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PROGRESS REPORT ON W.P. NO. 28/78, PART II

PROJECT NARRIK

N. Burrows. 1983.

SUMMARY

A comparison between the observed fire behaviour of seven mass ignition burns under dry conditions and fire behaviour predicted under two situations is discussed. Input data for the predictions were obtained from i) weather and fuel forecasts well in advance of the fire and ii) weather conditions measured at time of ignition and using a single mean value of fuel load, slope and wind ratio for the block to be burnt.

Predictions of fire rates of spread were largely below that actually observed, for both test situations. Poor accuracy of weather forecasts accounted for some of this discrepancy, but the fire prediction system of predicting a single spread rate did not adequately describe the dynamic behaviour of the accelerating fires observed in each plot. Fire behaviour was variable both in time and space, with the range of variation increasing as surface burning conditions became severe. Fires were more uniform and constant in behaviour, therefore were better able to be predicted, when spread rates did not exceed 50 m/hr. Fires burning on a low F.D.I. (23) showed no signs of inter-action, hence erractic behaviour. Predictability decreased with increasing F.D.I. and the time after ignition before fires coalesced and behaved erratically, decreased. The contribution of fire interaction on fire behaviour is currently being examined.

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PROGRESS REPORT NO. 2

PROJECT NARRIK

INTRODUCTION

Since burning the experimental plots at McCorkhill Block, weather and fuels data have been collated for analysis. The quantity of fuel consumed by the fires and scorch and defoliation heights have been assessed.

I am still awaiting copies of scale corrected and computer enhanced fire scans from C.S.I.R.O. Canberra. However, we have extracted some fire behaviour data from unscaled and poor quality scan prints. Data extracted from these scans are not expected to be of a high quality, but rather than wait, I have decided to commence analysis. This will give me a feel for the data and analytical techniques and enable the reporting of some results.

The ultimate goal of this working plan is to improve fire behaviour predictions. With the capability to predict fire spread and intensity, has come a need to determine how well the methods and procedures work in local fire situations, beit wild or controlled. The first stage of data analysis here is to verify the complete fire behaviour prediction system including the existing fire spread model (Sneeuwjagt & Peet, 1976) which is only one part of the overall prediction system. The following reports on the progress of this stage.

METHODS

The method of verifying the complete prediction system was simple. Data were obtained to make a fire rate of spread prediction which was then compared to the actual fire spread rate. There are a number of ways in which fire model input data (especially weather) can be obtained. This will in turn affect the fire spread prediction.

Three situations are most likely to be encountered. Only two of these situations are reported on here, but a description of the third is given.

Situation 1 - *Forecast Weather*

This test was conducted under similar conditions to what a duty officer would encounter when determining the F.D.I. and hence corrected fire spread rate from weather forecasts well before the time of expected fire development. All fire model input data are forecast or predicted, including all weather, fuel moisture and fuel load (based on the Forest Fire Behaviour tables). Topographical data can be obtained from plans or local knowledge. For this situation, contour plans were used. Likewise, forest type and stocking or canopy cover (for wind ratio determination) were visually assessed for each plot burnt. For a given forest block/forest type, this situation allowed for the determination of a single fire spread rate for the block based on forecast weather, fuel moisture and fuel age.

Situation 2 - *Observed Weather Prior to a Fire*

In this situation a rate of spread prediction was made using on site weather observations taken just prior to the fire. This is often the situation encountered on prescribed fires. It does not have the uncertainty of a weather forecast and all input data are available prior to the fire. Again, fuel load and other inputs were averaged for the block and a single spread rate was determined for observed weather and measured fuel moisture content.

Situation 3 - All Input Variables are Measured

This requires the careful measurement of fuels, fuel moisture, windspeed, temperature, relative humidity, slope and canopy cover (hence wind ratio). Weather and fuel moisture were measured continuously or at short time intervals throughout the duration of the fire. Slope and fuel values ~~are~~ were updated as fires spread. A description of fuel measurement within each plot is given in the working plan. Fuel moisture content was determined by the gravimetric analyses of 6 x 50 gm samples (3 S.M.C. and 3 P.M.C.) taken at hourly intervals. Wind speed and direction was measured at 1.5m above the forest floor, by 12 woeffle recording anemometers placed 'chronometrically' around the plot ~~to be~~ burnt. Four cup anemometers on 30m towers located equidist around the burn provided wind speed and direction measurements at canopy level. Temperature and relative humidity were continuously logged.

ACTUAL FIRE SPREAD

This was determined from poor quality prints of infra-red scans taken at measured time intervals (see an example in figure 5). I assumed that the Forest Fire Behaviour Tables predicted the quasi steady state spread rate. That is the spread rate that a free burning fire will reach in equilibrium with surface burning conditions. This condition was never reached in these fires, so the actual rate of spread prior to coalescence was used. This was identified by i) plotting spread rates with time after ignition and noting the time at which behaviour became erratic (coalescence) and ii) visual assessment of general fire shape as seen on the scans. Just prior to coalescence, fires either i) changed head fire direction or ii) changed shape (bulged) at the head or flanks. Scans were scaled using the known distances between ignition points. Distance of head fire travel between scans was measured using calipers. Spread rate (m/hr) was determined for each fire.

Fires in each plot were grouped according to their acceleration. Three groups were used as a matter of convenience and separate power curves were generated for each group.

RESULTS

The results of test situations 1 and 2 are presented here. Test situation 3 requires very detailed weather, fuel and topographical data collection and is still being pursued.

Predicted vs actual weather variables are presented in figure 1, along with calculated correlation coefficients and an equation of the form:

$$Rc = a + bRp$$

where Rp = predicted value (x)
Rc = actual value (y)
a = y intercept
b = slope - the closer it is to 1, the closer the regression line will parallel the line of perfect agreement.

The "r^2" value or the correlation coefficient is a measure of how well the data groups around the regression line. The closer it is to 1, the better is the grouping.

Data input to predict fire rate of spread for test situation 2 are shown in table 1 (a) - (g). Scattergrams of actual head fire rate of spread with time after ignition are shown in figures 2 (a) - (g). In the same figure, fires have been grouped according to their acceleration rates and a power curve has been determined for each group to describe rate of spread with time. The mean spread rate of all fires for a given time period is plotted and graphed in figures 3 (a) - (g) and an equation of the form; $y = bx^m$ is given.

where; y = spread rate (m/hr)
x = time since ignition (minutes)

The harmonic and arithmetic mean rates of spread has been determined for some power curves (e.g. figure 3 (d)).

$$\text{harmonic mean} = \frac{R.O.S.\ dt}{t}$$

$$= \frac{\frac{b\cancel{x}^{m+1}}{m+1}}{t}$$

$$\text{arithmetic mean} = \cancel{\frac{\frac{R.O.S.}{to-tx}}{No.\ of\ fires}} \qquad \frac{\sum_{I=1}^{N}\left(\sum_{i=1}^{n} HFROS\right)}{Nn}$$

where:
N = # Scans
n = # fires.
HFROS = head fire rate of spread (m/hr).

An average spread rate has also been calculated by;

$$\frac{\text{Total fire distance travelled}}{\text{Total time taken}} \text{ for duration of fire}$$

DISCUSSION

Weather Forecasts

Spot weather forecasts for McCorkhill block provided by Ocean Routes were generally less than the desired accuracy for predicting fuel moisture content and fire behaviour under those conditions. From figure 1 it can be seen that maximum temperature predictions were the most accurate but minimum relative humidity and windspeed were poorly predicted. All weather predictions were based on regular (2-3 hourly) on site weather observations sent to Ocean Routes to aid in forecasting. The sea breeze was probably the salient cause of poor predictions, together with a pausity of meteorological observations in the vicinity. The study site experienced winds from the south and the south west on most occasions, whereas predictions were largely for south-east and easterly winds. Temperature was generally under predicted by 1-2°, but relative humidity was very often over predicted by up to 15%. There was no tendency to over or under predict wind strength - predictions were fairly scattered.

Accuracy of forecasts received at the Nannup office were superior to those at the study site, which was some 26 km from Nannup. Weather conditions at the study site were dis-similar to those experienced in Nannup. Fire behaviour calculations based on weather forecast experienced at Nannup were not relevant to the study area.

Predicting fire behaviour at various locations within a Division could be considerably improved by using weather observations provided by remote weather stations strategically placed within a Division. Paying for an accurate weather forecasting service which predicts the weather to be experienced at the Divisional office may not necessarily result in real improvements in the ability to predict fire behaviour unless weather conditions remain constant throughout a Division or "intuitive" corrections are made.

Fire Behaviour

Generally, fuel and weather conditions were moderate, with fuel moisture contents ranging from 4.9% to 12%. Four of the seven mass ignition burns were carried out on an F.D.I. range of 23 - 53. Fuel and weather conditions at ignition time (used in test 2) are shown in table 1 (a) - (g). While it is not the scope of this report to dissect fire behaviour, it is neccesary to elaborate on the behaviour used in test situations 1 and 2.

Fires were dynamic, both in space and time. For the set of conditions given in tables 1 (a) - (g), fire behaviour within a plot varied considerably at any one time and with time. No single description of spread rate adequately described the fire behaviour experienced in each plot. The one exception to this was fire 6. Figures 2 (a) - (g) illustrates both the variation in fire intensity at any one instant after ignition and variation with time after ignition. Fires did not reach a quasi steady state but accelerated after ignition until coalescence and burn out. Grouping fires in each plot enabled acceleration to be expressed mathematically for each group until coalescence was observed and fire behaviour become erratic (figures 3 (a) - (g)). A single equation describing fire acceleration was completely inadequate (r^2 values of .1 - .3). The range of fire behaviour within a plot increased with the F.D.I. and with lighting intensity.

Head fire acceleration was largely a function of surface burning conditions but was also influenced by fire interaction. Surface burning conditions pre-empted both the timing and magnitude of fire interaction (coalescence), The absolute importance of fire interaction on the acceleration curves shown in figures 2 (a) - (g) is unknown at this stage. Inter-action only became obvious when fires changed shape and behaved erratically, which is outside the time period covered by the acceleration curves (see figures 3 (a) - (g)).

Twenty two percent of fires in Burn 6, which burnt under a F.D.I. of 23, took longer than 3 hours to reach a head fire spread rate of 30 m/hr. There was no obvious sign of fire interaction or erratic fire behaviour. By contrast, 61% of fires in Plot 3 (F.D.I. = 104) reached a spread rate of 225 m/hr in 35 minutes. Erratic and coalescing fire behaviour was observed 35 minutes after ignition. Thus, fire behaviour "feeds" upon itself. When surface burning conditions were severe, heat release rate was high (kw/sec.), which resulted in an earlier and more erratic coalescent fire behaviour. Heat release rate was also increased by increasing the lighting intensity.

Further analysis will attempt to describe the dynamics of fire development under these conditions.

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Test Situation 1

Predicted head fire spread rates based on forecasts conditions were within acceptable limits for spread rates of less than about 50 m/hr (Fig. 4(a)). Beyond this, predictions were generally considerably lower than actual. Reasons for this were; i) poor weather forecasts - under dry fuel conditions, variations in wind strength and fuel moisture content predictions resulted in amplified variations in fire behaviour because of its exponential relationship with these variables. This would not have been the major cause of under prediction as weather forecasts were not consistently higher or lower than observed conditions. ii) Inadequate data input - A mean description of the litter fuel conditions of a land unit of 100 - 200 hectares was unsatisfactory. Litter fuel load variations under dry fuel conditions resulted in considerable variation in fire behaviour. Vegetation up to 2m contributed to the fuel available for burning. This varied from 2.8 tonnes/ha to 12.5 tonnes/ha. The jarrah prediction tables do not adequately account for this. Slope changes across the block are not catered for although this in itself is not seen as a problem. However, here were serious under-estimations of head fire spread rates when slope (up to 9^{o}) and wind interacted. The McArthur slope corrections do not cater for cross slope/wind interactions (see Figs. 2 (d) and 3 (d)). Predicting a single wind ratio, or the wind strength experienced at 1.5m and in the forest, did not represent the range of vegetation cover/topographical conditions experienced in a forest block. There was some evidence that the wind ratio (interception) changed as scrub was burnt and the fire increased in size. However, unless the tree canopy was defoliated, this did not appear to be highly significant as most scrub was only about .5 - 1.0m tall. There were noticeable differences in fire spread between fires burning on exposed slopes and flats with little canopy cover and fires burning on sites with a heavy tree canopy. iii) Dynamic behaviour of fires. The Forest Fire Behaviour Tables predict a steady state or static condition of fire spread. This was not observed in any fires. Fire 6 (Figs. 2 (f) and 3 (f)) approached this condition but was the only massed fire to do so. Fire acceleration has been discussed earlier. Likewise, the variation in fire acceleration within a block has also been touched on. The verification tests 1 and 2 here did not use fire behaviour which was obviously generated from interaction or coalescence.

Test Situation 2

Predicted head fire spread rates were only slightly improved by using measured data. This would indicate that the reasons ii) and iii) above are the prime causes of inaccurate predictions. I believe test situation 3 (still in progress) will show a further improvement as the spread of each fire within each plot will be predicted separately and using data measured at the time the fire was burning. This means that for any one multiple burn, there will Need to be multiple predictions of spread rate - one for each ignition, hence one for each fire. This will not result entirely in accurate predictions, because of the acceleration of these fires. However, the maximum spread rate reached (before coalescence) should be approximated by the predictions.

CONCLUSIONS

The objective of this report was to present and discuss the results of two verification tests. On both accounts, the existing fire prediction system, including weather forecasting, fuel moisture content, fuel loads, wind ratios and fire modelling, has been found wanting for massed fires under these conditions. The exception to this is where fire spread rates did not exceed about 50 m/hr which was the case in fire 6. Here, the dry soil, but moist litter fuel profile, high R.H., low temperatures and low wind, resulted in only one of 3 night burns ~~and it~~ which behaved according to predictions. When litter fuel moisture content was ≤10%, fires became increasingly more difficult to

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predict with existing models. Predicting an average rate of spread for these fires was akin to summising that a man with his head in an oven and his feet in a fridge, is, on average, comfortable!

Although we have much more to do by way of fire behaviour analysis, it would appear that simply adding to the existing tables to enable the prediction of these fires, is futile. If it is seen to be necessary to understand fire behaviour under these conditions for the purpose of fire management, then I believe a new, dynamic modelling approach is necessary.

Table 1(a)

Surface burning conditions at ignition,

PLOT 17 1720 - 1920 hrs.

FUELS		MOISTURE CONTENT			WEATHER			
Litter Weight	Scrub Weight	S.M.C.	P.M.C.	S.D.I	Wind	Temp	R.H.	Predicted HFROS
6.54 t/ha	4.78	8.8	8.9	1465	6.5 km/hr	19	63	120

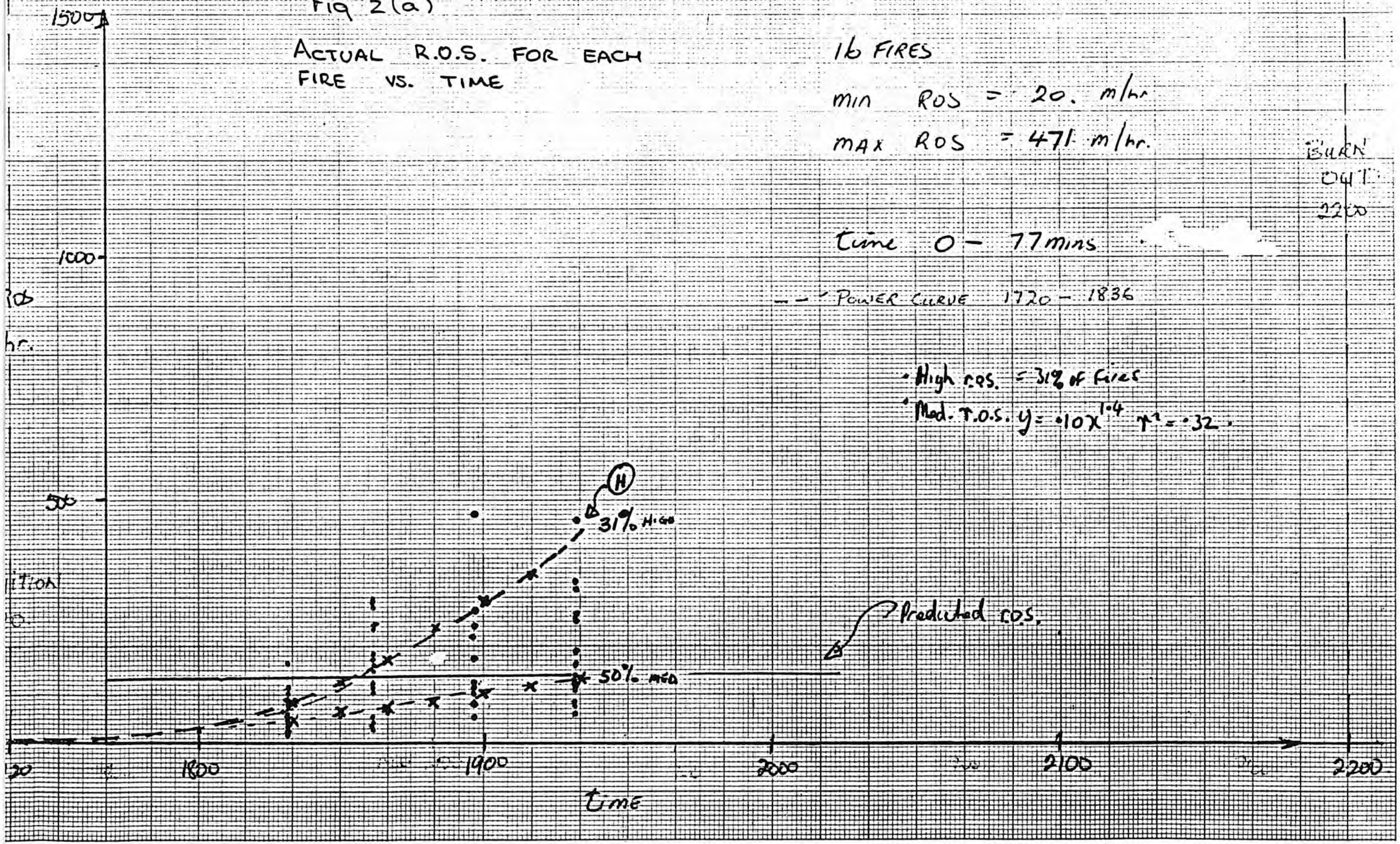
SPACING 300 x 300m

100/24

FIRE 1. BL_K 17. 10-1-83 300m x 300m

Fig 2(a)

ACTUAL R.O.S. FOR EACH FIRE VS. TIME



16 FIRES

min ROS = 20. m/hr

max ROS = 471 m/hr.

time 0 – 77 mins

– – – POWER CURVE 1720 – 1836

• High r.o.s. = 31% of fires

• Med. r.o.s. $y = \cdot 10x^{1\cdot 4}$ $r^2 = \cdot 32$.

SHEET

= 173

= 301

84

Fig 3(a)

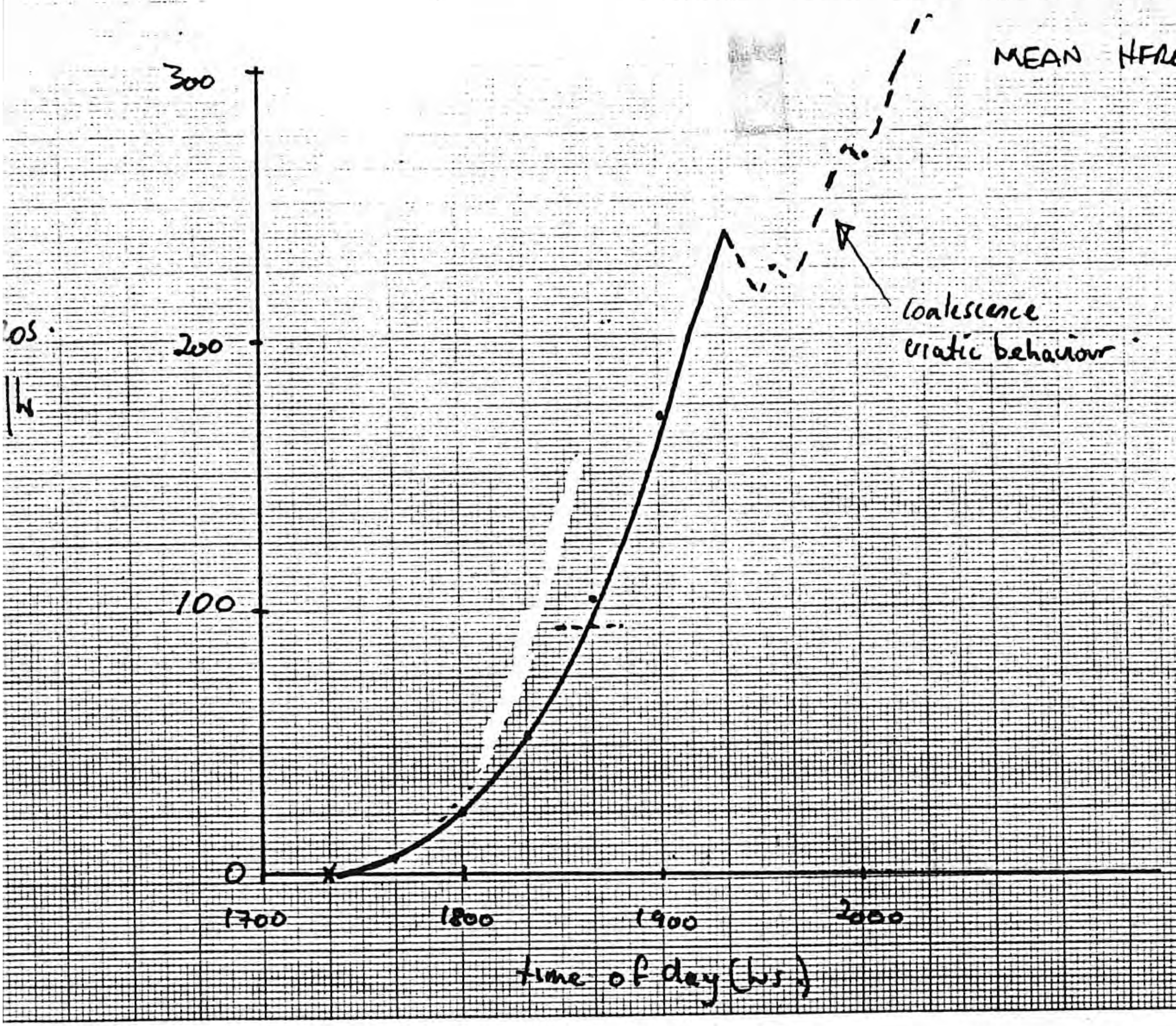
FIRE 1

PLOT 17.

Mean Accl. Curve. (all Fires)

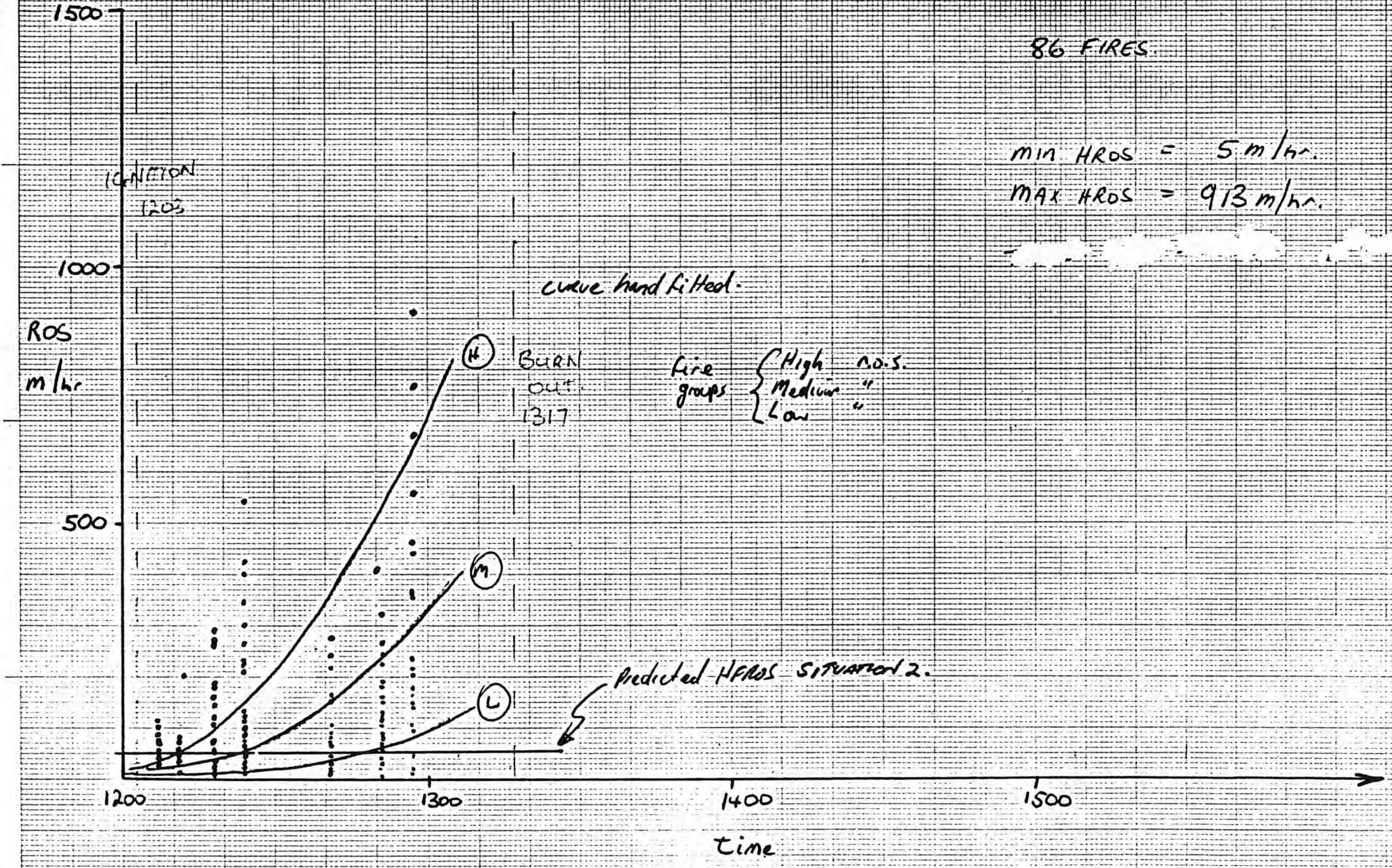
MEAN HFROS = $\cdot 011\,(t)^{2\cdot 08}$

$R^2 = \cdot 89$. (From $\bar{x}$ r.o.s. at each time scan)



FIRE 2 BLOCK 18 FIG 2(b) 100m X 100m

ACTUAL H.F.R.O.S. WITH TIME AFTER IGNITION.



86 FIRES.

min HROS = 5 m/hr.

MAX HROS = 913 m/hr.

Table 1 (b)

Surface burning conditions at ignition time.

PLOT 18 100m x 100m 21 - 1 - 83

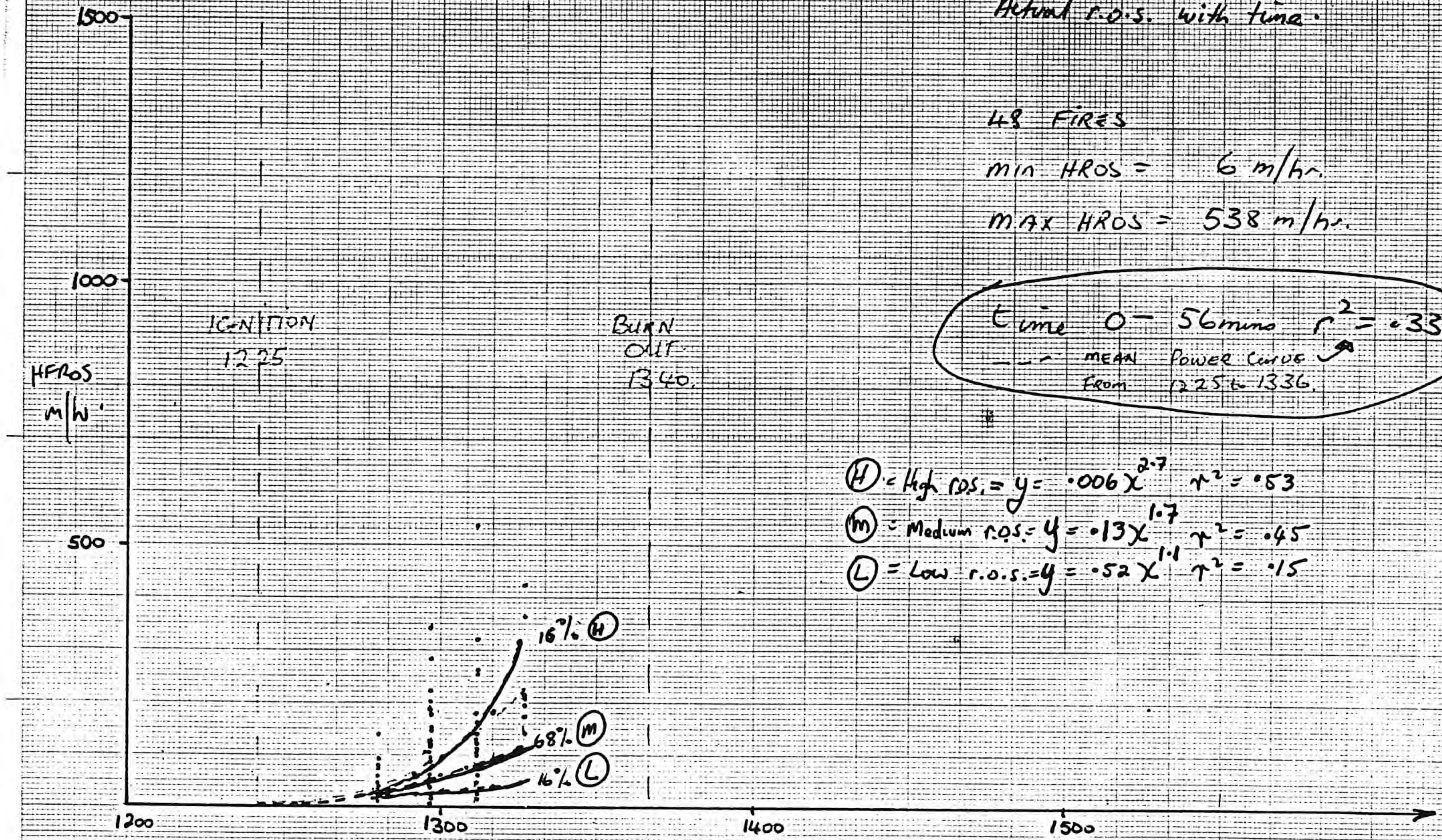
Fire #2

FUELS		MOISTURE CONTENT			WEATHER			
Litter Weight	Scrub Weight	S.M.C.	P.M.C.	S.D.I	Wind 1:1	Temp	R.H.	Predicted r.o.s.
4.7. t/ha	4.83	11.53	12.35	1575	5.8 Km/hr.	22	47.	47

FIRE 3 BLOCK 24 27-1-83 100mx100m

Fig 2(C)

Actual r.o.s. with time.



48 FIRES

min HROS = 6 m/hr.

MAX HROS = 538 m/hr.

time 0 – 56mins $r^2 = \cdot 33$

— — – MEAN POWER CURVE FROM 1225 to 1336.

Ⓗ = High r.o.s. = $y = \cdot 006x^{2\cdot 7}$ $r^2 = \cdot 53$

Ⓜ = Medium r.o.s. = $y = \cdot 13x^{1\cdot 7}$ $r^2 = \cdot 45$

Ⓛ = Low r.o.s. = $y = \cdot 52x^{1\cdot 1}$ $r^2 = \cdot 15$

Table 1(c)

Surface burning conditions at ignition.

PLOT 24
Fire # 3

100m x 100m

27-1-83

FUELS		MOISTURE CONTENT			WEATHER			sit. 1
Litter Weight	Scrub Weight	S.M.C.	P.M.C.	S.D.I	Wind	Temp.	R.H.	Predicted HFROS
5·4 t/ha.	4·66 t/ha	8·9	—	1626	5·35	32	23	63

FIG. 3(d)

FIRE 4, BLOCK 23

SCAN MEAN HFROS = $4.98 \times 10^{-8}(t)^{6.35}$

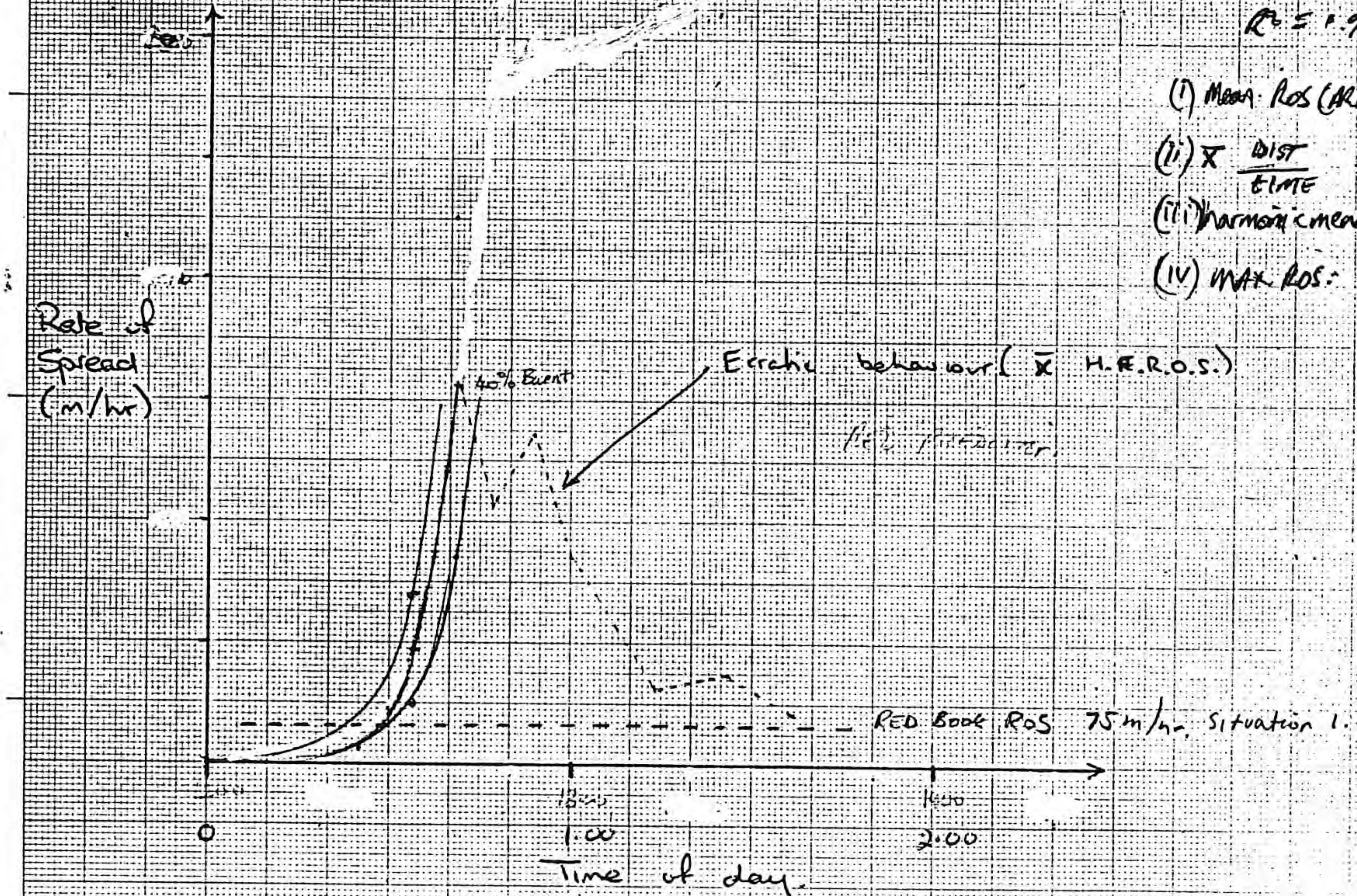
$R^2 = .90$

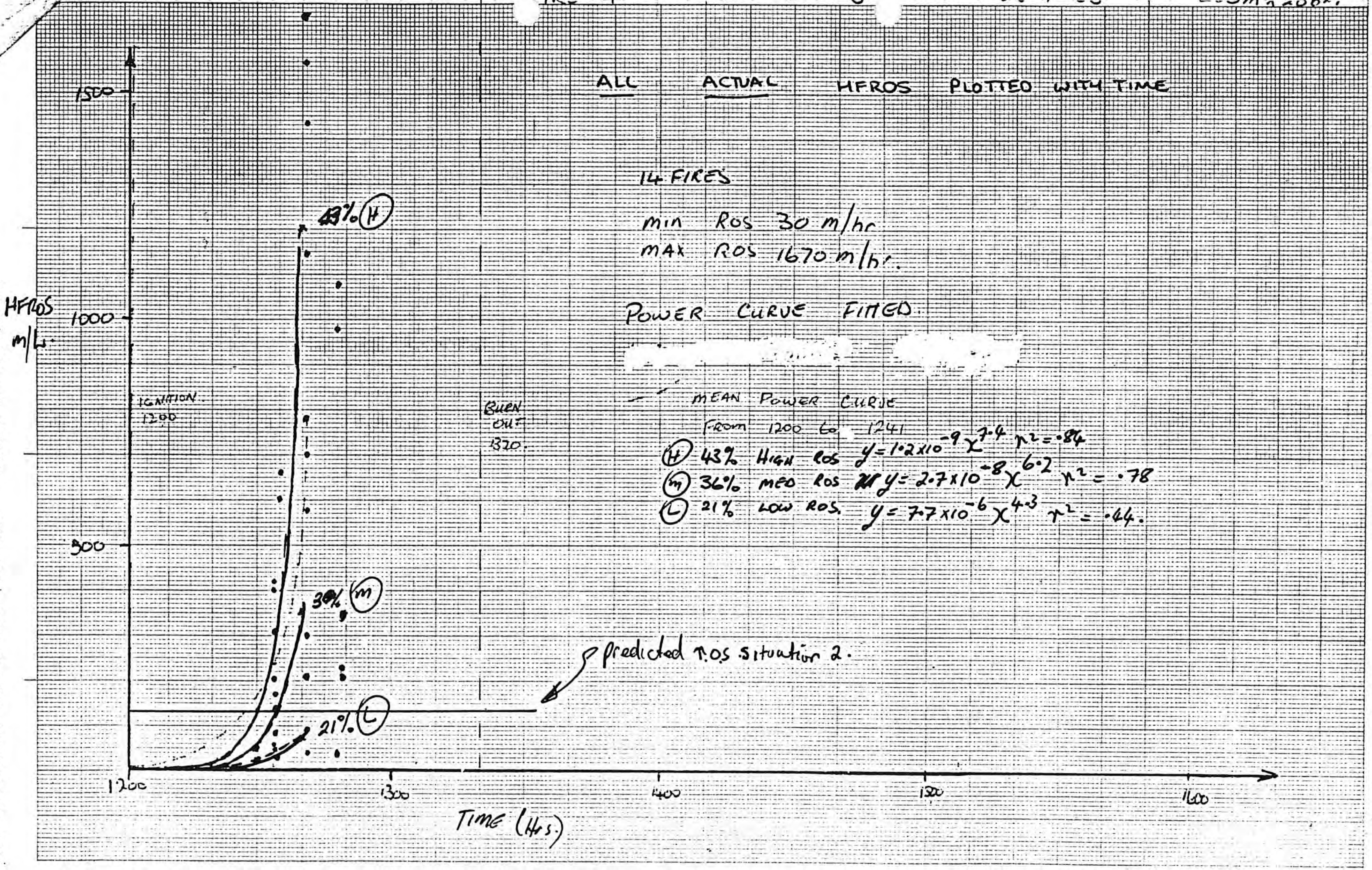
(i) Mean ROS (ARITHMETIC) = 387 m/h

(ii) $\bar{x}$ $\frac{\text{DIST}}{\text{TIME}}$ = = 288 m/hr

(iii) harmonic mean) = = 140 m/hr.

(iv) MAX ROS: 1986 m/hr.





ALL ACTUAL HFROS PLOTTED WITH TIME

14 FIRES

min ROS 30 m/hr
MAX ROS 1670 m/hr.

POWER CURVE FITTED

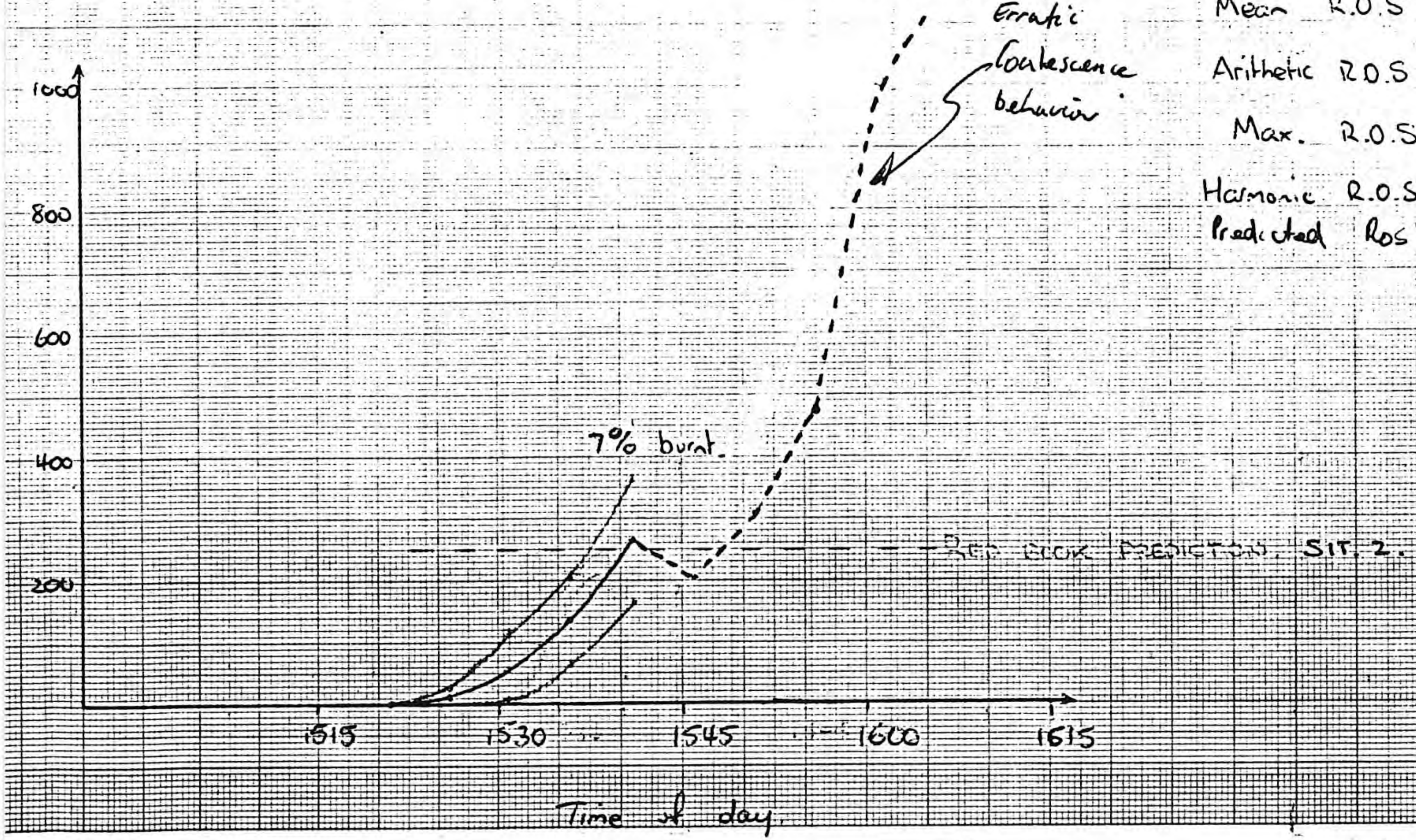
MEAN POWER CURVE
FROM 1200 to 1241
(H) 43% HIGH ROS $y = 1{\cdot}2 \times 10^{-9} x^{7\cdot4}$ $r^2 = \cdot84$
(m) 36% MED ROS $y = 2{\cdot}7 \times 10^{-8} x^{6\cdot2}$ $r^2 = \cdot78$
(L) 21% LOW ROS. $y = 7{\cdot}7 \times 10^{-6} x^{4\cdot3}$ $r^2 = \cdot44$.

Fig 3(e)

Mean H.F.R.O.S. + 95% c.L. for PLOT 3 (FIRE 5)

$$\text{H.F.R.O.S.} = 0\cdot 223\, t^{2\cdot 365}$$

$r^2 = 0\cdot 48$ (from $\bar{x}$ r.o.s. at each scan line)



Mean R.O.S : 345 m/hr ± 308 (95%

Arithetic R.O.S : 95 m/hr ± 25 (95%

Max. R.O.S: 1706 m/hr

Harmonic R.O.S: 79 m/hr.

Predicted Ros 250 m/hr.

SHEE

5	26	2
	8	
4	8 40	
11 36	16	1
13 23	28 136	1
26	80 592	2
	4	
57 47	277 273	4
2	3	
33	48	4

TABLE 1·(F)

Surface burning conditions at ignition

PLOT 1,2,5 & 6. 200m x 200m SPACING 3-3-83

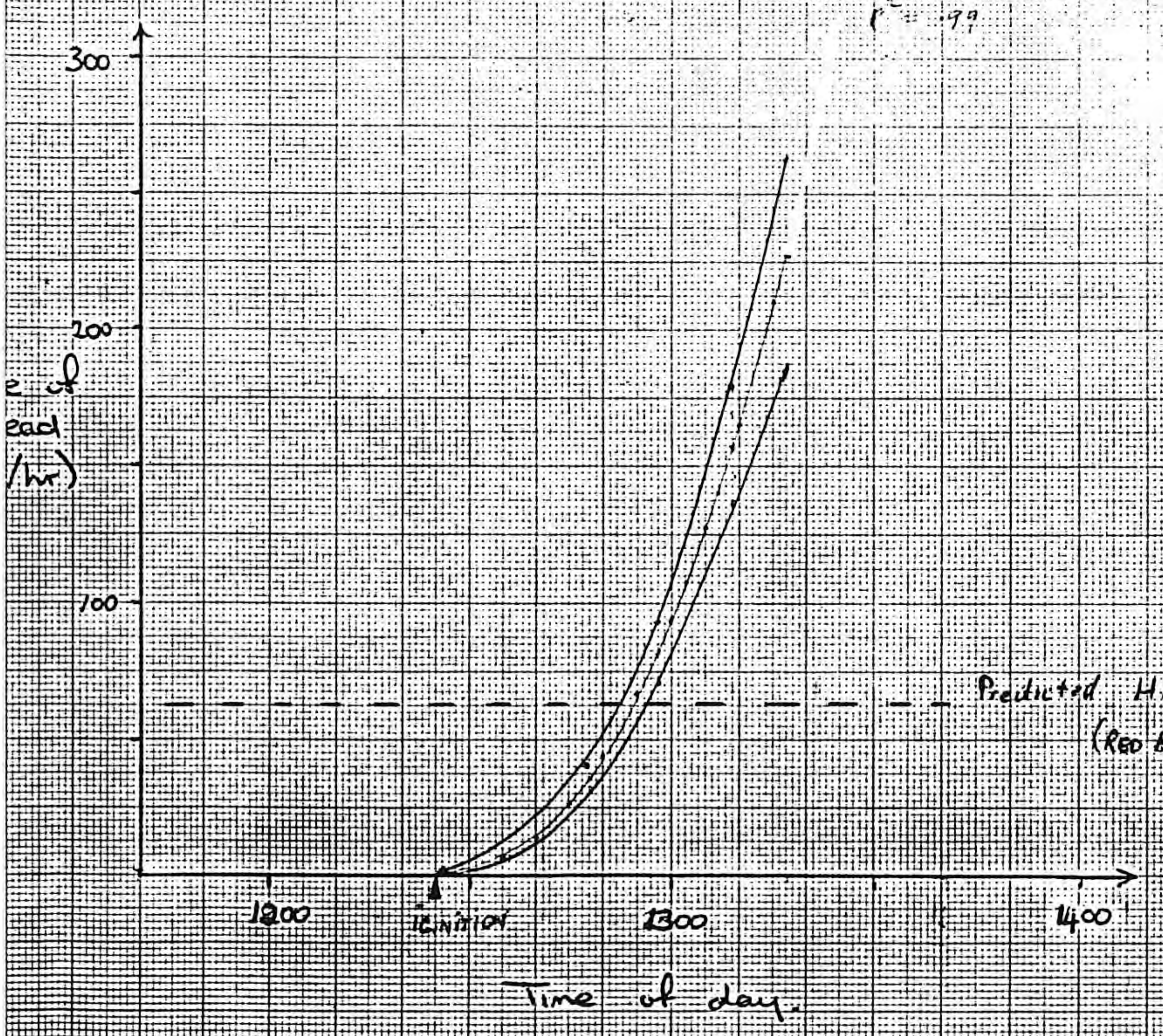
Fire # 6

FUELS		MOISTURE CONTENT			WEATHER			
Litter Weight	Scrub Weight	S.M.C.	P.M.C.	S.D.I	Wind	Temp	R.H.	PREDICT. HFROS. (m/h)
7·6 t/ha.	3·78	11·6	14·65	1343	2·42 km/hr.	18	76	32

NOTE This fire did not burn fuels down to mineral earth. It was also a patchy burn - many spots went out overnight. Ideal conditions are somewhere between this fire + the next fire - No 7 (for low intensity burns on dry soils)

Fig 3(c)

Mean HROS for each scan time vs time.



(TOTAL) MEAN ROS 127 m/hr.
(ARITH) MEAN. 61 m/hr.
HARMONIC. MEAN. 83 m/hr.
MAX HROS 538 m/hr.

21.0 Table 1 (d)

Surface burning conditions at ignition time.

PLOT 23   200 m x 200 m.   28 - 1 - 83

Fire # 4

FUELS		MOISTURE CONTENT			WEATHER			
Litter Weight	Scrub Weight	S.M.C.	P.M.C.	S.D.I	Wind 1:1	Temp	R.H.	Predicted HFROS
9.2 t/ha.	3.48 t/ha	9.6	9.6	1635	5.73	28	34.	113

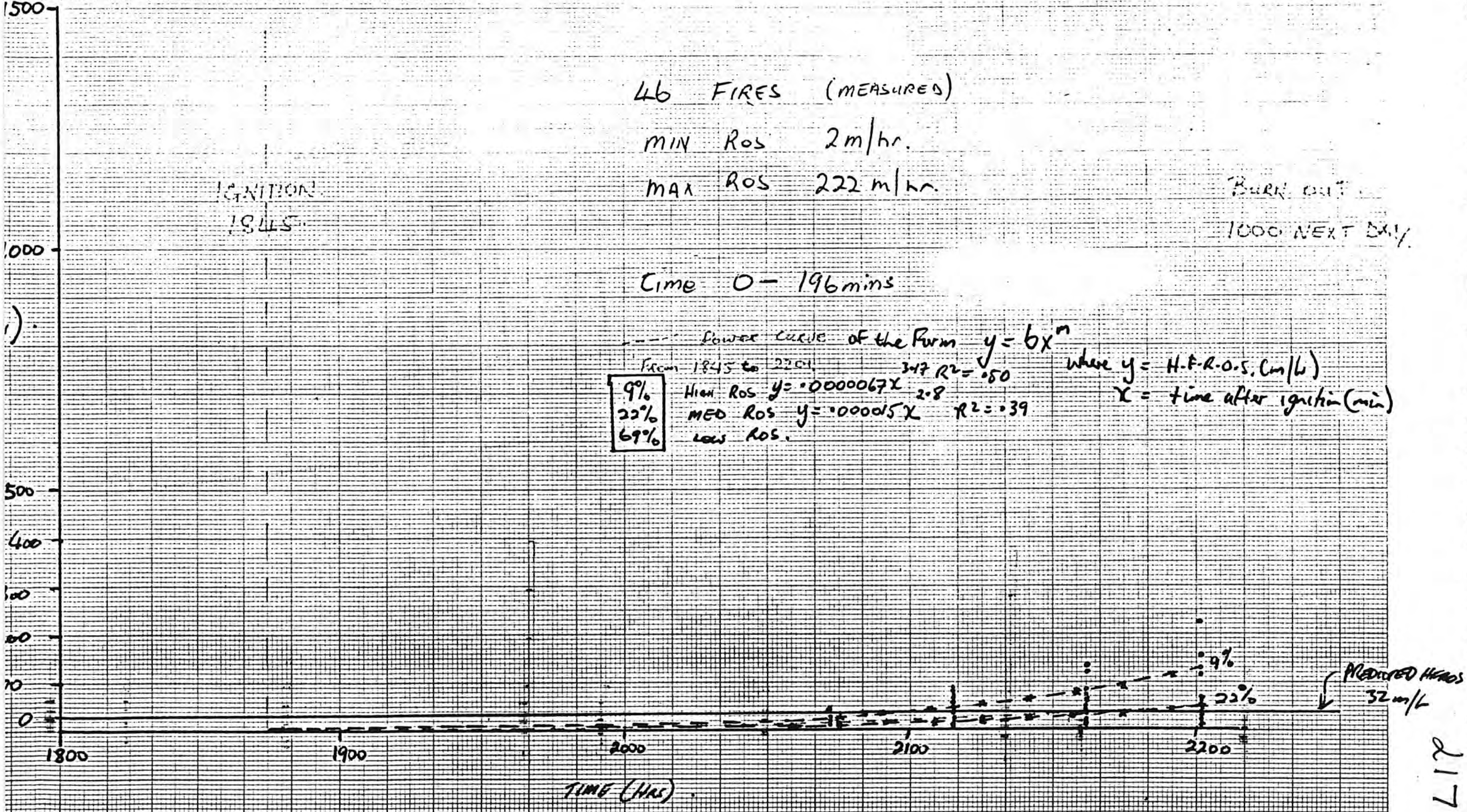
(+ SLOPE correct.)

IRE 6 100 5 16 5- 5m 100 spacing.

TOTAL AREA ~.

Fig. 2(f)

HFROS vs Time after ignition (ACCELERATION CURVE).



46 FIRES (MEASURED)

MIN ROS 2m/hr.

MAX ROS 222 m/hr.

Time 0 – 196 mins

---- Power curve of the Form $y = bx^{n}$ where y = H.F.R.O.S. (m/h)

x = time after ignition (min)

From 1845 to 2201.

9% High ROS $y = \cdot 0000067x^{3.17}$ $R^2 = \cdot 80$

22% MED ROS $y = \cdot 000015x^{2.8}$ $R^2 = \cdot 39$

69% Low ROS.

IGNITION 1845

BURN OUT 1000 NEXT DAY.

PREDICTED HFROS 32 m/h

217

TABLE 1(g)

Surface burning conditions at ignition time.

PLOT 10/14
FIRE # 7.

200m x 100m.
IGNITION TIME 1800 hrs.

FUELS		MOISTURE CONTENT			WEATHER			situation 2
Litter Weight	Scrub Weight	S.M.C. 10EQ	P.M.C.	S.D.I	Wind 1:1	Temp	R.H.	PREDICTED HFROS
9.4	3.7	10.0	9.7	1382	4.10	20	66	71

TABLE 1 (e)

Surface burning conditions at ignition.

PLOT 3

Fire # 5

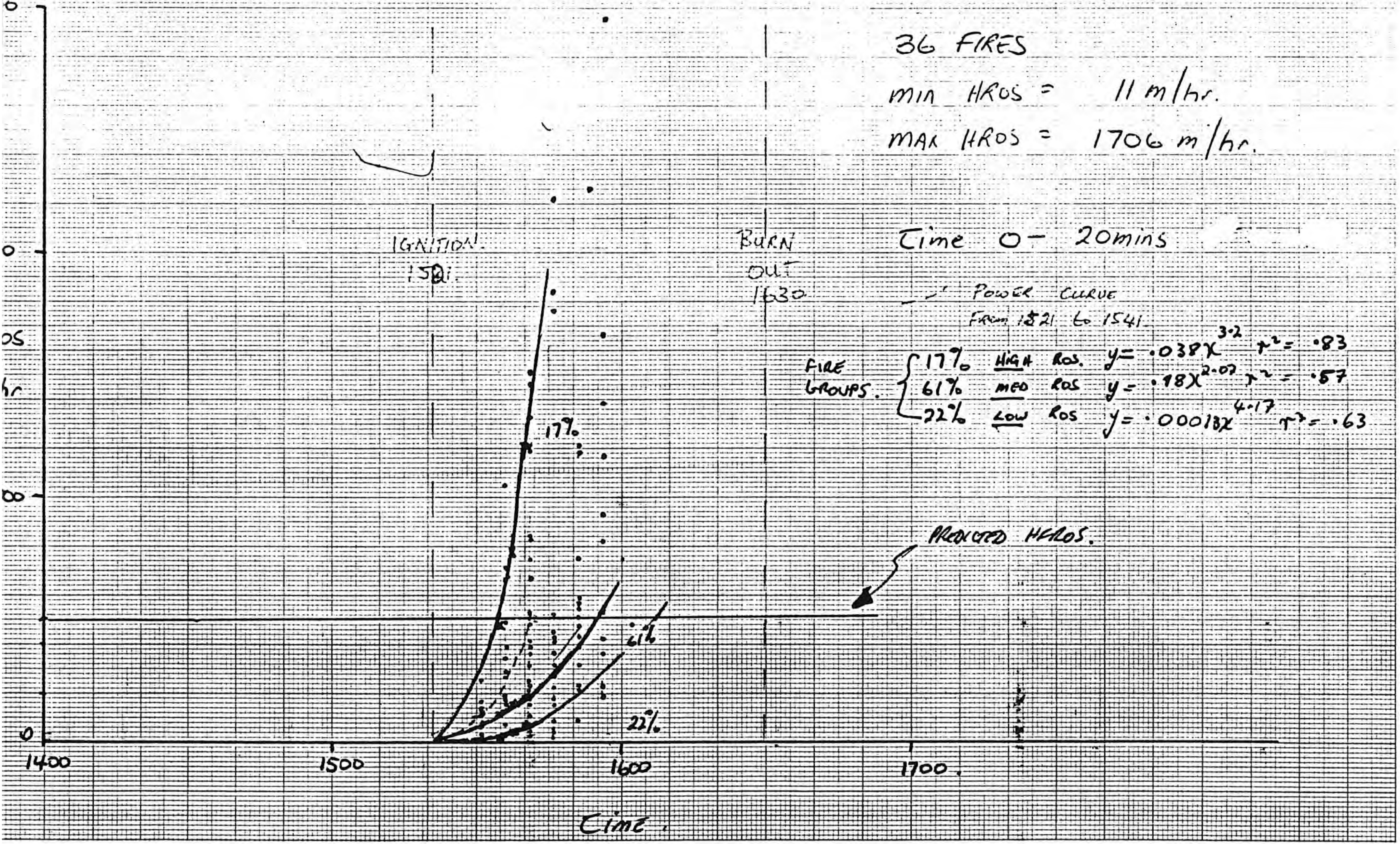
FUELS		MOISTURE CONTENT			WEATHER			
Litter Weight	Scrub Weight	S.M.C.	P.M.C.	S.D.I	Wind	Temp	R.H.	PREDICTED ROS
6-6 T/ha	5-24 T/ha	4.9%	9-5%	1627	5 kph	27°C	40%	250 mph.

SPACING: 100 m × 100 m

FIRE 5 PLOT 3. 2-2-83 100m x 100m spacing.

Fig 2(e)

ACTUAL SPREAD RATES WITH TIME FOR:



36 FIRES

min HROS = 11 m/hr.

MAX HROS = 1706 m/hr.

Time 0 – 20mins

- - Power curve from 1521 to 1541

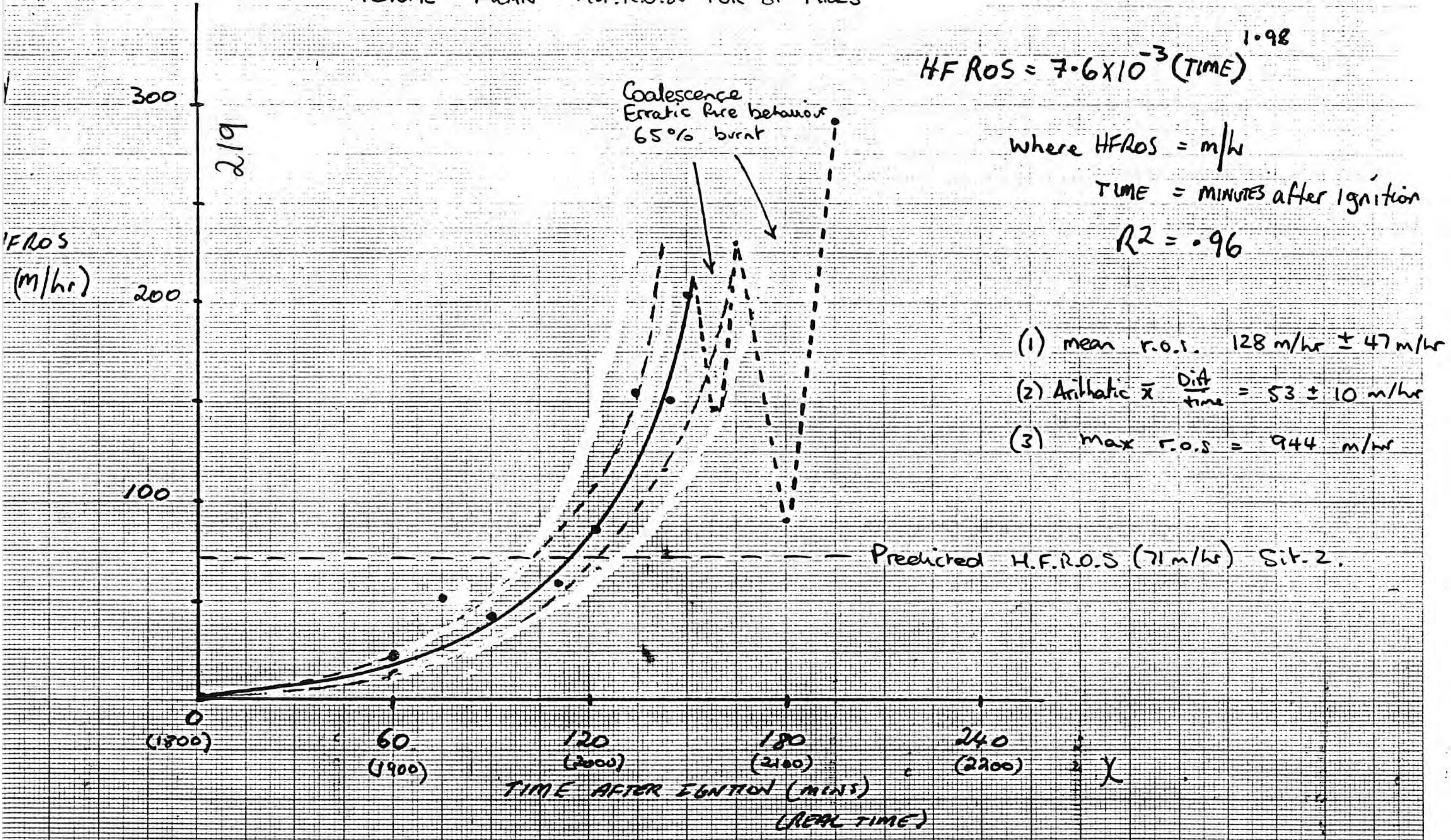
FIRE GROUPS.
- 17% HIGH ROS. $y = .038x^{3.2}$ $r^2 = .83$
- 61% MED ROS $y = .18x^{2.07}$ $r^2 = .57$
- 22% LOW ROS $y = .00018x^{4.17}$ $r^2 = .63$

214

26	27
8	7
8 40	14
16	1
28 136	1
80 592	2
4	
277 273	4
3	
48	

Fig 3(g) FIRE #7 PLOT 10/14.

ACTUAL* MEAN H.F.R.O.S. FOR 81 FIRES



$$HF\ RoS = 7{\cdot}6\times10^{-3}(TIME)^{1{\cdot}98}$$

Where HFRoS = m/hr

TIME = MINUTES after ignition

$R^2 = {\cdot}96$

(1) mean r.o.s. 128 m/hr ± 47 m/hr

(2) Arithatic $\bar{x}$ $\frac{Dist}{time}$ = 53 ± 10 m/hr

(3) max r.o.s = 944 m/hr

* MEAN H.F.R.O.S. FOR EACH TIME INTERVAL

φ = 75
9 ; SE =
~~76~~
$\bar{x}$ = = 4.9
No = 75
s = 3.78
No 76
= 6.0 (
No = 57
= 11 CL
52
= 18.3 C
~~36~~
= ~~26~~ CL
12 = ~~27~~
= 43 C
No - 16
56 C
No = 12
= 47 C
No = 11
= 14.4 (
SE = 5

ACTUAL HEAD FROS VS TIME (FOR ALL FIRES)