Exhibit 216 "Rediscovered"

from the
(records of the)
Board of Inquiry into
the Occurrence of
Bush and Grass Fires
in Victoria

Citation: VPRS 13230/P1/7
"Exhibits : Folder 9. No. 210 - 249"

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 471

No FM-1
Date 13 May 1977
JAH:DB

LABORATORY REPORT

TO: R E James, Bushfire Investigation Task Force

SUBJECT: AN EXAMINATION OF PARTICLES FROM CONDUCTOR CLASHES AS POSSIBLE SOURCES OF BUSHFIRE IGNITION

SUMMARY

The temperature-history and trajectory of particles ejected from clashing aluminium conductors have been calculated to determine whether such particles could have started certain of the bushfires of 12 February 1977. The character of the particles and their initial conditions were determined from a laboratory simulation of clashing. Other experiments were conducted to measure the temperatures at which particles of different sizes will ignite dry grass.

It is concluded that the metal particles ejected from clashes cannot be ruled out as possible sources of ignition of any of the fires in question.

SIGNED G E Pleasance
G E Pleasance
ENGINEER

SIGNED J A Hart
J A Hart
HEAD, FLUID MECHANICS SECTION

SUBMITTED BY: SECT/DIV/DEPT

PHONE:

ACCEPTED BY: SECT ON

ACTIVITY NO:

REMARKS:

AN EXAMINATION OF PARTICLES FROM CONDUCTOR CLASHES AS POSSIBLE SOURCES OF BUSHFIRE IGNITION

1 INTRODUCTION

The aim of the investigation described in this report was to determine if particles released from a clash of aluminium conductors 6 m (20 ft) in the air could cause fires on the ground 12 to 18 m (40 to 60 ft) down wind of the conductors in the weather conditions that existed on 12 February 1977.

Direct simulation of the field conditions was not possible because of the physical size of the test facility required, and scaled-down simulations that could be contemplated were not considered to correctly model the situation.

The problem has been broken into 3 parts and each treated as a separate investigation -

a The conductor clashes which produce the hot particles - experimental facilities were set up to determine the size, temperature and velocity of particles as they leave the conductor.

b The flight of the particle to ground - a mathematical model was used to determine the temperature-time history and the trajectory of a particle under the influence of ambient conditions, so as to ascertain the horizontal distance a particle travelled and its temperature on reaching the ground.

c The question as to whether the particle is hot enough when it reaches the ground to cause ignition of the grass - experiments were carried out to determine the temperatures at which a range of particle sizes could cause ignition of dry grass.

2 CONDUCTOR CLASHES

The purposes of these experiments were -

a To find the size and properties of particles produced by conductor clashes.

b To measure the temperature of particles as they leave the conductor.

c To determine the velocity of particles ejected from the conductors.

d To determine if the clash conditions (voltage between the conductors and the fault current) had any influence on (a) to (c) above.

2.1 Clashing rig

Two aluminium conductors (6/1/.118 ACSR) were strung over a span of 3.7 m (12 ft) and pushed apart by a rod which could be jerked free to allow the conductors to clash. Provision was made on the rig to catch particles and to allow filming of the clash. The general arrangement of the rig is shown in Fig 1. The required fault current for tests was obtained by electrically connecting the 2 conductors and adjusting the circuit resistance at a particular voltage drop across the circuit.

A test was conducted by separating the conductors with the spreader rod, electrically activating the circuit and then ejecting the rod from between the conductors to allow them to clash.

2.2 Tests performed

Tests were conducted with 240 and 415 volts across the circuit and for each voltage level at a fault current of 100, 300 and 500 A.

The 79 tests conducted are tabled in Appendix 1.

2.3 Measurements

The voltage across the resistance and the fault current during a clash were recorded for each test. Typical chart recordings are shown in Appendix 1.

Particles were collected for analysis after a number of clashes at a specified voltage and current level (see Appendix 1). The particles were analysed to determine their size distribution, density and metallurgical character and composition. The results of these analyses are given in Appendix 2.

2.4 Summary of results and discussion

The temperature measured was 1570°C $\pm$ 56°C. This applies to particles beyond a zone obscured by an intense flash, usually extending about 100 mm from the clash site (see Appendix 3).

The maximum measured particle speed 20 milliseconds after the clash for the 415 volt tests was 16 m/s at 500 A fault current, and for the 240 volt test was 11.5 m/s at 300 A. The direction of the particles varied according to the way the conductors clashed and for the purpose of further analysis it is assumed that particles could be ejected in any direction (see Appendix 4).

Particle sizing showed no significant difference in size distribution with current levels for the 415 volt tests. Some effect of current on the size distribution was found in the 240 volt tests, the size of particles increasing with increase in current. No significant difference in particle size was detected when the speed of approach of the conductors was increased (tests 65-69 compared to tests 70-74 and 42-47) to intensify the clash. Typically 10% of the particles are greater than 0.5 mm, 2% are greater than 1.0 mm and 0.5% are greater than 1.5 mm. The maximum size of particle collected was of the order of 2.5 mm.

The density of typical collected particles was 2300 kg/m^3 as compared to pure aluminium 2700 kg/m^3. Chemical analysis showed that a significant proportion of the particles collected had oxidised. The measured proportion of aluminium as oxide varied between 20 and 64% (Appendix 2). These measurements are consistent with microscopic examination of individual particles, details of which are described in Appendix 2. However, due to the small samples collected and the destructive nature of the tests together with the limited time available no definite conclusion has been established.

3 TESTS TO DETERMINE REQUIRED PARTICLE TEMPERATURE FOR IGNITION

The purpose of these tests was to determine the temperature that a particular sized particle has to have to ignite a bed of flammable material.

Particles were heated to a known temperature, dropped onto a bed of pre-dried flammable material, and the result observed. Several particle sizes and a range of temperatures were used.

The tinder material, a dried-grass hay with no significant lucerne content, was chosen on the advice of forestry officers as typical of readily-ignitable bushfire fuel. It was dried to less than 1% contained moisture; 3% is regarded as extremely dry in the field. The grass was formed into a bed which could be ignited instantly by a match and burnt fiercely. During a test the bed was exposed to a blown air stream designed to simulate the fanning effect of wind. Ignition was judged to have occurred whenever significant smouldering occurred, whether or not flame followed. The test method and results obtained are described in detail in Appendix 5.

Typical results were that the grass was ignited by 4 mm particles hotter than about 800°C, and by 2.5 mm particles above 1000°C. Unfortunately the facilities available did not enable particles to be heated above 1200°C so the ignition temperature of particles less than 2 mm could not be measured. However, conservative extrapolation of the results suggest a 1 mm particle would need to be hotter than 1400°C to cause ignition.

4 TEMPERATURE-TIME HISTORY AND TRAJECTORIES OF PARTICLES

Using the data obtained from the clashing tests to define the initial conditions of a particle, the temperature-time history and trajectory of particles from the conductor to the ground have been computed for the conditions obtaining on 12 February 1977 (45 mph winds, 35°C ambient temperature). Details of the calculation methods are given in Appendix 6.

4.1 Description of particle flight

On leaving the conductor with some initial speed, a particle falls to the ground under the action of gravity and is also dragged horizontally by the wind. As it does so some heat is radiated away from the particle and some is convected away by its motion relative to the air. As the particle oxidises heat is also generated within the particle. If the rate at which heat is generated is greater than that at which it is lost the temperature of the particle will increase, and vice versa.

4.2 Calculations and results

In the results of the calculations presented in Table 1, the rate of heat release has been adjusted so that in ambient conditions similar to the conductor clash tests a particle starting at some temperature between the melting point of aluminium and 1600°C increases to 1600°C and then decreases such that a specified amount of aluminium oxide is formed before the particle solidifies; the derived rate constants have then been applied under field conditions but of course a different quantity of oxide will form.

The calculation procedure is otherwise a straightforward marching integration of the differential equations governing particle motion - Newton's Second Law - and the heat balance.

Due to the limited time available and the complication introduced by the particles oxidising during their flight only a few of the possible combinations of input parameters have been tested.

5 CONCLUSIONS

It is emphasised that in the limited time available it has not been possible to resolve points of uncertainty to the extent normally expected in a scientific investigation. The chief matters incompletely resolved are, first, the temperature above which particles 1 mm or less in diameter can ignite dry grass, and, second, the extent to which molten aluminium particles oxidise in flight.

It is also pointed out that the calculation procedure has not been verified by experiment. However, based on the considerable experience of Fluid Mechanics Section in the computation of particle motion[1,2,3] it is considered that any errors in the approximate equation of motion solved, or in estimated particle properties (such as shape) used, are small in the context. It has also been possible to draw on accumulated expertise in heat transfer at the Herman Research Laboratory to justify, for example, neglecting particle conductivity in the heat balance and to select an appropriate particle emissivity.

Subject to these provisos it is concluded that:

1. The particles ejected from a conductor clash are mostly smaller than 1 mm diameter, with a few as large as 2.5 mm.

2. Particles of smaller than 2 mm diameter can cause fires if they fall into dry grass with temperatures in excess of 1300°C.

3. The temperature of particles shortly after ejection from a clash site is about 1600°C.

4. The subsequent temperature history of particles is strongly dependent on the extent to which they oxidise, but the assumption is that no more than 30% of the aluminium in the larger particles is oxidised.

5 Only a few of the particles (1-2%) produced by clashes are large enough (greater than 1 mm) to retain sufficient temperature, whilst being blown more than a few ~~inches~~ metres from a distribution line, to ignite fires even in exceptionally ~~long~~ dry grass.

6 Within the admissible ranges of wind speed and particle characteristics, it must be concluded that the probability of grass fire initiation from low voltage conductor clashing at a height of 6.0 metres above ground varies with distance from the line and at a distance of about 30 metres from a distribution line is extremely low.

ACKNOWLEDGEMENTS

The test program and evaluation of results was carried out with the assistance of officers from -

Electrical Plant Testing Section
Transmission Operations Department

Construction Section
Distribution Engineering Department

Meter and Tests Section
Distribution Engineering Department

Communications Division
Public Relations Department

Analytical Chemistry Section
Research and Development Department

Coal Science Section
Research and Development Department

Fuels Section
Research and Development Department

Laboratory Services Group
Research and Development Department

Materials Technology Section
Research and Development Department

The high-speed cine photography was done by Mr V Jones of John Hadland (Aust) Pty Ltd.

The authors wish to record their appreciation of the willing co-operation and effective participation of all concerned.

REFERENCES

1 Green, J M and Llewelyn, R P - Particle trajectories in gas streams, Scientific Division Report No MR-177, 1969.

2 Llewelyn, R P and Hart, J A - Separation of solid particles in a sink-vortex flow, Scientific Division Report No 220, 1971.

3 Hart, J A - Note on a possible source of error in sampling gas-borne pulverised fuel, Scientific Division Report No 229, 1970.

4 Bird, R D, Stewart, W E and Lightfoot, E N - Transport phenomena, Wiley & Sons Inc, New York, 1960.

5 Kreith, F - Principles of heat transfer, 2nd edition, International Textbook Company, Scranton, Pennsylvania, 1965.

TABLE 1 : RESULTS OF CALCULATIONS OF PARTICLE TRAJECTORIES AND TEMPERATURE-TIME HISTORY

REF NO	PARTICLE DIAMETER mm	WIND SPEED km/h (mph)	REFERENCE % ALUMINIUM OXIDE	INITIAL PARTICLE TEMP °C	INITIAL VELOCITY km/h	INITIAL PARTICLE DIRECTION (→ WIND, ↓ VERT DOWN)	FINAL PARTICLE TEMP ON REACHING GROUND	HORIZ DIST TRAVELLED m (ft)	% ALUMINIUM OXIDE ON REACHING GROUND	VARIABLE BEING TESTED
1	1	75 (47)	30	670	0	·	1232	36 (119)	21	Standard
2	1	75 (47)	60	670	0	·	1660	38 (126)	32	% Aluminium oxide
3	1	75 (47)	0	670	0	·	297	28 (92)	0	"
4	1	75 (47)	30	1200	0	·	1275	37 (122)	21	Initial particle temperature
5	0.5	75 (47)	30	670	0	·	530	57 (186)	32	Particle diameter
6	1.5	75 (47)	30	670	0	·	1566	25 (83)	15	"
7	2.0	75 (47)	30	670	0	·	1580	19 (62)	11	"
8	1	50 (31)	30	670	0	·	1242	23 (76)	21	Wind speed
9	1	75 (57)	30	670	4.4	↘	1450	21 (69)	15	Initial velocity and direction
10	1	75 (57)	30	670	4.4	↑	950	58 (190)	26	"
11	1	75 (47)	30	670	3.1	↘	1400	25.6 (84)	17	"

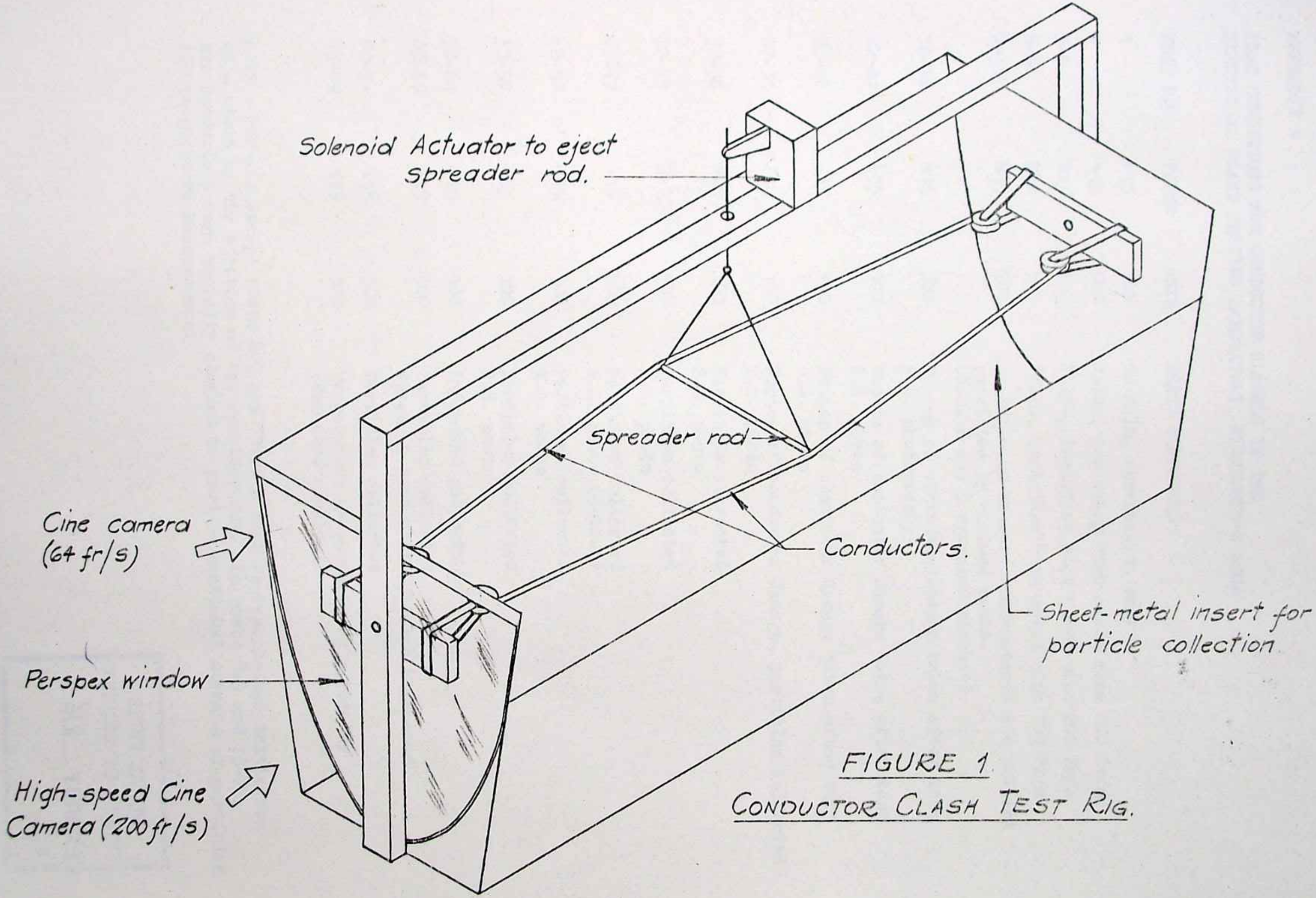


FIGURE 1

CONDUCTOR CLASH TEST RIG.

APPENDIX 1

TEST CONDITIONS FOR CONDUCTOR CLASHES IN THE ELECTRICAL PLANT TESTING LABORATORY, FISHERMEN'S BEND

TEST NO	VOLTS	AMPS	TESTS CONDUCTED
1	415	500	No film, observation only
2	415	500	Films, including high speed cine 200 fr/s
3-4	415	100	Films, including high speed cine 200 fr/s
5-6	240	100	Films, including high speed cine 300 fr/s
7-11	415	500	Attempts to measure temperatures and collect particles by various means. (Test 8 and 9 repeated clashes)
12-16	415	500	Photos of conductor damage taken after test H.S. photography
17-21	415	300	Photos of conductor damage taken after test H.S. photo
22-26	415	100	Photos of conductor damage taken after test H.S. photo
27-31	240	100	Photos of conductor damage, particles collected H.S. photo
32-36	240	300	Particles collected H.S. photo
37-41	240	500	Particles collected H.S. photo
42-47	415	500	Particles collected H.S. photo (colour)
48-52	415	300	Particles collected H.S. photo
53-57	415	100	Particles collected H.S. photo
58-64	415	500	Infra-red photography
65-69	415	500	Particles collected Speed of conductor approach increased
70-74	415	500	Particles collected
75-79	415	500	Temperature measurement by pyrometry (Repeated clashes)

NOTE : For all except tests 8-9 and 75-79 a test represents the initiation of a clash by the ejection of the spreader rod. In tests 8-9 and 75-79 the conductors were manually clashed to produce continual streams of particles for temperature measurement.

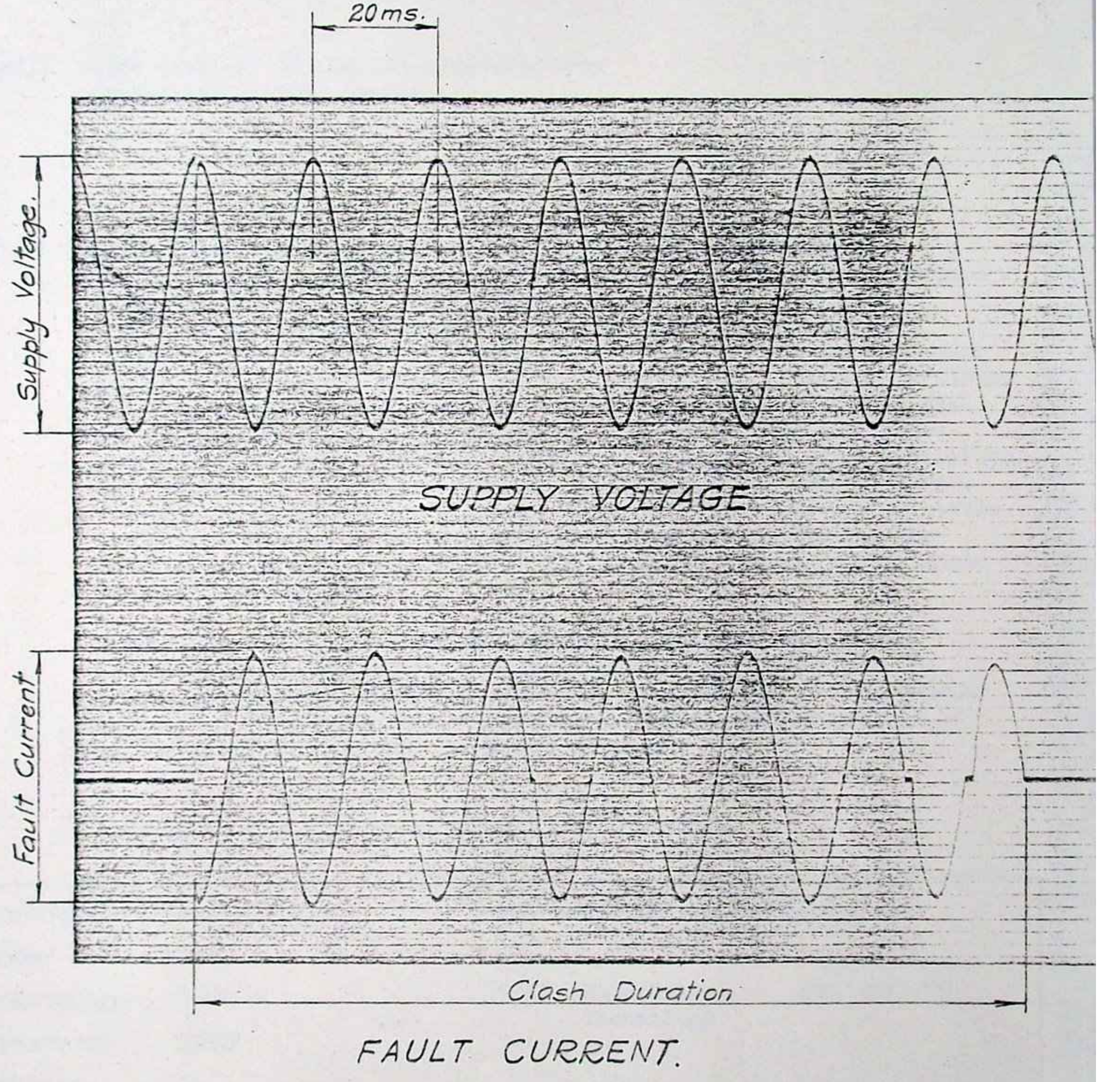


FIGURE A1. TYPICAL VOLTAGE & CURRENT RECORDINGS.

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 400

APPENDIX 2.1
No M77-85
Date 12 May 1977
RMC:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Size Analysis of Particles Arising From Conductor Clashing Tests.

REPORT Size distributions of aluminium and aluminium oxide particles retrieved from conductor clashing tests were requested for 8 samples from tests under varied conditions. The samples as received contained much extraneous matter (arising from the collection process). Large pieces of rubbish were picked out and the remainder sorted by "riffling" on paper - the more spherical aluminium particles rolled clear of the other matter. The entire sample from each test was spread out on an area approximately 35 mm by 40 mm and photographed at 2X magnification. Prints were enlarged to 5X magnification for counting of particles on the Zeiss TGZ3 particle size analyser. This machine assesses the diameter of the equivalent projected circle from the specimen and is therefore only ideally suitable for the counting of spherical particles. The reduced range and linear scale were used in counting.*

Results for the 8 tests are plotted in Fig 1 as the cumulative percentage of particles finer than a particular size against the equivalent particle projected diameter. The results are reproduced in Table 1 to indicate the numbers of particles and percentages of particles in various size ranges of interest.

* Counting of particles was done by Mr D Pardee.

SUBMITTED BY:	G E Pleasance	SECT/~~DIV/DEPT~~	Fluid Mechanics		
PHONE:	394				
ACCEPTED BY:	J Ellis	SECT	Materials Technology	ON	26/4/77
ACTIVITY NO:	93337				
REMARKS:					

SIGNED Richard Coldham

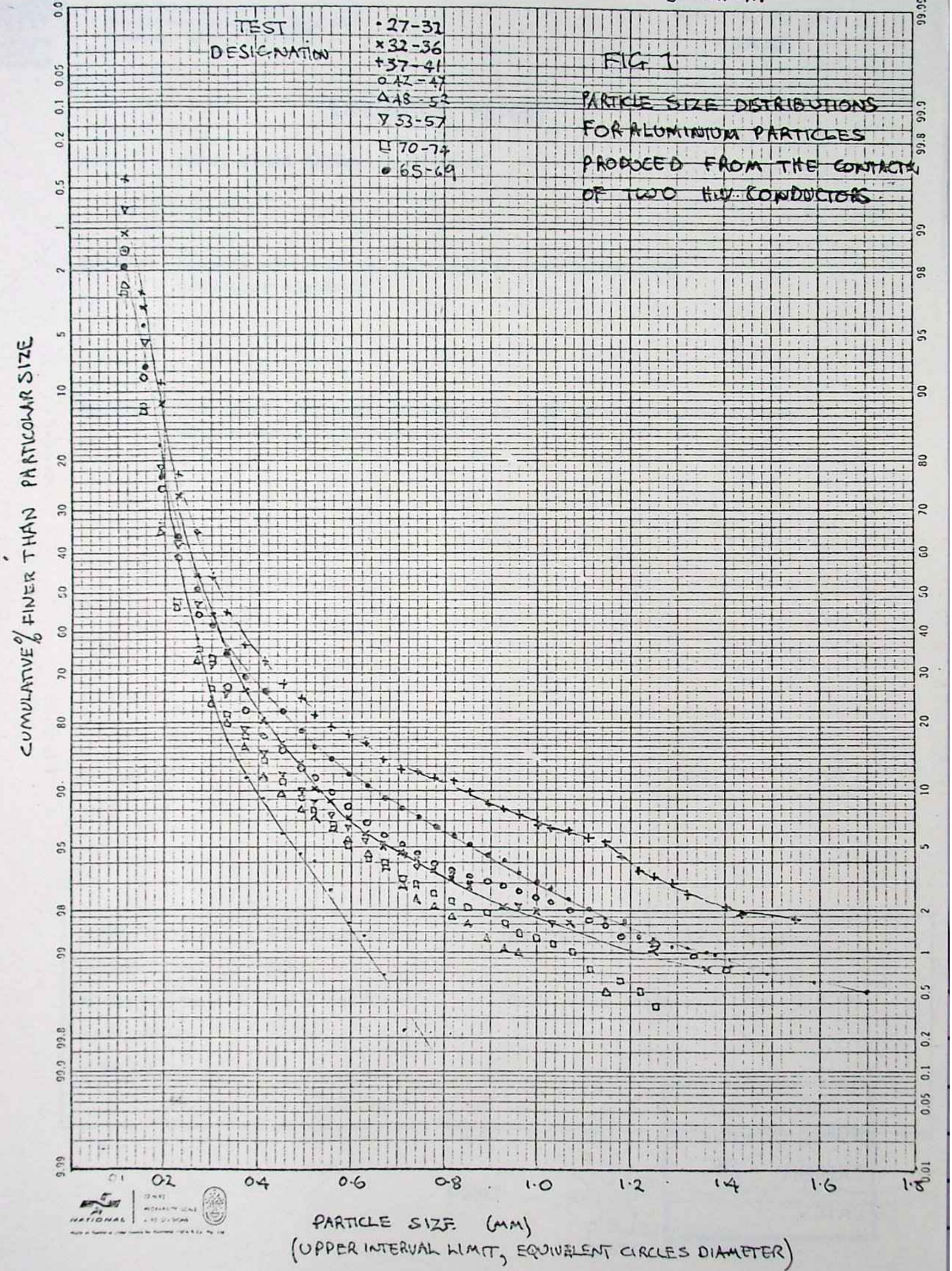
R M Coldham
METALLURGIST

TEST DESIGNATION

PARTICLE SIZE (mm)	27-31		32-36		37-41		42-47		48-52		53-57		65-69		70-74	
	Ni	%	Ni	%	Ni	%	Ni	%	Ni	%	Ni	%	Ni	%	Ni	%
<0.25	161	36.4	297	28.5	136	21.4	1148	41.7	551	54.3	151	36.9	1271	37.2	1040	52.5
0.25 - 0.50	261	57.1	604	58.0	347	54.6	1240	45.1	383	37.7	220	53.8	1511	44.3	759	38.3
0.50 - 0.75	19	4.3	96	9.2	76	12.0	249	9.1	58	5.7	23	5.6	383	11.2	125	6.3
0.75 - 1.00	1	0.2	24	2.3	33	5.5	47	1.7	13	1.3	6	1.5	147	4.3	32	1.6
1.00 - 1.25			9	0.9	20	3.1	37	1.3	6	0.6	5	1.2	62	1.8	19	1.0
1.25 - 1.50			5	0.5	10	1.5	18	0.7	1	0.1	2	0.5	17	0.5	2	0.1
1.50 - 1.75			3	0.3	4	0.6	8	0.3	1	0.1	2	0.5	7	0.2	3	0.2
>1.75			3	0.3	8	1.3	3	0.1	2	0.2			17	0.5	2	0.1
Total No of Particles	442		1041		636		2750		1015		409		3416		1982	

TABLE 1 : Number of particles in a particular size range, Ni, and percentage of total number of particles in that range, for the 8 series of tests analysed.

5th MAY 1977



TEST DESIGNATION
• 27-32
× 32-36
+ 37-41
○ 42-47
△ 48-52
▽ 53-57
□ 70-74
● 65-69
FIG 1
PARTICLE SIZE DISTRIBUTIONS FOR ALUMINIUM PARTICLES PRODUCED FROM THE CONTACT OF TWO H.V. CONDUCTORS.
CUMULATIVE % FINER THAN PARTICULAR SIZE
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
PARTICLE SIZE (MM)
(UPPER INTERVAL LIMIT, EQUIVALENT CIRCLES DIAMETER)

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 463

SEC

APPENDIX 2.2

No BCR77/20

Date 12 May 1977

DJA:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Density of particles as supplied from laboratory conductor clashes.

REPORT The density of the particles supplied as measured by mercury displacement is 2300 kg/m^3.

SUBMITTED BY:	G E Pleasance	SECT /DIVXDEPT	Fluid Mechanics		
PHONE:	394				
ACCEPTED BY:	D J Allardice	SECT	Coal Science	ON	30/4/77
ACTIVITY NO:	93337				
REMARKS:					

SIGNED ....

D J Allardice
RESEARCH SCIENTIST

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 486

SEC

APPENDIX 2.3

No A/77/82

Date 12 May 1977

KB:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Mixture of aluminium and aluminium oxide (Bushfire Investigation)

REPORT Difficulty was experienced in dissolving the sample. 20.6% of the original sample (from conductor test No 9) remained undissolved. The undissolved sample was eventually taken up into solution after fine grinding and fusion with lithium tetraborate.

Chemical analysis -

		DISSOLVED PORTION	UNDISSOLVED PORTION
Total aluminium	Al%	92.7	44.6
Aluminium metal	Al%	84.4	
Aluminium oxide	Al_2O_3%	15.6	100
Iron	Fe%	1.2	0.047
Copper	Cu%	0.045	0.028
Zinc	Zn%	0.02	0.03

SUBMITTED BY: G E Pleasance SECT/~~DIV/DEPT~~ Fluid Mechanics

PHONE: 394

ACCEPTED BY: K Burnell SECT Analytical Chemistry ON 3/5/77

ACTIVITY NO: 93337

REMARKS:

SIGNED K Burnell

K Burnell
SCIENTIFIC OFFICER

RD 535-1 (OP)

APPENDIX 2.3

Report No A/77/82

2

Chemical analysis of samples of conductor material and particles from conductor tests 32-36 and 42-47.

	ALUMINIUM CABLE	ALUMINIUM AND OXIDE SAMPLE 32-36	ALUMINIUM AND OXIDE SAMPLE 42-47
Total aluminium	>99	72.7	69.7
Aluminium as Al%	>99	41.9	35.7
Aluminium as Al_2O_3%		58.1	64.3
Iron as Fe%	0.33	0.36	0.36
Zinc as Zn%	0.04	0.30	0.16
Copper as Cu%	0.038	0.069	0.055

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 483

APPENDIX 2.4
No M77/96
Date 12 May 1977
JDN:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Metallurgical examination of particles ejected from clashing aluminium conductors.

REPORT PARTICLE MORPHOLOGY AND COMPOSITION

Randomly selected particles from a range of clashing conditions were examined using both optical and scanning electron microscopy. In addition non-destructive analysis using an energy dispersive x-ray analyser was carried out. The particles were aluminium, aluminium oxide or a mixture of the two.

The shape of the particles was varied, ranging from spheres to elongated cylinders of varying diameters in the one particle. The whole range of particles was present in almost every sample collected from each clashing test, but the proportions varied.

a Contiguous Spheres

These consisted of a major spherical particle covered with a heavy oxide scale and having a remnant oxide tail, attached to the major sphere was a small sphere, see Figs 1 and 2. The smaller spheres always had a more pronounced metallic lustre than the larger spheres. Microsections showed that the spheres were intimately connected (Fig 3) and were both made up of rather porous aluminium. The major sphere always had a continuous oxide covering and this was either absent or patchy on the minor sphere. Careful preparation and chemical etching revealed that the microstructure was continuous

SUBMITTED BY: G E Pleasance		SECT/DIV/DEPT Fluid Mechanics	
PHONE: 394			
ACCEPTED BY: J D Newton		SECT Materials Technology	ON 26/4/77
ACTIVITY NO: 93337			
REMARKS:			

SIGNED John D Newton
J D Newton
MATERIALS RESEARCH SCIENTIST

from one sphere to the other. This indicated that they were both solidified from the same melt. It was therefore concluded that the contiguous spheres were formed when a drop of molten aluminium erupted through the solid oxide covering the initial molten particle. The eruption probably occurred on contact with the ground at a relatively low temperature which explains the absence of extensive oxidation on the small sphere.

b Spheres with oxide "skirts"

A number of large particles were found where a small aluminium sphere surmounted a large friable mass of aluminium oxide (Fig 4). The aluminium spheres again showed a metallic lustre similar to that described for the small contiguous spheres. Removal of the friable oxide revealed the presence of a large aluminium sphere (Fig 5). Thus it was obvious that these particles were identical with the contiguous spheres except that the degree of oxidation of the original particle was greater.

c Spherical particles

Numerous oxidised spherical particles of aluminium were found (Fig 6); these were the predominant product from the low voltage/low current clashing tests. There was no evidence of eruptions having occurred and it is likely that these particles were cooler when they reached the ground than the contiguous spherical particles.

d Others

There were numerous elongated metallic particles present in all samples, a good example is shown in Fig 1. In addition there were also small approximately spherical particles of alumina formed from aluminium spheres completely oxidised before they reached the ground.

Figure 1 - Tests 48/52 X30

A contiguous spherical particle, showing the erupted smaller sphere and the remnant oxide tail on the major sphere. In addition there is an elongated metallic particle.

Figure 2 - Tests 37/41 X30

Further contiguous spherical particles.

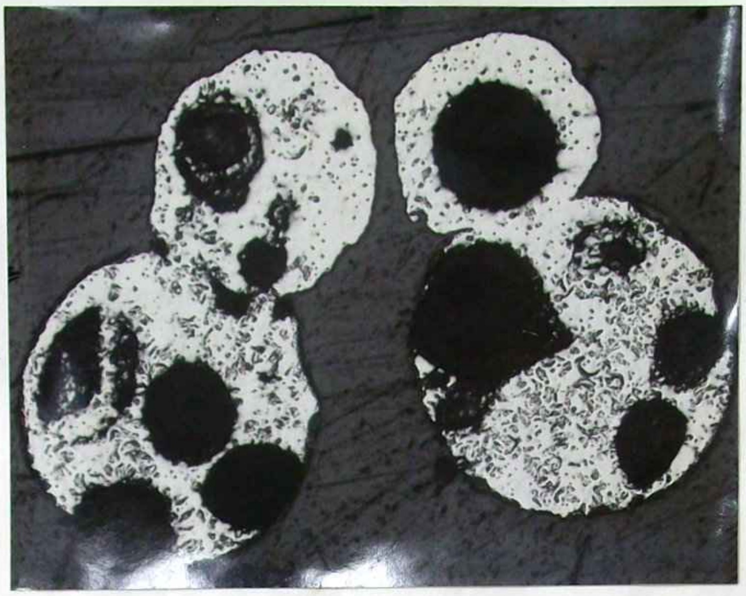


Figure 3 X50

Microsections through both of the contiguous spherical particles which show the porous nature of the aluminium.

Figure 4 - Test 9 X30

Large particle consisting of small metallic sphere and an oxide "skirt".

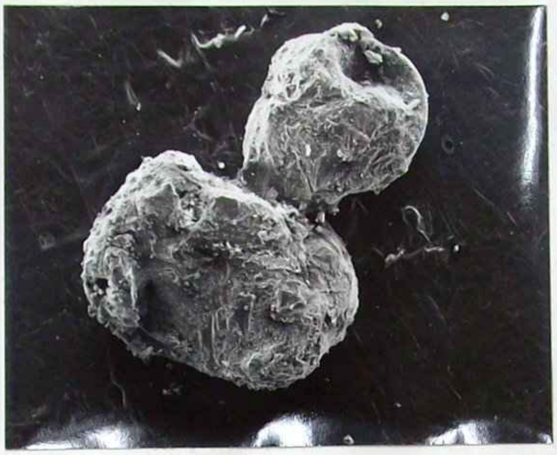


Figure 5 X30

Large particle shown in Fig 4 with the oxide skirt removed to show size of underlying aluminium sphere.

Figure 6 X30

Oxidised aluminium spheres.

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 225

APPENDIX 3

No F/77/2

Date 12 May 1977

PTW:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Temperature of sparks ejected during conductor clashing tests at Fishermen's Bend on 21 and 26 April 1977.

REPORT Temperatures were measured using both Land and Leeds & Northrup disappearing-filament optical pyrometers. The conductors were energised to 415 V, with a fault current of 500 A. The pyrometers were situated 2 to 3 m away from the point of clashing and were sighted on the sparks immediately below the point of conductor contact during clashing.

Observed temperature = 1400°C $\pm$ 50°C
(the $\pm$ 50°C tolerance is due to both uncertainty in colour match, and actual variation in observed spark temperature).

The observed temperature must be corrected for the emissivity of the particles, which consist of molten aluminium and aluminium oxide. The spectral emissivity at the pyrometer wavelength of 0.65 µm (red light) is estimated to be <u>0.3</u> $\pm$ 0.05 (data from Land Tech Note No 101 and from BS2082). The correction, based on Wien's Law, is read from BS2082 as -

Correction = + 170°C $\pm$ 25°C
(the $\pm$ 25°C tolerance is due to uncertainty of emissivity).

$$\text{Corrected temperature} = 1570^\circ C \pm \sqrt{50^2 + 25^2}$$
$$= 1570^\circ C \pm 56^\circ C$$

SUBMITTED BY: G E Pleasance   SECT/~~DIVISION~~ Fluid Mechanics

PHONE: 394

ACCEPTED BY: P T Waring   SECT Fuels   ON 26/4/77

ACTIVITY NO: 93337

REMARKS:

SIGNED P.T Waring.
P T Waring
RESEARCH ENGINEER

RD 535-1 (OP)

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 418

SEC

APPENDIX 4

No FM/2

Date 12 May 1977

RJG:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Velocity of particles ejected from laboratory conductor clashes.

REPORT Below is a tabulated summary of particle velocity analyses made from high-speed films of aluminium conductor clashes. Twenty-five test films were studied and for each film 4 particles (on average) were tracked, and, of these, those that appeared to have the highest speeds were analysed. The peak and mean speeds are given at time intervals of 10 and 20 milliseconds (equivalent to 2 and 4 frames) after the clash. The particles selected for tracking and analysis, in so far as possible, were those moving in a plane perpendicular to the conductor at the clash point. High speed particles were selected, but their size is not known.

A total of 66 particles was analysed and the maximum computed velocity 10 ms after clash was 29 m/s.

SUBMITTED BY:	G E Pleasance	SECT/XXXXXXX Fluid Mechanics
PHONE:	394	
ACCEPTED BY:	R J Griss	SECT Fluid Mechanics ON 26/4/77
ACTIVITY NO:	93337	
REMARKS:		

SIGNED R J Griss

R J Griss
ENGINEER

D 535-1 (OP)

APPENDIX 4

Report No FM/2

2

TEST NO	E	I	t = 0.01s		t = 0.02s		REMARKS
			V MAX	V MEAN	V MAX	V MEAN	
	V	A	m/s	m/s	m/s	m/s	
27-31	240	100	14.7	8.5	4.3	3.5	'Free' clash of conductors, estimated contact speed 1.3 m/s
32-36	240	300	18	11	11.5	6	"
37-41	240	500	14	10	11	8	"
42-46	415	500	29	19	16	8	"
48-52	415	300	12	8	6	5	"
53-57	415	100	16	9	6	4	"
70-74	No high-speed films taken.						"
65-69	"	"	"	"	"		'Forced' clash of conductors, estimated contact speed 5.5 to 8.2 m/s

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 225

APPENDIX 5

No F/77/1

Date 12 May 1977

PTW:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Ignition of grass by hot aluminium particles.

REPORT Tests were conducted to determine the sizes and temperatures of aluminium particles which would cause ignition of dried grass. A range of particle sizes from 1.6 to 5.6 mm dia, and a range of temperatures from 700 to 1200°C were used.

In each test, 10 particles of similar size were heated to the required temperature in a "spoon" placed in an electric furnace. The spoon was made of a block of stainless steel drilled out to provide a separate and deep pocket for each (molten) particle. The temperature of the spoon was monitored by a thermocouple embedded in it. A bed of dried grass about 40 mm thick, and lying on a sheet of asbestos board, was prepared, and the hot particles were tipped onto the grass from a height of 80 mm above the grass surface. To simulate the effect of wind, a fan was used to produce an air velocity of 2.75 m/s at the grass surface.

When the particles were tipped onto the grass, one of 3 events occurred -

i the grass burst into flame, or

ii it smouldered, or

iii there was no ignition.

SUBMITTED BY: G E Pleasance		SECT/~~DIV/DEPT~~ Fluid Mechanics	
PHONE: 394			
ACCEPTED BY: P T Waring		SECT Fuels	ON 19/4/77
ACTIVITY NO: 93337			
REMARKS:			

SIGNED P. T. Waring
P T Waring
RESEARCH ENGINEER

The results are shown in Fig 1 with the appropriate symbols for the event observed. Larger and hotter particles were more likely to produce flame.

The equipment used for the tests is limited to a maximum temperature of 1200°C. The possibilities of extending the work to higher temperatures, without a commitment to a major effort, are being investigated.

The grass was obtained by the Commission's Forestry Officer in the form of baled hay and was said to be similar to that which grew in the grassfire areas. Before being tested it was dried in an oven at 105°C to bring its moisture content to below 1%. The aluminium particles were made by cutting aluminium wire of various diameters into very short lengths. After each test they were collected, weighed, and their equivalent spherical diameters calculated.

Further tests were carried out using pieces of warm dry cottonwool 10 mm thick, instead of grass. These tests were begun in an attempt to reproduce results achieved some years ago by CSIRO with carbon particles from tractor exhausts. However, this attempt failed, as the composition of cottonwool has changed in the interim. Nevertheless, the tests with aluminium particles on cottonwool were continued, on the basis that cottonwool is a more reproducible material, from test to test, than is grass. With cottonwool, either it flamed or there was no ignition at all. The results, given in Fig 2, show the effects of particle size and temperature.

The results generally accord with the plausible idea that particles must be both 'hot' and 'large' to cause ignition, hence the tendency for the ignition threshold to asymptote to a minimum temperature for larger particles and to a minimum heat content for smaller particles. The reported temperatures are considerably higher than the threshold of 350-400°C informally quoted by Dr R Vines of CSIRO Division of Building Research from the abovementioned tests but the difference is believed to be consistent with the fact that the carbon particles would have been impregnated with volatile hydrocarbons and actually burning after heating to 400°C.

FIGURE 1.

Effect of temperature & size of aluminium particles on the ignition of DRY GRASS.

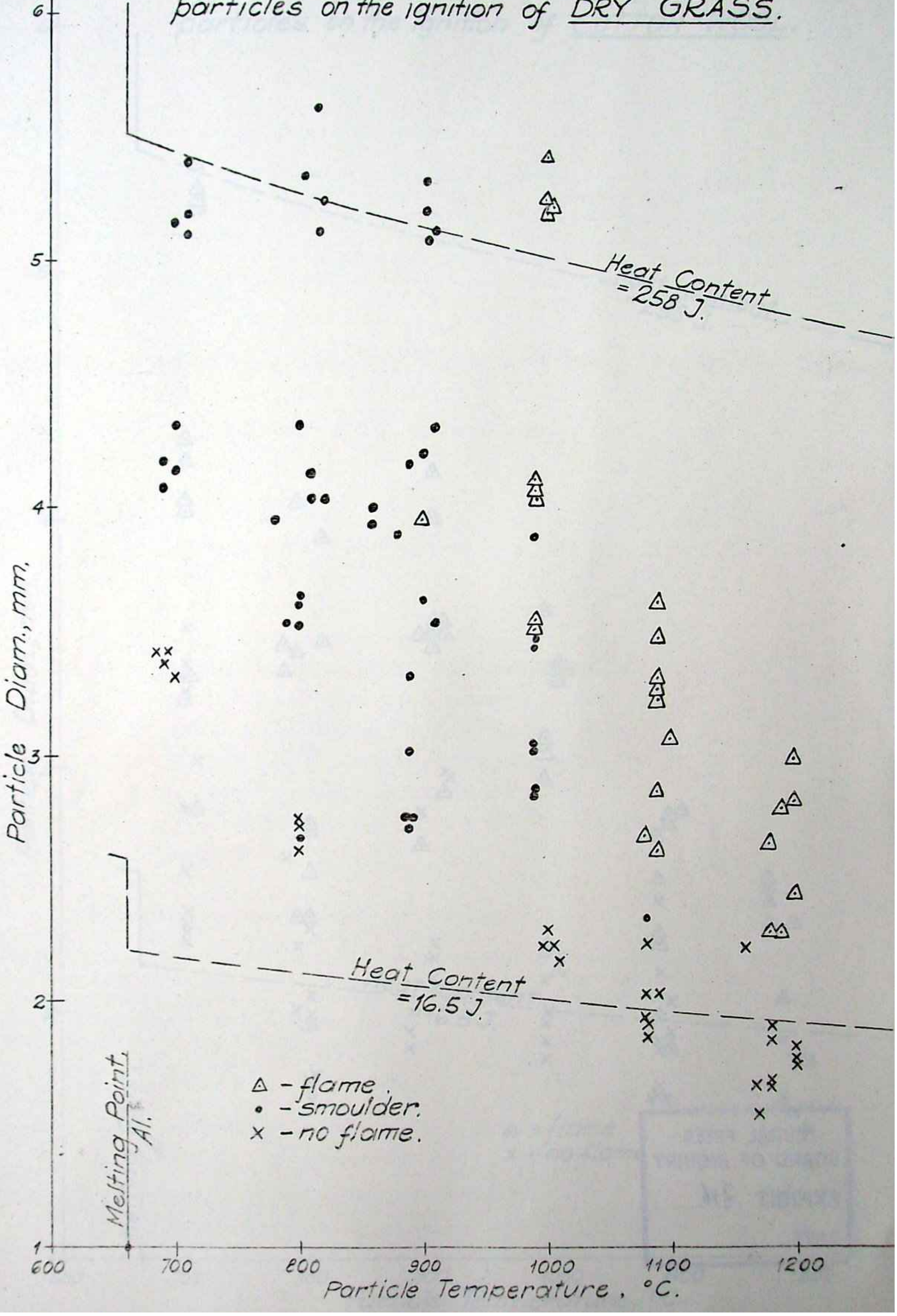
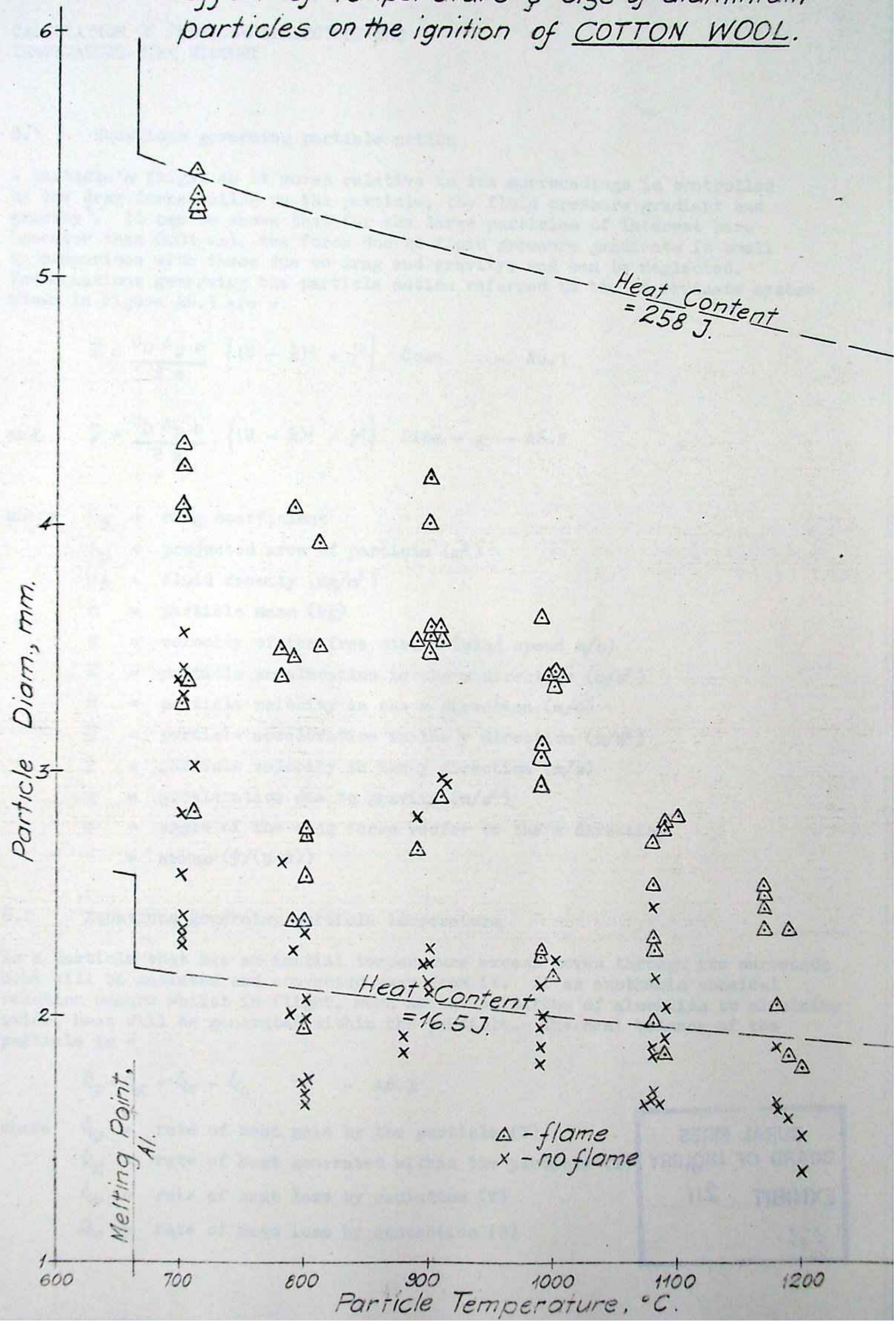


FIGURE 2.

Effect of temperature & size of aluminium particles on the ignition of COTTON WOOL.



The rate of heat loss by radiation[4] is given by -

$$\dot{Q}_r = \sigma \, \varepsilon \, A_s \, T_s^{\,4} \qquad - \text{ A6.4}$$

where σ = Stefan-Boltzmann constant

= 5.81×10^{-8} ($W\ m^{-2}\ K^{-4}$)

ε = particle emmisivity (see Appendix 6.1)

A_s = particle surface area (m^2)

T_s = particle surface temperature (K)

The rate of heat loss by convection[4] is given by -

$$\dot{Q}_c = A_s \, H \, (T_s - T_g) \qquad - \text{ A6.5}$$

where H = heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)

T_g = temperature of surrounds (K)

The rate of heat generation within the particle depends on the mechanism of formation of aluminium oxide, i.e. does the oxide grow on a particle and diffuse inwards or does it wash off the particle and expose further aluminium to direct contact with the air? Because of this complication and the difficulty of finding the rate constants for the reaction rate equation an empirical correlation has been used to determine the heat released by oxidation -

$$\dot{Q}_g = Q_f \, \frac{B \exp(-T_{max}/T)}{E \, M_r + 1} \qquad - \text{ A6.5}$$

where T_{max} = maximum temperature of particle

M_r = the mass of aluminium oxide formed at time t

Q_f = the heat of formation of aluminium oxide

= 16 500 kJ/kg

B&E are constants for a particular particle flight.

The mean temperature of the particle (T) can be considered to be equal to the particle surface temperature T_s provided the Biot number[5] (the ratio of heat transfer away from the particle to the heat transfer within the particle) is less than 0.1. This is the case for both aluminium (≃ 0.002) and aluminium oxide (≃ 0.06). The rate of (mean) temperature change within the particle is then -

$$\frac{dT}{dt} = \frac{\dot{Q}_p}{m \, C_p} \qquad - \text{ A6.6}$$

where C_p = specific heat of the particle ($kJ\ kg^{-1}\ K^{-1}$)

t is the time (s)

The rate of production of aluminium oxide is -

$$\frac{d\,M_o}{dt} = \dot{Q}_g / Q_f \qquad - \text{A6.6}$$

6.3 Solution to the equations

Equations A6.1 to A6.6, when combined with the particle properties and initial conditions, are sufficient to describe the particle motion and its temperature-time history. The differential equations were solved using standard numerical techniques.

6.4 Particle properties

For the purpose of calculations the particles have been assumed to be spherical. The measured diameters of non-spherical particles are never exactly equal to the diameters of spheres with identical aerodynamic properties but the non-sphericity of particles collected from conductor clashes was insufficient to warrant correcting for shape.

The drag coefficient of a sphere can be expressed as[1] -

$$C_d = \frac{24}{R_p}\, 10^{\,L + (L^3 + 1/6)^{\frac{1}{3}}} \qquad - \text{A6.7}$$

where $L = \log_{10} (R_p)^{\frac{1}{2}}/8$

R_p is the particle Reynolds Number.

The heat transfer away from a sphere is found from[6] -

$$N_u = \frac{HD}{K} = 2.0 + 0.6\ R^{\frac{1}{2}}\ P_r^{\frac{1}{3}} \qquad - \text{A6.8}$$

where N_u = Nusselt number

P_r = Prandtl number

D = particle diameter (m)

K = particle thermal conductivity ($W\ m^{-1}\ K^{-1}$)

The constants B and E in equation A6.5 were determined such that a particle ejected from a conductor under similar conditions to the test clashes would reach a maximum temperature equal to that measured in these clashes (nominally 1600°C) and have a specified aluminium as aluminium oxide content (30% or 60% by weight) on solidifying.

6.5 General comments

Throughout the calculations it has been assumed that the formation of aluminium oxide does not alter the character of the particle other than to generate heat on formation. The errors introduced by this assumption are not thought to be significant since the relevant properties of aluminium and aluminium oxide are similar. Accounting for the variation is only a matter of computer program sophistication and could be included, time permitting.

It has been assumed that the wind speed is constant with height. This will overestimate the distance a particle travels since the wind speed increases with height in the earth's boundary layer. However, as both the mean wind speed and the boundary layer profile can vary locally it is sufficient for present purposes to gauge the effect of varying the speed of a uniform wind.

The extent to which aluminium particles oxidise is both considerable and important in determining the temperature history of particles in flight, but fundamental reaction kinetic data are so dependent on the physical circumstances under which oxidation proceeds, and those circumstances are so imperfectly understood from the limited metallurgical evidence available, as to make pointless any attempt to compute the oxidation rate from first principles. Instead, an empirical approach has been constructed on the well-based experimental result that the temperature peaks at about 1600°C, and the extent of oxidation varied numerically to evaluate its effect on the final temperature.

6.6 Typical results of calculations

Figure A6.2 shows the trajectory and temperature history of a 1 mm particle which on leaving the conductor 6 m above the ground in a 20 m/s (47 mph) wind at 35°C has a temperature 10°C above its melting point (660°C) and a vertical velocity of 11 m/s. The constants A and E in equation A6.5 were determined for a similar particle's flight in still air such that a maximum temperature of 1600°C was reached and the final aluminium as aluminium oxide content was 30% by weight on solidification.

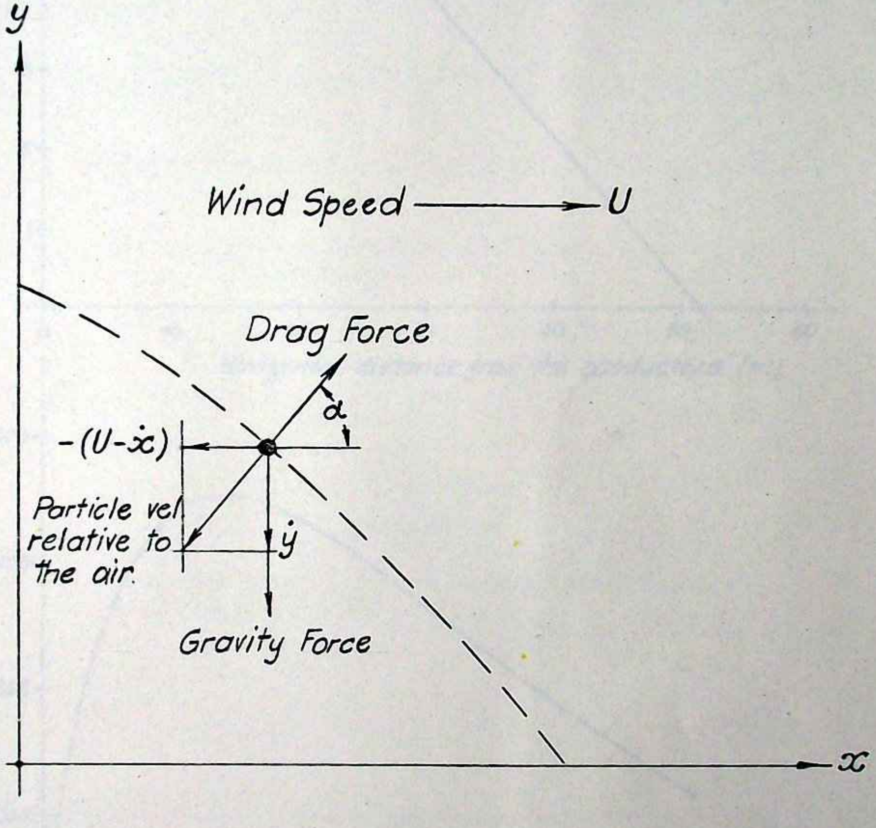

y
Wind Speed U
Drag Force
α
-(U-ẋ)
Particle vel relative to the air.
ẏ
Gravity Force
x

FIGURE A6·1

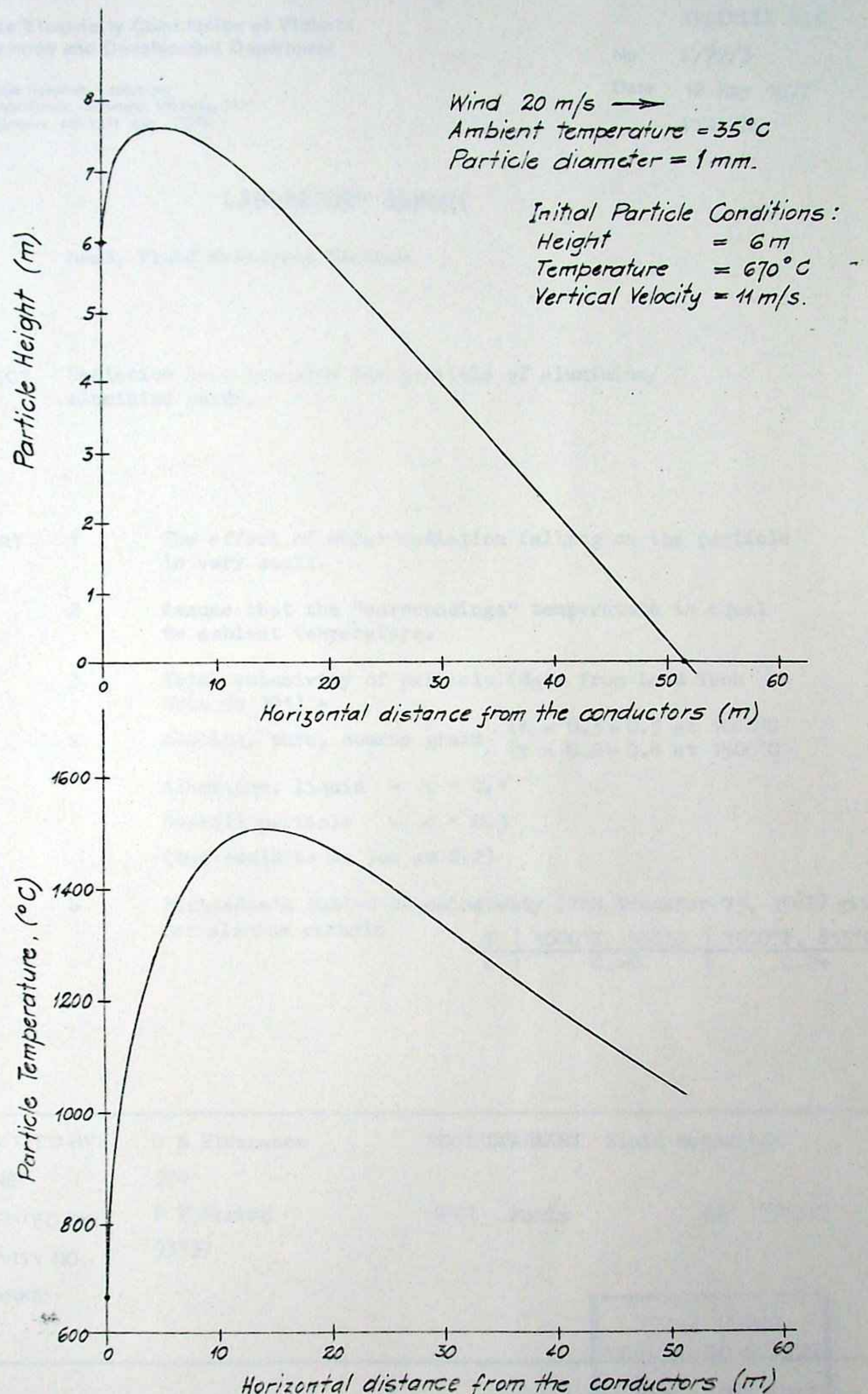


FIGURE A6.2. Typical trajectory & temperature history of an aluminium particle ejected from a conductor clash.

State Electricity Commission of Victoria
Research and Development Department

Herman Research Laboratory
Howard Street, Richmond, Victoria, 3121
Telephone: 429 1511 Ext 225

APPENDIX 6.1

No F/77/3

Date 12 May 1977

PTW:DB

LABORATORY REPORT

TO Head, Fluid Mechanics Section

SUBJECT Radiation heat transfer for particle of aluminium/ aluminium oxide.

REPORT

1 The effect of solar radiation falling on the particle is very small.

2 Assume that the "surroundings" temperature is equal to ambient temperature.

3 Total emissivity of particle (data from Land Tech Note No 101) -

a Alumina, pure, coarse grain (ε = 0.3 - 0.5 at 1000°C
(ε = 0.2 - 0.4 at 1500°C

Aluminium, liquid - $\varepsilon \approx 0.1$

Overall particle - $\varepsilon \approx 0.3$

(but could be as low as 0.2)

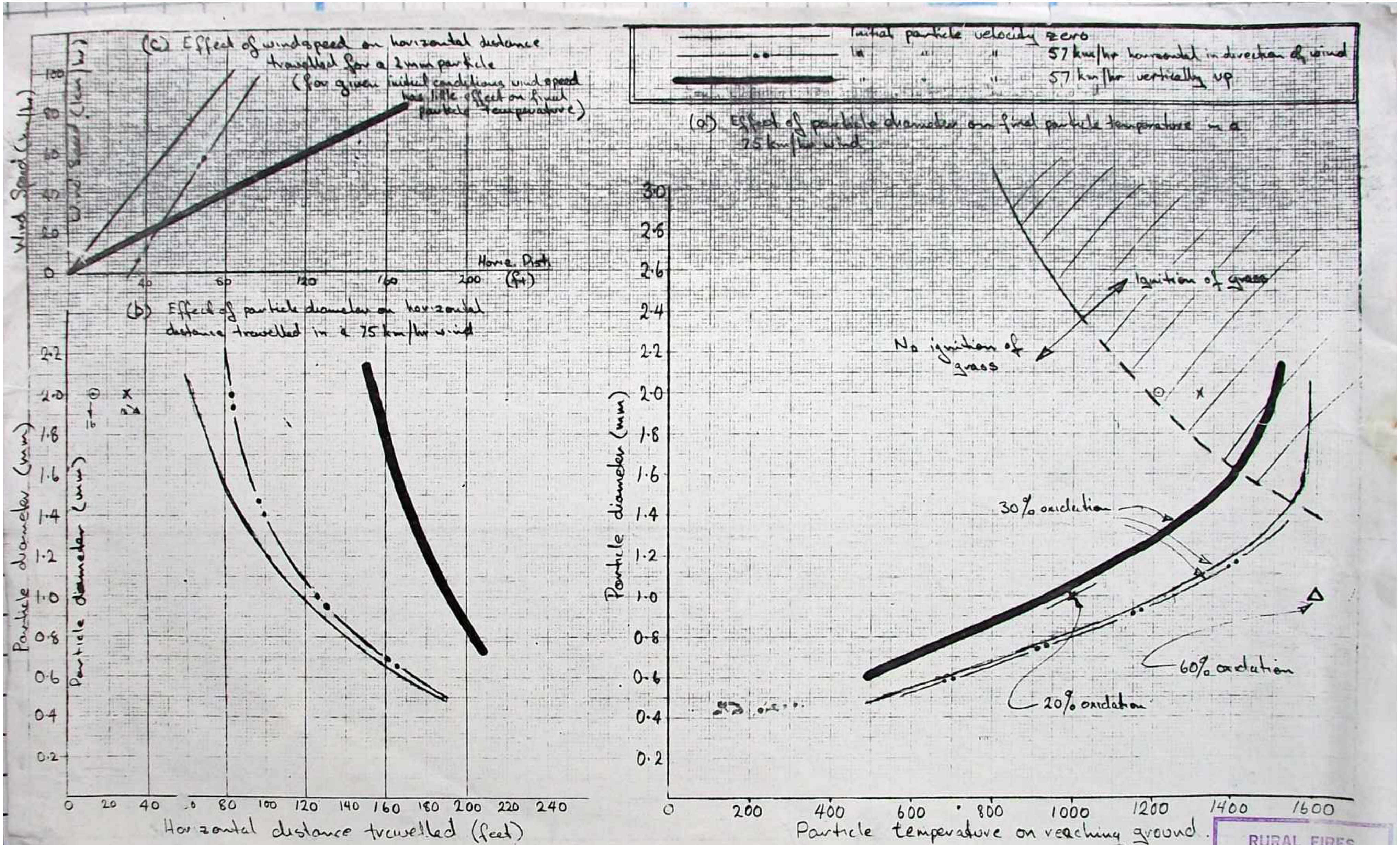
b Fishenden's tables of emissivity (JHM Transfer V5, 1962) give for alumina ceramic

T	1000°F, 538°C	1500°F, 815°C
ε	0.40	0.24

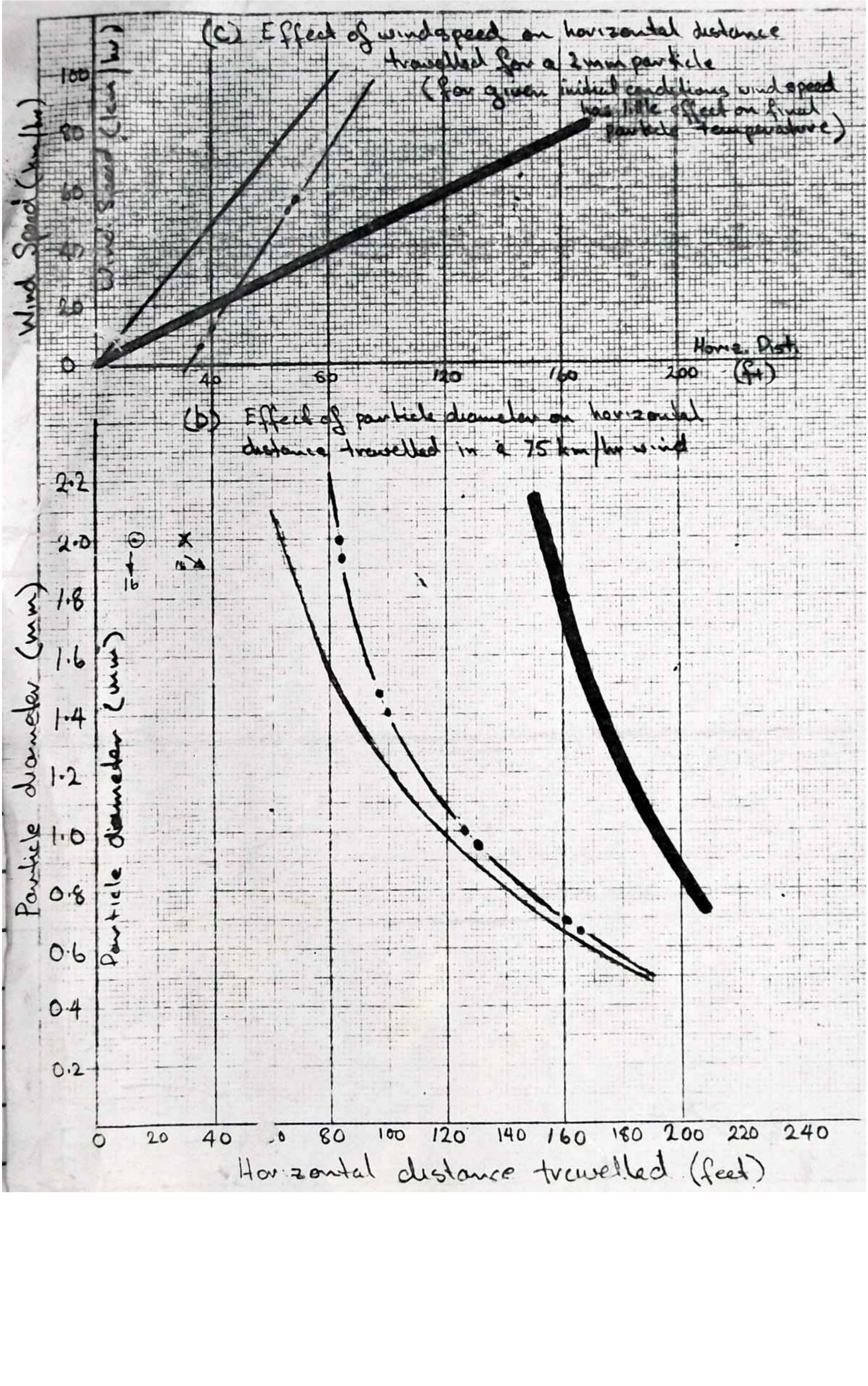
SUBMITTED BY:	G E Pleasance	SECT/DIV/DEPT	Fluid Mechanics
PHONE:	394		
ACCEPTED BY:	P T Waring	SECT Fuels	ON 3/5/77
ACTIVITY NO:	93337		
REMARKS:			

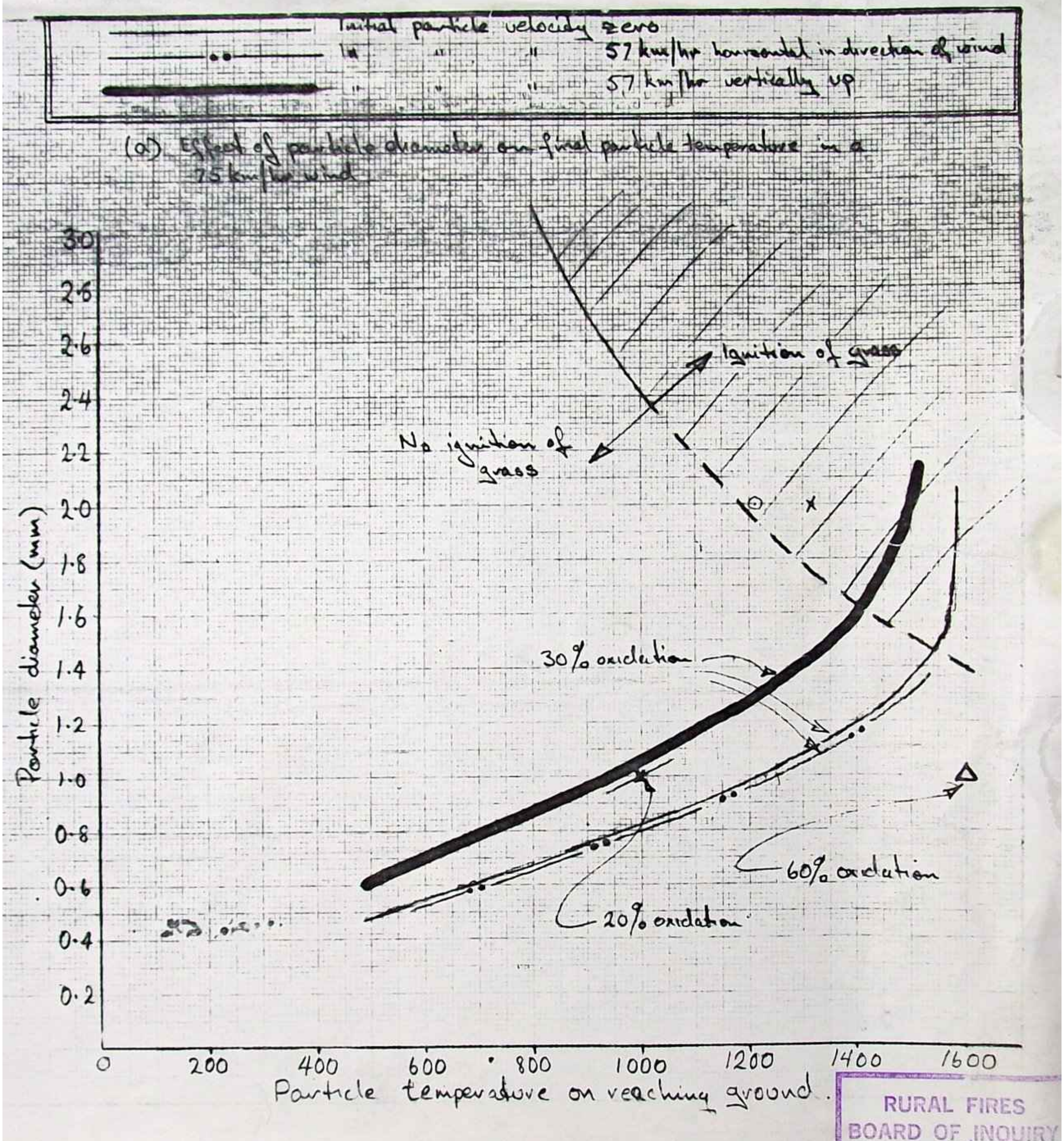
SIGNED P.T. Waring

P T Waring
RESEARCH ENGINEER



Initial particle velocity zero
" " " 57 km/hr horizontal in direction of wind
" " " 57 km/hr vertically up
(c) Effect of windspeed on horizontal distance travelled for a 2mm particle
(for given initial conditions windspeed has little effect on final particle temperature)
Wind Speed (km/hr)
Horiz. Dist. (ft)
(b) Effect of particle diameter on horizontal distance travelled in a 75 km/hr wind
Particle diameter (mm)
Horizontal distance travelled (feet)
(a) Effect of particle diameter on final particle temperature in a 75 km/hr wind
Ignition of grass
No ignition of grass
30% oxidation
60% oxidation
20% oxidation
Particle diameter (mm)
Particle temperature on reaching ground


(c) Effect of windspeed on horizontal distance travelled for a 2mm particle
(for given initial conditions windspeed has little effect on final particle temperature)
Wind Speed (km/hr)
100
80
60
40
20
0
40
80
120
160
200
Horiz. Dist. (ft)
(b) Effect of particle diameter on horizontal distance travelled in a 75 km/hr wind
Particle diameter (mm)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
20
40
80
100
120
140
160
180
200
220
240
Horizontal distance travelled (feet)



Initial particle velocity zero
" " " 57 km/hr horizontal in direction of wind
" " " 57 km/hr vertically up
(a) Effect of particle diameter on final particle temperature in a 75 km/hr wind
Ignition of grass
No ignition of grass
30% oxidation
60% oxidation
20% oxidation
Particle diameter (mm)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
0
200
400
600
800
1000
1200
1400
1600
Particle temperature on reaching ground.