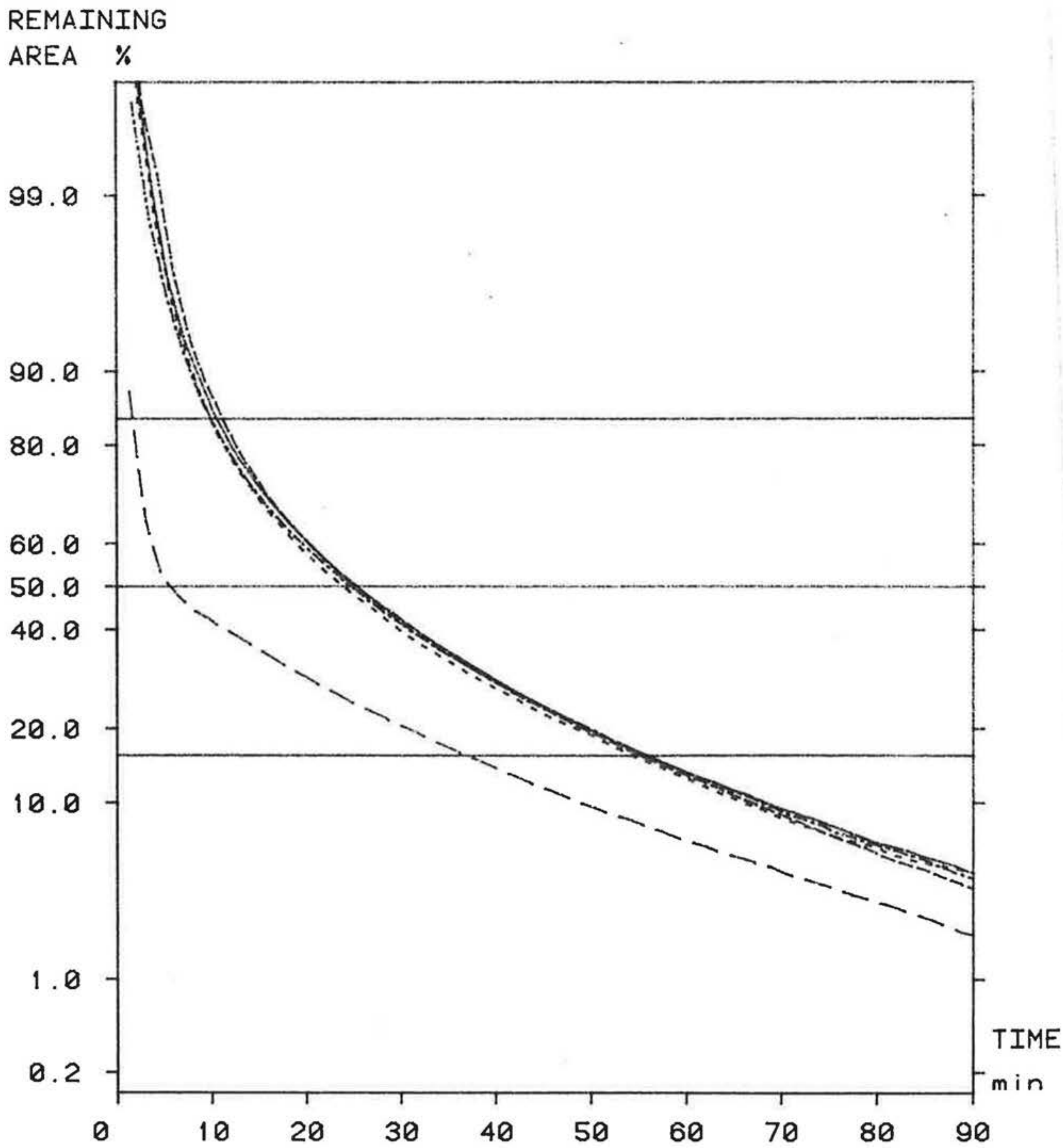


FIGURE 6A.

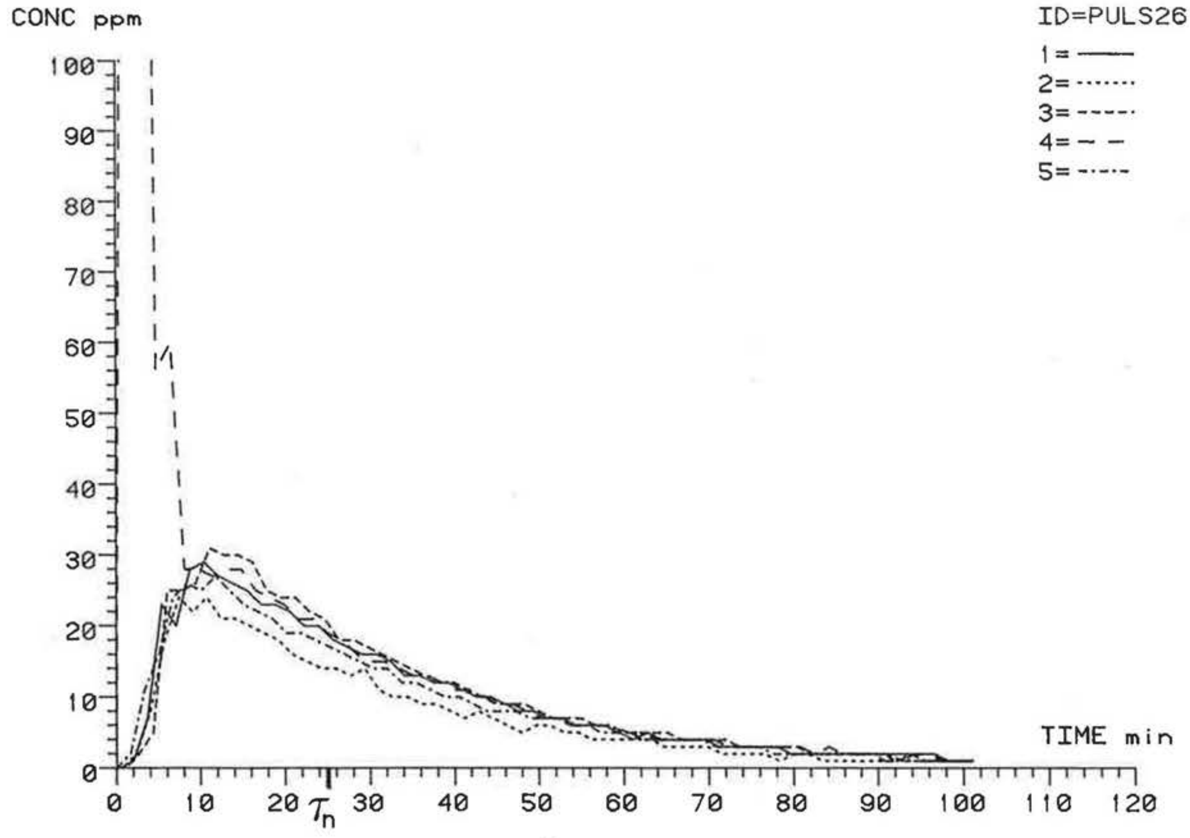


FIGURE 6B.

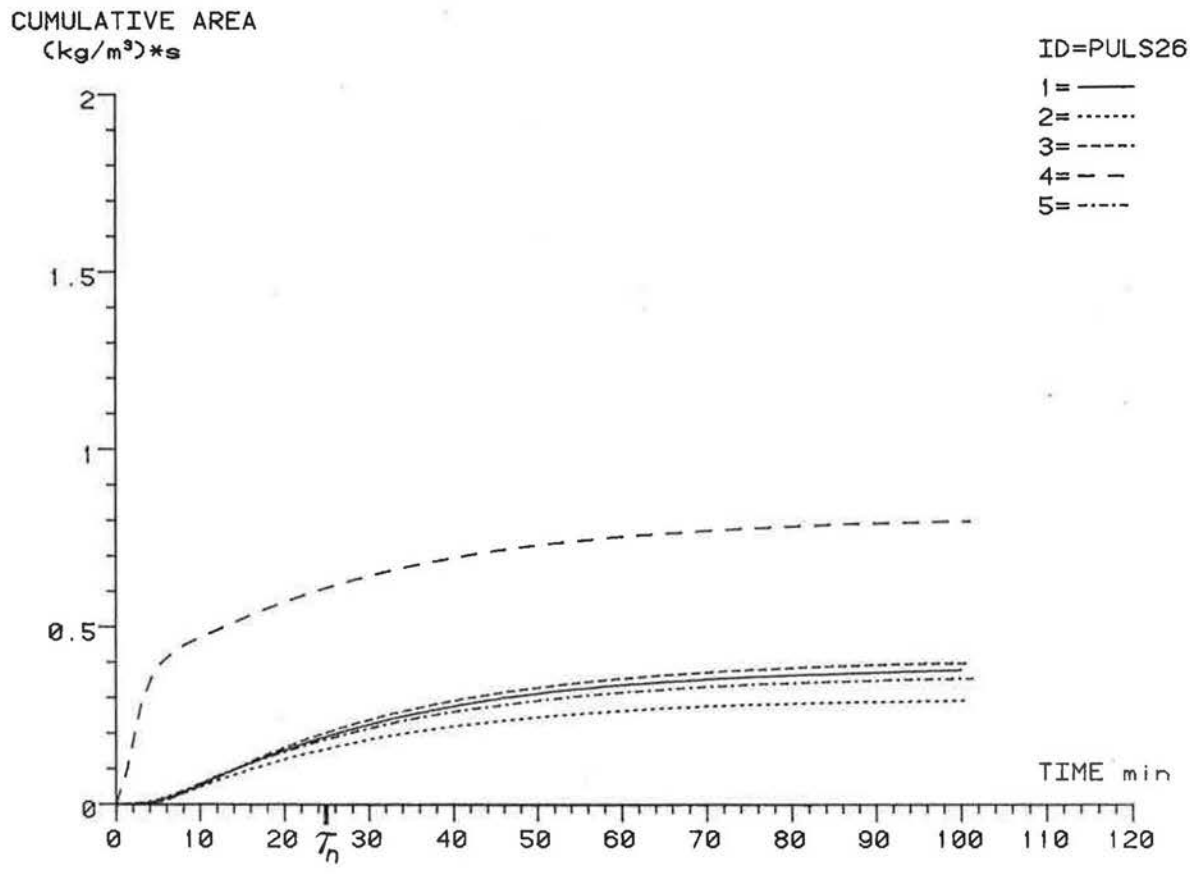


FIGURE 6C.

ID=PULS27

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	———	41.4	27.2	1.1	3.8	0.60	0.69	
2	-------	40.7	23.8	0.9	3.0	0.38	1.05	
3	------	32.2	26.9	1.5	5.2	1.89	0.38	
4	— — —	22.3	23.7	1.7	5.9	5.66	0.05	
5	-·-·-·-	42.4	27.7	1.1	3.8	0.49	0.82	1.05

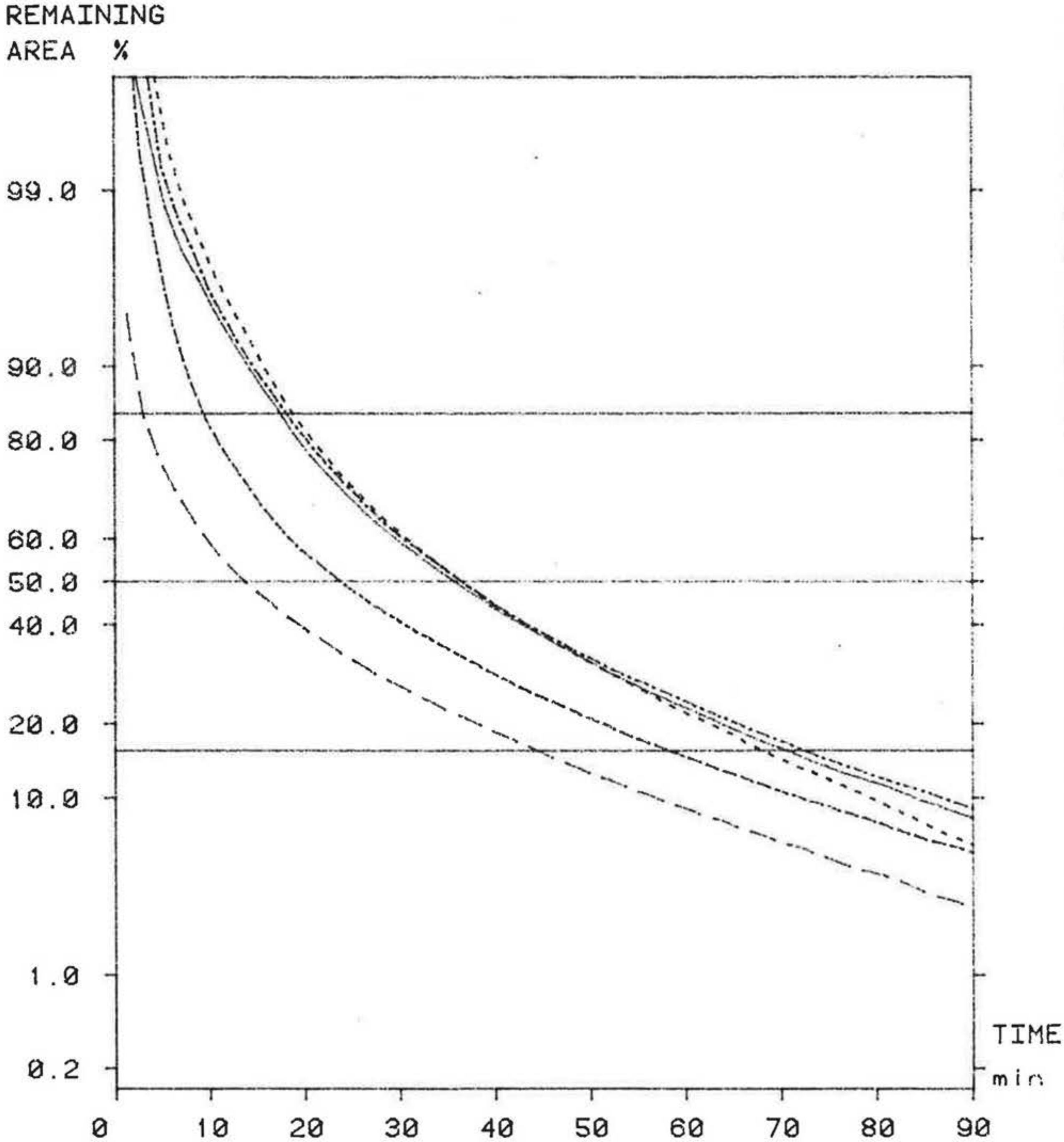


FIGURE 7A.

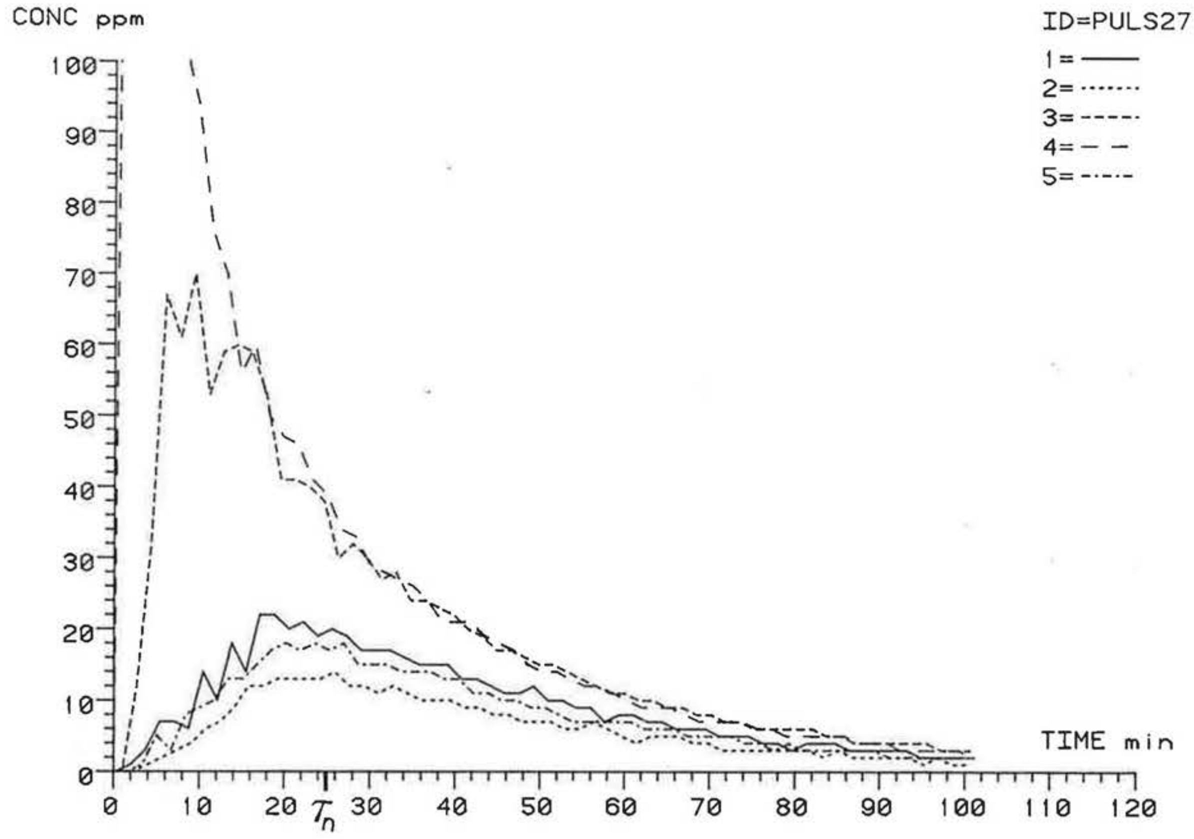


FIGURE 7B.

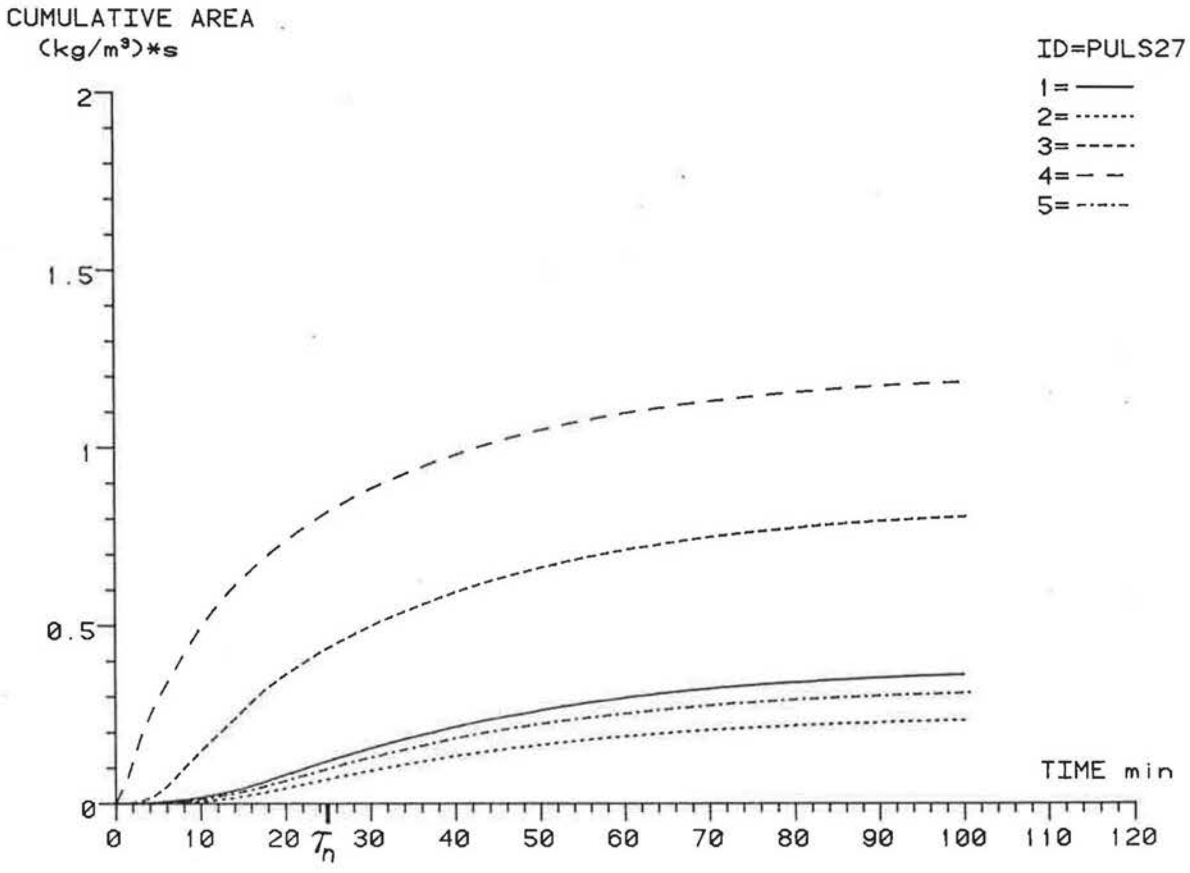


FIGURE 7C.

ID=PULS28

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$
1	————	36.2	24.7	1.3	4.5	1.27	0.56
2	- - - - - - -	36.8	25.1	1.3	4.5	1.25	0.50
3	-·-·-·-	36.6	24.9	1.3	4.5	1.08	0.65
4	— — —	38.2	25.4	1.3	4.4	0.95	0.80
5	-··-··-	35.2	25.5	1.3	4.6	1.25	0.41

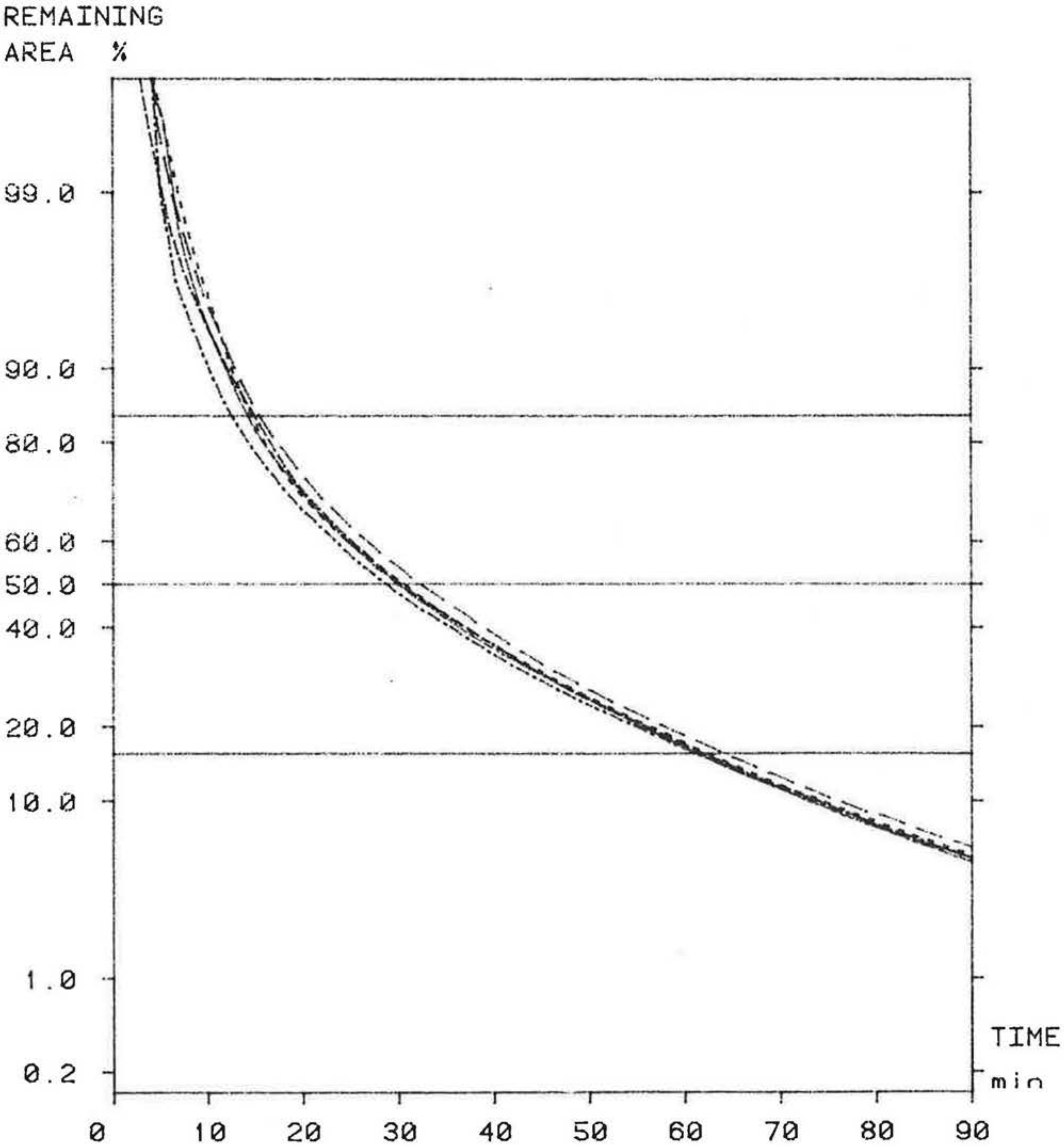


FIGURE 8A.

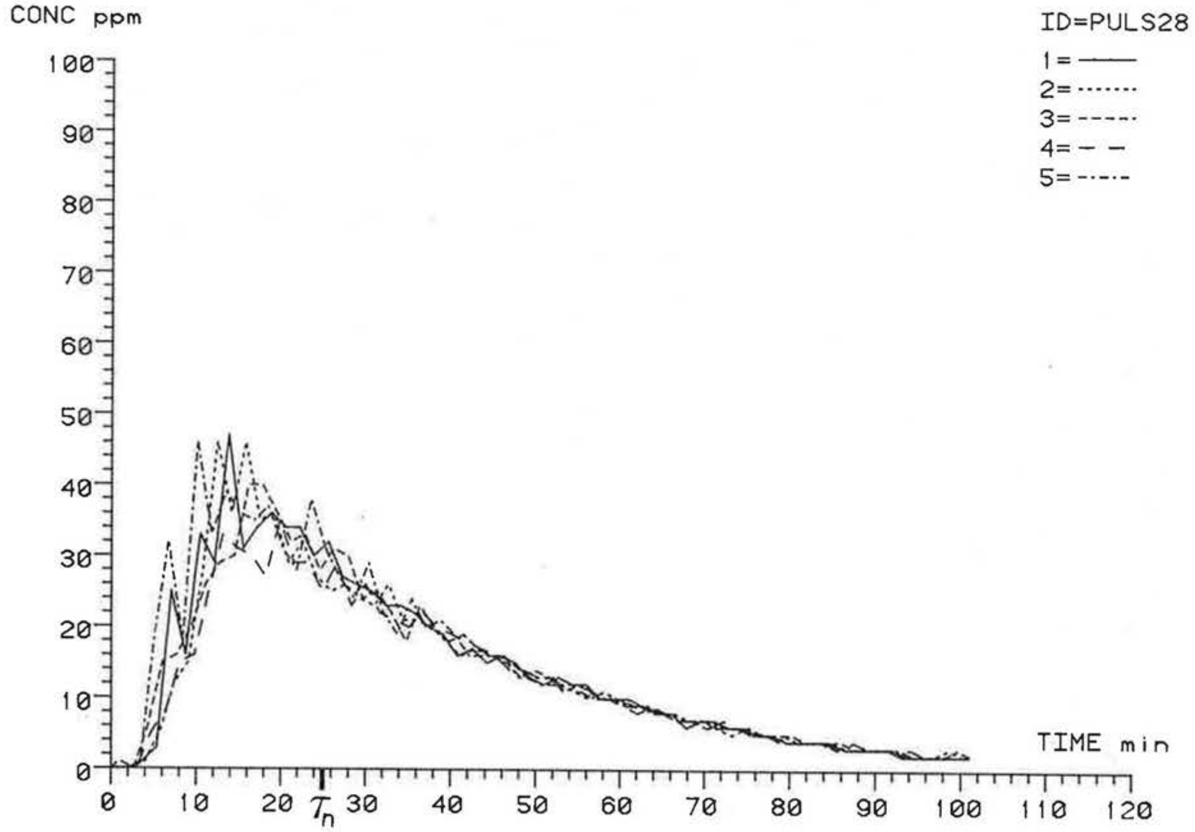


FIGURE 8B.

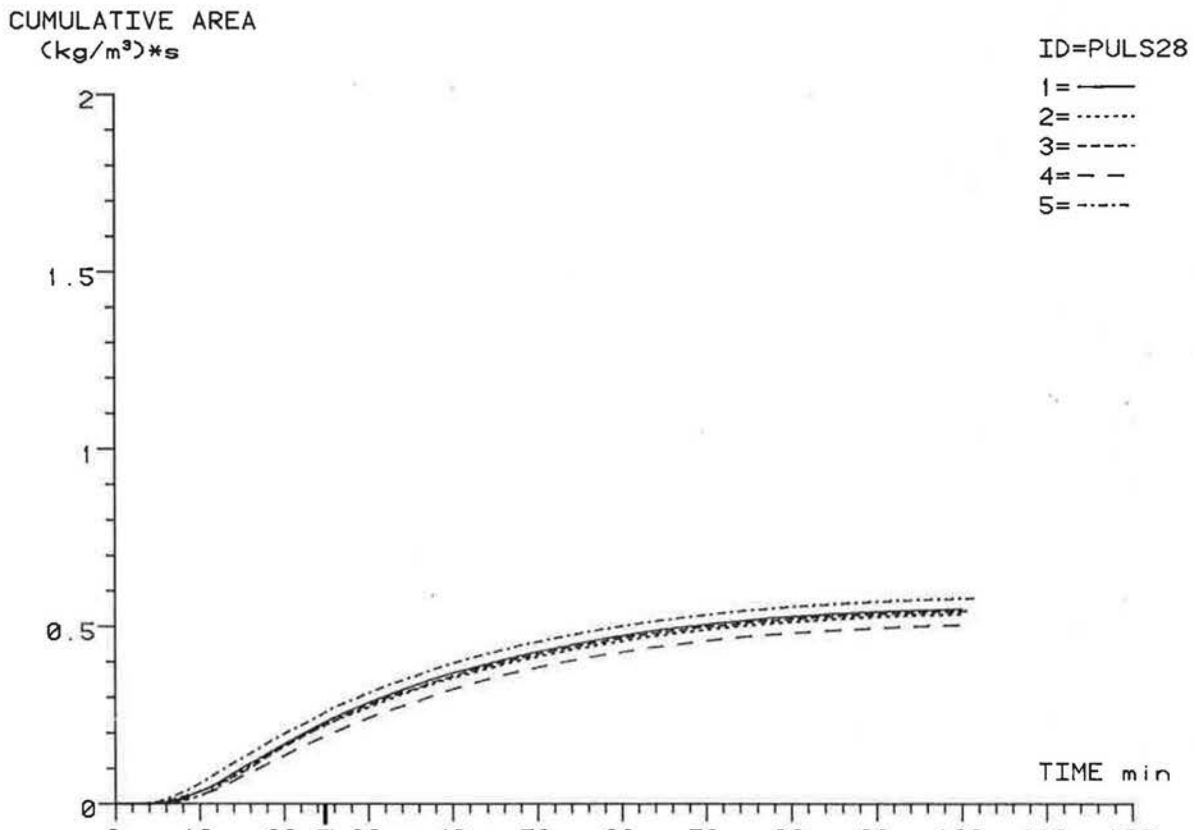


FIGURE 8C.

ID=PULS41

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	25.8	19.3	1.1	3.9	1.04	0.22	
2	-------	23.0	18.7	1.2	4.1	1.18	0.09	
3	------	22.5	20.4	1.2	3.9	2.35	0.11	
4	— — —	14.8	19.0	1.7	5.4	11.38	0.05	
5	-·-·-·-	23.8	19.6	1.1	3.8	1.18	0.14	1.01

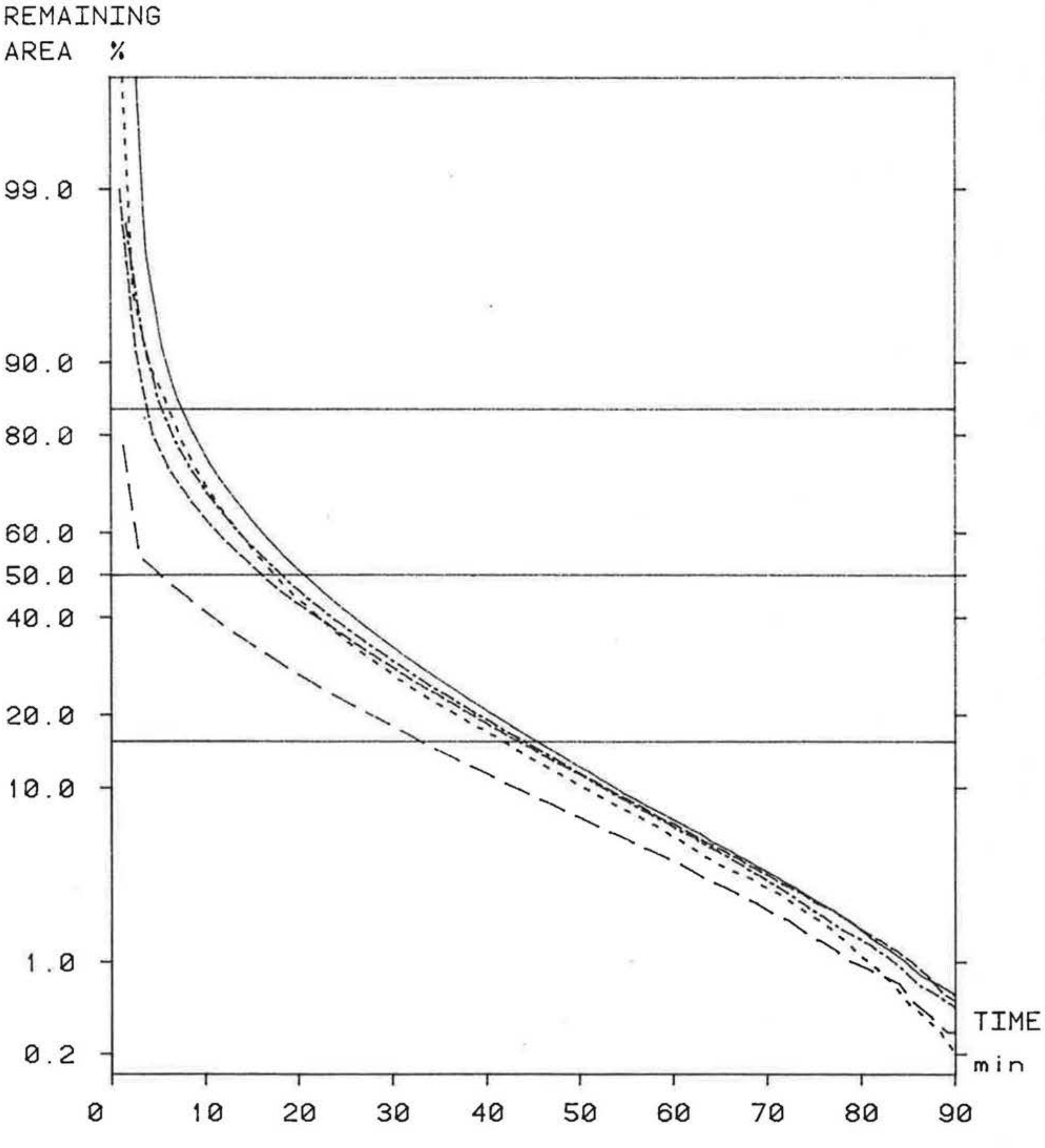


FIGURE 9A.

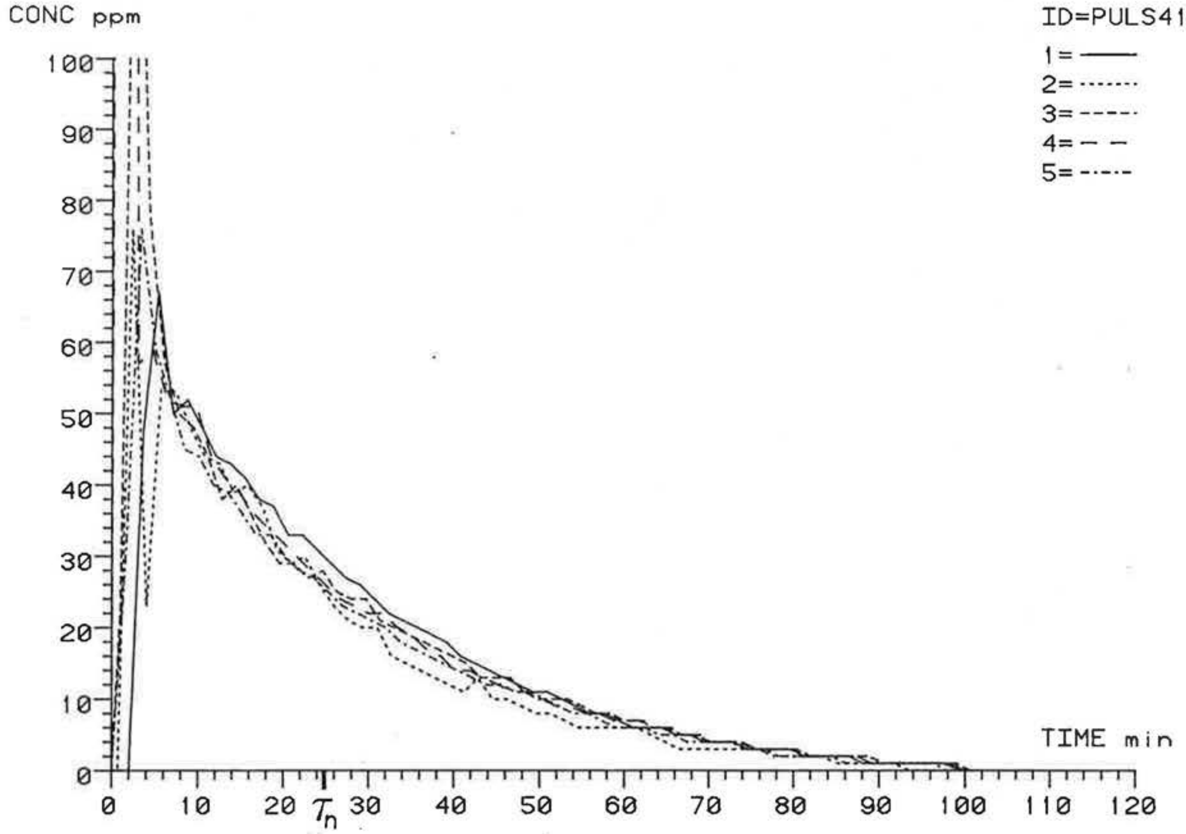


FIGURE 9B.

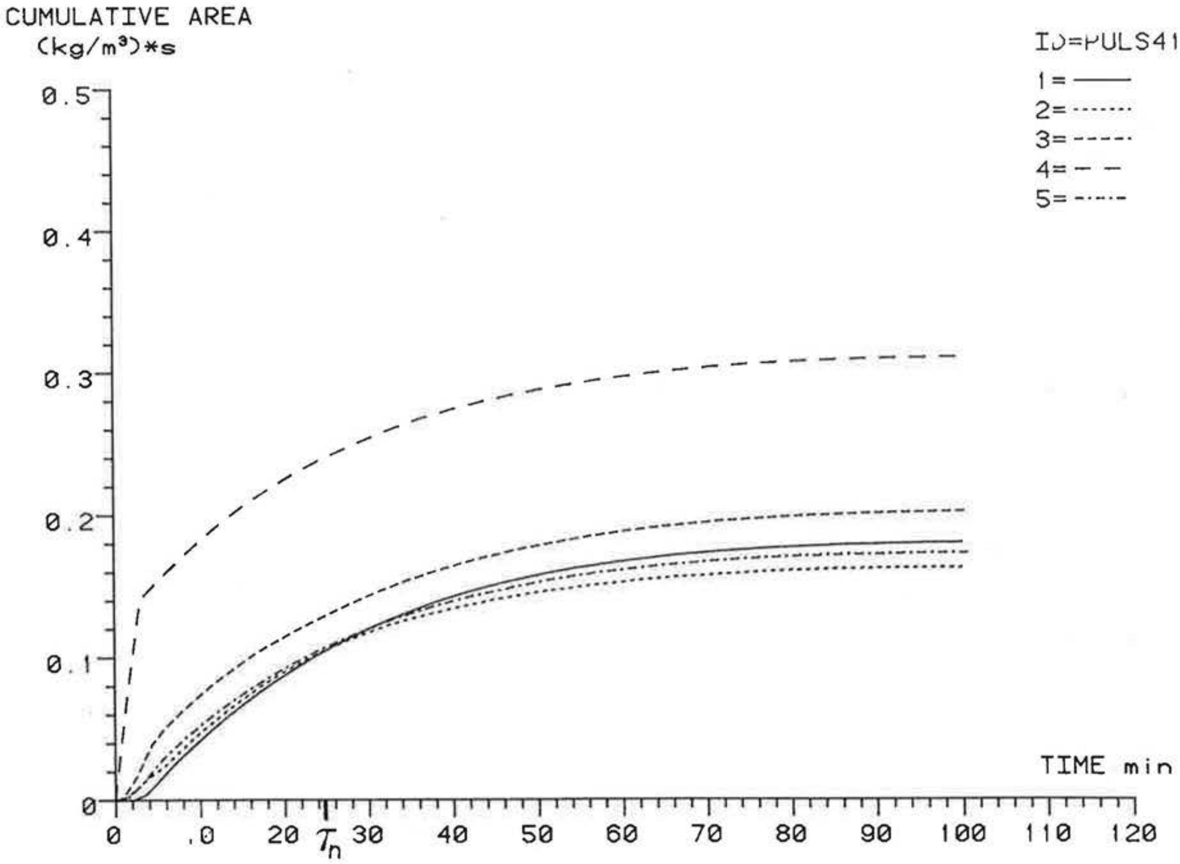


FIGURE 9C.

ID=PULS42

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	29.7	25.0	1.4	4.9	0.84	0.29	
2	- - - - - - -	24.8	22.5	1.4	4.6	1.88	0.09	
3	–·–·–·–	29.4	24.8	1.4	5.0	1.13	0.18	
4	— — —	28.3	25.1	1.5	5.2	1.06	0.19	
5	-·-·-·-·	29.7	25.3	1.5	5.1	0.84	0.20	0.94

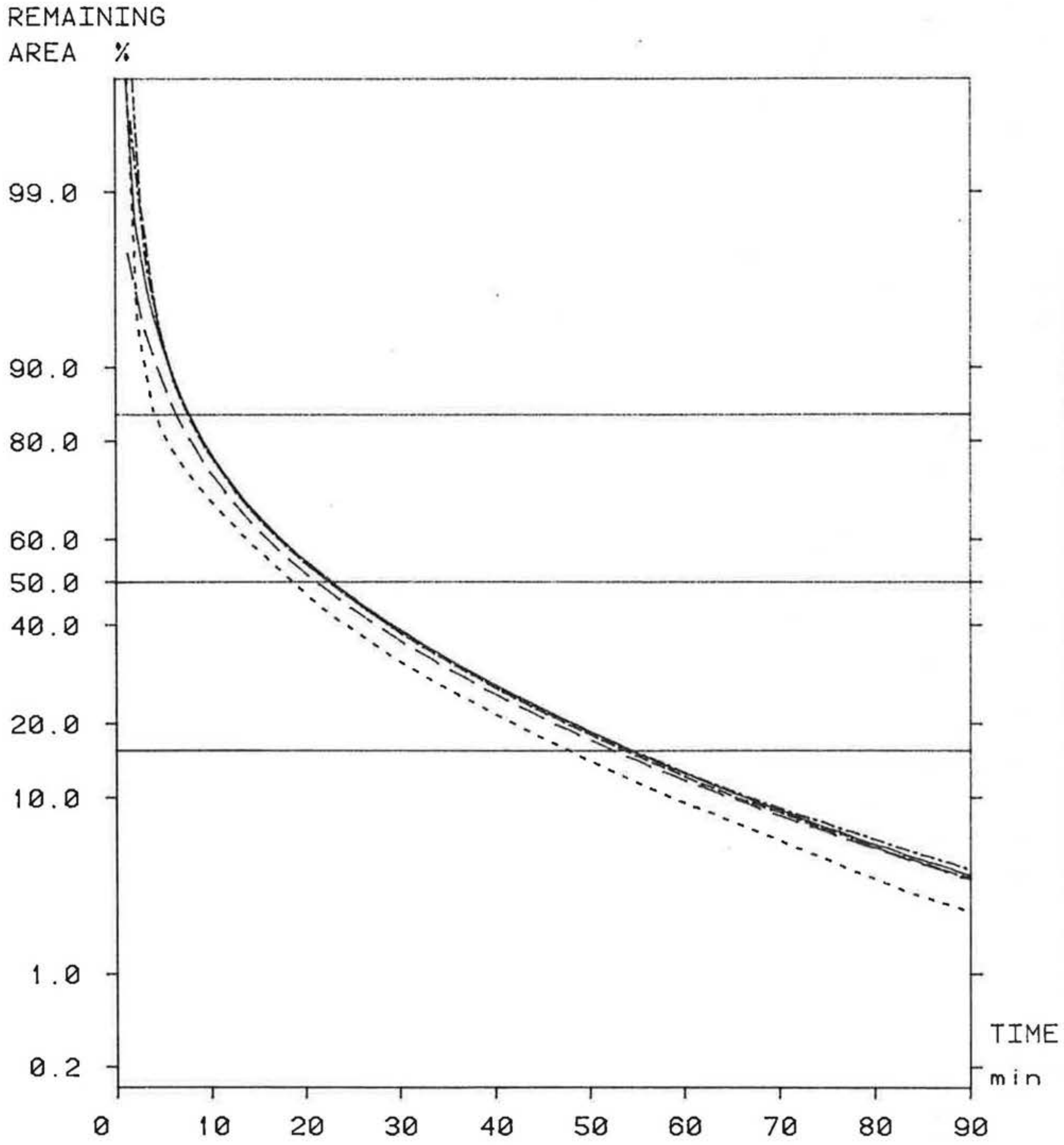


FIGURE 10A.

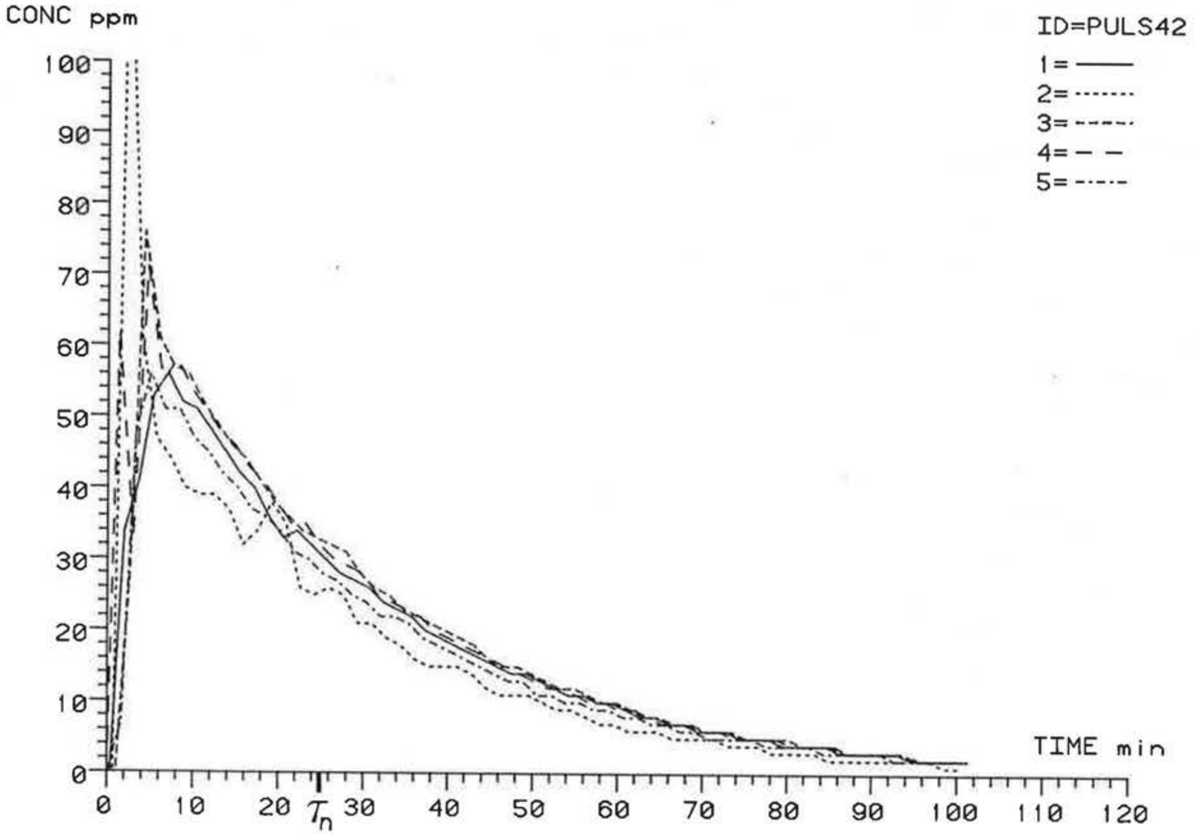


FIGURE 10B.

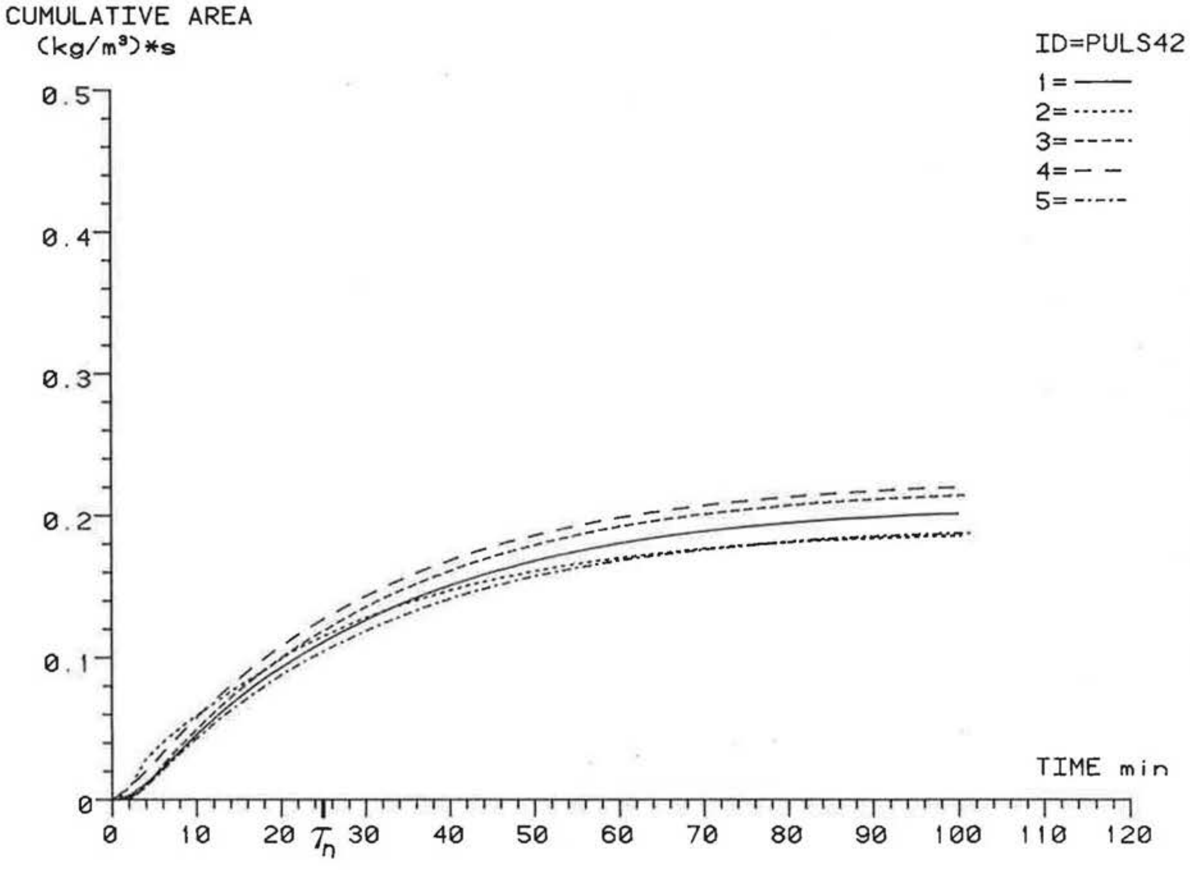


FIGURE 10C.

ID=PULS45

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	34.6	28.1	1.3	4.1	0.72	0.22	
2	- - - - - - -	34.0	24.8	1.1	3.5	0.62	0.44	
3	--------	32.4	27.7	1.3	4.3	1.84	0.18	
4	— — —	20.0	26.6	1.8	6.0	16.56	0.05	
5	-·-·-·-·-	36.2	28.8	1.3	4.1	0.69	0.34	0.85

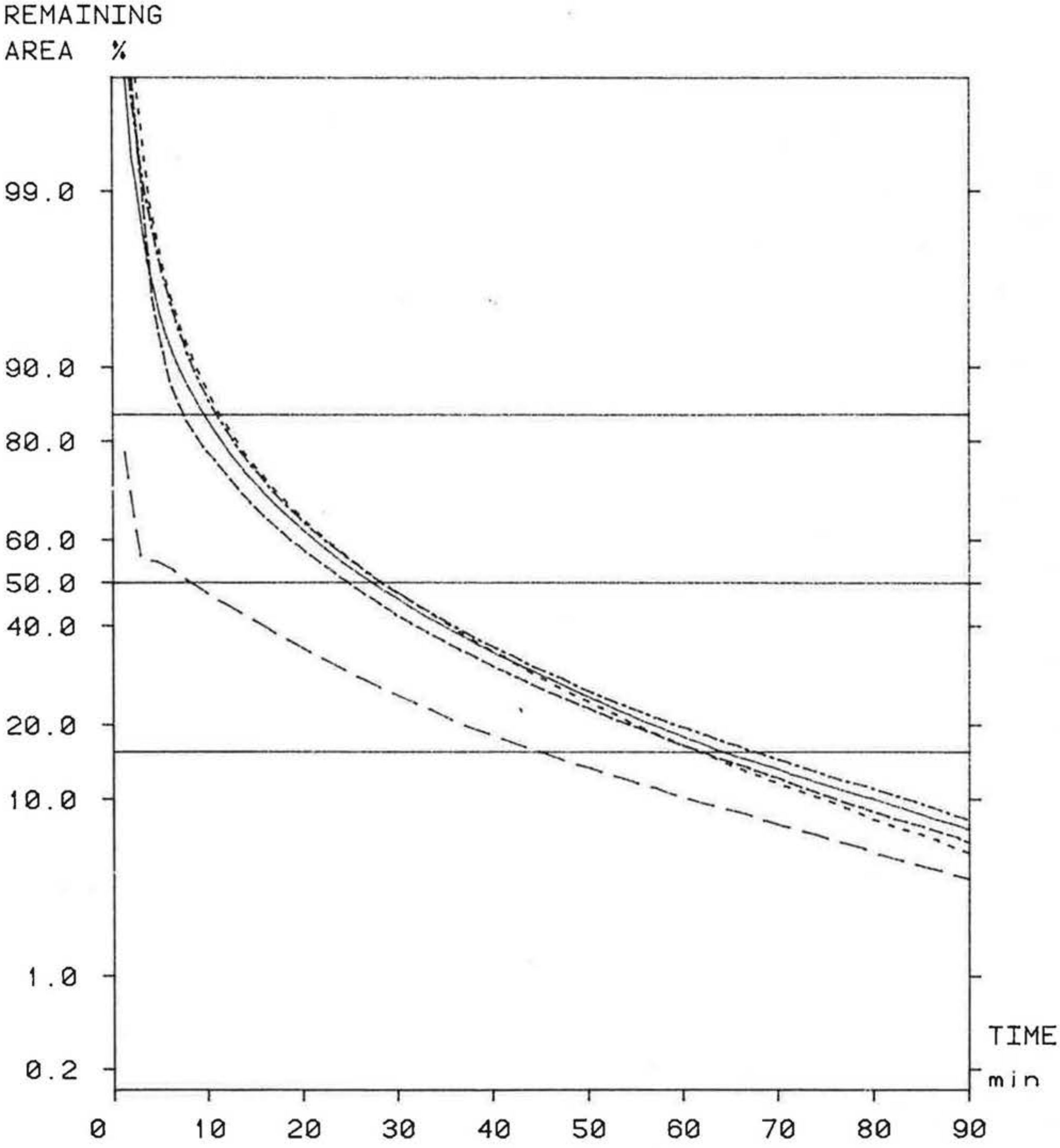


FIGURE 11A.

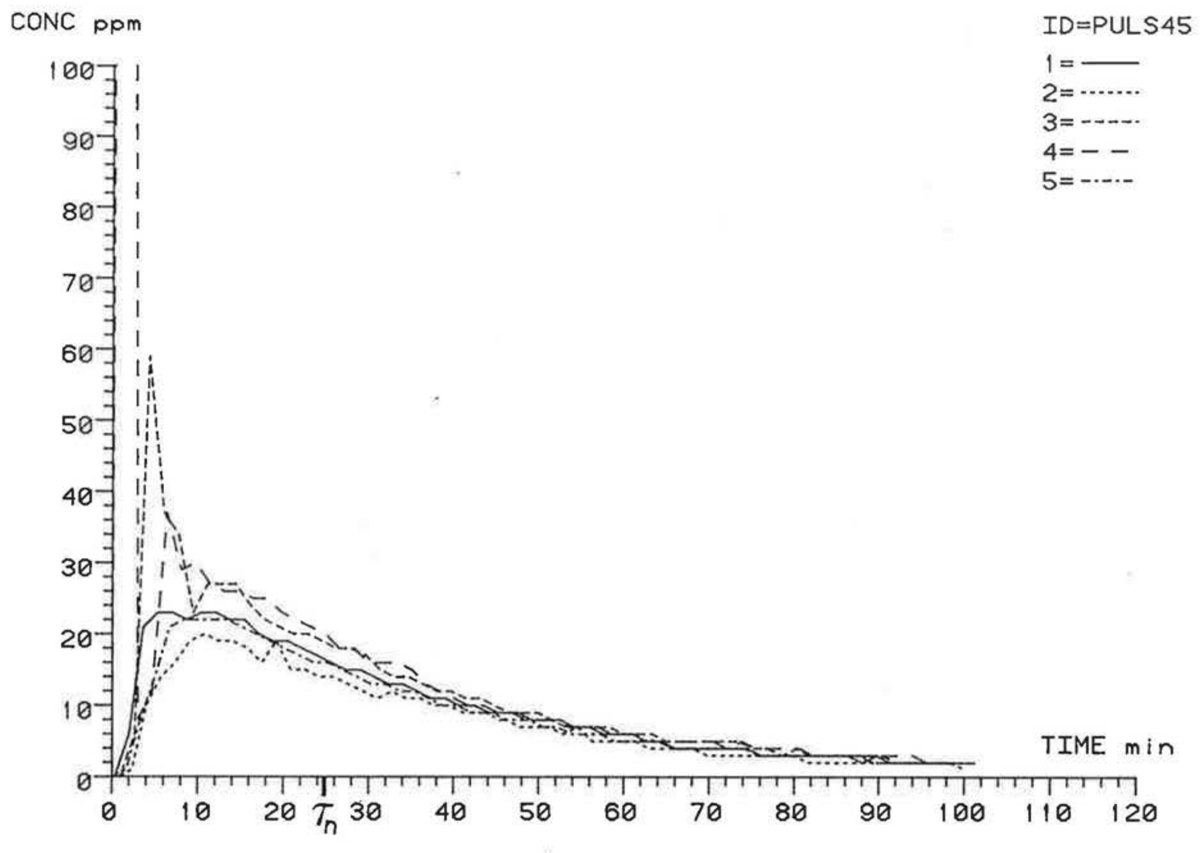


FIGURE 11B.

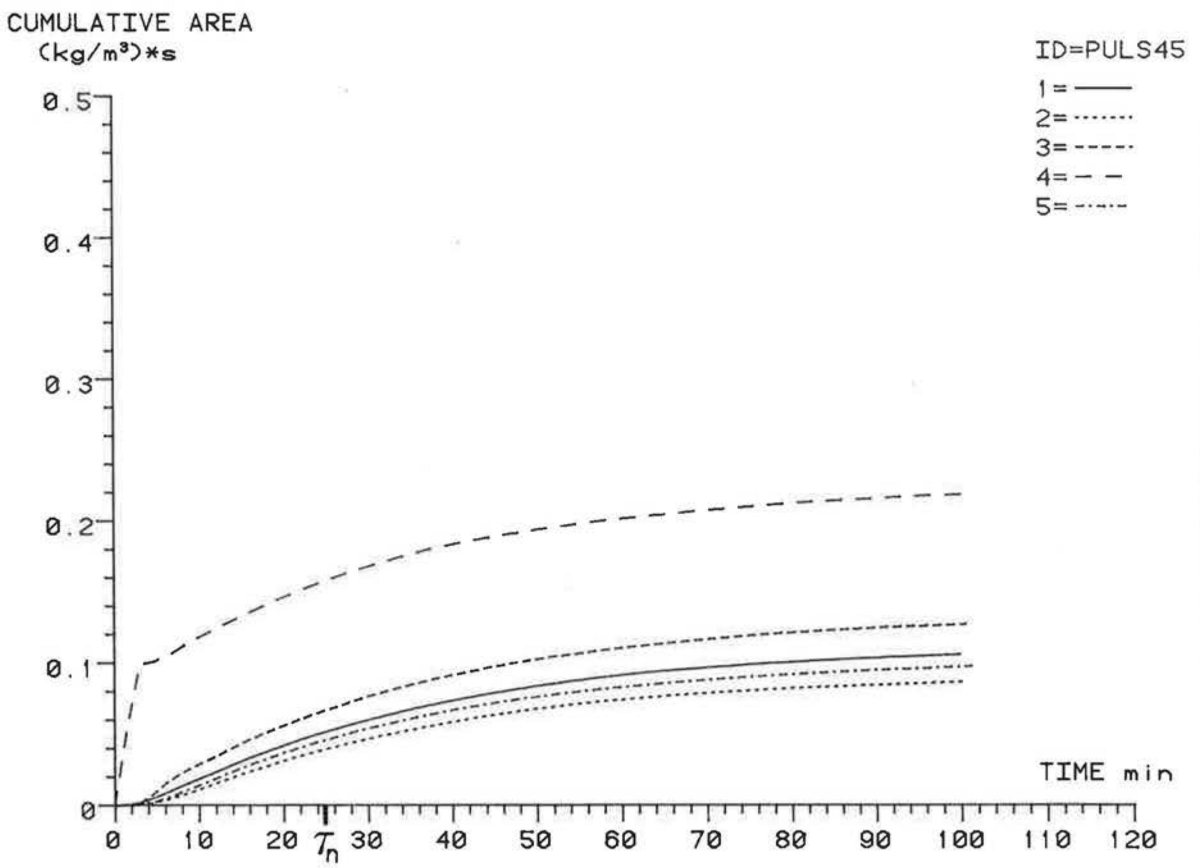


FIGURE 11C.

ID=PULS46

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	31.0	24.1	1.2	4.0	0.87	0.29	
2	-------	28.8	24.3	1.3	4.1	1.16	0.16	
3	------	25.4	25.0	1.3	4.3	2.12	0.11	
4	— — —	24.0	25.2	1.4	4.5	5.43	0.05	
5	-·-·-·-	29.4	24.7	1.3	4.1	1.08	0.14	0.87

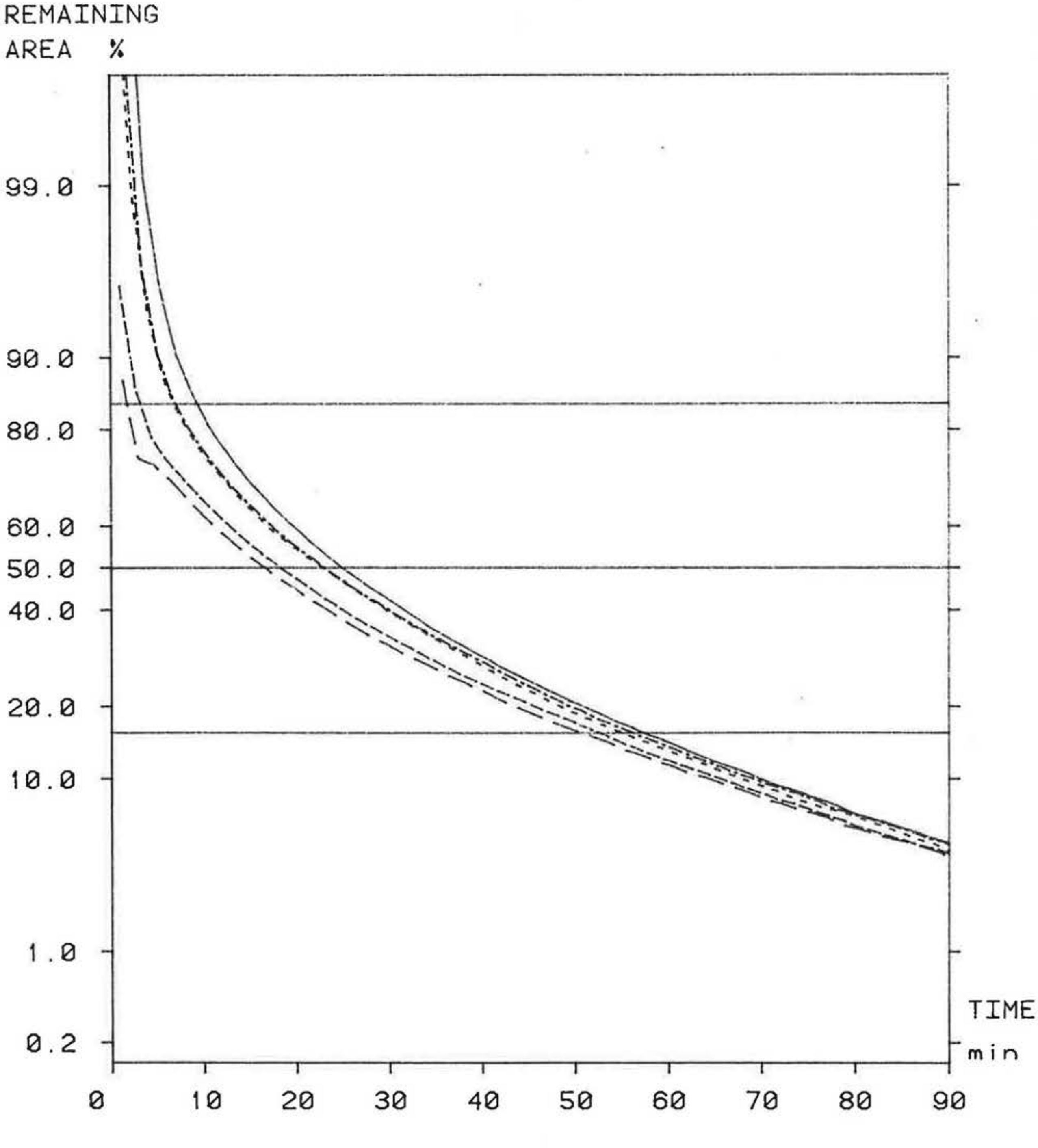


FIGURE 12A.

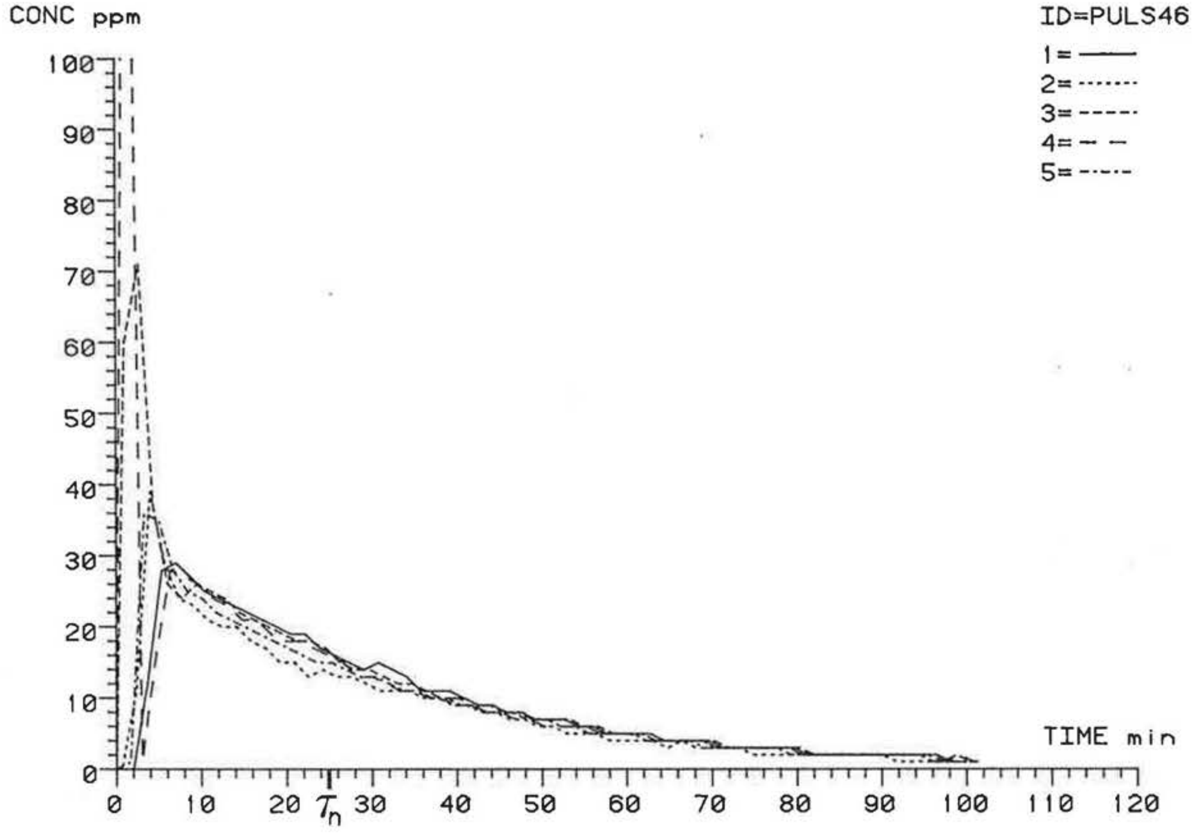


FIGURE 12B.

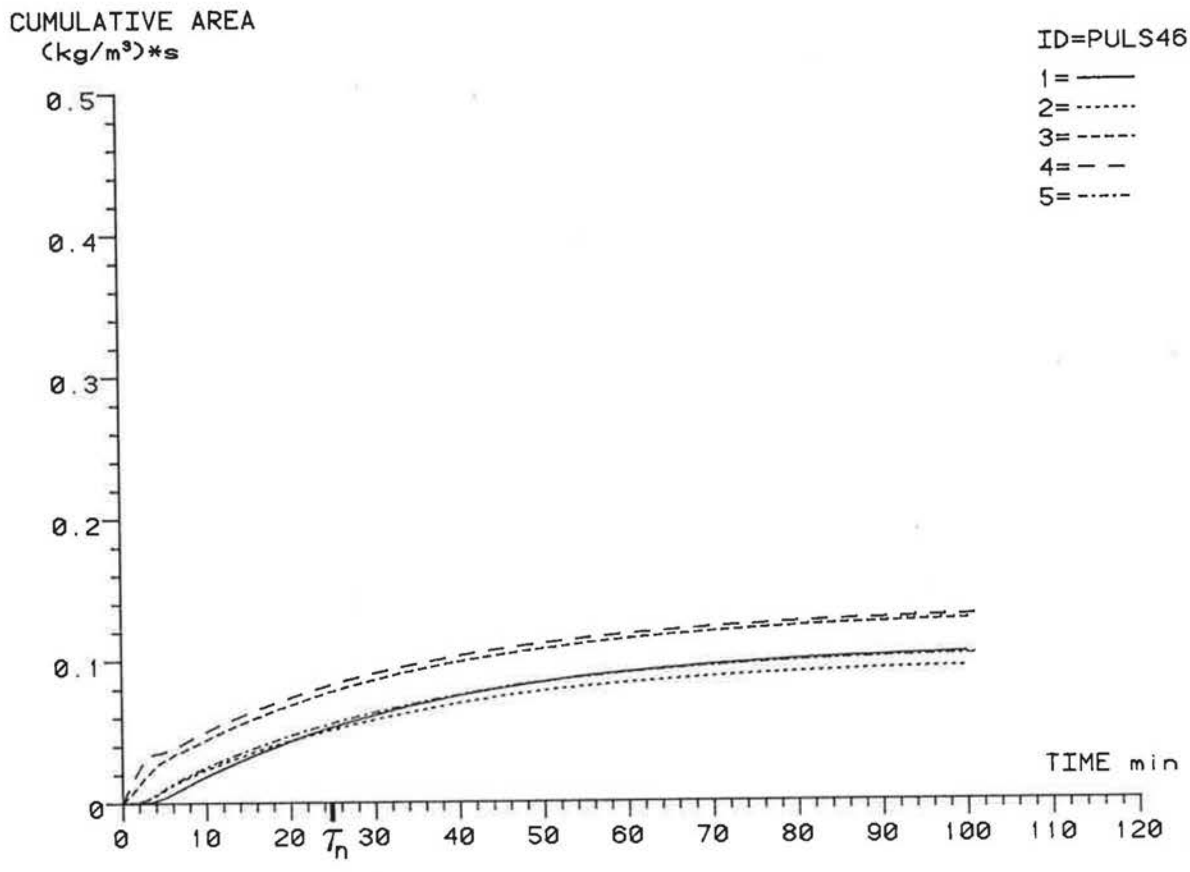


FIGURE 12C.

ID=PULS30

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	33.9	23.2	1.6	6.4	0.65	0.63	
2	- - - - - - -	29.9	21.5	1.6	6.4	0.63	0.50	
3	-·-·-·-	24.5	22.0	1.8	7.3	1.60	0.25	
4	— — —	17.8	20.4	2.2	9.0	3.56	0.19	
5	-··-··-	28.0	22.0	1.7	6.6	0.88	0.41	1.07

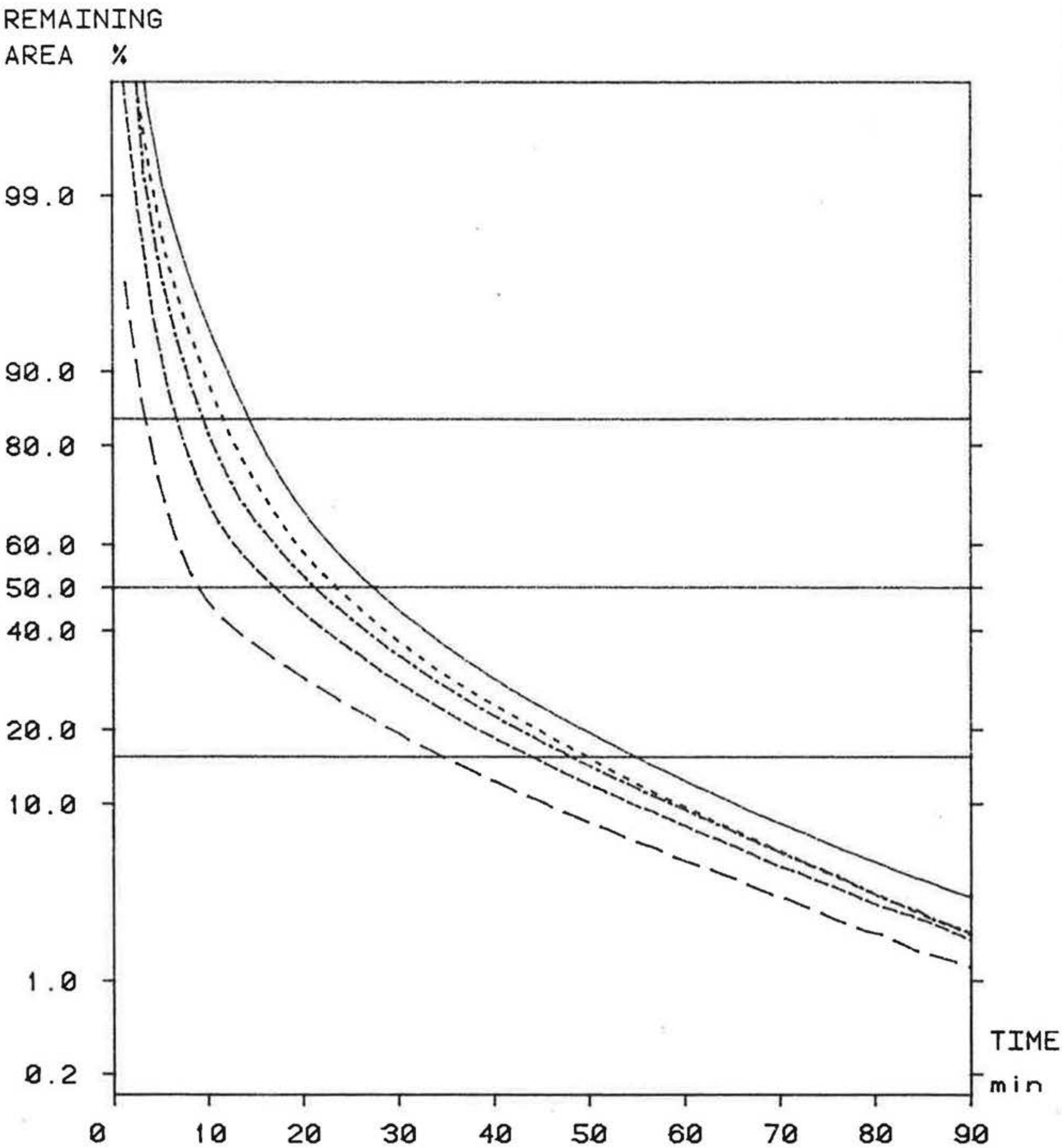


FIGURE 13A.

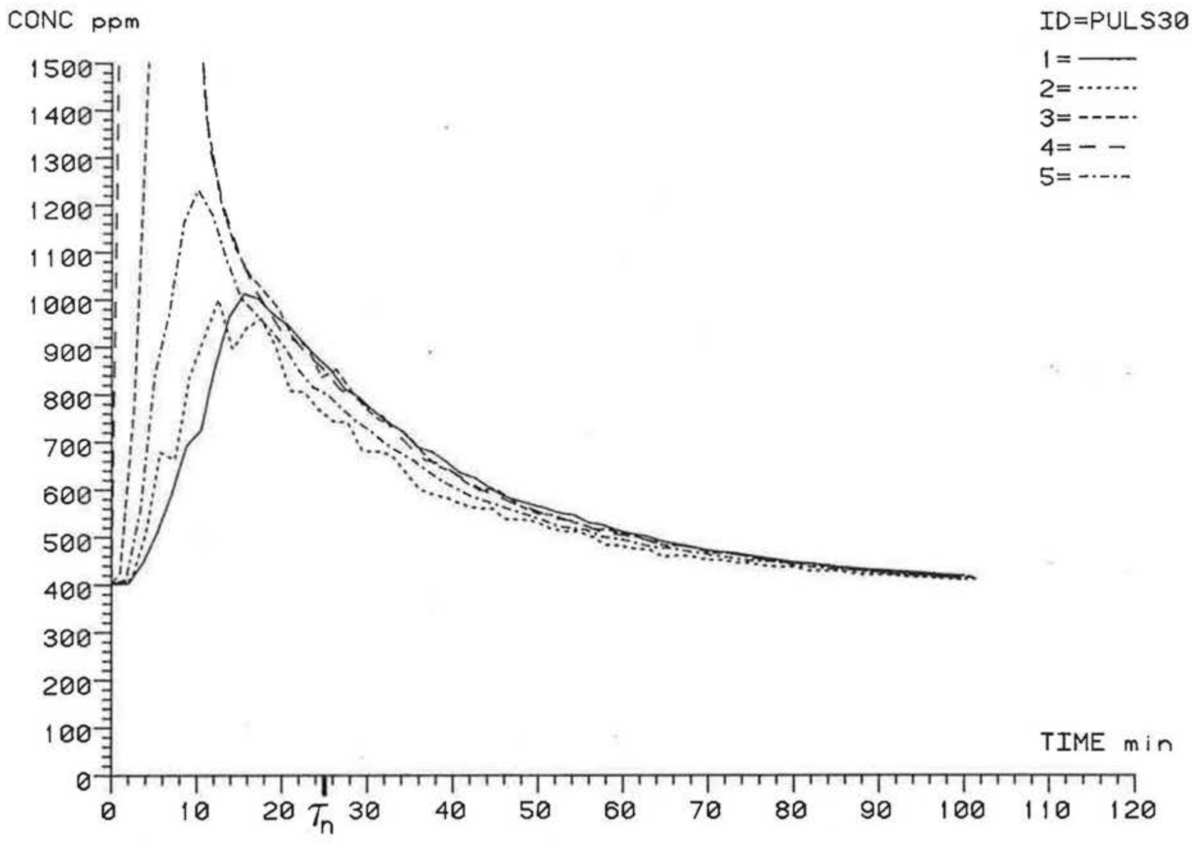


FIGURE 13B.

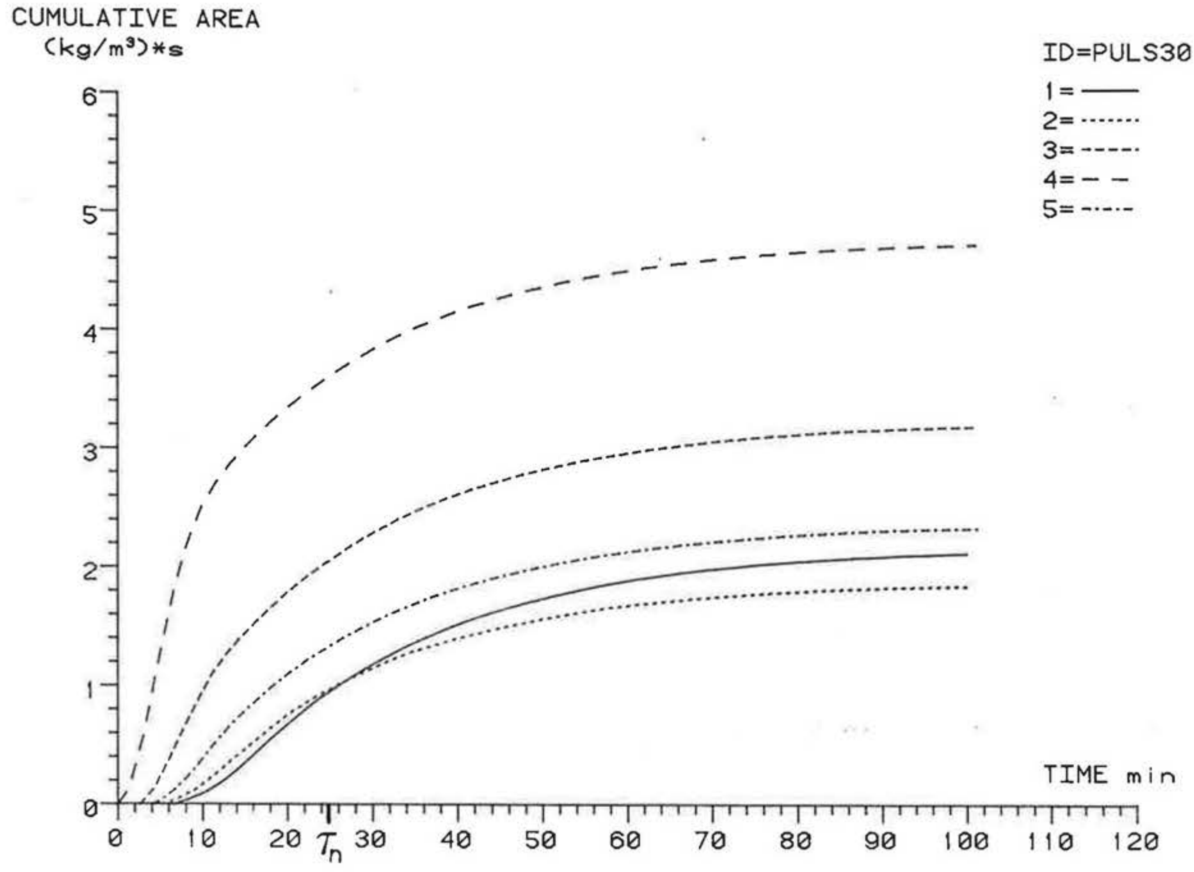


FIGURE 13C.

ID=PULS32

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	36.9	24.9	1.6	5.8	0.69	0.69	
2	- - - - - - -	35.0	25.7	1.6	6.0	0.64	0.57	
3	-------	29.9	24.5	1.7	6.3	1.28	0.45	
4	— — —	19.3	21.6	2.3	9.5	4.25	0.26	
5	-·-·-·-	34.1	25.5	1.6	6.0	0.72	0.54	0.99

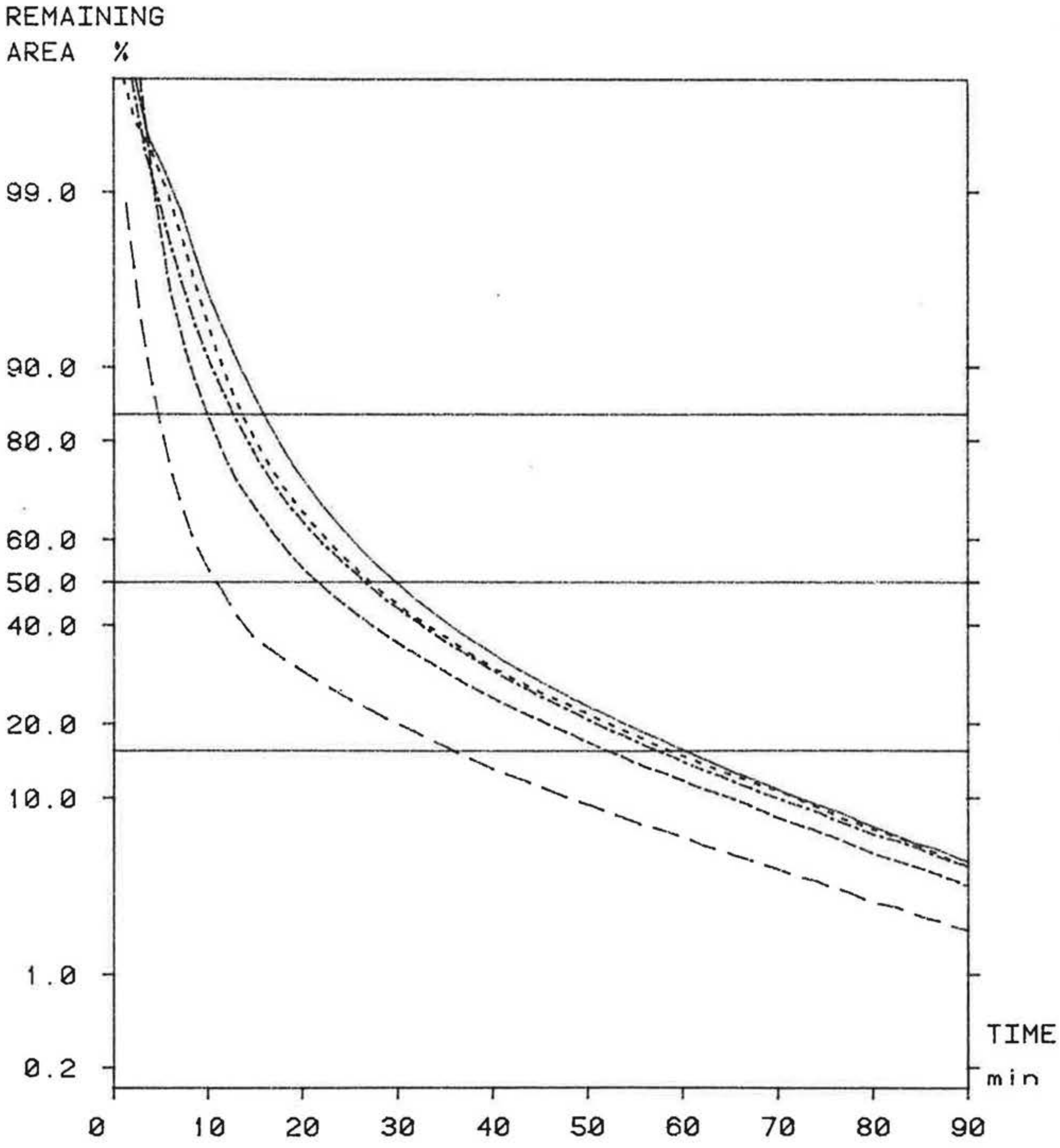


FIGURE 14A.

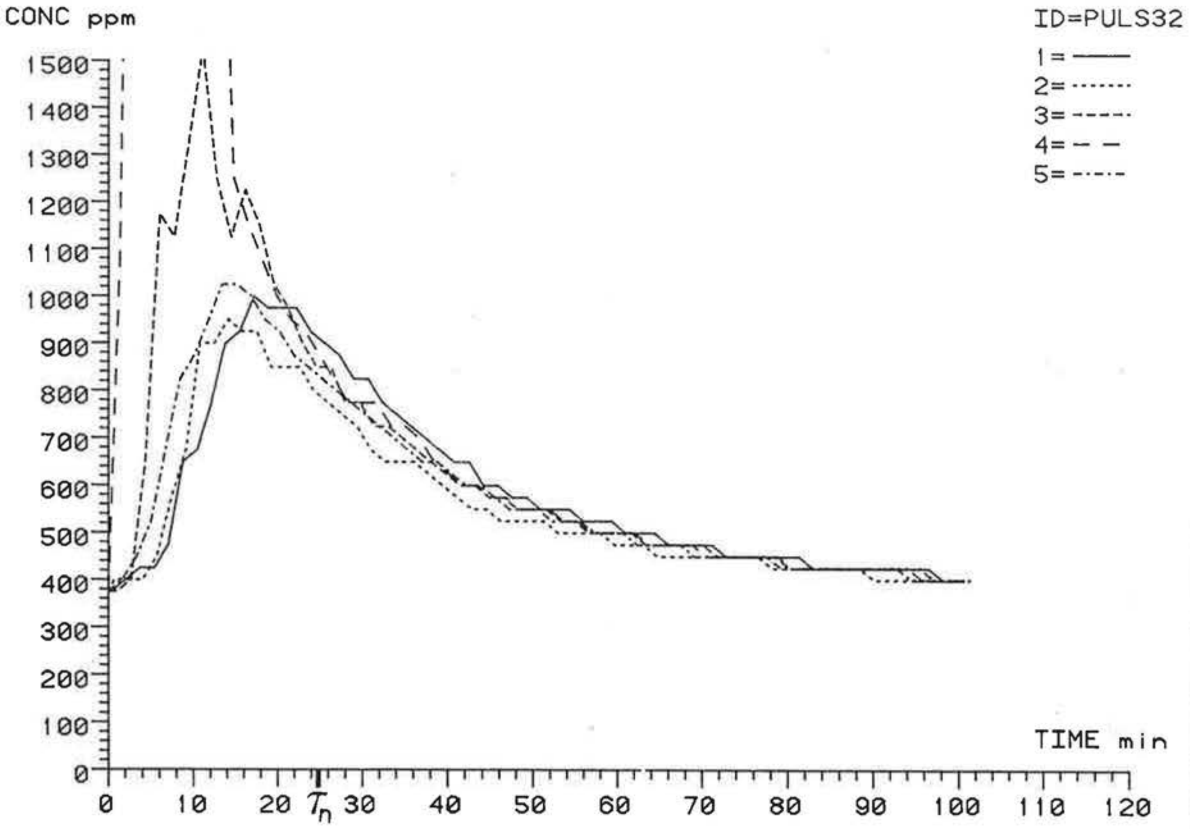


FIGURE 14B.

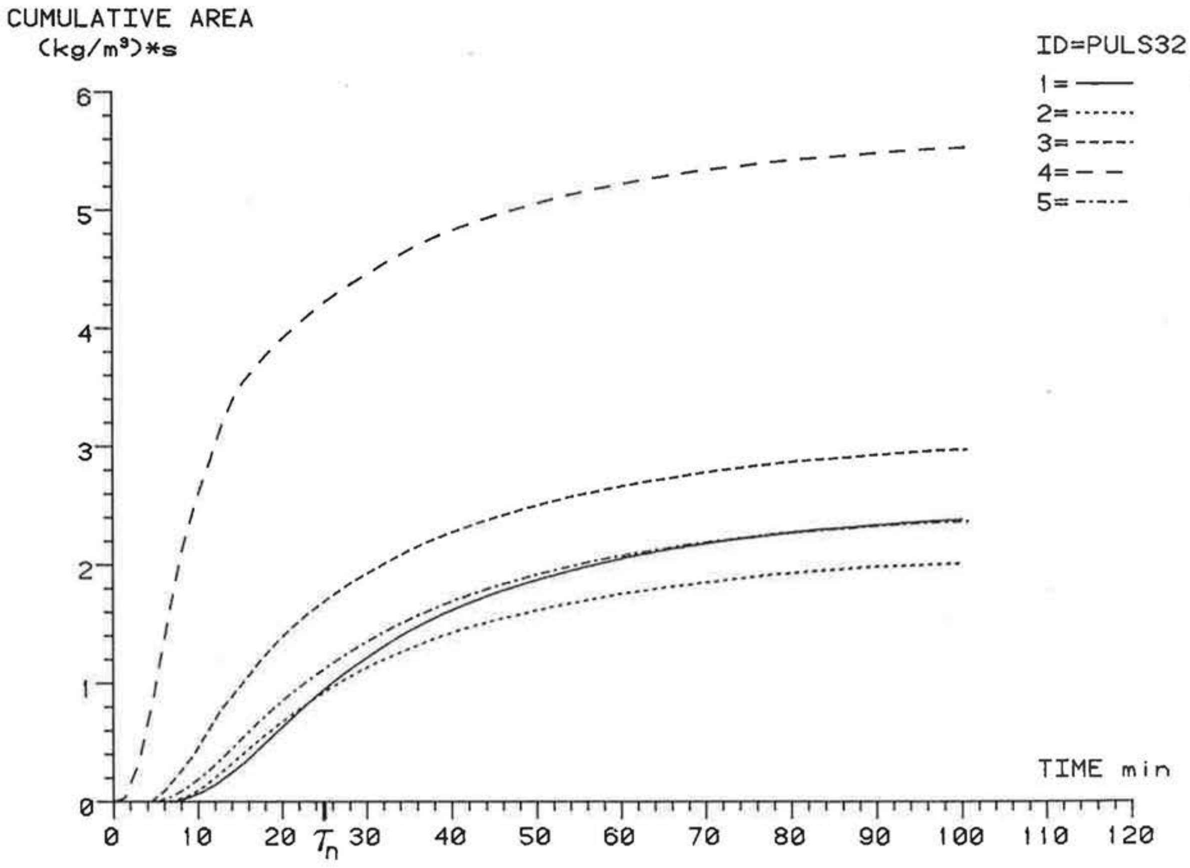


FIGURE 14C.

ID=PULS33

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	———	31.9	24.6	1.7	6.5	0.78	0.49	
2	-------	30.7	26.1	1.8	6.5	0.75	0.37	
3	------	31.2	24.8	1.7	6.5	1.03	0.45	
4	— — —	30.7	25.3	1.7	6.3	1.17	0.12	
5	-·-·-·-	31.9	25.3	1.7	6.5	0.72	0.41	1.03

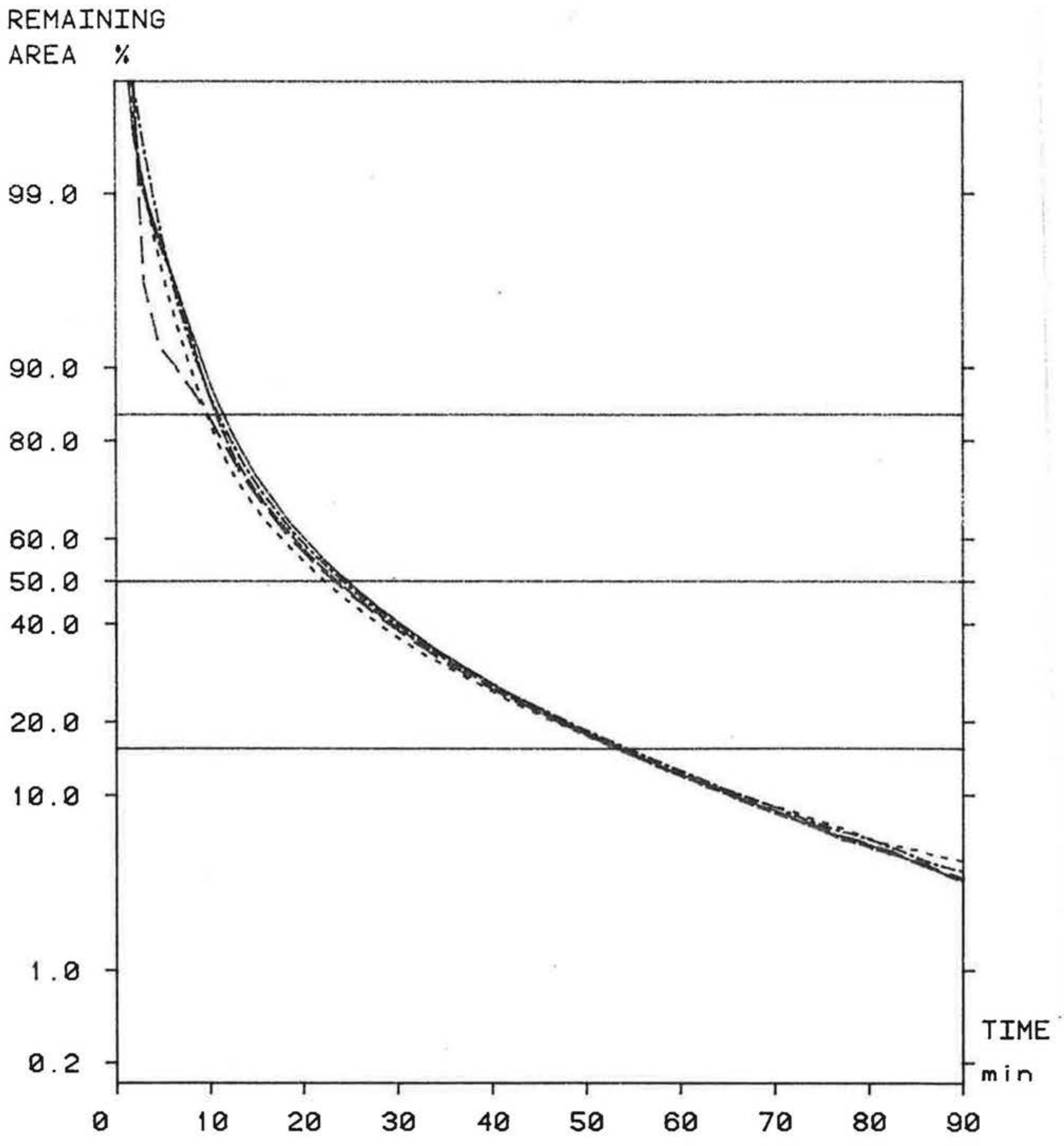


FIGURE 15A.

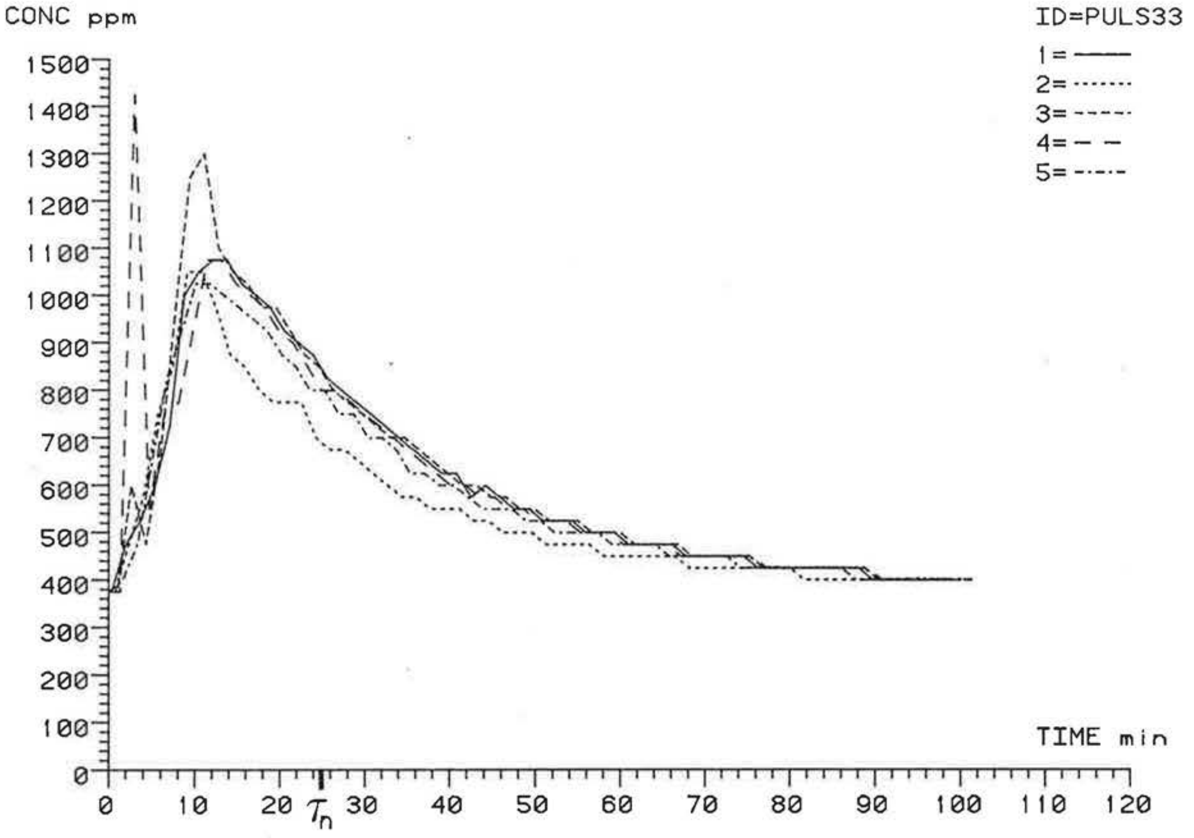


FIGURE 15B.

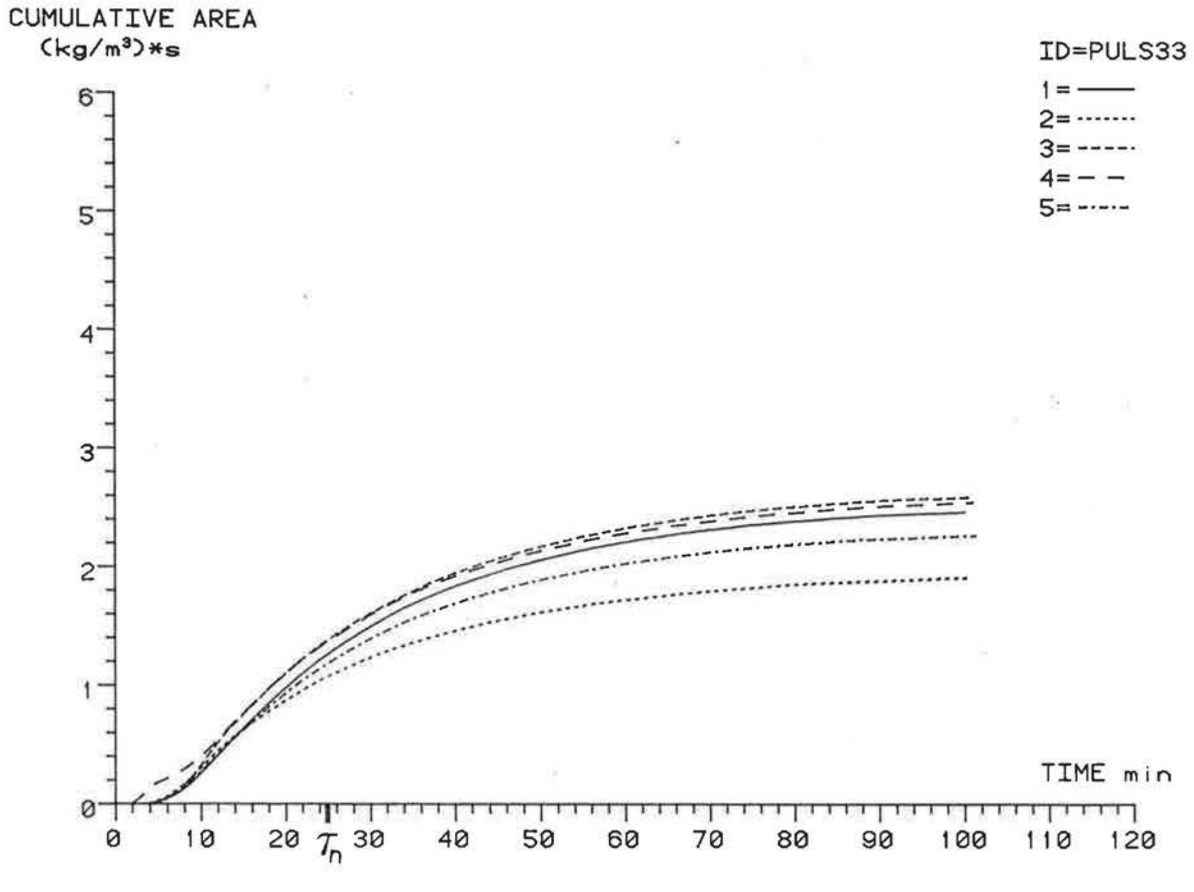


FIGURE 15C.

ID=PULS34

CHAN	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	———————	34.8	30.0	1.6	5.3	0.79	0.35	
2	-------	35.3	31.4	1.5	5.0	0.85	0.30	
3	------	34.8	29.8	1.6	5.5	1.11	0.38	
4	— — —	21.8	28.0	2.0	7.4	4.55	0.05	
5	-·-·-·-	36.4	31.4	1.5	5.1	0.74	0.34	1.00

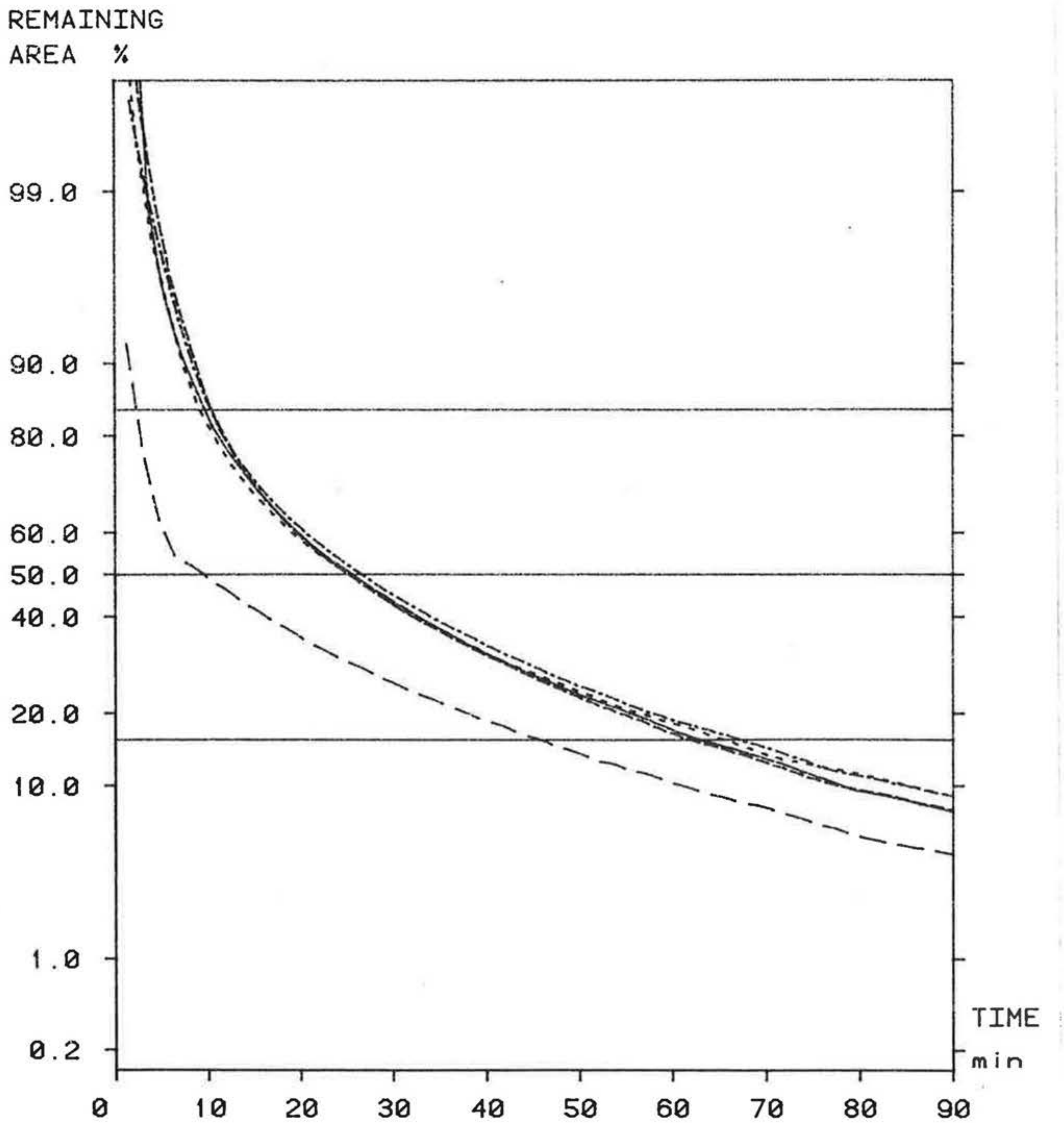


FIGURE 16A.

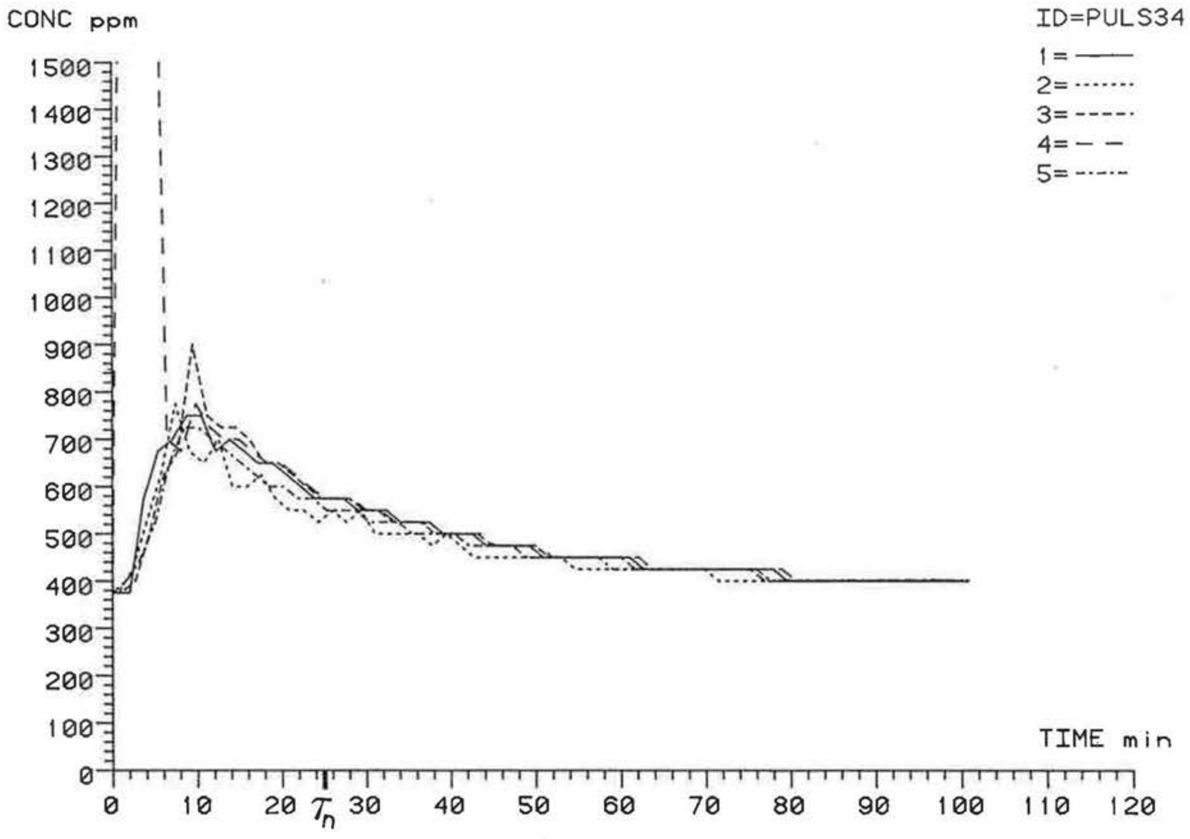


FIGURE 16B.

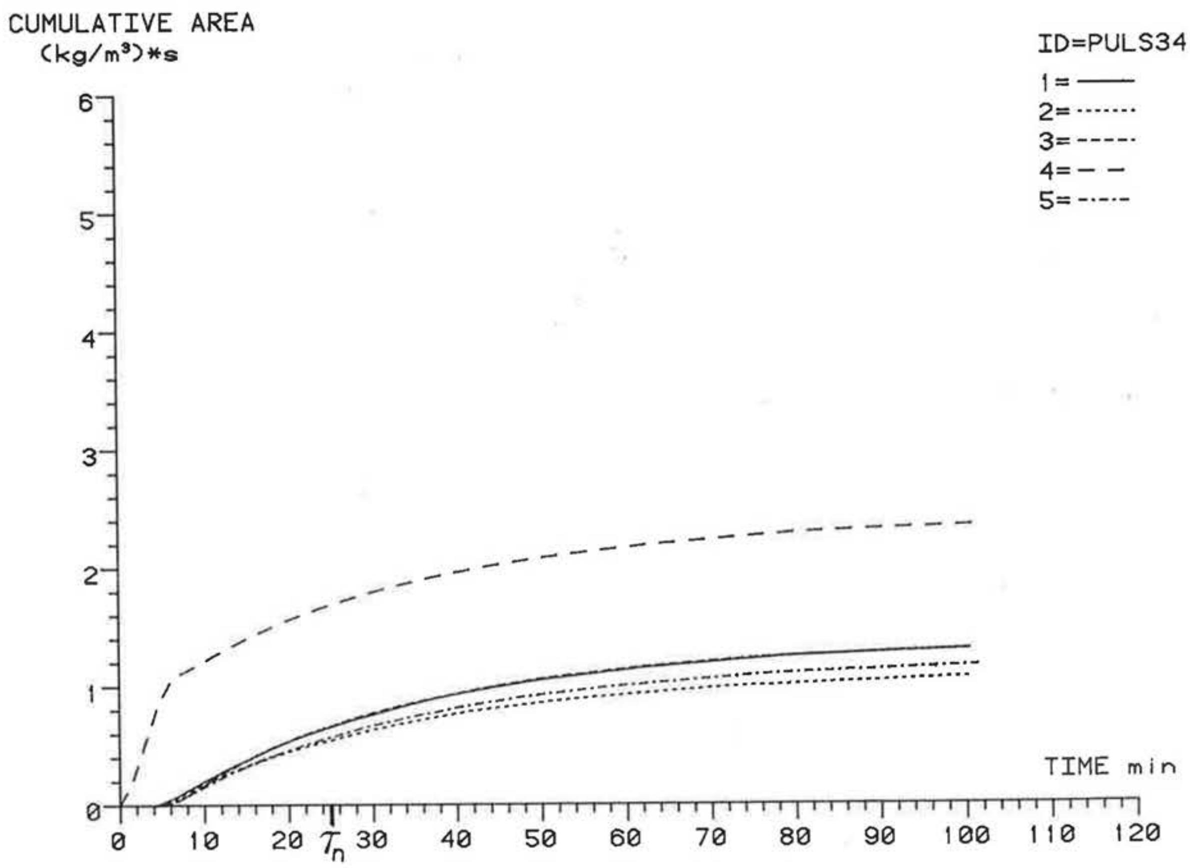


FIGURE 16C.

ID=PULS35

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	————	26.0	17.5	0.9	3.0	0.78	0.29	
2	- - - - - - -	24.9	15.9	0.9	3.1	0.72	0.30	
3	-·-·-·-·	22.2	16.9	1.1	3.6	1.00	0.18	
4	— — —	15.5	16.0	1.5	4.6	2.89	0.12	
5	-··-··-	23.1	16.5	1.1	3.5	0.83	0.27	1.23

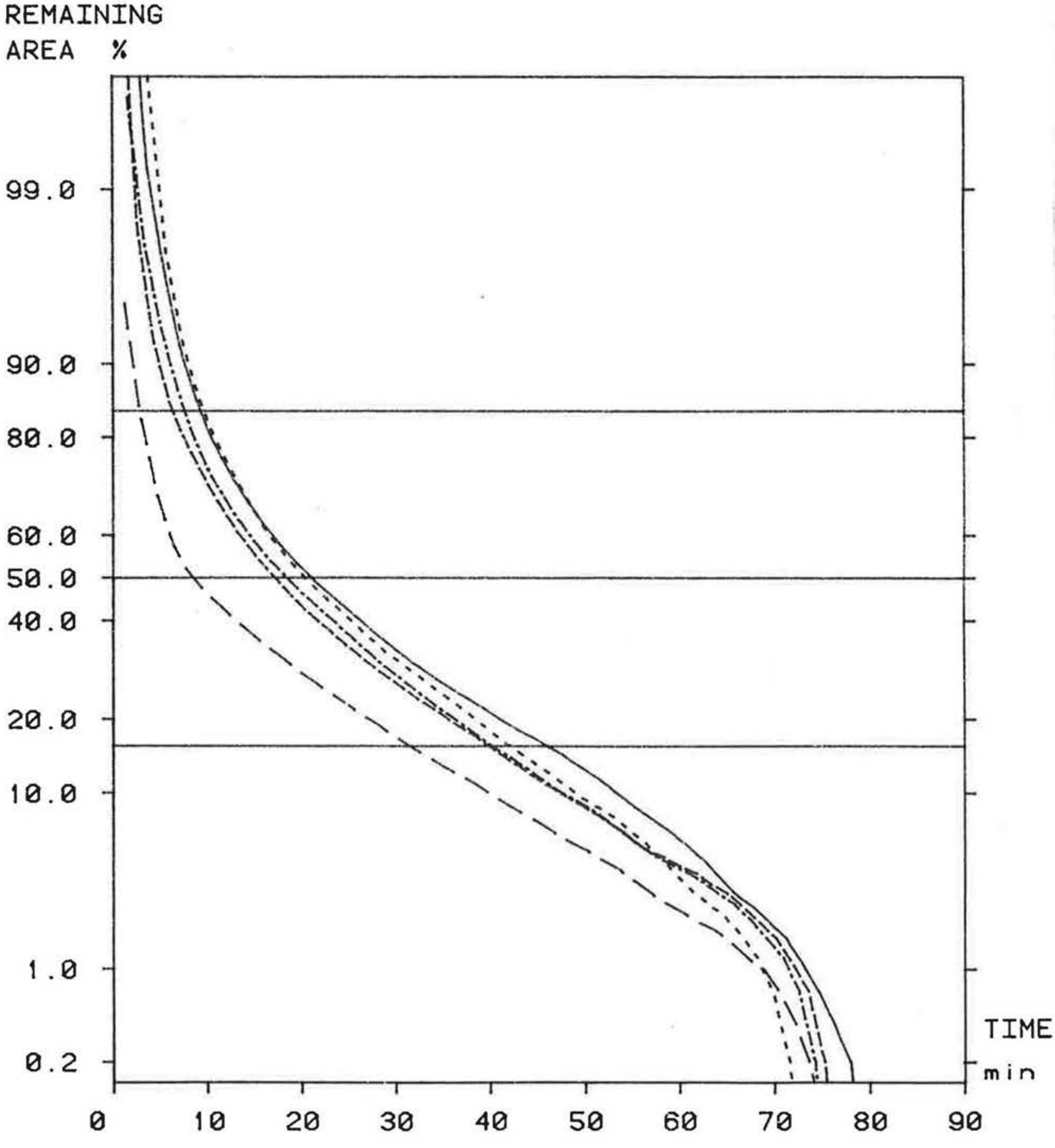


FIGURE 17A.

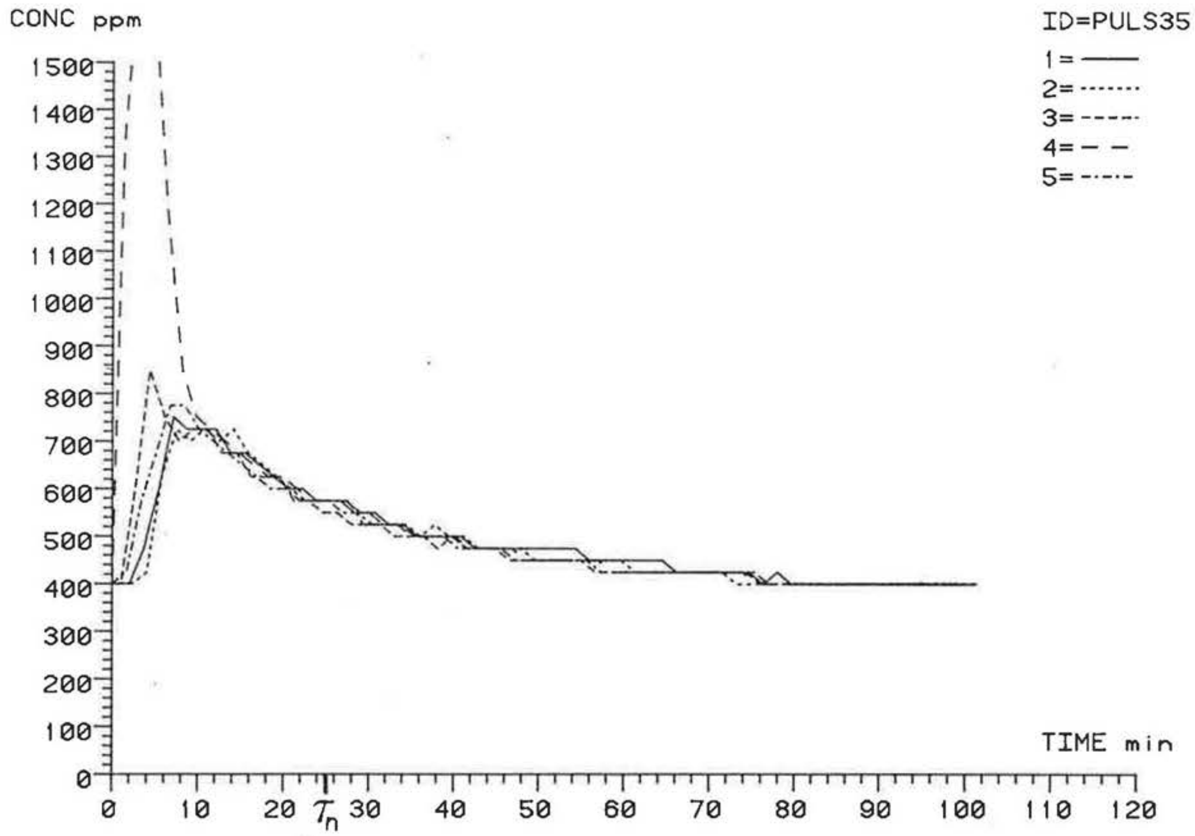


FIGURE 17B.

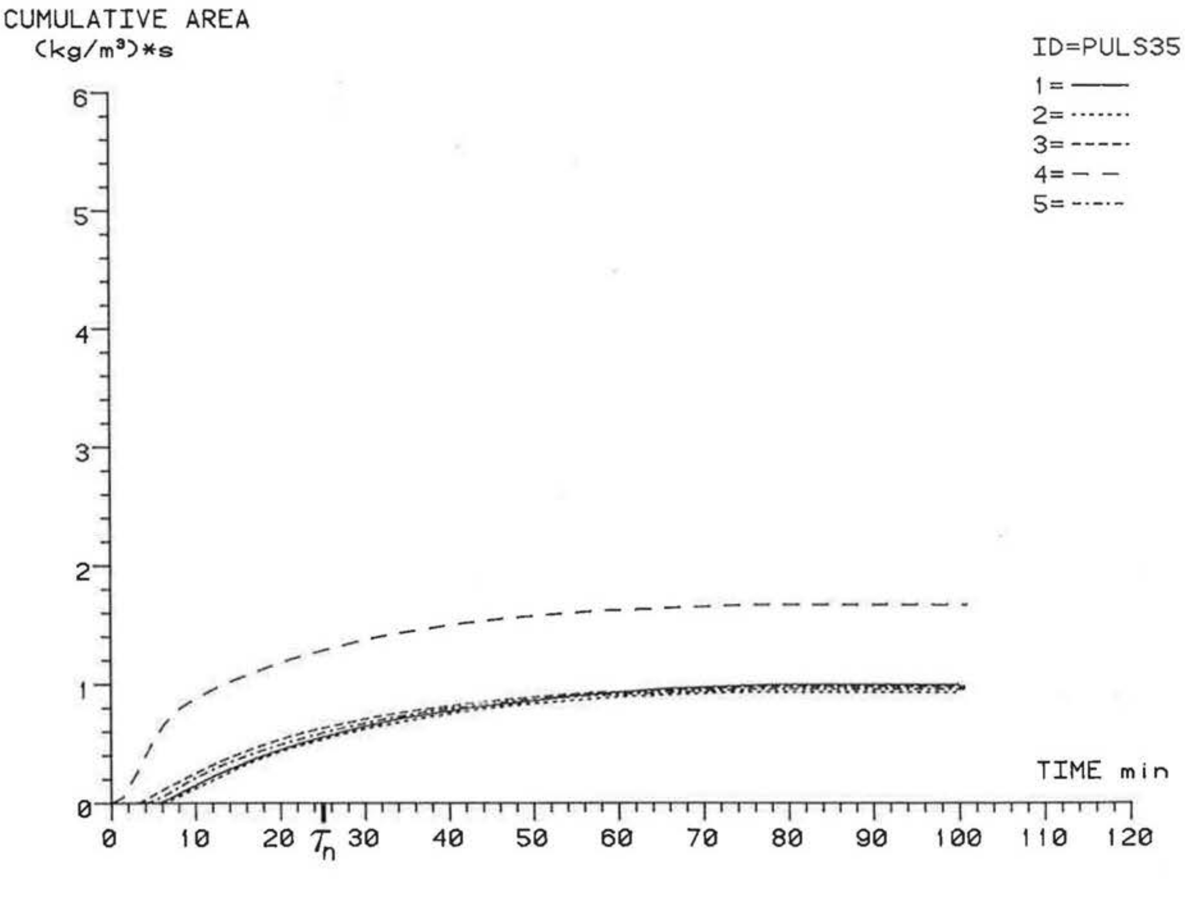


FIGURE 17C.

ID=PULS36

CHAN.	SYMBOL	MEAN min	STDV min	S	K	$\widehat{CMAX}$	$\widehat{TMAX}$	$\frac{m}{m_e}$
1	———	28.1	23.1	1.7	6.7	0.89	0.35	
2	-------	27.4	22.8	1.7	6.5	0.73	0.30	
3	------	26.0	23.4	1.8	6.9	1.42	0.18	
4	— — —	22.6	22.8	1.8	7.1	2.29	0.12	
5	-·-·-·-	27.2	22.8	1.7	6.5	0.95	0.27	1.12

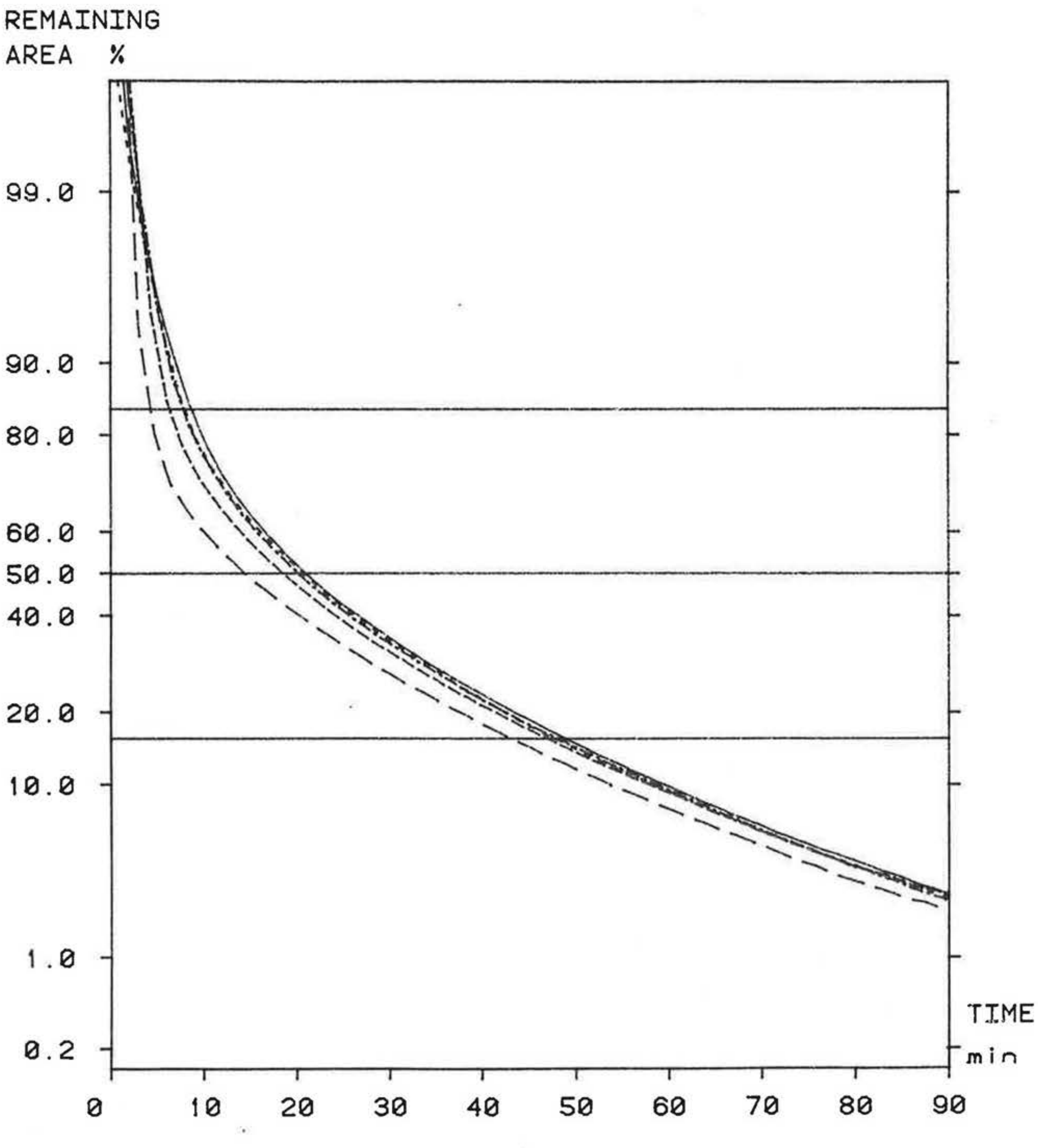


FIGURE 18A.

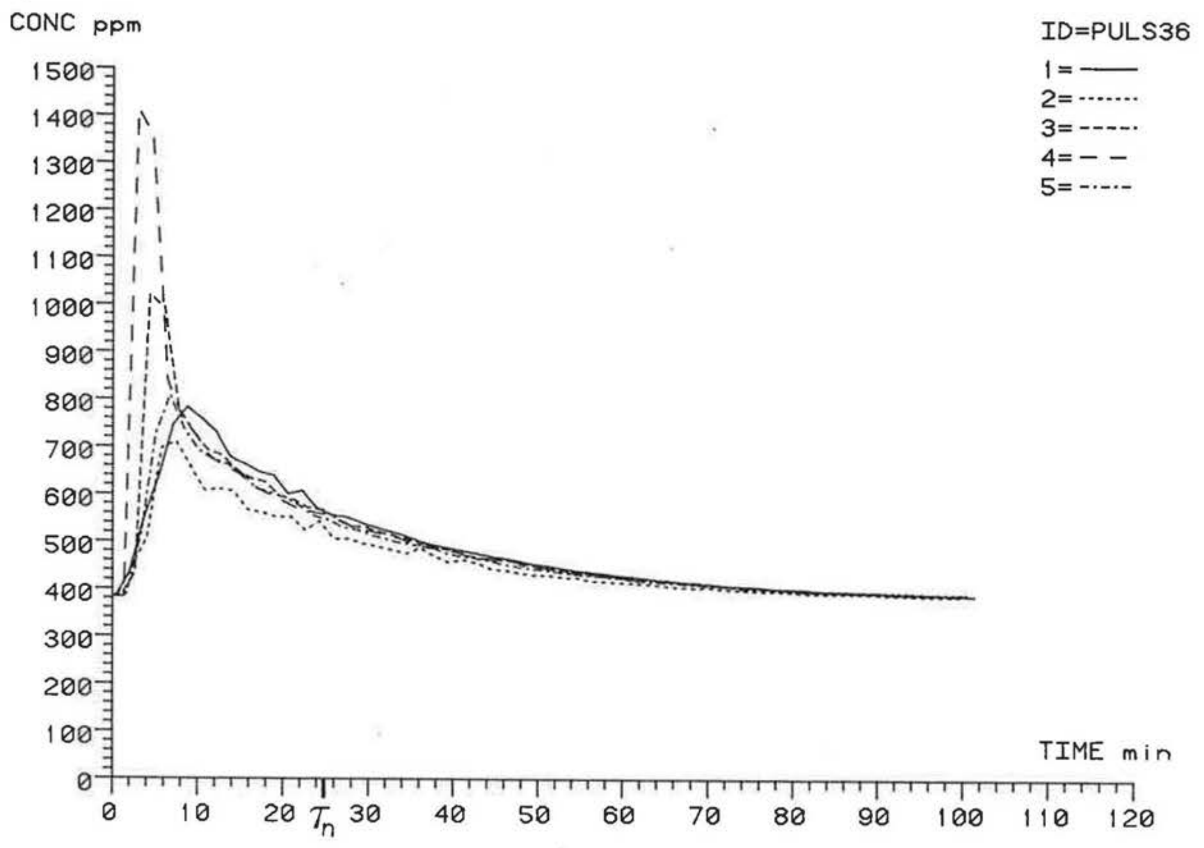


FIGURE 18B.

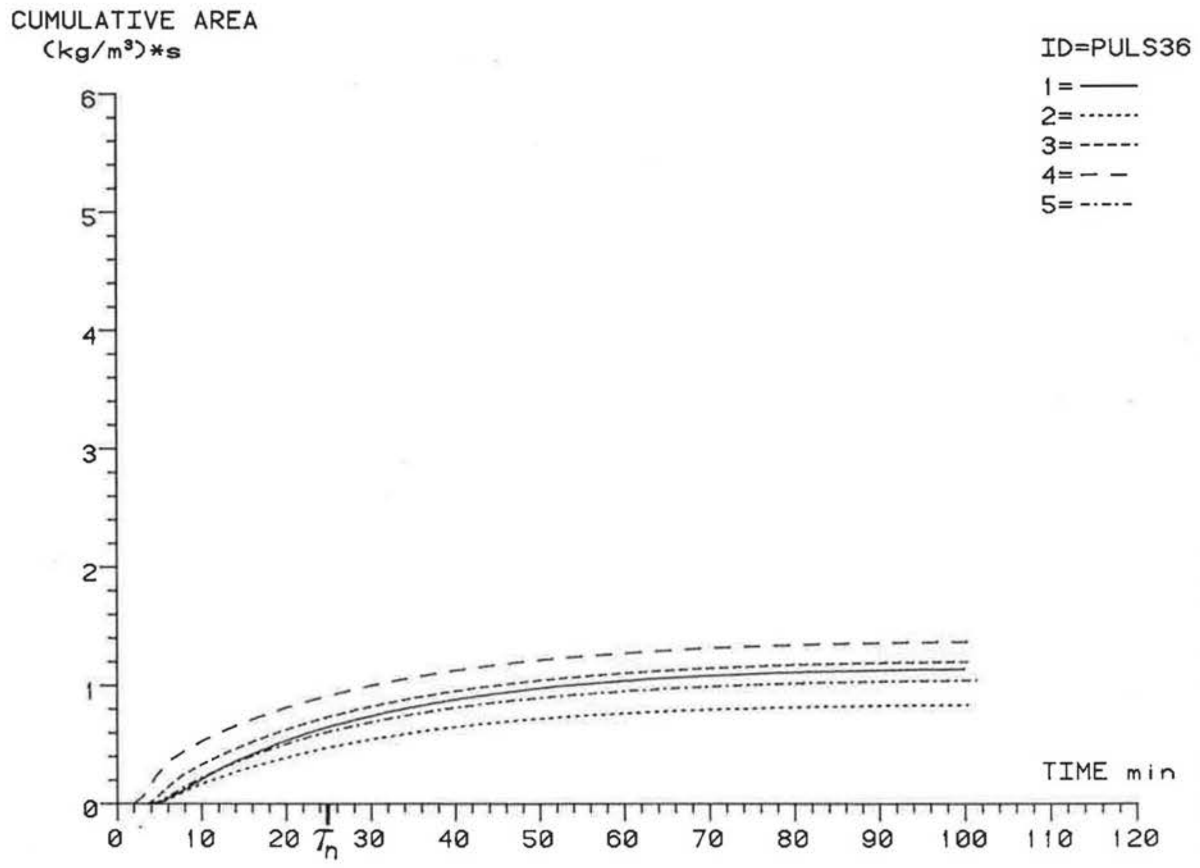


FIGURE 18C.

THE STEP-UP METHOD

The step-up method was also used to simulate a 'contaminant source'. The gas was released with a continous flowrate into the chamber through the 'source' described earlier. Both the gas flowrate, $\dot{m}$, and the initial velocity, U_o, of the gas were varied between the tests. U_o was varied by sealing off a number of the 27 nozzles in the 'source'. Before each test, the tubing was flushed with gas in the same manner as described earlier.

Table 4 shows the test conditions together with the following calculated results and parameters:

- The densimetric Froude number:

$$F_o = \frac{U_o}{\left(g \cdot \left(\frac{\rho_g - \rho_a}{\rho_a}\right) \cdot r_o\right)^{0.5}}$$

where

$\rho_g - \rho_a$ = the density difference between the tracer gas and the ambient air.

r_o = the radius of the nozzles in the 'contaminant source'.

- The amount of tracer gas in the chamber at steady state conditions:

$$M(\infty) = Q \cdot \sum_{i=1}^{\infty} (C_{e(\infty)} - C_{e(i)}) \cdot \Delta\tau$$

where

e = exhaust

Q = volume flow of air in the exhaust duct, as measured with the step-down method.

- The turn-over time:

$$\tau_t = \frac{M(\infty)}{\dot{m}}$$

Plots of concentration versus time are shown in Figures 19-32.

TABLE 4. The step-up method

Test no	Tracer	$\dot{m}$ [l/s]	U_o [m/s]	F_o [1]	$M(\infty)$ [1]	τ_t [h]
48	SF_6	$0.72\cdot10^{-3}$	0.009	0.044	1.39	0.54
50	"	$0.72\cdot10^{-3}$	0.009	0.044	1.42	0.55
57	"	$0.72\cdot10^{-3}$	0.12	0.589	0.88	0.34
59	"	$0.72\cdot10^{-3}$	0.12	0.589	0.96	0.37
52	"	$1.00\cdot10^{-3}$	0.012	0.059	1.69	0.47
54	"	$1.00\cdot10^{-3}$	0.012	0.059	1.50	0.42
63	"	$1.00\cdot10^{-3}$	0.16	0.785	2.02	0.56
49	N_2O	$0.17\cdot10^{-3}$	0.002	0.028	0.41	0.67
56	"	$0.17\cdot10^{-3}$	0.028	0.395	0.24	0.38
51	"	$0.33\cdot10^{-3}$	0.004	0.056	0.87	0.73
58	"	$0.33\cdot10^{-3}$	0.055	0.776	0.56	0.47
53	"	$0.75\cdot10^{-3}$	0.009	0.121	1.51	0.56
55	"	$1.00\cdot10^{-3}$	0.012	0.169	2.00	0.55
62	"	$1.00\cdot10^{-3}$	0.16	2.26	1.39	0.39

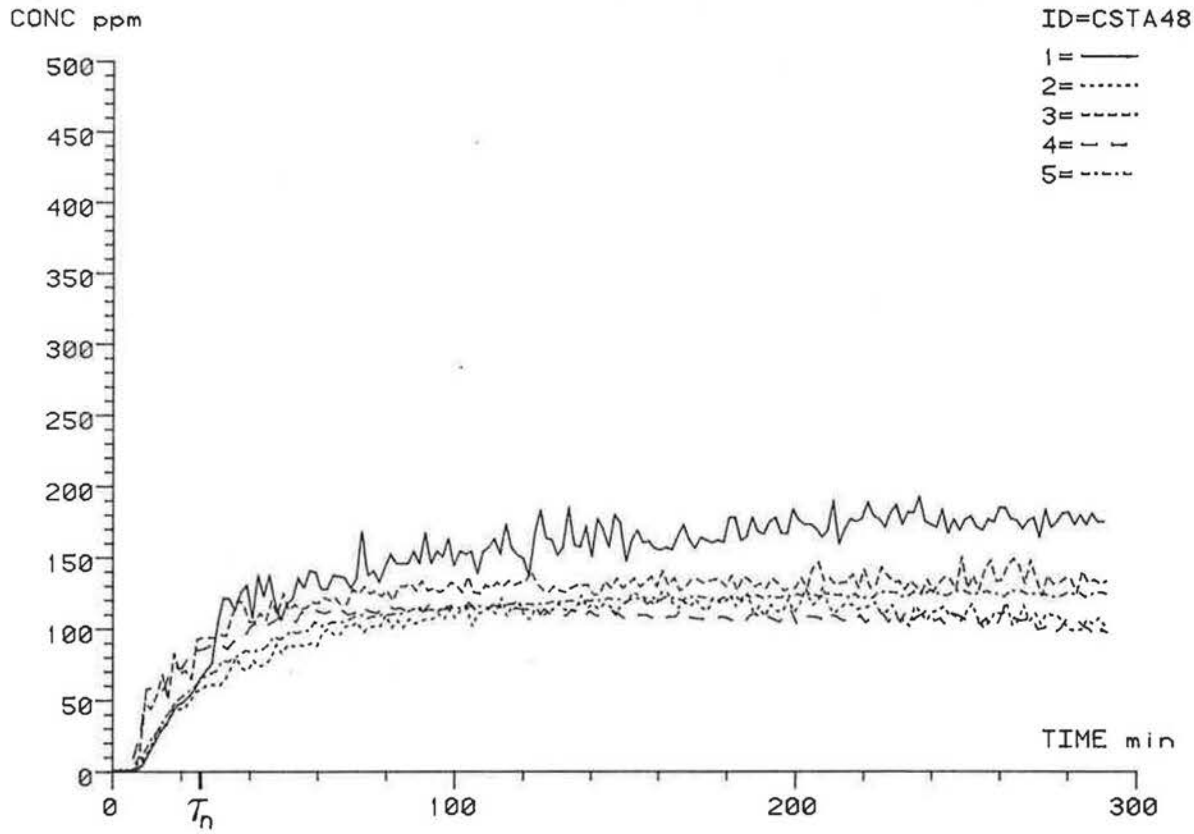


FIGURE 19.

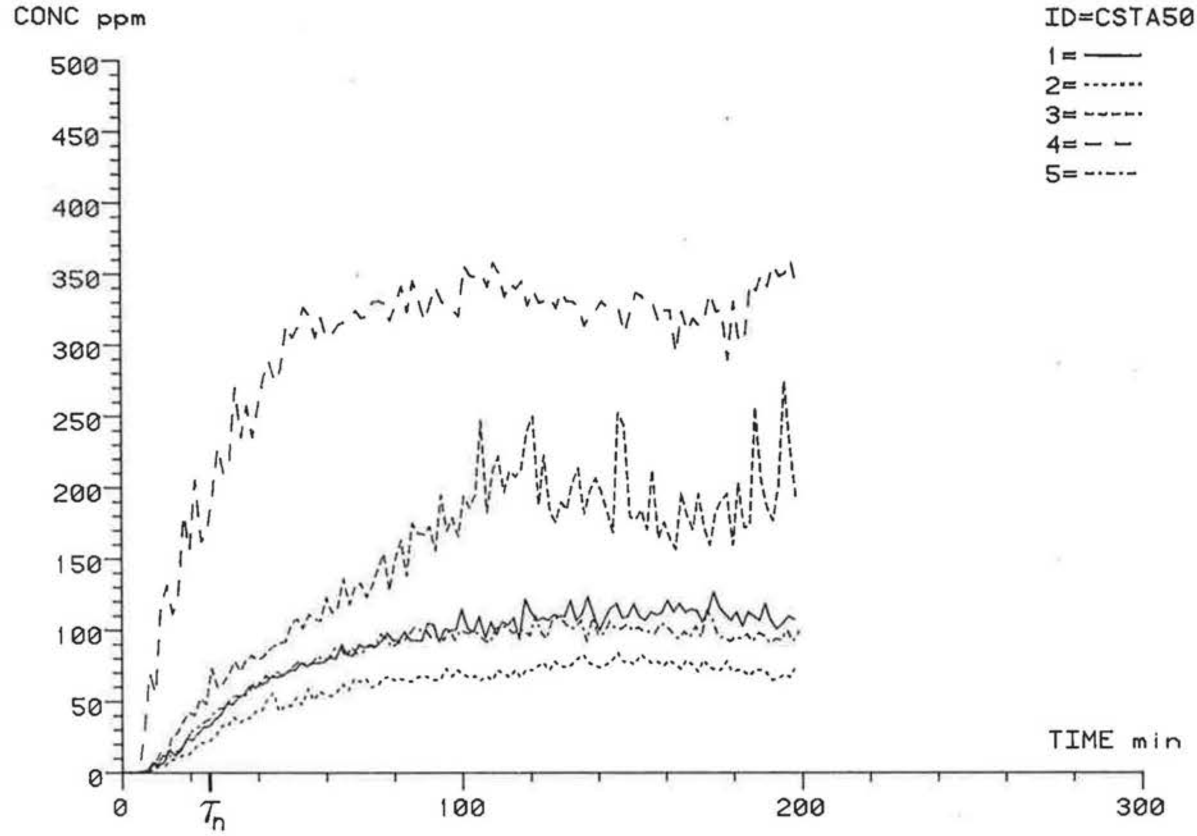


FIGURE 20.

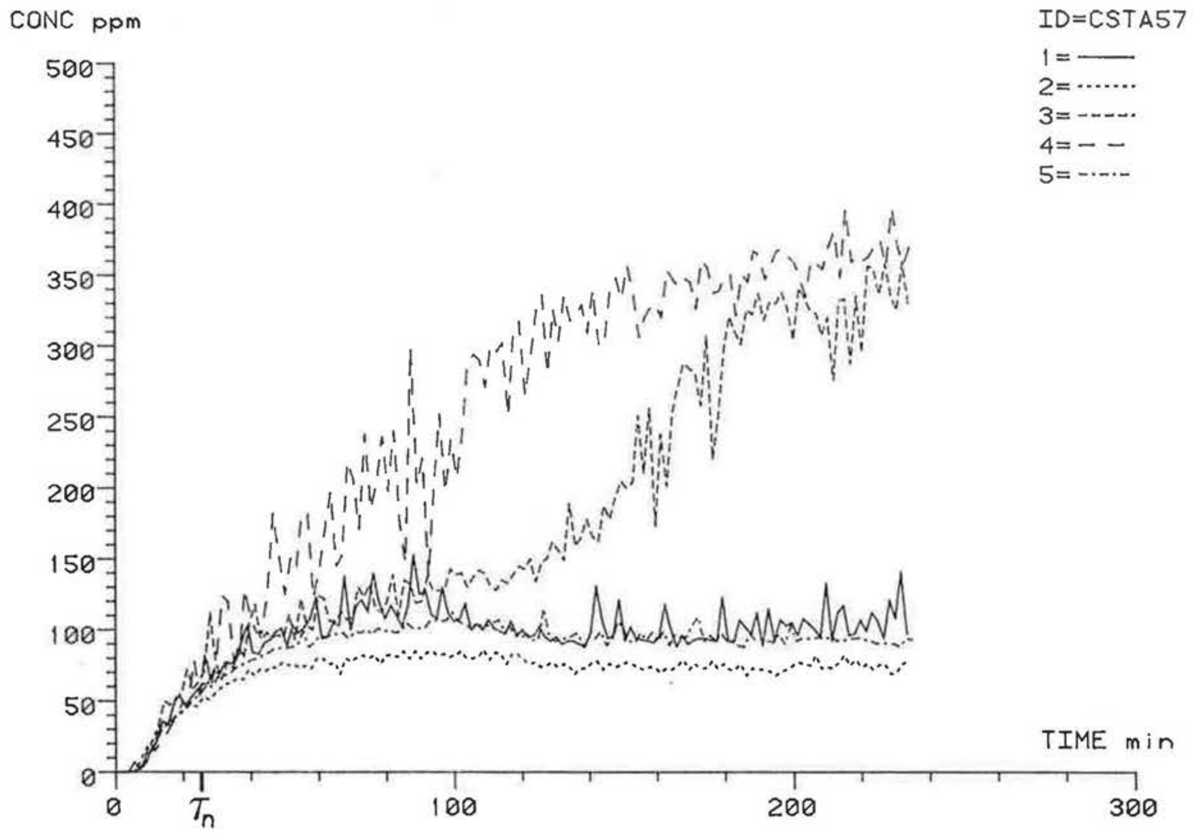


FIGURE 21.

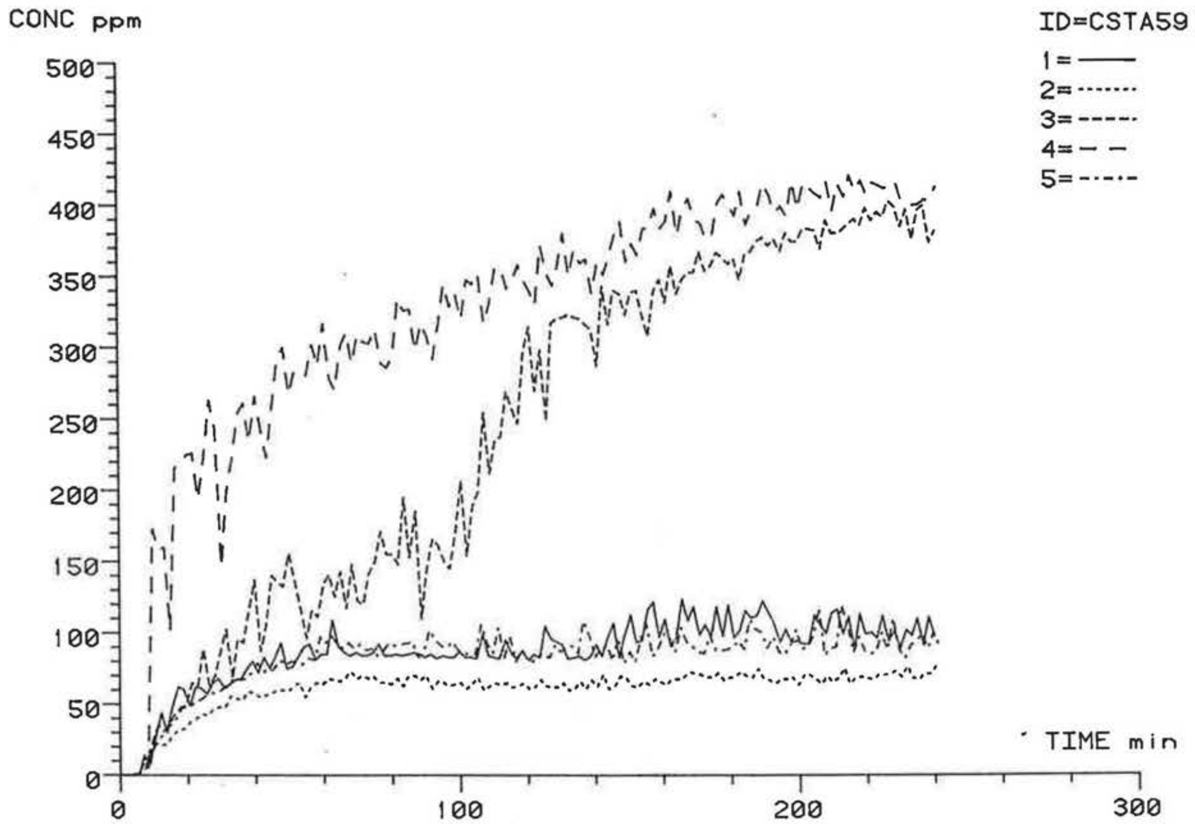


FIGURE 22.

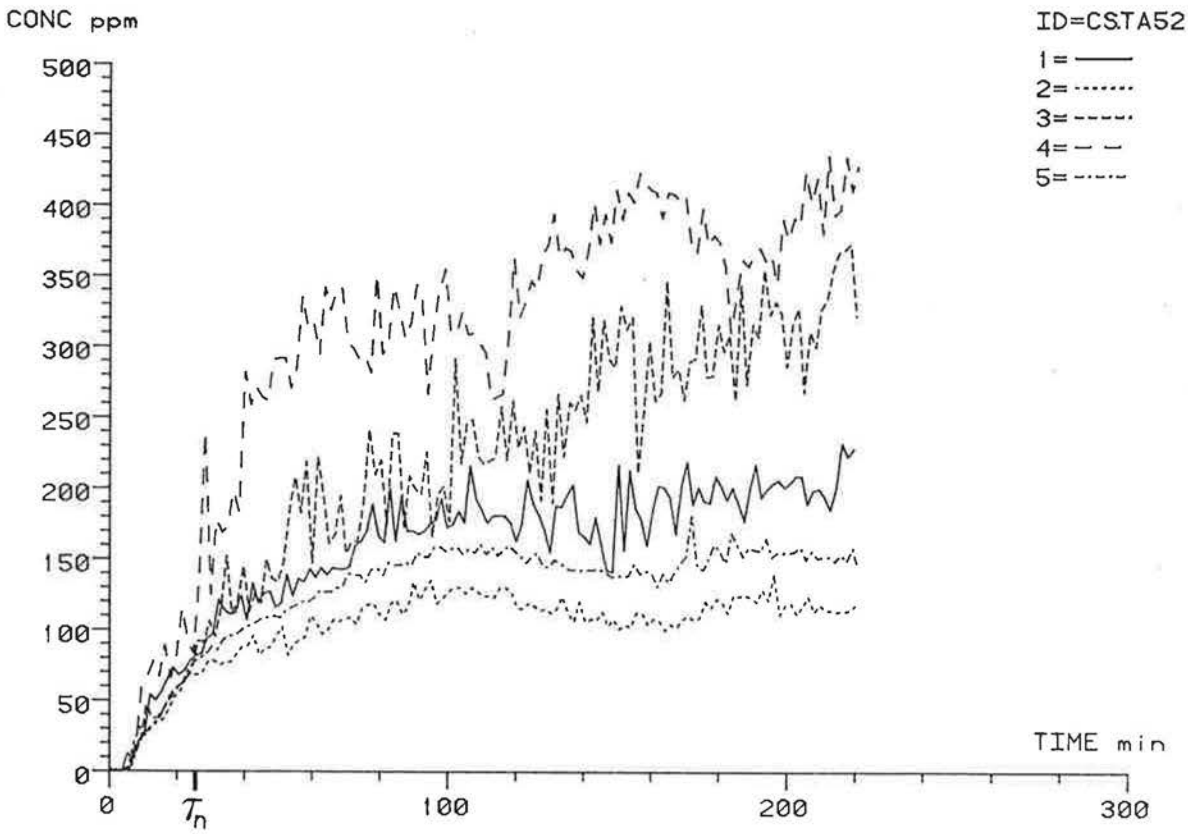


FIGURE 23.

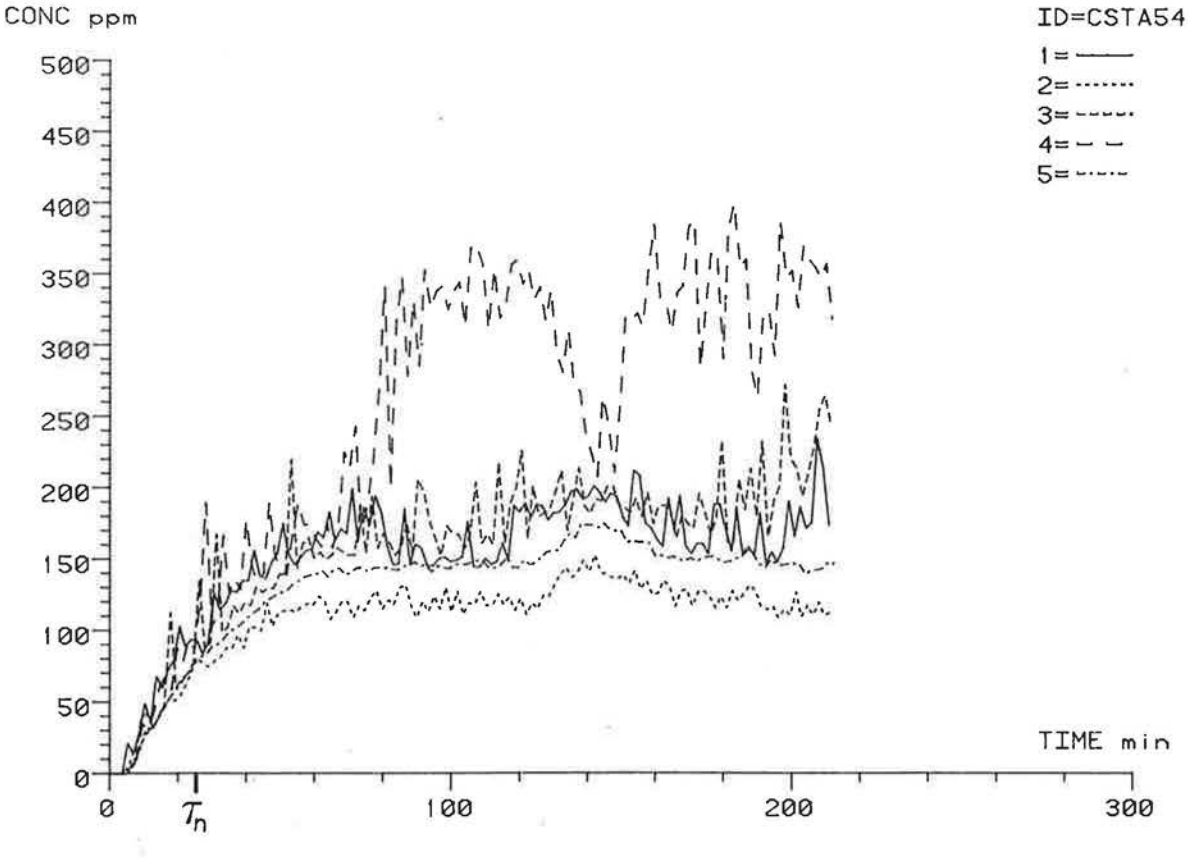


FIGURE 24.

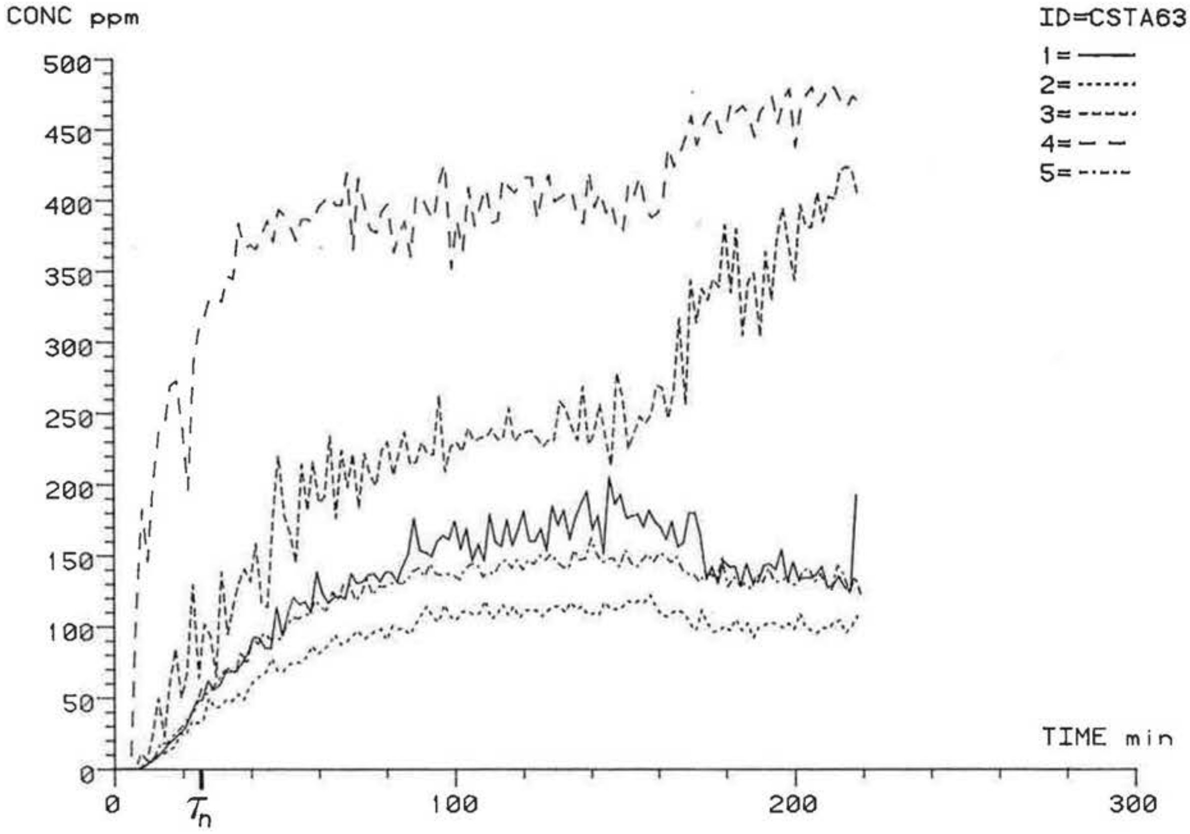


FIGURE 25.

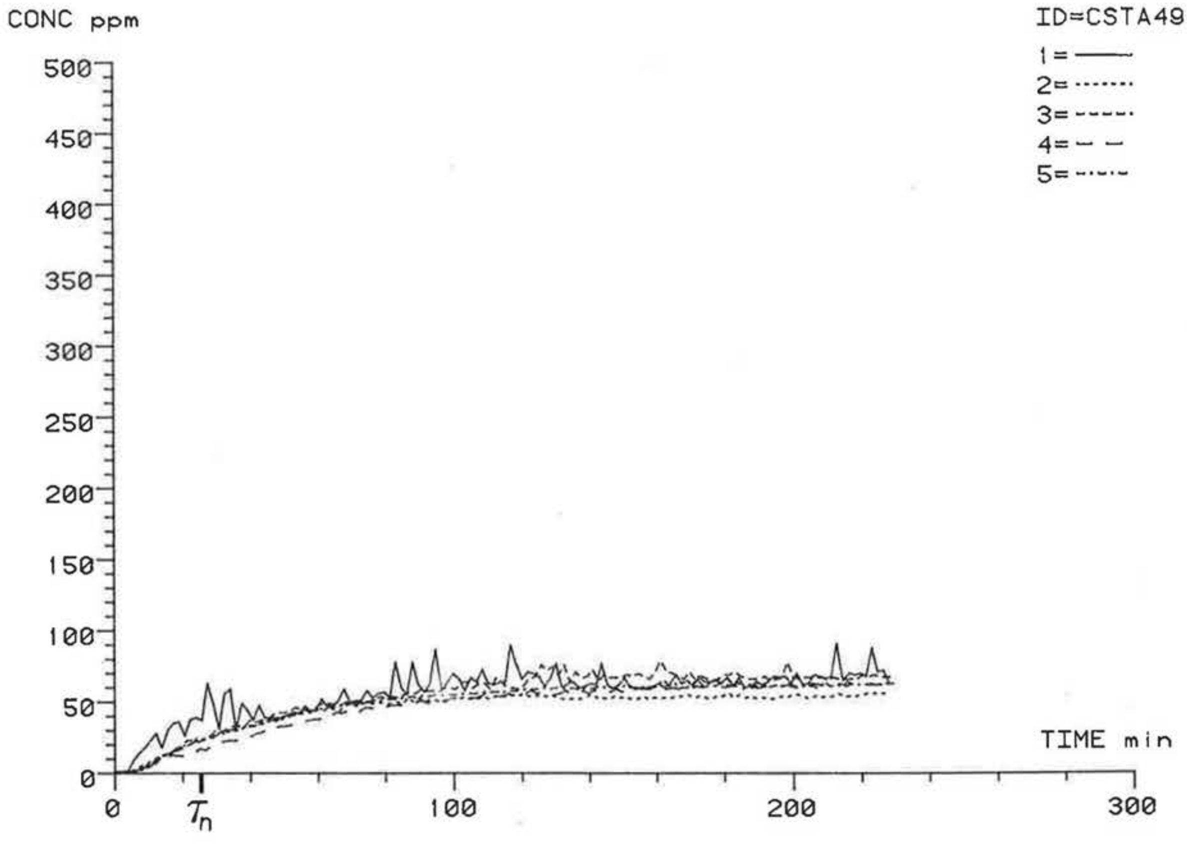


FIGURE 26.

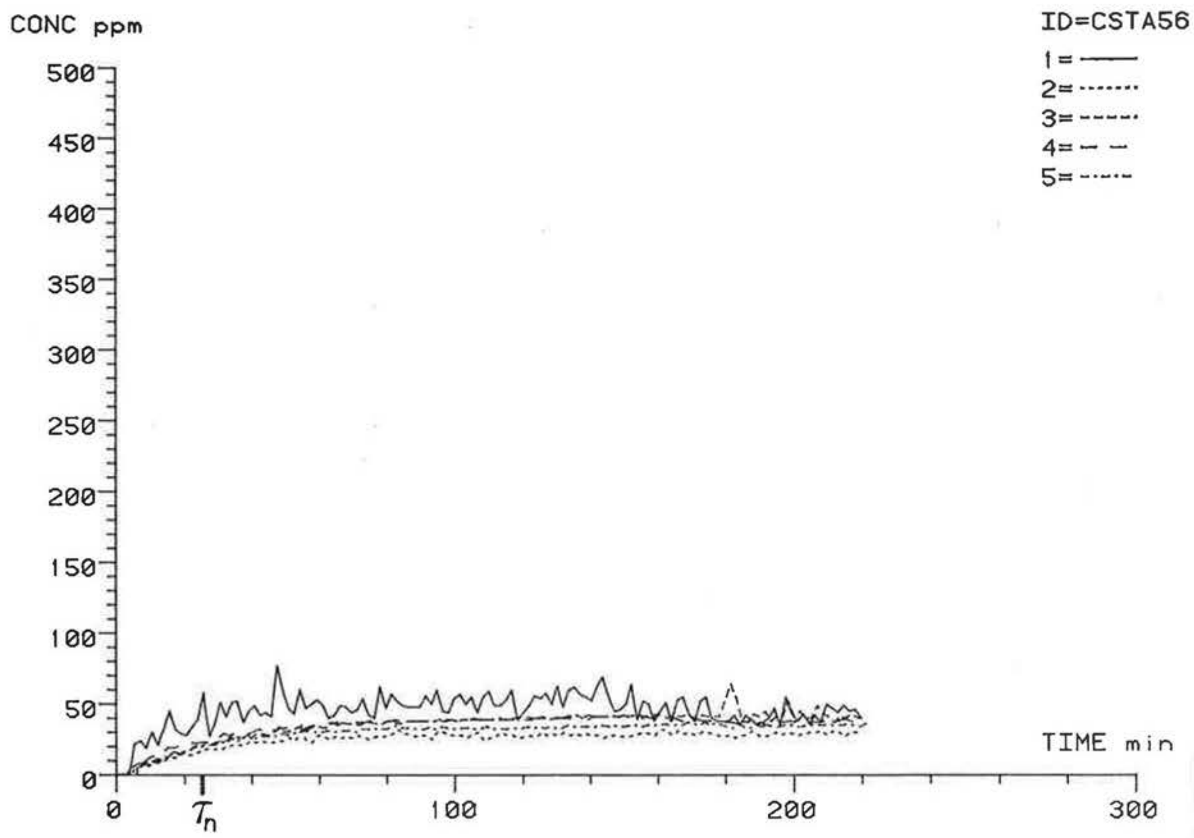


FIGURE 27.

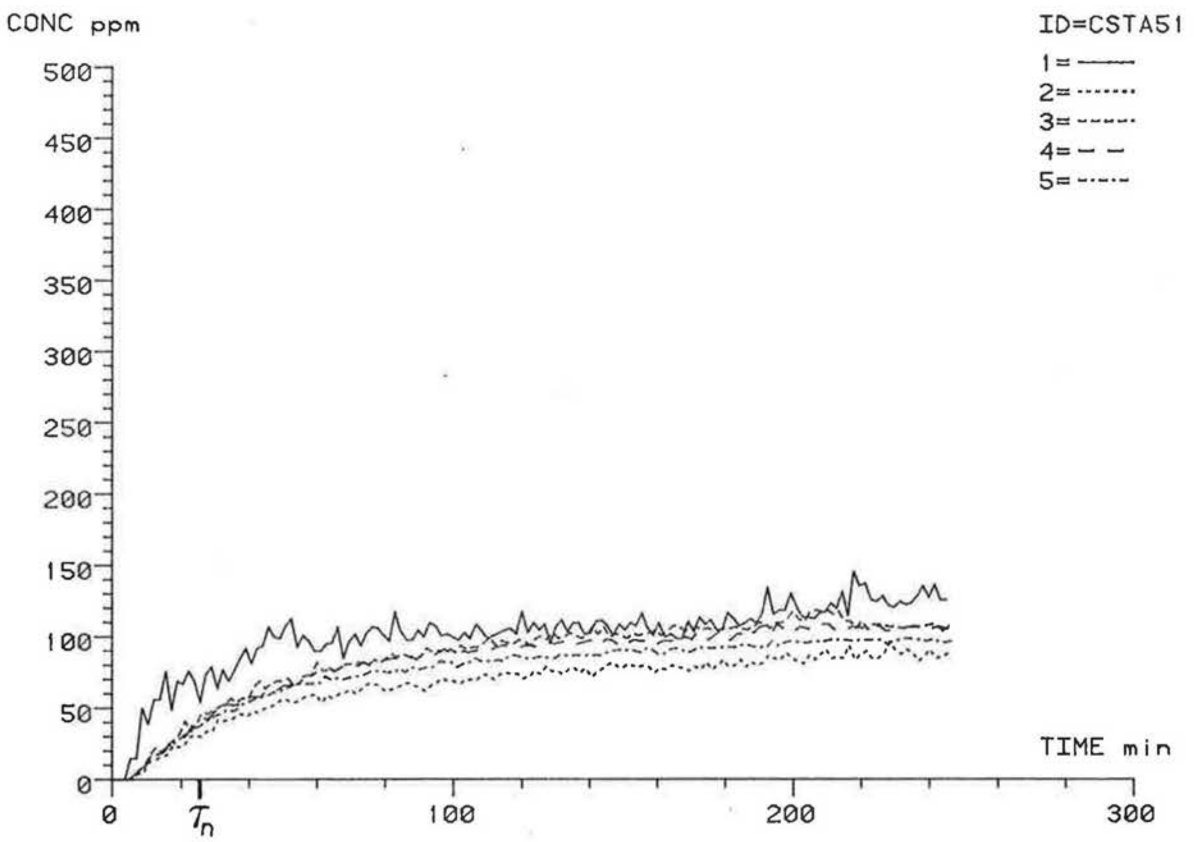


FIGURE 28.

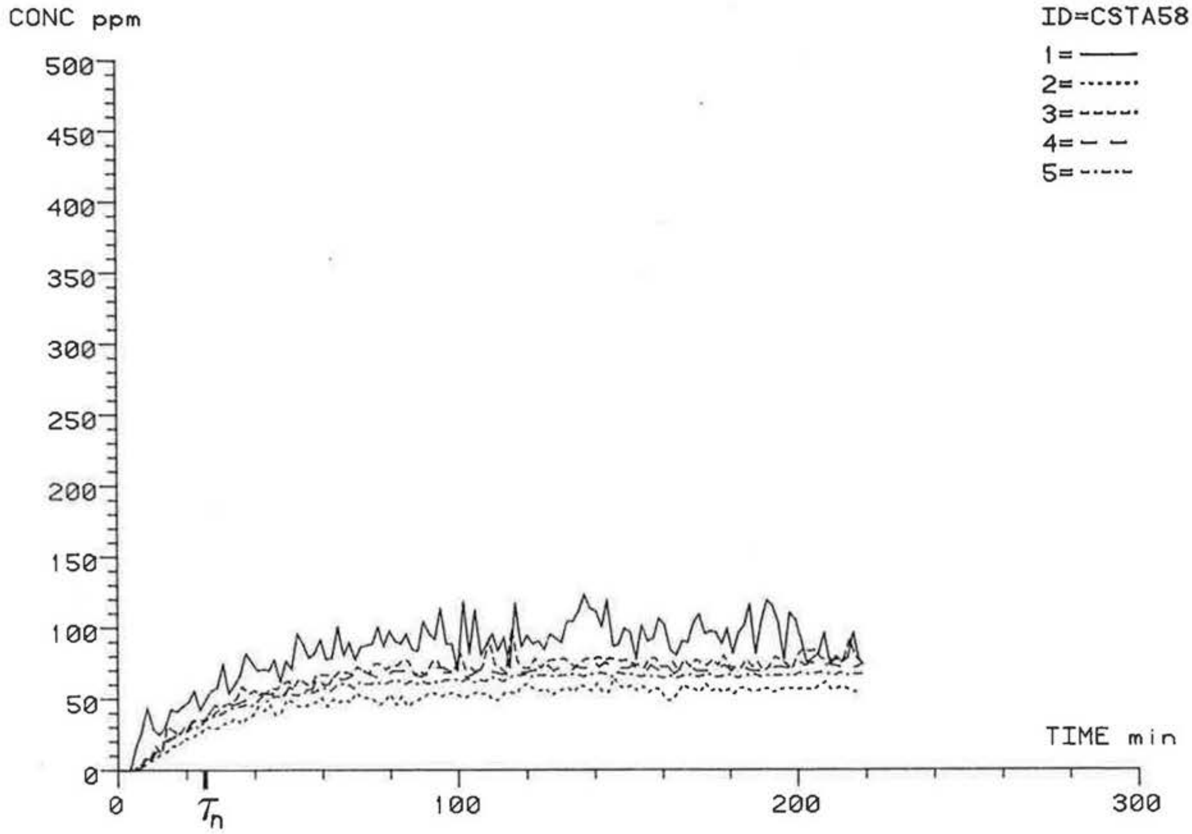


FIGURE 29.

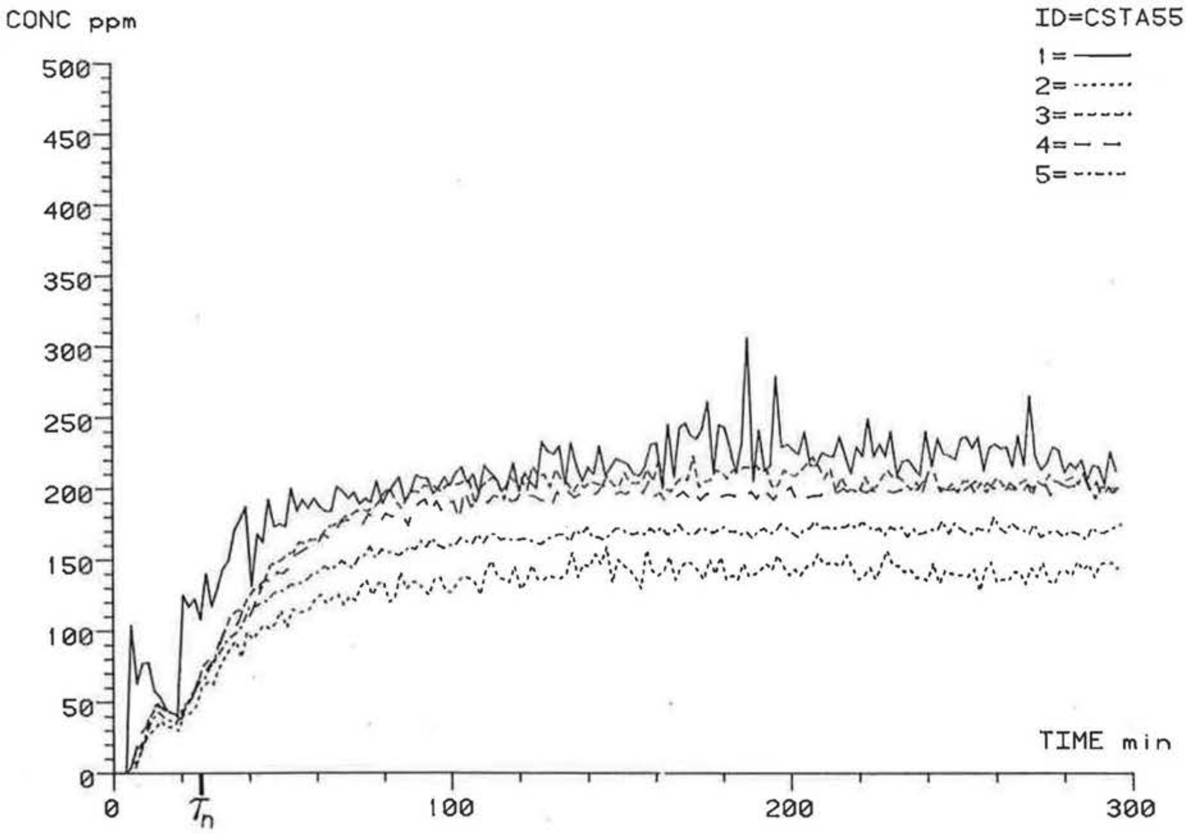


FIGURE 30.

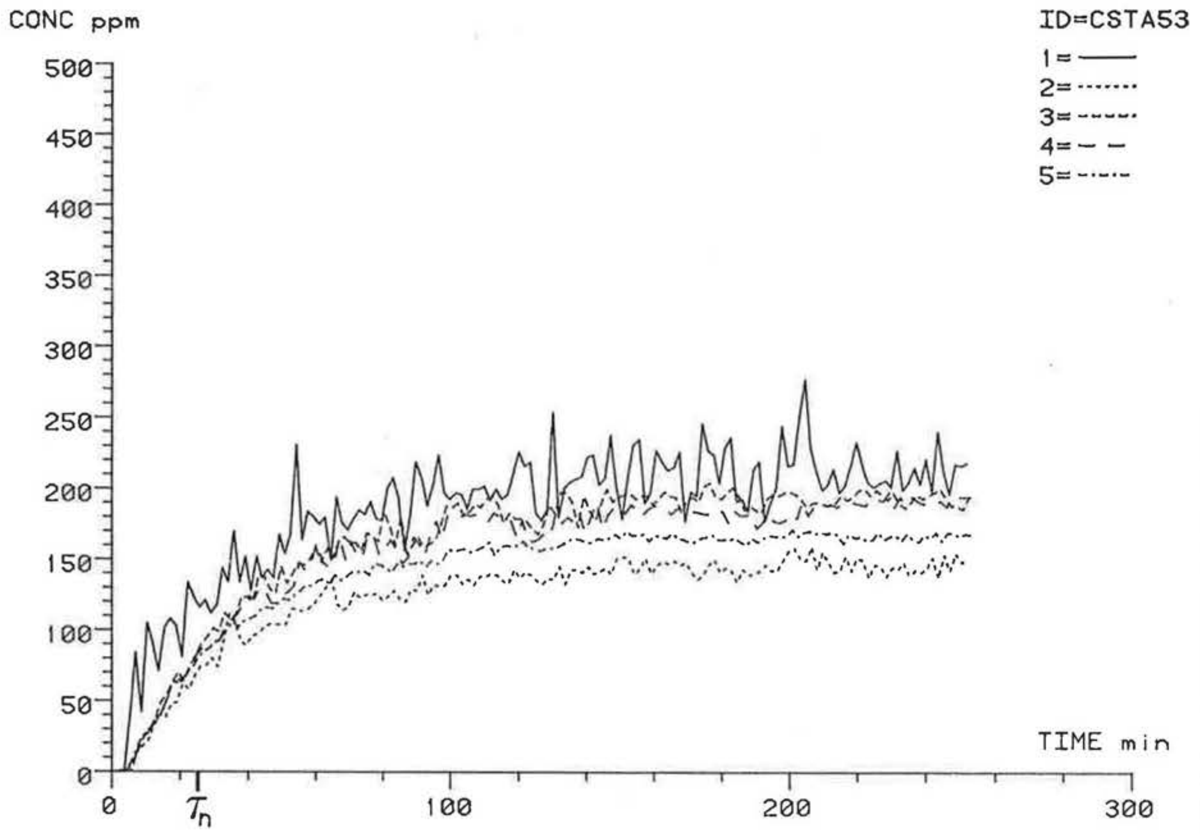


FIGURE 31.

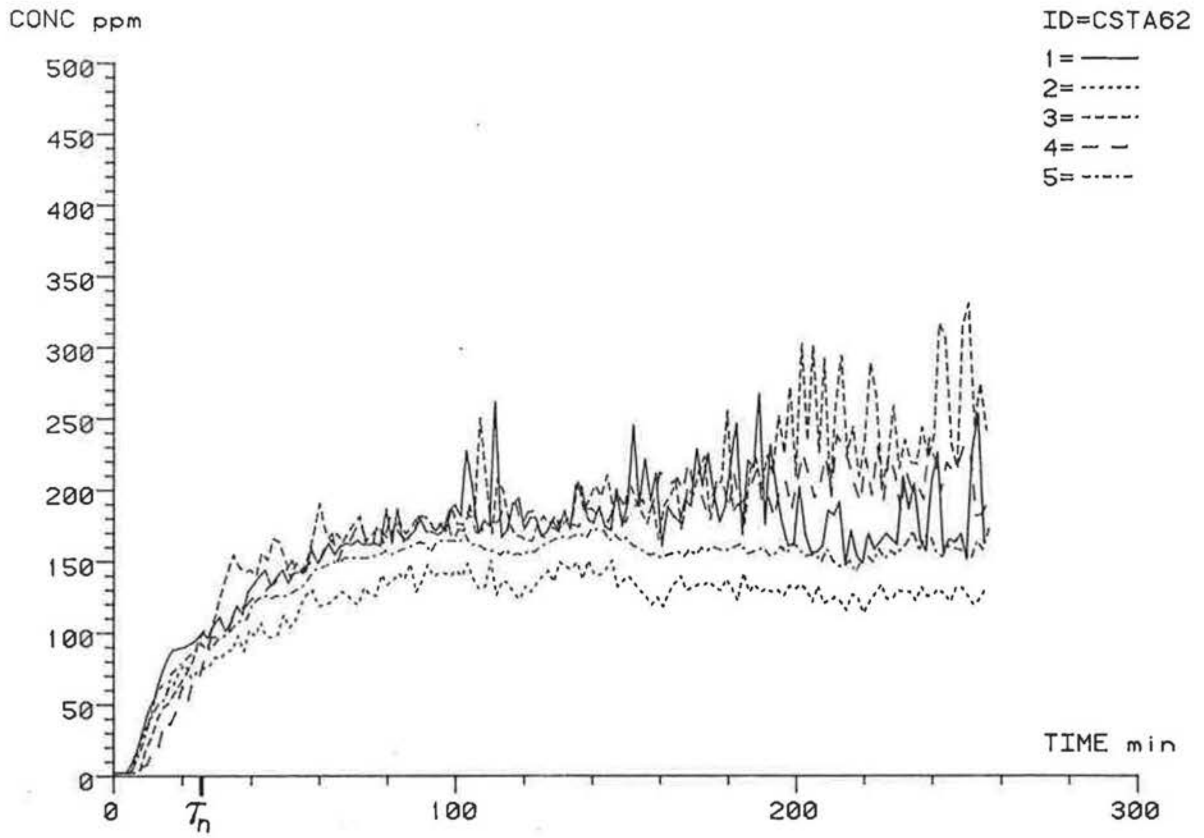


FIGURE 32.

ACKNOWLEDGEMENTS

All measurements were carried out during spring 1981 at the Building Research Establishment (BRE), Garston, England. I wish to thank BRE for making the visit possible and also to thank all the members of the staff who contributed to the work with their skilful help and advice.

I also wish to thank Mats Sandberg for useful guidance, Folke Glaas and Karl-Einar Johannesson for the artwork and Inger Ivares for the typing.

REFERENCES

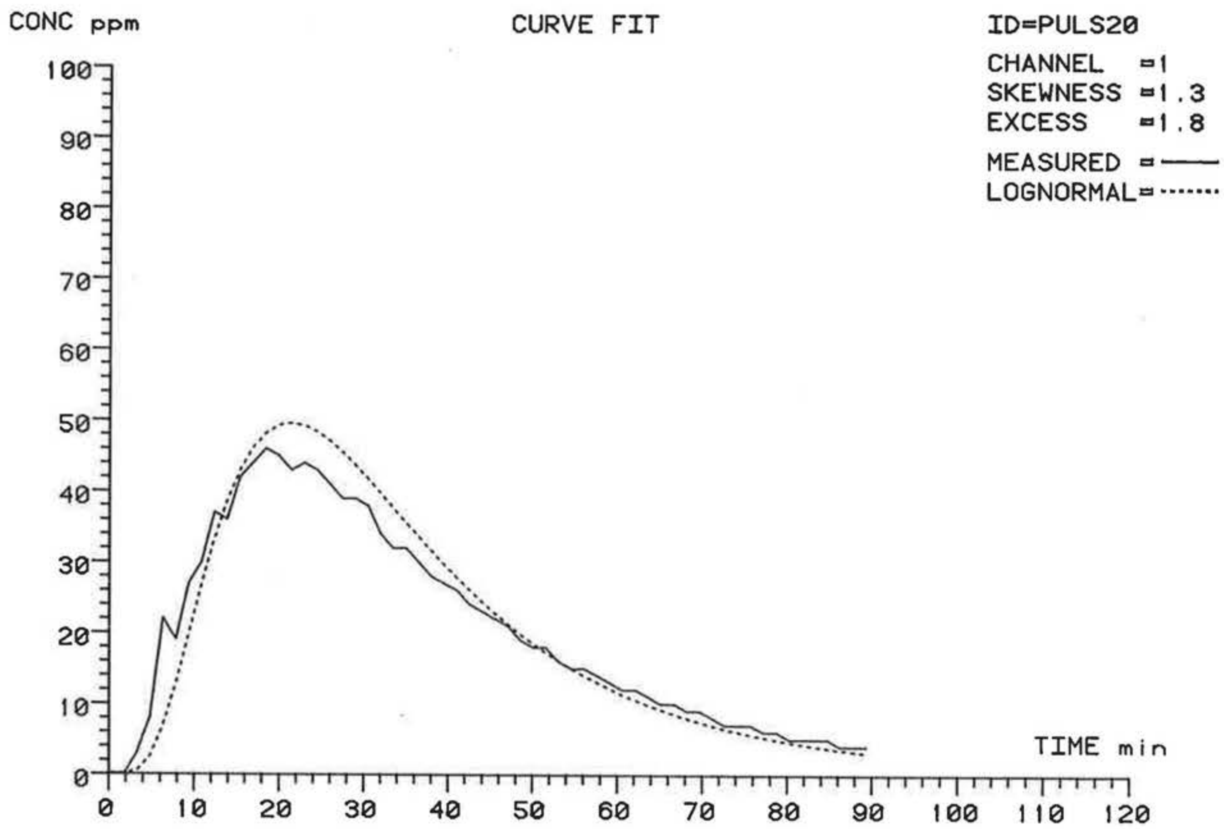
1. M. Sandberg and M. Sjöberg: 'The use of moments for assessing air quality in ventilated rooms'. Building and Environment, Vol 18, No. 4. (1983).

2. M. Sandberg, C. Blomqvist and M. Sjöberg: 'Warm air systems, part 2'. Bulletin M82:23, The National Swedish Institute for Building Research. (1982).

APPENDIX 1.

The following five pages contains examples of curve fittings for two 'pulse-tests', using a log-normal distribution.

Test 20 is chosen as an example of a good fit, while Test 40 shows a poorer result.


CONC ppm
CURVE FIT
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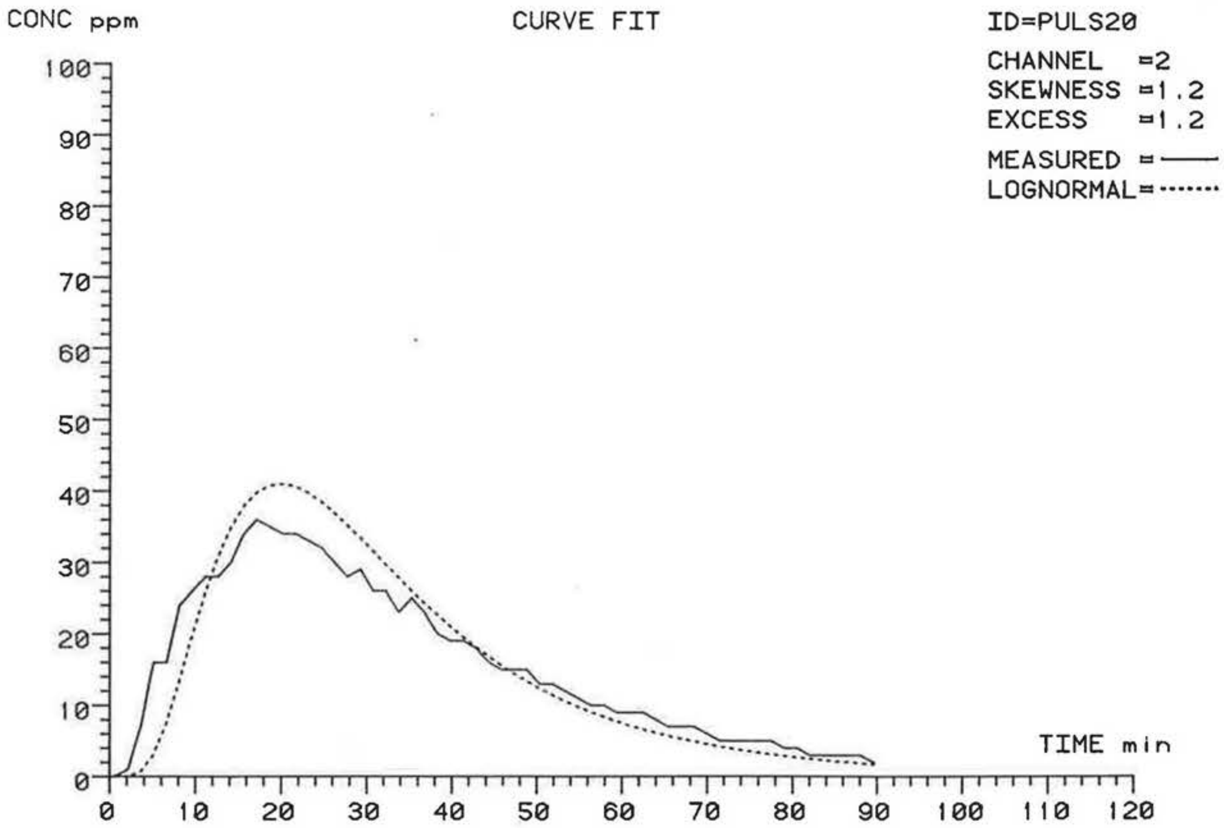
CHANNEL =1
SKEWNESS =1.3
EXCESS =1.8
MEASURED =
LOGNORMAL=
100
90
80
70
60
50
40
30
20
10
0
TIME min
0 10 20 30 40 50 60 70 80 90 100 110 120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CURVE FIT
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CHANNEL =2
SKEWNESS =1.2
EXCESS =1.2
MEASURED =
LOGNORMAL=
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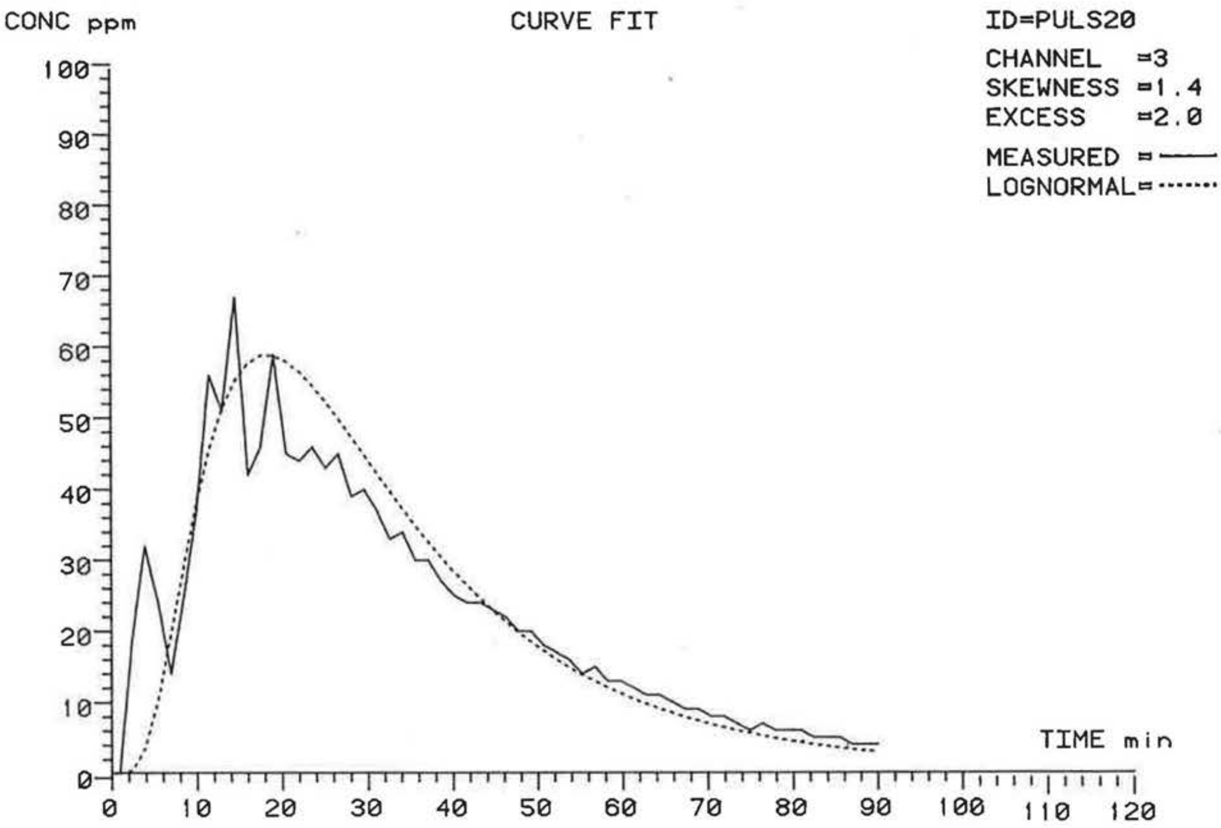
90
80
70
60
50
40
30
20
10
0
TIME min
0 10 20 30 40 50 60 70 80 90 100 110 120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CURVE FIT
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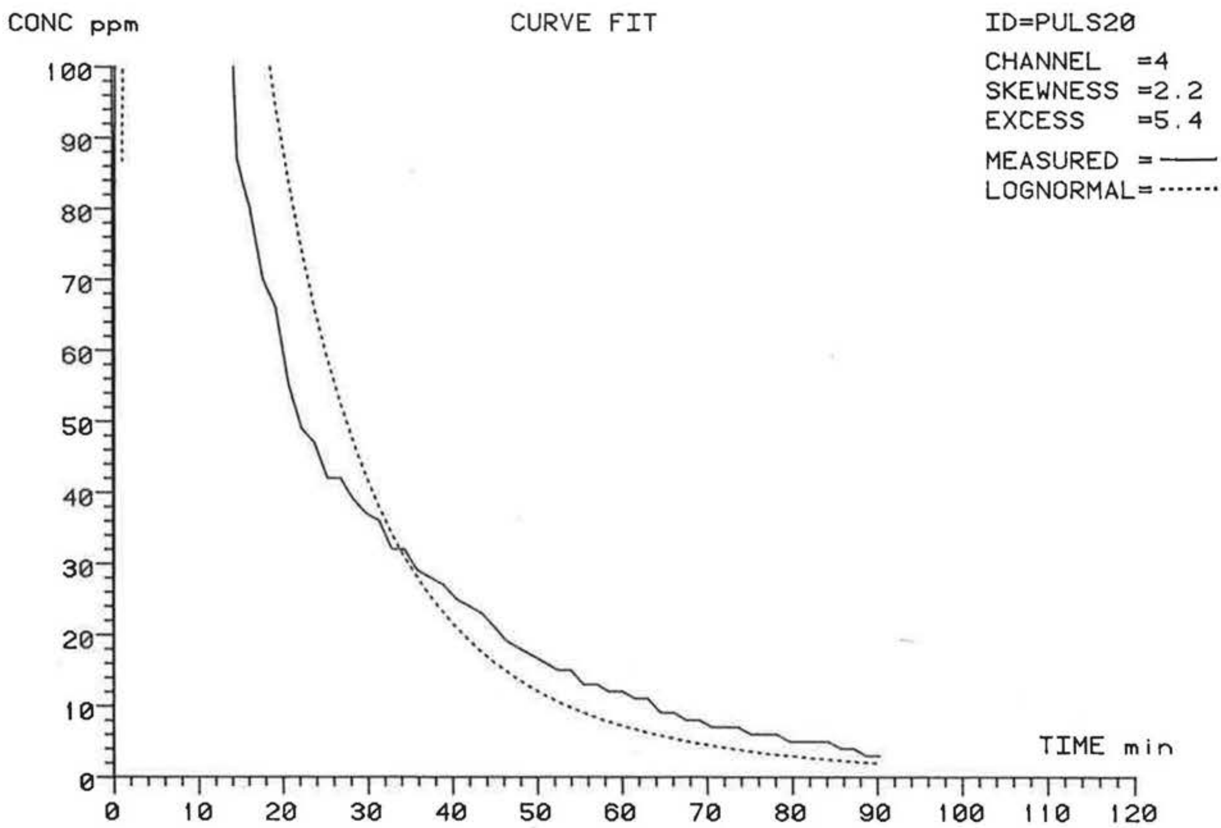
CHANNEL =3
SKEWNESS =1.4
EXCESS =2.0
MEASURED =
LOGNORMAL=
100
90
80
70
60
50
40
30
20
10
0
TIME min
0
10
20
30
40
50
60
70
80
90
100
110
120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CURVE FIT
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CHANNEL =4
SKEWNESS =2.2
EXCESS =5.4
MEASURED =
LOGNORMAL=
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90
80
70
60
50
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30
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10
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TIME min
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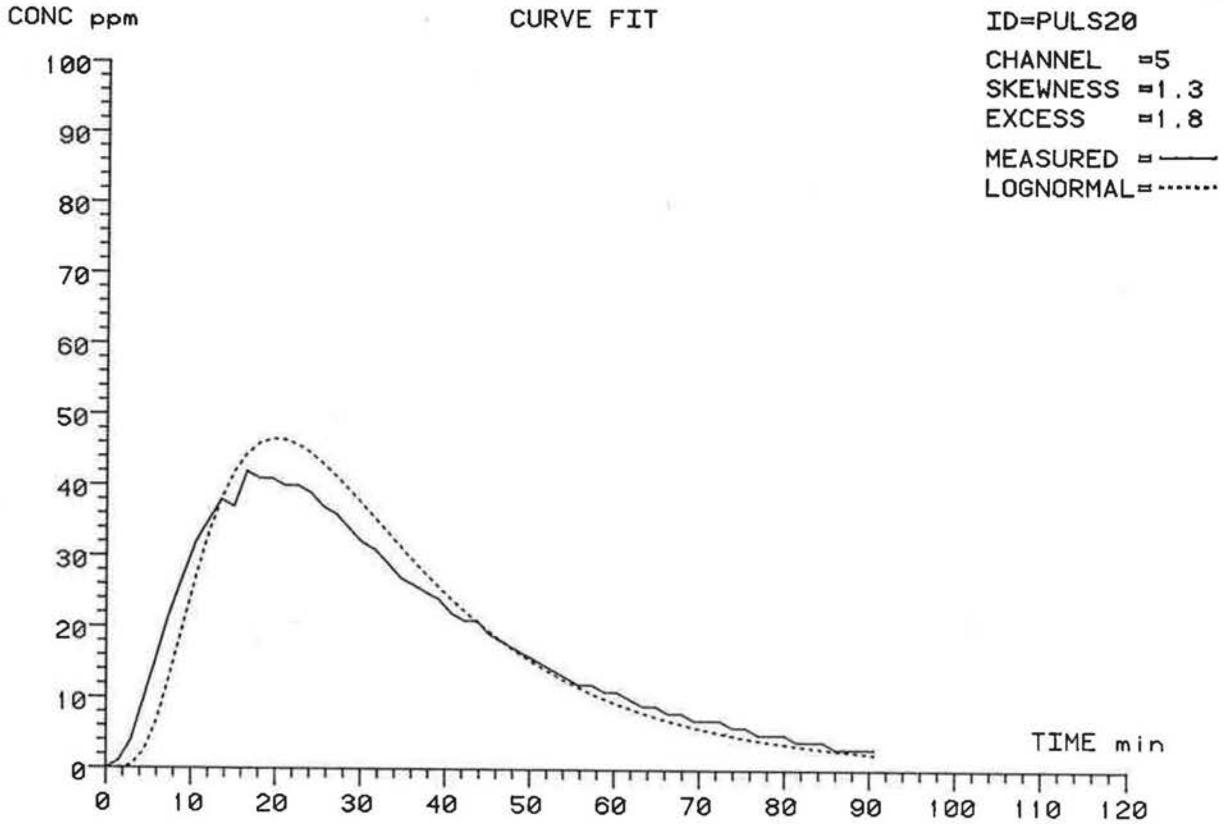
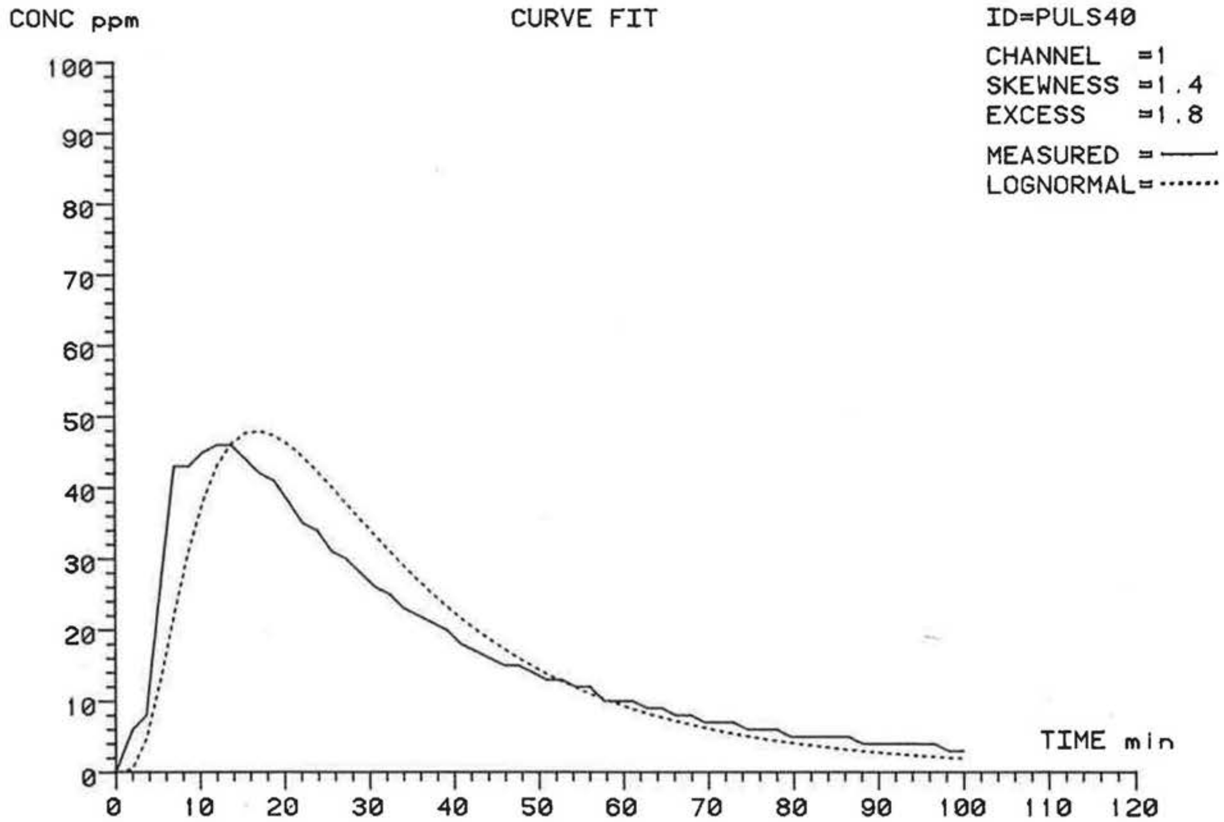
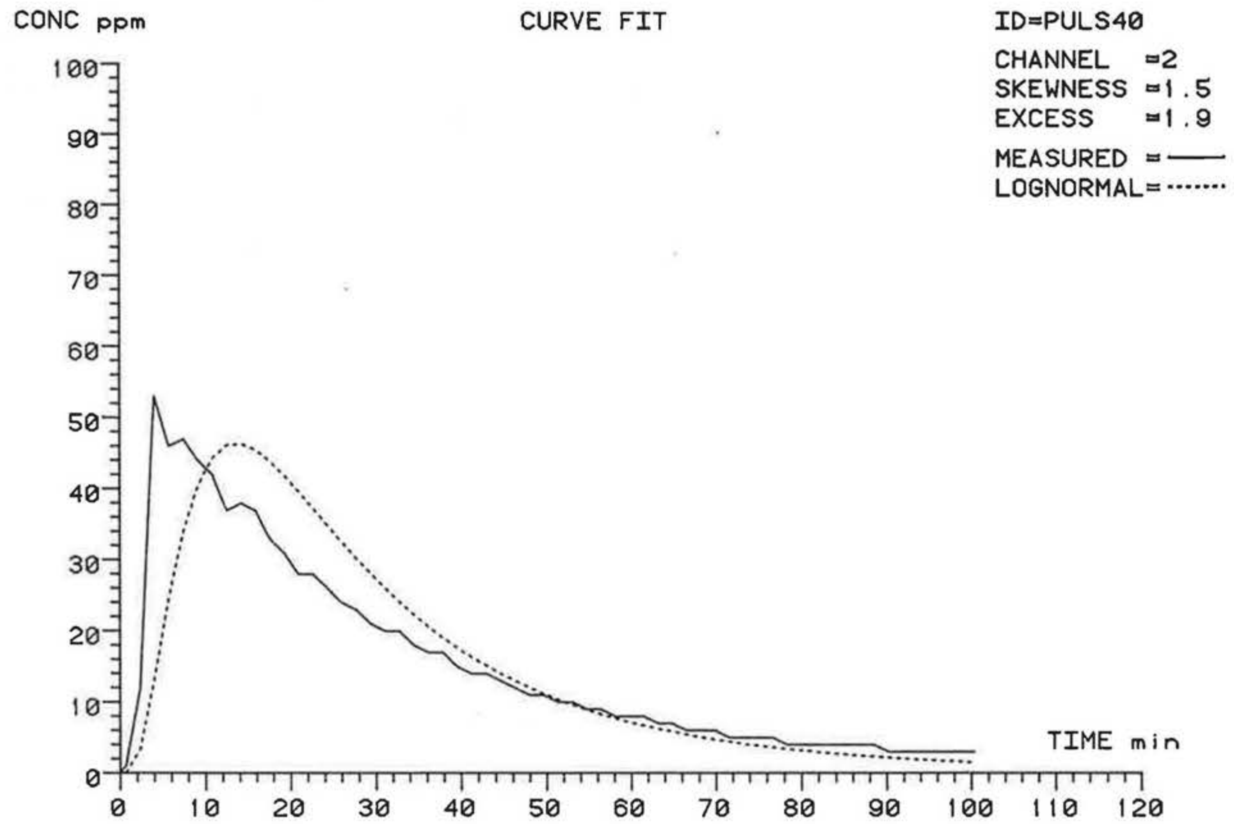
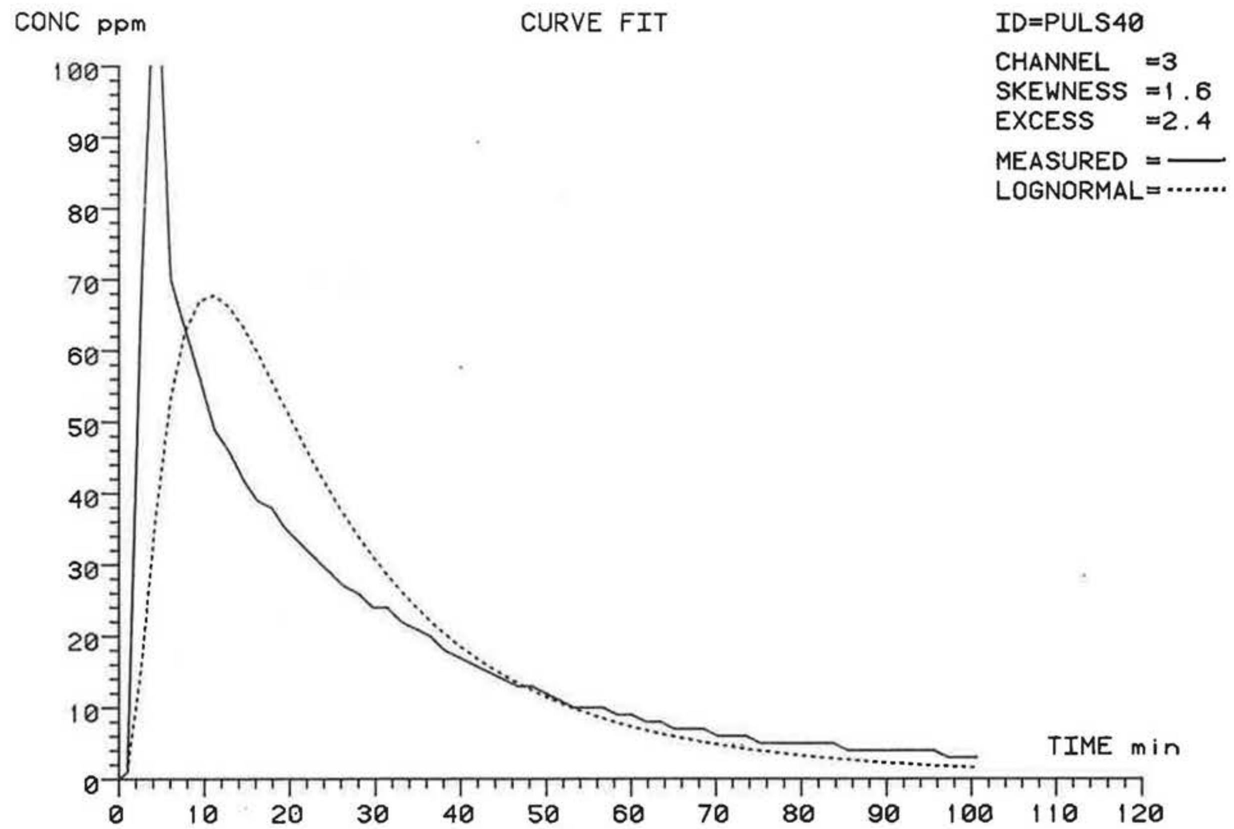
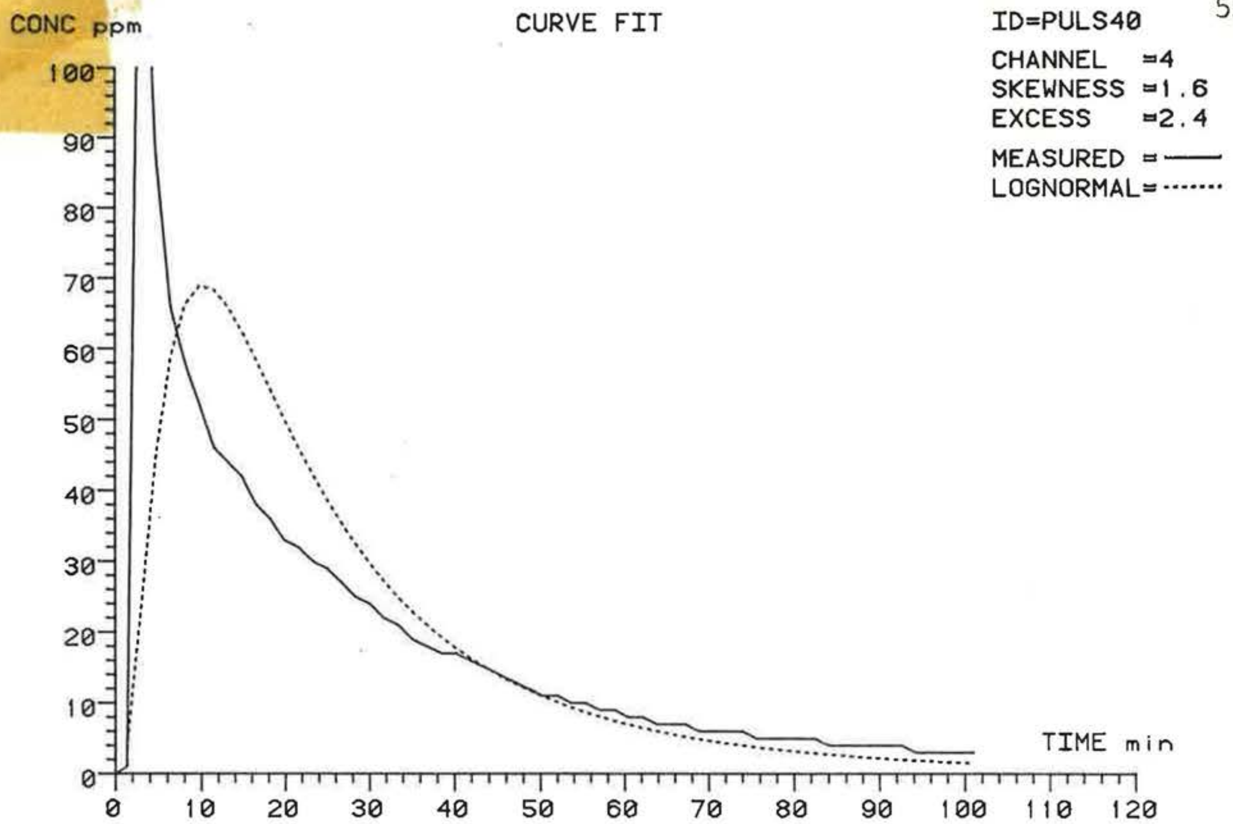
10
20
30
40
50
60
70
80
90
100
110
120

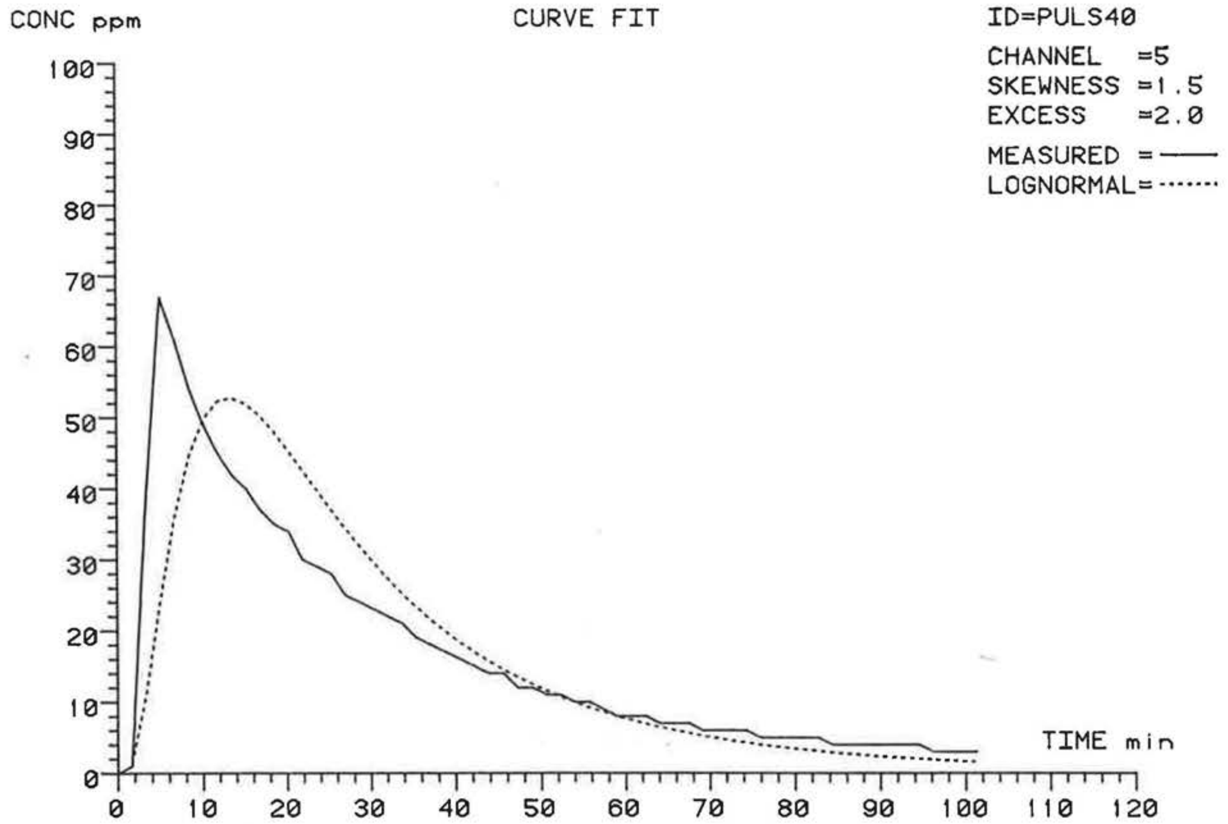

CONC ppm
CURVE FIT
ID=PULS20
CHANNEL =5
SKEWNESS =1.3
EXCESS =1.8
MEASURED =
LOGNORMAL=
TIME min
0
10
20
30
40
50
60
70
80
90
100
110
120


CONC ppm
CURVE FIT
ID=PULS40
CHANNEL =1
SKEWNESS =1.4
EXCESS =1.8
MEASURED =
LOGNORMAL=
TIME min
0
10
20
30
40
50
60
70
80
90
100
110
120


CONC ppm
CURVE FIT
ID=PULS40
CHANNEL =2
SKEWNESS =1.5
EXCESS =1.9
MEASURED =
LOGNORMAL=
TIME min
0
10
20
30
40
50
60
70
80
90
100
110
120


CONC ppm
CURVE FIT
ID=PULS40
CHANNEL =3
SKEWNESS =1.6
EXCESS =2.4
MEASURED =
LOGNORMAL=
TIME min
0
10
20
30
40
50
60
70
80
90
100
110
120


CONC ppm
CURVE FIT
ID=PULS40
CHANNEL =4
SKEWNESS =1.6
EXCESS =2.4
MEASURED =
LOGNORMAL=
TIME min
0
10
20
30
40
50
60
70
80
90
100
110
120


CONC ppm
CURVE FIT
ID=PULS40
CHANNEL =5
SKEWNESS =1.5
EXCESS =2.0
MEASURED =
LOGNORMAL=
TIME min
0
10
20
30
40
50
60
70
80
90
100
110
120