THE EFFECT OF A NEW MANUFACTURING PROCESS ON AN INDUSTRIAL ORGANISATION

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DOCTOR OF PHILOSOPHY

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This research project has been carried out at Serck Heat Transfer, an operating division of Serck Industries Ltd. This division specialises in producing heat exchangers for mobile and stationary engines. It is organised into three semi-autonomous manufacturing divisions and a small central services group. The Advanced Development Department in which I worked is a part of this central group. It is a small department which conducts medium and short-term development projects aimed at improving manufacturing methods and cutting costs.

When I joined the company they were acquiring a licence on a new manufacturing process, and I was given a brief to participate in the development of this process. The programme was to last three years and the objective was to learn the potential and limitations of the process, and to assist in the design of manufacturing plant for several of S.H.T.'s divisions. Unfortunately, the licenced process was discovered to be uneconomic. Luckily a cheaper process had been developed and this process was now adopted. This led to more research being done than was originally planned, and caused delays and some confusion in the rest of the programme.

My research has involved both practical exercises, such as analysing the costs and benefits of the new process, chemical research, environmental tests and market research; and a more general look at the organisation - in particular a comparison of the theory and practice of R & D Management and planning. My conclusions are that the new process has had little direct effect on the organisation, but it has had some effect on the structure of the research and development department. It could have a considerable effect on the organisation in the future, both directly and by influencing changes in its structure.

KEY WORDS : INNOVATION ; RESEARCH AND DEVELOPMENT ; MANAGEMENT

I would like to thank George Keeling and Murray Forbes of Serck, and Dr. Alastair Cochran and Professor Colin Lewis of Aston University, my supervisors, for their help with this project.

The thesis and many of my reports have been most beautifully typed by Doreen Crotty, to whom I am very grateful.

Simon Bennett and Liz Saunders have provided inspiration and encouragement throughout my three years of research.

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*References are also given at the end of each chapter.

CHAPTER ONE

INTRODUCTION.

My research project is based in industry and I have spent half my time with Serck Limited., who have employed me as a management trainee. The remainder of my work has been carried out at Aston University Management Centre. This unusual arrangement has been organised by the Interdisciplinary Higher Degree Department at Aston.

I.H.D.

I.H.D. is a research scheme aimed at training graduates for careers in industry and public service. It involves working on a practical problem within a sponsoring organisation and at Aston University, and takes graduates with science or social science backgrounds. There is a similar 'Total Technology' scheme for engineers and physical scientists. The research leads to a Ph.D or M.Phil and the student spends two or three years as a member of the organisation in which the project is based, between 30% and 70% of this time being spent with the organisation and the rest at the University.

There are many different types of organisations involved in the scheme and so a wide choice of projects is available. The student has considerable influence on the direction the project takes and can select relevant course-work from any University classes. The project is jointly supervised by the University and the organisation.

SERCK LIMITED

My sponsor - Serck, is a broadly based British engineering group providing specialised and related products and services.
It is a major supplier of capital goods and services to such industries as natural gas gathering and distribution, petroleum, chemicals, petrochemicals,

electricity generation and distribution, process engineering, ship building, transportation and water supply.

The group is organised into seven operating units in this country. These are divisions of Serck Industries Ltd., the British holding Company. There are several overseas subsidiaries and associated companies, wholly or partly owned by Serck, and in addition sales offices and agents who cover most of the world.

The company's turnover in 1976 was £68 million, giving a profit of £7.06 million before tax (£3.6 million after tax). Total assets employed were £33.3 million. £31.4 million of the sales were abroad, mainly in Europe. The group employed 5100 people, 4314 of whom were in the U.K. Diagram one shows the British subsidiaries in more detail.

HISTORY.

The founder of the company was Peter Oscar Serck, a Russian born Norwegian, who bought a partnership in the Zimmerman Engineering Co. in Mannheim in 1904. This company first developed and patented the honeycomb radiator. He set up in London in 1905 and moved to Birmingham in 1911. In 1913 the partnership was dissolved and Peter Serck became the owner of the British business.

During the first World War the company was taken over by the Government and became the first national radiator company. At this time a tube mill was added to the factory. After the war the factory was offered back to Peter Serck who formed Serck Radiators Ltd. as a public company in which he held more than half the shares, and was the managing director. By 1922 about 180 people were employed at Serck.

DIAGRAM 1

DIVISION	SERCK AUDCO VALVES (Industrial Valves)	SERCK HEAT TRANSFER (Heat transfer equipment)	SERCK SERVICES (Service exchange pa[illegible] for motor vehicles)	SERCK TUBES (Tubes in non-ferrous metals)	SERCK CONTROLS (Process control systems)	SERCK VISCO (Environmental control equipment and systems)	SERCK WATER PROCESSING (Effluent and water treatment and systems)
Products and Services:	Plug valves; Ball valves; Butterfly valves; Control valves and instrumentation; Power actuators.	Tubular coolers; Air Coolers; Aircraft engine heat exchangers; Small engine coolers; Heavy vehicle radiators.	Replacement and remanufactured parts for vehicles.	Non-ferrous and bi-metallic tubes.	Electronic supervisory systems.	Dust collection equipment; Filtration equipment; Evaporative water cooling equipment.	Effluent and Water treatment plant.
Principal applications:	Oil Industry; Gas Industry; Steel industry; Chemical and Petrochemical industries; Power Stations; Mining; Process Plant.	Ship and aircraft power plant; Locomotives; Small engines; Heavy vehicles; Power Stations; Process Plant.	Motor trade fleet and plant operators.	Power stations; Chemical and Petrochemical industries; Oil Industry; Heat exchangers; General Engineering.	Oil industry; Gas industry; Electricity industry; Water and sewage control; Chemical and Petrochemical industries.	Process plant; Steel industry, Ceramic industry; Manufacturing plant; Non-ferrous metals; Food and Drink.	Oil Industry; Manufacturing industry; Iron & Steel, Glass, Food Non-ferrous metals, Vehicles Chemicals, Pharmaceuticals; Potable water supply; Power Stations.
Sales 1976 (including intra-group sales)	£29.3m	£17.9m	£13.3m	£3.7m	£1.2m	£1.7m	£1.0m
Capital Employed	£14.0m	£7.1m	£4.6m	£1.9m	£0.5m	£0.4m	£0.1m
Employees	1780	1510	1210	290	90	110	50

Between the wars the company continued to concentrate on motor vehicle radiators, but also extended its activities to include equipment for marine diesel engines, rail traction and aircraft. By 1936 the company employed around 900 people and had branches in several parts of the country.

During the Second World War the company was again comandeered by the Government and concentrated on aircraft and marine engine coolers. The London branch made fuel tanks, and vehicle radiators were provided for service vehicles, fire pumps, engines and other essential transport. This war time work established Serck's reputation for quality and reliability.

In the post war years the company continued to expand. In 1955 Audley Engineering Co., a valve manufacturer, was taken over by Serck and became Serck Audco Valves. In 1957, Serck Services and Serck Tubes were formed from Serck Radiators and Serck Ltd. became the parent company of the four divisions. In the 1960's Serck Visco was acquired and Serck Glocon, a specialist valve manufacturer, formed by buying a licence from an American organisation to make the valves used in Blue Streak, combined with some in-house expertise. This division was later merged with Serck Audco. In 1961 a joint venture - Jamesbury Serck Ltd. was undertaken between Serck Ltd. and the Jamesbury Corporation of Massachusetts to make ball valves. Serck bought out Jamesbury in 1967 and renamed the company Serck Jamesbury Ltd. In 1970 this was merged with Serck Audco.

Herman Oscar Serck, Peter's brother, had set up a business in Manchester in 1929 to manufacture and service radiators. This was bought by the company on his retirement in 1964 and became the H.O. Serck division.

In 1968 the last car radiator was made by Serck Radiators and the division was renamed Serck Heat Transfer and H.O. Serck became part of this division. Between 1967 and 1972 there was a Central Research and Development Division, from which there emerged Serck Water Processing, Serck Instruments - later to become Serck Glocon, and a Power hydraulics business which was later sold off. This division came out of Serck Controls, which had itself come from Serck Heat Transfer's research laboratory. By the early 1970's the company had reached its present structure, having expanded its fields of activity considerably within less than twenty years. Since then Serck has adopted a policy of growth of the present business rather than diversification.

SERCK HEAT TRANSFER

I work in the Advanced Development Department of Serck Heat Transfer. This division is organised into product based manufacturing groups which are semi-autonomous, and a central services group. This structure was set up in 1972 and is shown in detail in diagram 2. The division is based in Birmingham except for H.O. Serck, which is in Manchester. Most of Serck Heat Transfer's work is concerned with cooling equipment for engines and they have a strong position in several parts of the British Market (see diagram 2).

The Advanced Development Department was set up in 1972 as a central service. At present it consists of a Manager, three development engineers and two students and uses the engineering laboratory for much of its experimental work. The department conducts medium and short term development projects to enhance the present product range by improving manufacturing methods and cutting costs.

DIAGRAM 2

DIVISION	AIRCRAFT EQUIPMENT DIVISION	AIR COOLING DIVISION	TUBULAR COOLER DIVISION	SMALL ENGINE COOLER DIVISION	H.O. SERCK DIVISION	AFTER SALES DIVISION	CENTRAL SERVICES
Product/Market	Ultra lightweight high performance heat exchangers for aerospace, power generation and marine gas turbine engines	Air cooled heat exchangers for large engines; industrial plant	Shell and tube heat exchangers particularly for marine use and in power generation.	Guided flow oil coolers for diesel engines up to 1000 h.p.	Specialist radiators for diesel and petrol engines	Spares, repairs and servicing of almost any commercial or industrial heat exchanger	Personnel, Accounts Engineering, Quality Control, Marketing, Advanced Development, Management Services, and others.
Position in Market	Near monopoly of fuel cooled oil coolers in U.K. Sales abroad especially to U.S.A. World leaders in aircraft engine cooling market - 25% to 30% share	50% share of large engine market (3000 h.p. +) 25 to 30% of smaller engines. Very strong in charge air coolers.	80% share of large marine cooler market, 30% of smaller coolers.	Very strong in U.K. with some sales abroad	One of the largest specialist radiator manufacturers in U.K. - 20% of market	Recently established - no figures available	
Turnover	£1.1 million	£5.0 million	£5.5 million	£1.75 million	£1.0 million	£0.6 million	
Employees	63	259	237	129	164	53	500
Capital Employed	£0.5 million	£1.5 million	£1.7 million	£0.85 million	£0.5 million	-	

THE PROJECT

When I joined Serck Heat Transfer in September 1975 they were just acquiring a licence on a new method of soldering which was claimed to have a number of advantages over present methods - in particular that of soldering aluminium easily to itself and other metals, which was apparently not previously possible. My project title was "The Impact of a New Manufacturing Process on an Industrial Organisation" and I was given a brief to participate in the development and introduction of the new process.

CHAPTER TWO

THE PROJECT

The project outline given to me by Serck when I started was as follows:

THE COMMERCIAL USE OF A NEW METHOD OF SOLDERING

INTRODUCTION

Serck has entered into an agreement with an overseas organisation for the use of a new method of soldering that brings substantial advantages in the manufacture of some forms of heat exchangers.

For certain of Serck's existing heat exchanger designs it has the prospect of reducing production costs, improving product quality and improving working conditions.

It should also provide the opportunity to use lower cost materials in some heat exchangers. This may require some design changes and, in particular, would require the assessment of suitability and acceptability in the market.

THE PROJECT

To participate in the evolution and carrying through of a strategy for Serck to obtain maximum benefits from the use of the new method. Some of the stages are likely to be:-

- understanding the method and ensuring proper recording of the information transferred from the licensor.

- reviewing the potential for the method over the range of Serck products.

- co-operating in the introduction of the method for the manufacture of existing Serck products, analysing the cost advantages gained, the improvement in working conditions, and the increased market potential due to improved product quality.

- assessing the appropriate ways of extending these benefits to other Serck products.

- assessing the potential for use of cheaper materials.

- encouraging the full use of the capability of the method in the design of new heat exchangers.

- considering the possibility of gaining income by sub-licensing of the process to other companies.

THE 'UNIBOND' PROCESS

I spent the first two weeks at Serck reading the files about the new process,called the 'Unibond' process. I discovered that Serck had first heard of it in March 1972. They had tested the process as set out in the patent, found that it worked and started licence negotiations. The final agreement was signed in October 1975 and the process details delivered shortly afterwards.

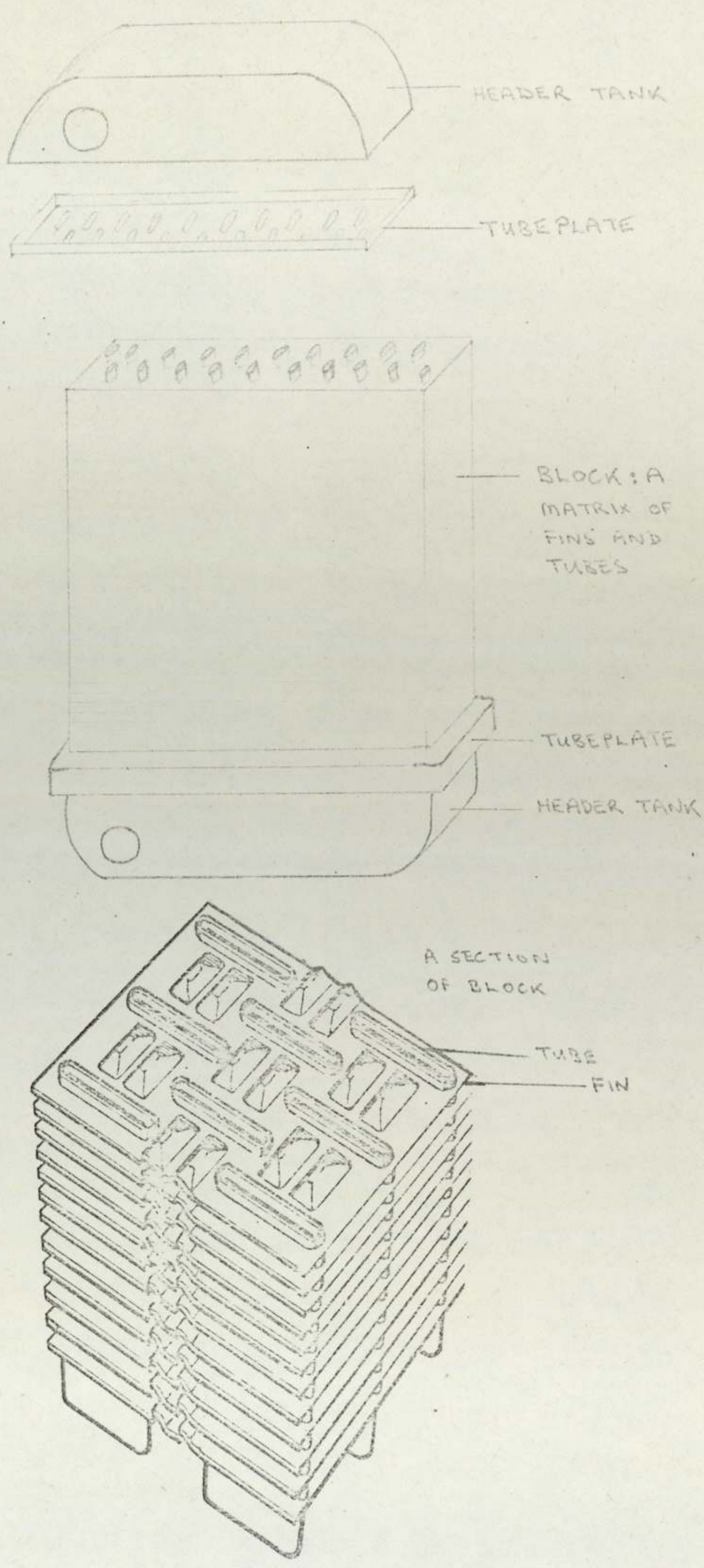
The 'Unibond' process is based on soldering in a hot oil bath and had been used by the licensors to make vehicle radiators and heater cores. The process is similar to conventional methods of making radiators, but offers the advantage of being able to solder aluminium to itself and other metals. It was this ability to bond many types of metal together which led to the trade name 'Unibond' being used.

A typical fin and tube vehicle radiator is shown in diagram three. It is made from a core of flat sided, solder coated brass tubes laced into copper fins, the ends of which are enclosed in two tanks. The hot water flows through the tubes and is cooled by air flowing across the fins. The tubes are soldered to the fins in a hot air oven, and then the tubeplates and tanks soldered on by hand.

The 'Unibond' process is claimed to produce a better quality product than conventional soldering techniques because the soldering temperature remains constant and is easily controllable, also the unit being soldered reaches a uniform temperature very quickly. Using aluminium instead of copper for the fins of a radiator could produce a substantial cost saving without reducing the performance of the unit, depending on the relative prices of the metals. Because the tubes remain brass there are no corrosion problems with the water circuit.

Other current aluminium joining techniques used to make heat exchangers involve the use of expensive plant, highly corrosive fluxes and expensively treated, or "clad" aluminium and do not allow aluminium to be easily bonded to other metals. By comparison the 'Unibond' process uses normal soft solders and the aluminium does not have to be "clad", although a surface treatment is necessary in some cases. The flux is non-corrosive and the joining temperature is lower than in most other processes, so the aluminium is less annealed.

Diagram 3


HEADER TANK
TUBEPLATE
BLOCK: A MATRIX OF FINS AND TUBES
TUBEPLATE
HEADER TANK
A SECTION OF BLOCK
TUBE
FIN

The process appears to have few disadvantages - there is a possible safety problem with the hot oil and fumes. Also some of the recommended solders are more expensive than conventional ones, and the aluminium has to be surface treated if cheaper solders are used. The major problem is likely to be that of electrochemical corrosion of the aluminium caused by the proximity of the other metals. This is a common difficulty with any aluminium heat exchangers.

THE DEVELOPMENT PROGRAMME

A development programme had been drawn up before I joined the company. It had two main objectives. The first was to learn the potential and limitations of the oil bath technique, to assist in the design of manufacturing equipment for several of Serck Heat Transfer's divisions and to investigate other applications of the process. The second objective was to investigate the possibility of substituting aluminium for copper. The development projects are set out in more detail in diagram four.

I was asked to plan and supervise one of the projects - the environmental tests, and to help plan the other projects. I worked out a flow chart for the projects and calculated the critical path and time for each. I compared the flow charts to see if there were any times at which resources would be over-stretched and drew up a chart to help monitor the progress of the projects. The critical path analyses are set out in the appendix

MY PROJECT - STRUCTURING

By the end of my first two months with Serck I had decided that the initial brief needed some modification to make it into a project. I wrote out a set of objectives which were to constitute the first stage of my work. My first aims were to find out as much about making radiators as I could, and to get the environmental test programme

DIAGRAM 4

PROJECT 1. The 'Unibond' Process

(a) Learn by laboratory experiments the potential and limitations of the process.

(b) Assist in the design of manufacturing equipment for the application of the process to radiator manufacture.

(c) Investigate the application of the process to the manufacture of other heat exchangers.

1.1 Standards programme- specify standards for soldered fin and tube and tube to tubeplate joints.

(a) Provide basic data for designs.

(b) Compare results with present products.

(c) Determine the best solder alloys, base metal combinations and coating thickness.

(d) Specify tolerances.

1.2 Help design and install a production facility at H.O. Serck division.

1.3 Develop a system to use the process in the manufacture of guided flow oil coolers in Small Engine Cooler Division. Help design and install a production facility.

1.4 Develop a system to use the process in the manufacture of sectional air coolers and ribbon wound tube in Air Cooling Division. Help design and install a production facility.

PROJECT 2. Substitute aluminium for copper in heat exchangers.

2.1 Environmental test programme - manufacture field trial and laboratory test samples. Conduct a series of corrosion tests in the field and in the laboratory.

running. I was then going to move on to look at other possible uses of the new process. These objectives are shown in diagram five.

My supervisors and I discussed the objectives and decided that in the long term I should look at the marketing opportunities presented by the new process and also monitor and evaluate the introduction of the new process.

I spent three months working on the application of the 'Unibond' process to radiator manufacture and planning the environmental test programme. I then decided to do some market research into customer reactions to the proposed change in product and possible associated changes in price and quality. The aim of this exercise was to draw up a marketing strategy to maximise returns from the new process.

During May and June 1976 a discovery which came from the development programme had a significant impact on the future of the 'Unibond' project and on my project. I started an investigation into soldering and soldering fluxes which continued until early 1977 and became a major part of my project.

By the middle of 1976 I had nearly completed the planning of my project - I wrote a first annual review paper which was discussed by my supervisors and from this I worked out a list of thesis chapter headings.

The final shape of the project is shown in diagram six. My aim in structuring it this way was to take part in as many stages of the development programme as possible without becoming involved in the

DIAGRAM 5

1. IMMEDIATE OBJECTIVES

1.1 Derive simple models of the production process at the Manchester factory using materials, labour and variable overheads as inputs. These will be based on brass tube, copper fin radiators so as to directly compare the present and proposed soldering systems. This will take account of changes in production methods, labour factors and market factors in order to produce a comparison of production costs and an estimate of profits.

1.2 Compare the returns and capital expenditure of the new method to give a guide to the return on investment.

1.3 Assess the model of the new production method in the light of actual results as they are available.

1.4 Supervise a programme of environmental tests. This will provide management experience and help in assessing product quality.

It is hoped that the majority of this work will be completed in 6-9 months although section 1-3 and parts of section 1-4 will not be concluded for 2 years or more.

2. LONG TERM OBJECTIVES

2.1 Explore the possibilities of changing the materials used in radiator production at Manchester.

2.2 Investigate the potential uses of the new method in the manufacture of other Serck products, with particular regard to sectional air coolers and guided flow oil coolers.

2.3 Identify new markets which Serck could profitably enter using the new process.

2.4 Inquire into the prospects of sub-licensing the new process to other companies.

detailed engineering. At the same time I wanted to obtain an over-view of the process of research and development in Serck Heat Transfer and see how this affected the progress of the 'Unibond' programme.

DIAGRAM 6

1. An analysis of the costs and benefits of using the 'Unibond' process to make radiators.

2. A literature search and experiments on soldering and soldering fluxes.

3. Planning and supervising a programme of environmental tests.

4. Market Research.

5. A literature search on research and development management and planning in industry.

6. Find out how Serck Heat Transfer organises its research and development and how this has affected the progress of the 'Unibond' project.

7. Compare the Serck system with the literature models and suggest any ways in which Serck could improve its system.

CHAPTER THREE

COST COMPARISONS

SECTION I: INTRODUCTION

My first objectives were:

(a) to derive a simple model of the production process for radiators at the Manchester factory.

(b) to derive a similar model for the new process

(c) to compare the two models and estimate the savings obtained by using the new process.

To accomplish these objectives it was necessary for me to understand the production process so I spent three days on the factory floor in Manchester being shown round by the foremen. During this time I learned how a radiator was made, and also the details of the costing system used at Manchester.

Production at Manchester is on a jobbing basis, dealing mainly with small orders and producing many variations on basic units to suit customers' requirements. Present sales are mainly to a specialised section of the radiator market - off highway vehicles, cranes, compressors and agricultural equipment. The radiators are all of the fin and lock-seam tube type, at present using copper fins and brass tubes. The copper used in the radiator is one of the major parts of the cost of the unit, and as the market price of copper tends to vary considerably, an allowance for this has been built into the price quoted. The division is planning to greatly increase sales over the next few years and to increase the average size of the units it makes to cater for the more powerful end of the engine market.

SECTION 2: THE PRESENT PROCESS

A flow chart of the present manufacturing process is shown in diagram 1. This is explained in detail below.

Tube Manufacture: 1.3" wide brass strip is automatically solder coated on both sides with 70:30 lead:tin solder, formed into a lock seam tube and cut to length. (See diagram 2). Seam strength and tube length are checked by the operator.

Fin Manufacture: Fins are automatically stamped out and cut to length. They are sorted and stacked by the operator as they come off the machine.

Assembly: The fins are placed in a jig and the tubes laced in, their ends having been dipped in a lubricant. A full length lacing tool is used and no expander is needed. The lacing tool resembles a sword, the blade of which is run inside the tube. An expander is a tip placed on the lacing tool which is sometimes used to widen the holes in the fins.

Checking and Squaring: The block is checked and squared up on a metal base plate.

Flux Dip: Two or three units are dipped in Bakers No.1 Flux at the same time, and the excess allowed to run off. The flux is acidic and removes metal oxides from the solder and surfaces to be soldered. It also helps the solder to flow when molten.

Diagram 1

The Present Manufacturing System

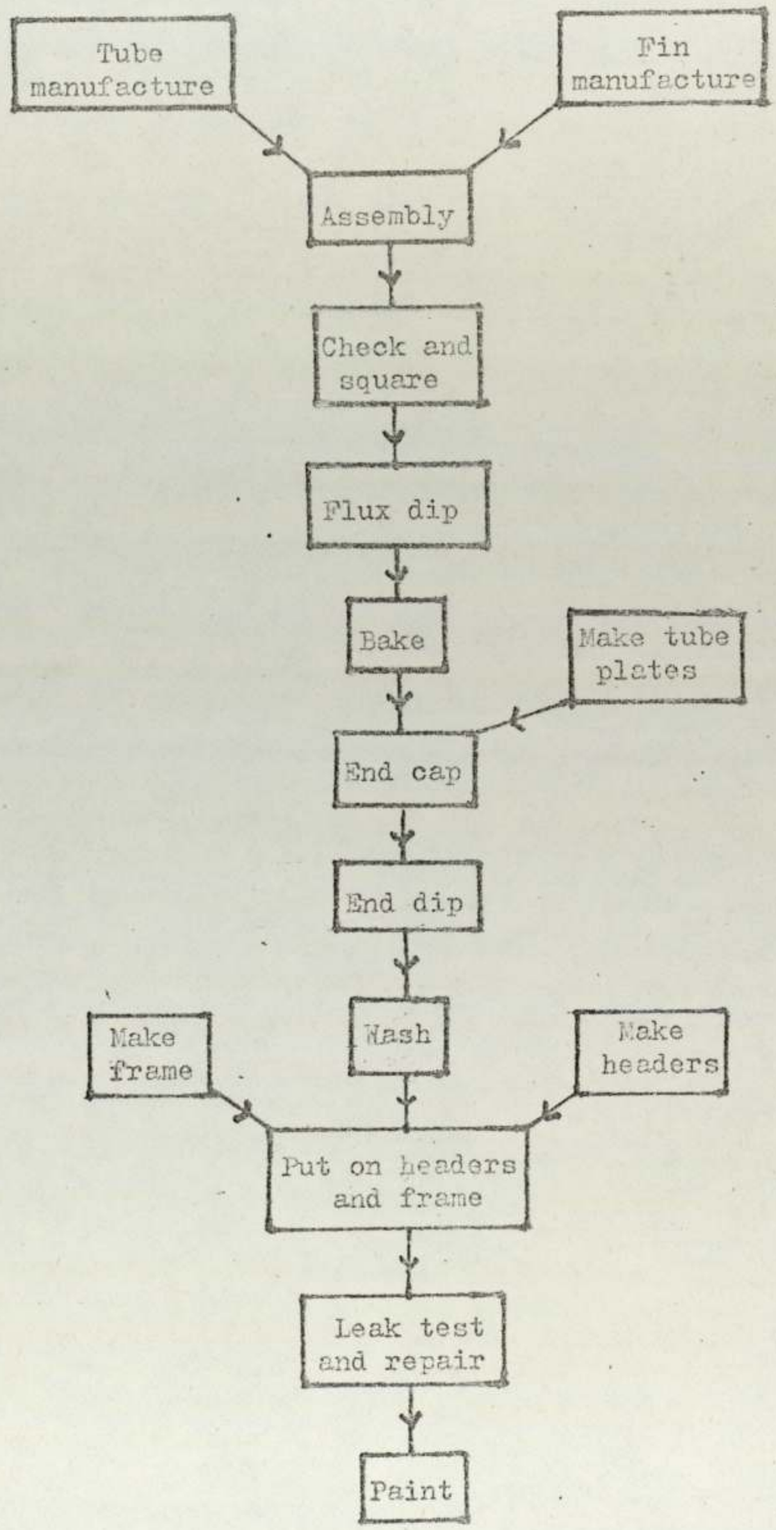
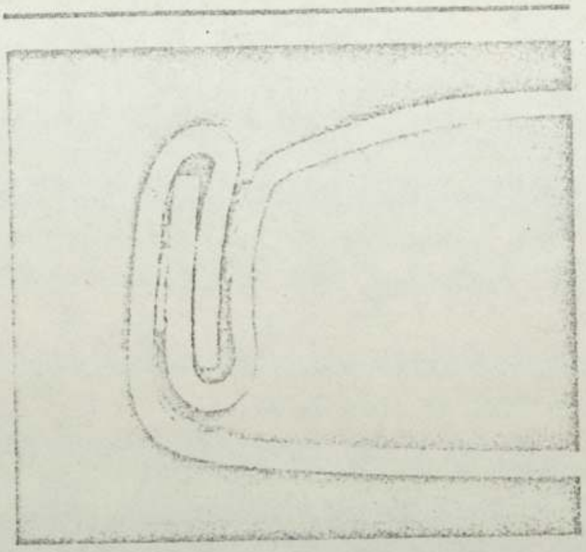
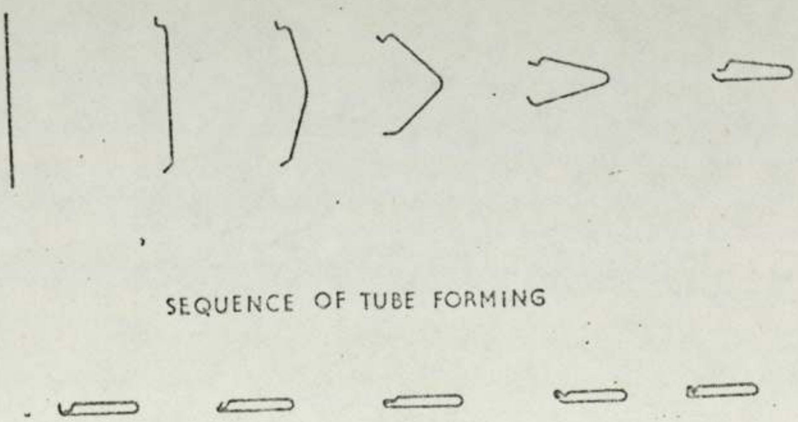


Diagram 2

Lock seam tube





SEQUENCE OF TUBE FORMING

Baking: Units are baked in an oven at about 300°C for between 4 and 12 minutes, depending on their size, in lots of two or three. They are then placed in a press and allowed to cool until the next units are baked.

Tubeplate Manufacture: A standard size plate is cut out of brass strip and holes punched out. The plate is then pressed into shape. It is large enough for an 8 row unit.

End Capping: The two tubeplates are put on and eight small metal strengtheners are put in the corner tube ends on each side. These are cut from brass strip.
The tube ends are then checked and opened out if necessary. The tubeplate positions are checked and then they are hammered into place.

End Dipping: The ends of the unit are flux dipped in a shallow bath, then the units are stood to drain and warm up. The ends are solder dipped in 70:30 lead:tin solder and air is blown through to clear the tubes. The outsides of the tubeplate are wiped clean and the joints inspected visually.

Washing: The units are washed in dilute acid, followed by an air and water jet, and finally dipped in hot water. They are then stood to dry.

Header Manufacture: The headers are stamped out of a cut to size sheet of brass in several operations, and annealed. The sides are squared on a cutter and holes drilled out for the pipes. The pipes are cut to size and assembled by brazing. The components are then cleaned and degreased.

Frame Manufacture: The frame is manufactured from steel components, cut to size and welded together as required.

Fitting Headers and Frame: The header tanks are sprung into place on the tube plate and soldered. Header pipes are soldered in and the frame soldered on all using a fluxless solder.

Leak Testing and Repairing: The completed unit is air pressure tested under water and all leaks repaired. A final check is carried out and any damage repaired.

Painting: The units are spray painted in Radiator Black, and then packed for despatching.

A breakdown of the manufacturing times and costs of an average sized radiator is shown in Table 1. This unit has a block measuring 560 mm by 610 mm. The figures used are all standard accounting data except for solder usage which is an estimate (which I have checked and found to be accurate). The costing system in use is rather crude, based partly on historical data and partly on work study measurements, with a blanket allowance for relaxation and repair time added on. Overheads are allocated on a direct labour hour basis (250% of labour

TABLE 1: TYPICAL TIMES AND DIRECT COSTS OF THE PRESENT MANUFACTURING SYSTEM

The cost analysis is for a series 500 block, and all cost figures are in pounds. Copper parts have been priced with copper at a market price of £450 per ton and brass at £349 per ton. The variation factor, or amount to be added to each radiator for a movement of £10 in the copper price is £.11. Time costs include a 20% relaxation and repair allowance, and the labour rate used is £1.35 per hour. Block solder used on tubes and in end dipping is all entered against end dipping, and is an estimate. Miscellaneous materials used in the final assembly such as filler cap and labels are entered against "Test Radiator".

CORE			TIME TAKEN (mins)	MATERIALS (£)	LABOUR (£)
Tubes	190 at 2 secs. each		6.33	2.261	.1709
Fins	197 at 2 secs. each		6.57	2.1473	.1774
Stack	197 at 5 secs. each		16.42		.4433
Lace	190 at 5 secs. each		15.83		.4274
Comb	1 core at 2.50 mins		2.50		.0675
Bake	1 core at 6.00 mins		6.00		.1620
Plates	2 manuf. at 3.00 mins each		6.00	.6808	.1620
Plates	2 cleaned and fitted at 3.50 mins each		7.00		.1890
Dip	1 core dipped both ends at 4.00 mins		4.00	1.5000	.1080
Wash	1 core at 3.00 mins		3.00	.0144	.0810
		TOTAL:	73.65	6.6035	1.9885
Tanks		TOTAL:	14.25	2.7374	.3848
Frame		TOTAL:	16.00	.5540	.4320
Assembly					
Assemble tanks to core and solder 2 at 10.00 mins each			20	)	.5400
Solder fittings at 5.00 mins			5	) 1.350)	.1350
Solder frame at 6.00 mins			6	)	.1620
Test radiator			6	.7468	.1620
Fit overflow			2	.0284	.0540
Paint radiator			6	.2500	.1620
		TOTAL:	45	2.3752	1.2150
		TOTAL FOR RADIATOR:	148.9	12.27	4.0203

cost). Stock costs are ignored and inter-process stocks allow a considerable amount of slack.

SECTION 3: THE 'UNIBOND' OIL BATH PROCESS

The oil bath process is an improved method of soldering which offers the advantages of being able to solder aluminium to brass, increasing production without increasing the labour employed in soldering, and giving a greater throughput. It also gives a better quality bond between the fins and tubes, thus improving the heat transfer. The price of aluminium is relatively stable, and although its heat transfer characteristics are not as good as those of copper, using a double-thickness of aluminium, and with the improvement in bond quality, aluminium finned units will perform the same duty as the equivalent copper finned units. A further advantage in the use of aluminium is that it is much less dense than copper and so a smaller weight of material is used to produce a radiator.

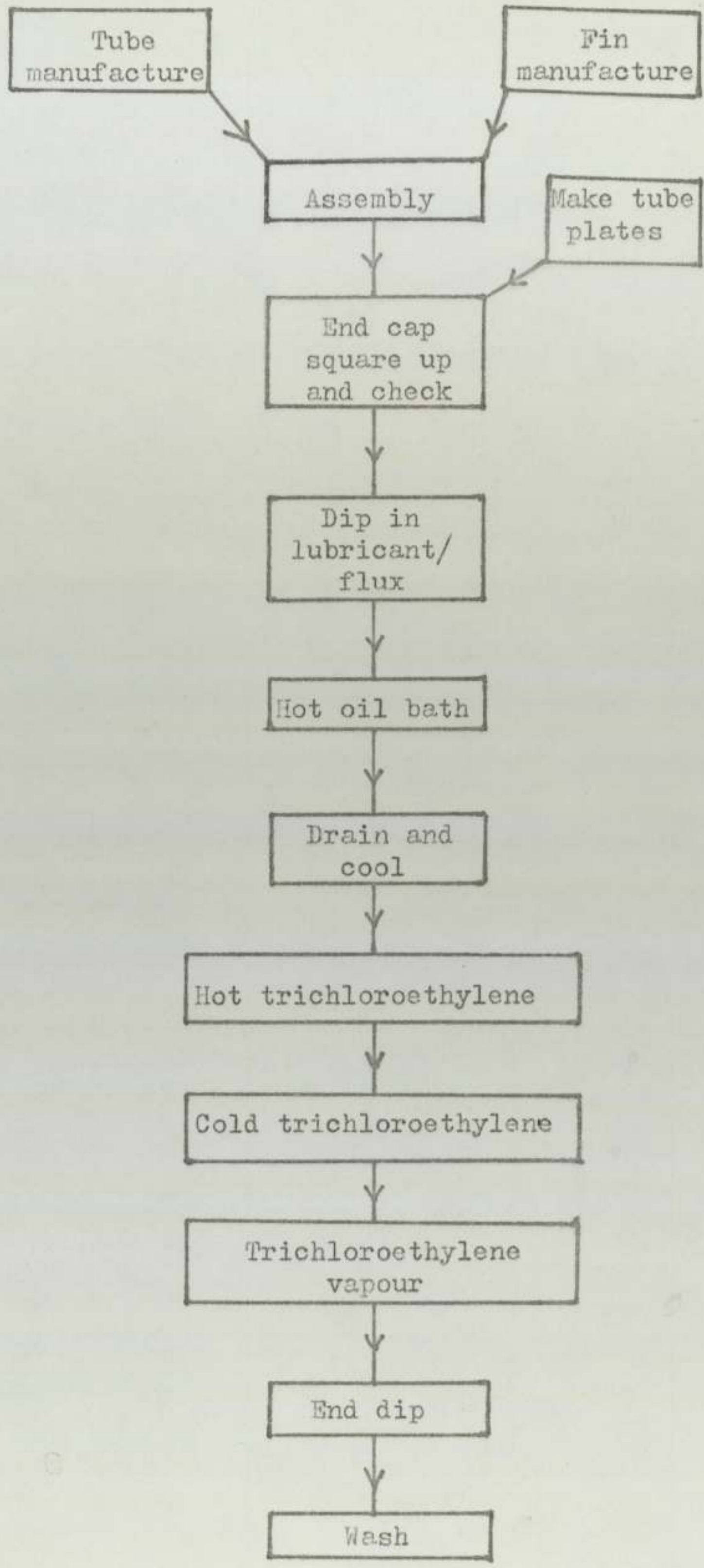
The main difference between the present system and the oil bath is that the oil bath system contains a semi-automated soldering plant. This comprises a hot oil bath, a cooling station, a hot trichlorethylene bath, a cold trichlorethylene bath and a vapour degreasing station.

Units have to be end capped and placed in a jig before soldering, and the fins and tubes may need one of several pretreatments - either applied during manufacture, or to the completed block by dipping. The pre-treatment required depends on the type of solder used and the fin material.

Units remain in the oil bath for about 3 minutes, and the complete soldering cycle takes 32 minutes. The plant will be fed by a conveyor belt and can take a unit every 3 minutes. The oil bath composition requires checking every day. (See diagram 3)

DIAGRAM 3

The Proposed Manufacturing System



Three variants appear likely to be used for fin and tube units, and the details of these and the required pretreatments are discussed below.

Variant	Solder Used	Fin Pretreatment	Lubricant required Tube	Lubricant required Fin
A	30-60% Tin/Lead	D_3Z for Aluminium	DP_{10}	-
B_{10}	60% Tin/Lead	D_3Z	DP_{10a}	DP_{10a}
B_{30}	80% Tin/Zinc	None	M_{25}	M_{25}

D_3Z: The fin coil is pretreated before it enters the stamping machine. This may affect the rate of fin production as there is a limit of 5 meters a minute on this stage. The solution requires a density check twice a day. Treated fin stocks can only be kept for 10 days before use.

DP_{10}: This is a tube lubricant/flux and could be applied to the tube by spraying after it has been formed, before it is cut to length. Alternatively the assembled block can be dipped in DP_{10} solution as there is a danger that the coating could be rubbed off the tube during lacing.

DP_{10a}: This is a fin and tube lubricant/flux and could be applied to fins and tubes before assembly or to a completed block by dipping.

M_{25}: This serves a similar purpose to DP_{10a}, but is much more viscous. It could also be applied before or after block assembly.

Further to these pretreatments, if aluminium fin units are made, some form of corrosion preventing coating may need to be applied to the soldered unit.

There are several further cost saving developments possible with this process. These are:-

(a) One-shot soldering of the block and the tubeplates - this will require a method of preplacing solder on the tubeplates and would eliminate the need for end dipping and washing.

(b) If a one shot technique cannot be developed, then a non-corrosive flux could be used in end dipping - thus eliminating the washing stage.

(c) As a continuation of (a) above it may be possible to simultaneously solder on the tubeplates, header tanks, and inlet/outlet pipes, leading to a considerable saving on labour.

A further modification to this process is discussed in Section 6.

SECTION 4: COST COMPARISONS

In order to compare costs I chose to study three sizes of unit; a small one, a medium one and a large one (Series 200, 500 and 700). These sizes of unit account for about 50% of present sales (15%, 30% and 5% resp.) with the medium sized unit representing an average of the present output mix. For each of these sizes of unit chosen the costs of each variant were compared and also an overall comparison of returns and capital expenditure was made.

The metal prices used were extrapolated from a comparison of the London Metal Exchange annual average prices with the Index of Basic Materials and Fuels Purchased by Manufacturing Industry , issued by the Department of Industry. (See appendix). The other assumptions made in comparing costs are:

(a) The quality of the bond between fin and tubes is as good with the new process as the old, and unaffected by the type of solder used.

(b) Solder use, chemical use and power use have been estimated.

(c) Overheads have been ignored as has the possibility of a reduction in repair time due to improved bond quality, and any changes in stock costs.

The savings achievable by using the oil bath process are in:

(a) Substituting aluminium fins for copper fins

(b) Using a semi-automated plant and thus saving labour.

The costs are:

(a) Either extra solder costs because more expensive solders are used or if standard production solders are used it is necessary to pretreat the fins.

(b) The cost of chemical fluxes.

(c) The extra cost of power.

The savings are dependant on the relative prices of metals and on the level of output. Flux and power costs are relatively minor factors except for Variant B_{30} where the flux cost is relatively high. The detailed calculations (see appendix) show that using the oil bath process to make copper finned units would save 3% or less of the total material and labour cost of a conventional product. The use of aluminium in the radiator gives rather better results - savings of between 2 and 15% for Variant A, ½% to 12% for Variant B_{10} and -1% to 11% for Variant B_{30}, depending on the price of copper. (See graphs 1 to 4).

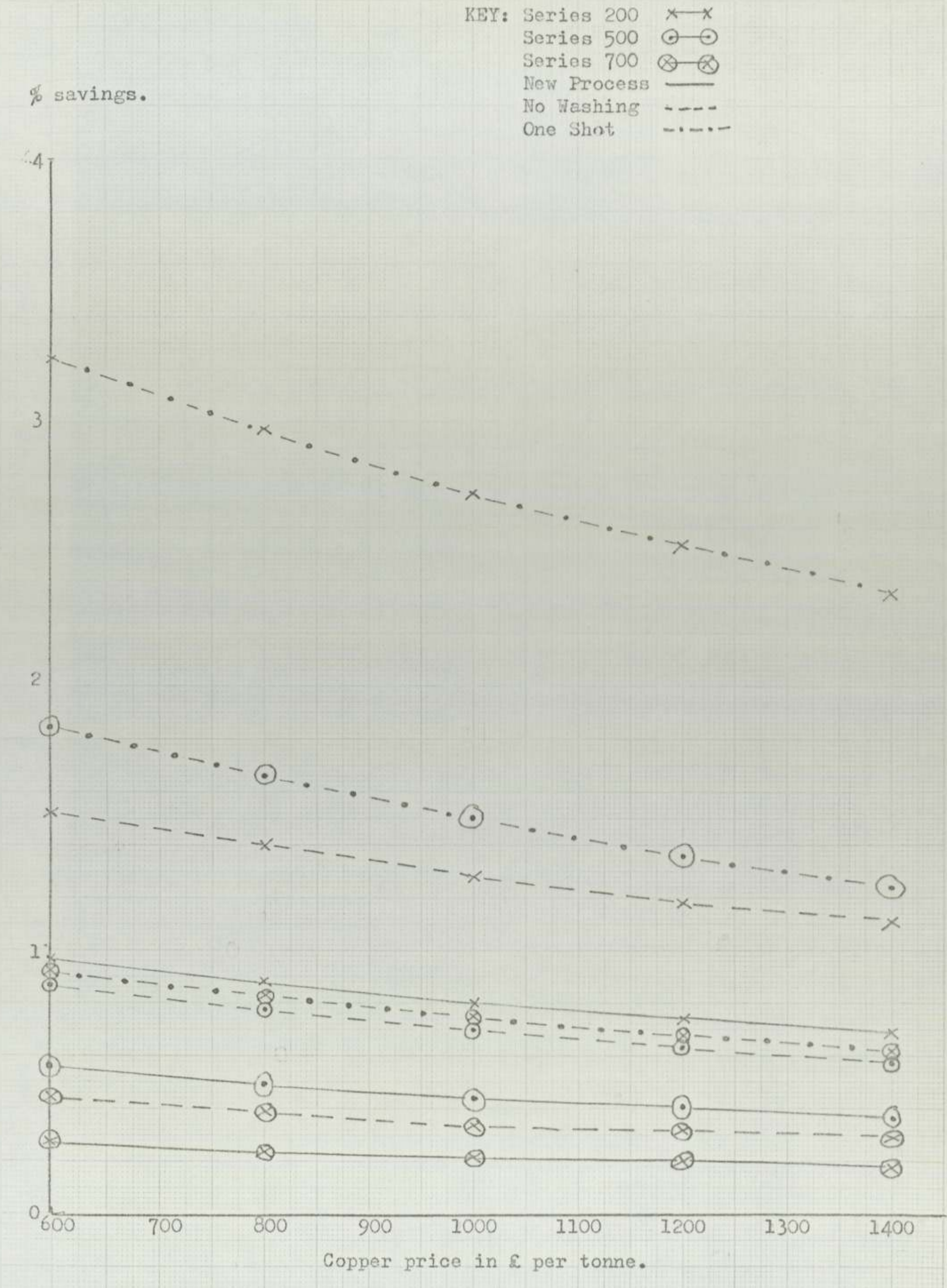
These results were based on the following metal prices (in £ per tonne):

Aluminium	£600
Tin	£4,000
Zinc	£425
Lead	£310

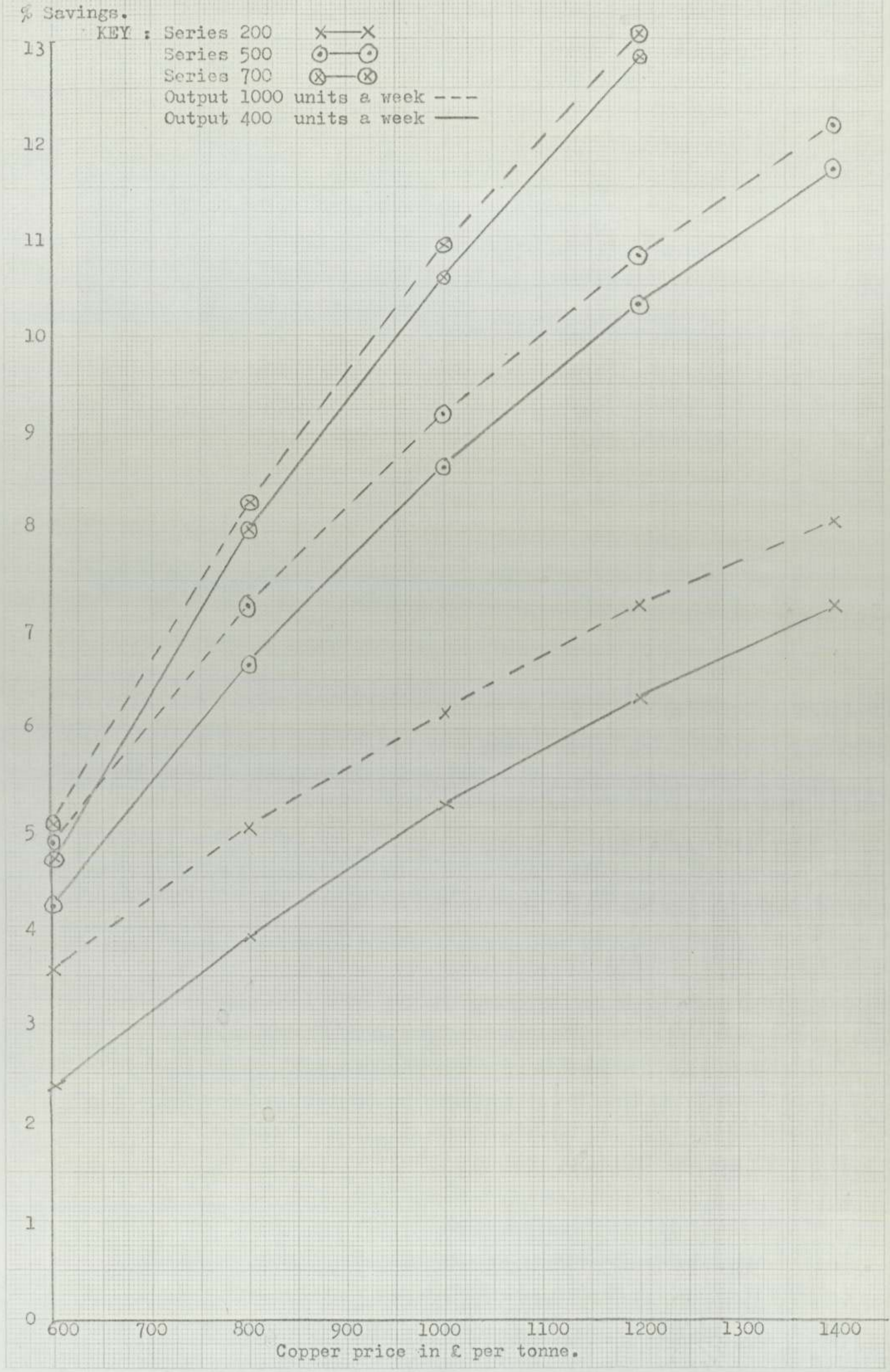
Subsequently the price of tin has risen sharply to £6,000 and the price of zinc fallen to £320. These changes will decrease the savings of variants B_{10} and B_{30} by about 2%. An increase in the price of Aluminium by £100 would decrease the savings of all variants by between ½ and 1%. Being able to solder the block and tubeplates simultaneously would add 2% to the savings of Series 200 units, 1% to series 500 units and ½% to Series 700 units.

GRAPH 1.

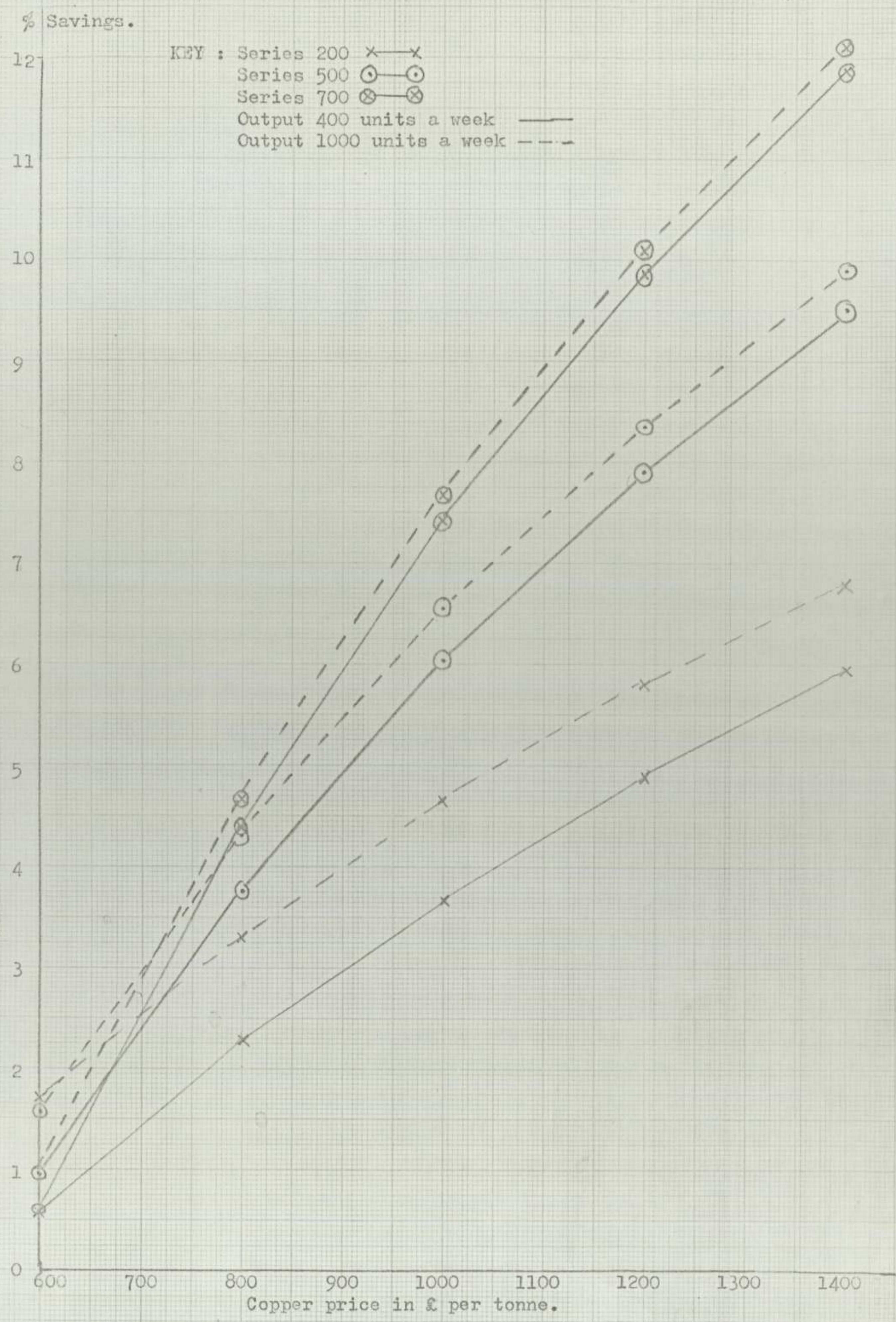
The % savings acheived by using the oil-bath process with copper finned units



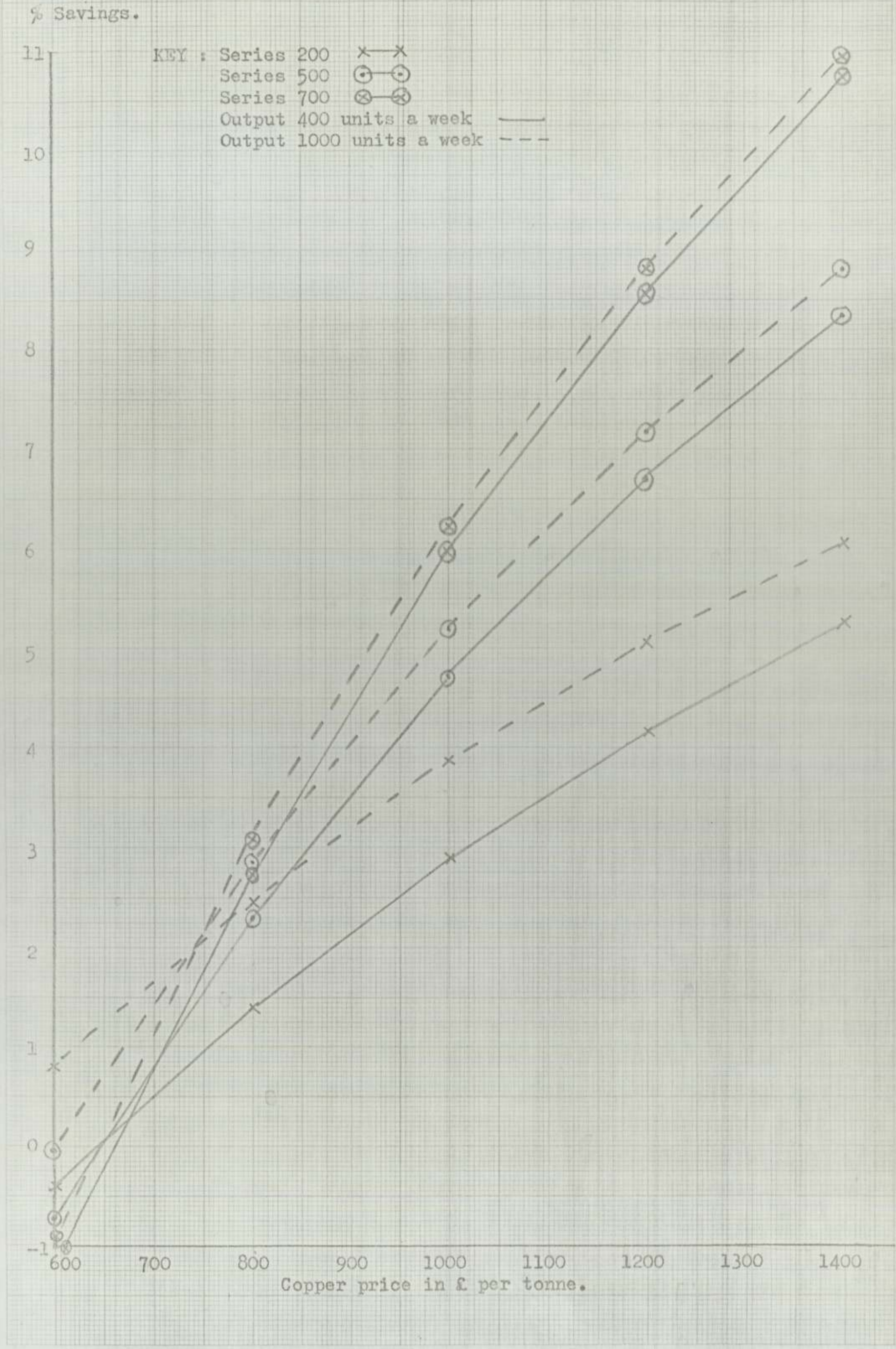
Graph 2 % Savings versus the price of copper - Variant A.



Graph 3 : % Savings versus the price of copper - Variant B_{10}



Graph 4 % Savings versus the price of copper - Variant B_{30}



SECTION 5: DISCOUNTED CASH FLOW ANALYSIS

In this section the rate of return on investment in the oil bath process is investigated. It is assumed that a series 500 unit can be used as a representative unit - which is at present reasonable.

The capital cost of installing the oil bath process in Manchester is estimated to be £180,000, made up as follows:

Nominal cost of plant including installation, commissioning and training	£100,000
⅓ of royalties	44,000
⅓ of Know-how	6,000
Development costs	20,000
Materials	10,000
	£180,000

Three possible output growth patterns are considered over a 10 year period:

(a) S shaped growth curve - see graph 5

(b) 15% a year growth

(c) 5% a year growth

For all of these it is assumed that the proportion of output made with aluminium fins will follow an S shaped growth similar to that of output pattern (a) - see graph 5.

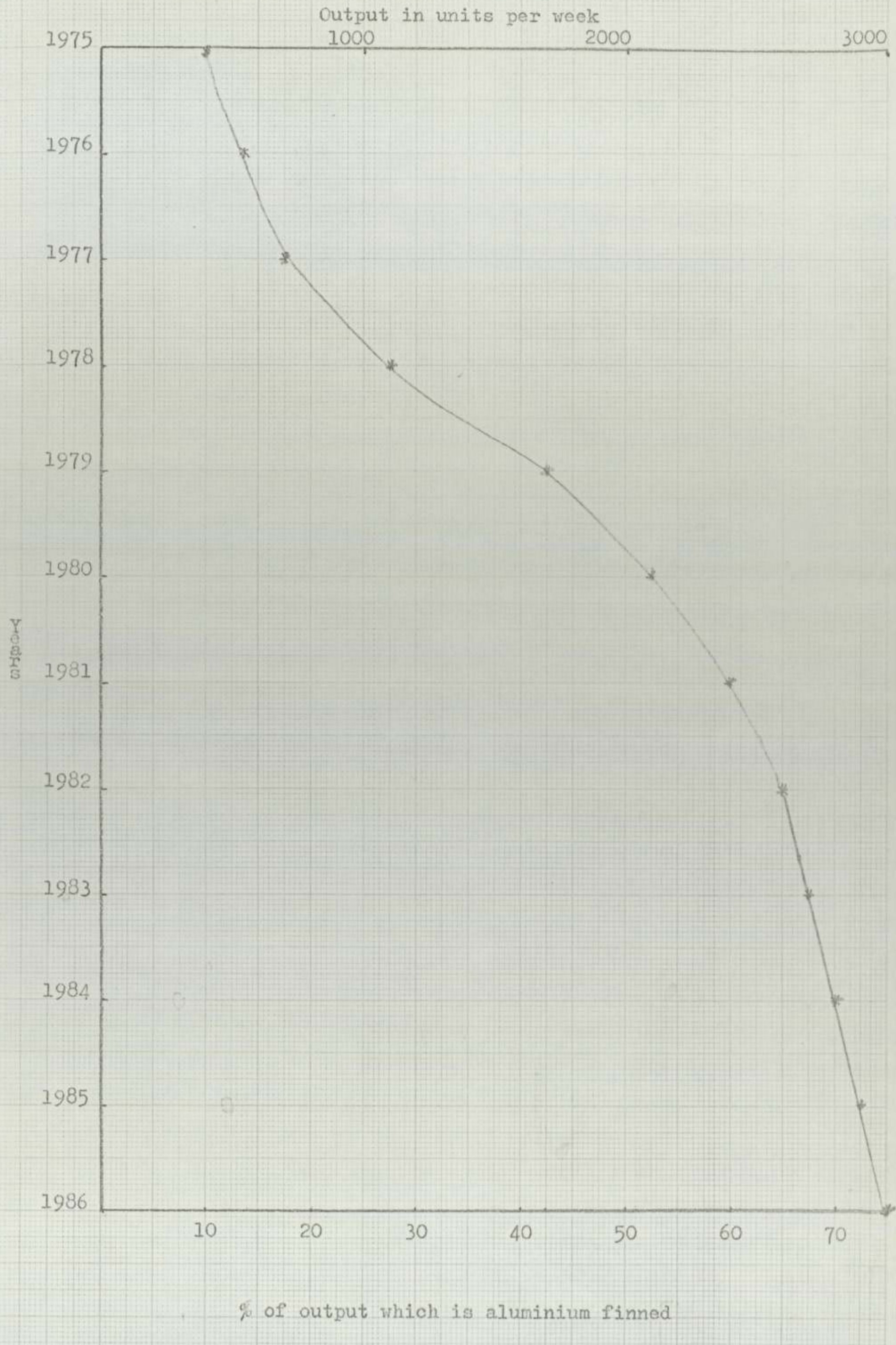
The resulting figures for output are shown in the appendix.

Also it is assumed that:

(a) 50% of the cost savings realised by using the oil bath process to manufacture aluminium finned units is given

GRAPH 5

S shaped growth curve for output
and proportion of aluminium finned units



to the customer as a reduction in price, thus realising approximately half of the true rate of return.

(b) Tax is not taken into account, and inflation is assumed to affect costs and benefits equally.

(c) The project is assessed over 10 years.

The analysis is in two sections:

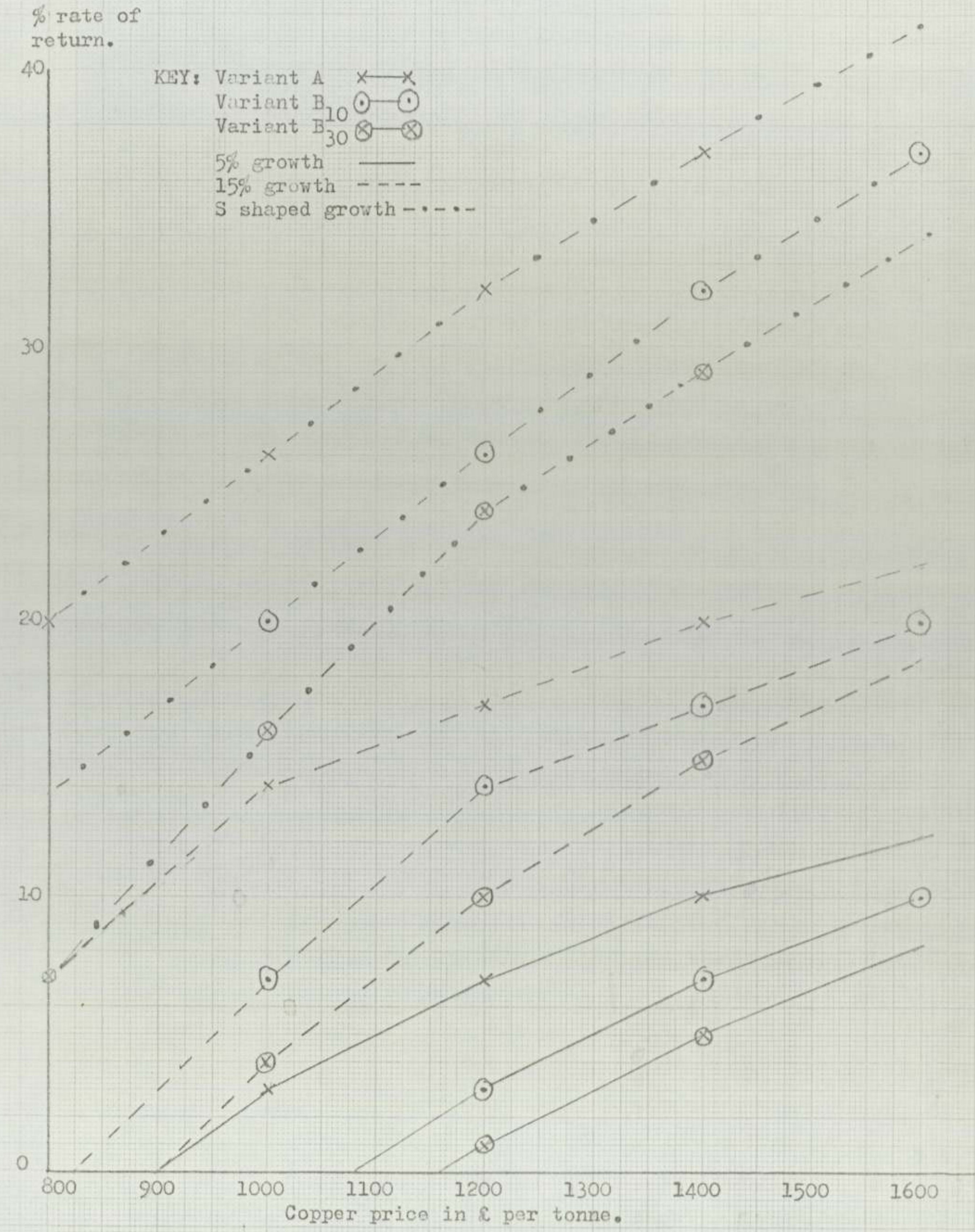
(a) The three variants are compared and the effect of copper price and output assessed - see graph 6. Detailed figures are given in the appendix.

(b) The results of saving labour by eliminating washing and by tube to tubeplate bonding are calculated.

(i) If a non-corrosive flux is used in end dipping and the aluminium units do not require washing then about ½% is added to the rate of return.

(ii) If a one-shot tube to tubeplate bond is possible then about 1% is added to the rate of return.

Graph 6 : Discounted cash flow rates of return - oil bath plant.



SECTION 6: BAKING USING 'UNIBOND'

During April and May 1976 a discovery arising out of the development programme had significant repercussions on the 'Unibond' project and the cost comparisons. It was found that the 'Unibond' fluxes and solders could be used to solder aluminium in an ordinary baking oven. The semi-automated oil bath plant could be replaced by a semi-automated baking oven and trichlorethylene washing tank, making the process simpler and cutting the capital costs.

The development affects the costs in three areas:

(a) There will be no power costs

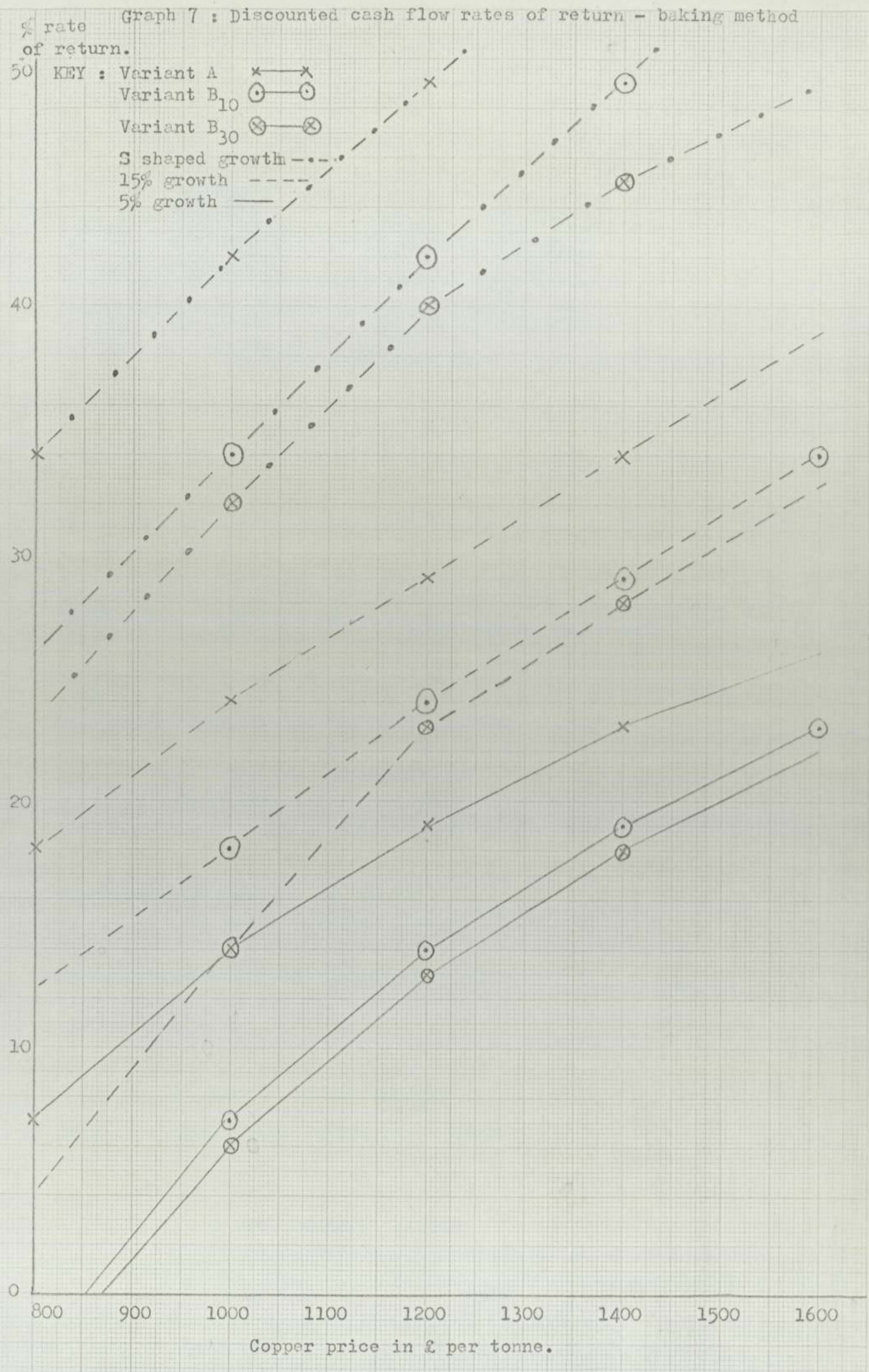
(b) Only M_{25} can be used as a flux, and less is used than for the oil bath process.

(c) The plant cost and hence the capital cost change.

The savings achieved using variant A increase by about .2%, for variant B_{10} by about .1% and for variant B_{30} by about .7%. For details of these see the appendix.

The rates of return of this process have been assessed in a similar way to those of the oil bath process. The only change is that the plant cost is about £20,000 and so the total capital cost is £100,000. The rate of return given is again about $\frac{1}{2}$ of the true rate because 50% of the savings are assumed to be given to the customer as a price reduction.

(a) Comparison of variants and output growth rates - see graph 7. Detailed figures are given in the appendix.


Graph 7 : Discounted cash flow rates of return - baking method
% rate of return.
KEY : Variant A
Variant B_{10}
Variant B_{30}
S shaped growth
15% growth
5% growth
0
10
20
30
40
50
800
900
1000
1100
1200
1300
1400
1500
1600
Copper price in £ per tonne.

(b) If a new plant is not installed and hence no labour saving is made on soldering, assuming a 15% growth pattern the increase in the rate of return is 4 to 5% over those given above. It would be advisable to install new plant if output is expected to rise substantially above 1000 units a week.

SECTION 7: SUMMARY OF RESULTS

The conclusions at this stage were that the economic success of the 'Unibond' process depended mainly on five factors. These are:

(a) At least one of the variants must be demonstrated to be satisfactory.

(b) Modifications of the process to increase the return, e.g. the baking method, tube to tubeplate bonding, solder saving.

(c) The level of output achieved at Manchester and the proportion of output with aluminium fins.

(d) The relative prices of copper and aluminium over the next few years.

(e) Which variants are best at resisting corrosion.

Variants A and B_{10} are the cheapest but may not be as good at resisting corrosion as variant B_{30}.

The oil bath plant is expensive and therefore provides a relatively low return on capital unless the price of copper becomes high for some years. The baking method appears to be attractive, providing a fair return for a low copper price whatever the variant chosen.

It is important that some research is carried out into the areas of tube to tubeplate bonding, solder economy and corrosion proofing. In view of the effect of output on rate of return it would be useful if some market research were carried out on customers' reactions to the proposed change in product and any associated changes in price and quality.

SECTION 8: FURTHER DEVELOPMENTS

The baking process was developed as the main process because of its more attractive financial outcome, and the development programme concentrated on cost cutting by using cheaper solders, which at the same time would resist corrosion better than the original variants. This led to the use of higher zinc content zinc:tin solders.

In May 1977 the costings were updated and extended so that the progress and potential of the whole project could be judged. The total costs were estimated to be £248,800 including royalties, all being incurred in the first three years. The benefits received were estimated to be between £44,000 and £250,000 a year. A summarised cash flow of a likely estimate of the benefits is given below:

YEAR	OUT (Cumul.)	IN (Cumul.)	BALANCE
1 (1975/6)	25,600	-	(25,600)
3	248,800	23,000	(225,800)
5	248,800	218,000	(30,800)
7	248,800	428,000	179,200
10	248,800	743,000	494,200
15	248,800	1,268,000	1,019,200

These benefits included some licence income, using the process to make guided flow oil coolers and to make Manchester's oil cooler.

Later in 1977 the figures for radiators and oil coolers were updated and the savings presented in graph form - see appendix. As can be seen from these updated figures, with copper at its present price of between £600 and £700 per tonne, heat exchangers with aluminium fins are not commercially attractive unless the cheaper high zinc solders can be used. If copper increases to £1400 or more then the savings are considerable.

At the present stage of development the benefits provided by the project are mainly from spin-off; Labour saving at Manchester through using a quick-bake oven and non-corrosive flux, labour saving at Small Engine Cooler Division for the same reason, and solder saving at S.E.C.D. because of using a baking process instead of a dipping process. The total value of these savings is £44000 p.a. - the minimum figure mentioned above.

SECTION 9: CONCLUSIONS

This proved to be an interesting and useful introduction to the 'Unibond' project. It gave me an insight into the production techniques involved in radiator and oil cooler manufacture and into the new process. The exercise highlighted the need to look for cheaper plant and solders than those used in the original process, and also showed the dependence of the return on the relative prices of copper and aluminium, and the market acceptance of the new product, leading to some market research later in the project.

The impact of the new process appears to be potentially greater for oil coolers than for radiators, and the main benefits to the company so far have been labour and solder savings because of the use of semi-automated plant and non-corrosive fluxes. The use of aluminium is not likely unless the price of copper rises to above £1400 per tonne.

The exercise also pointed out the necessity of corrosion testing and process development to discover a cheap and corrosion resistant solder. The corrosion testing is considered later in the thesis, and the process development in the next chapter.

CHAPTER FOUR

SOLDERING AND FLUXES.

SECTION 1: INTRODUCTION

The 'Unibond' process originally consisted of a hot oil soldering plant and several combinations of flux and solder which could be used for different types of product. Its main advantage was that it could solder aluminium easily to other metals, using non-corrosive fluxes. This was not thought to be possible using normal soldering techniques.

It was discovered at an early stage in the development programme that it was possible to use the recommended fluxes and solders to solder aluminium in an ordinary baking oven. This was a major breakthrough, saving a considerable capital cost, and led to the present Serck 'Unibond' process.

The solders and fluxes were now seen to be the key element in the success or failure of soldering. I therefore decided to do some research to see if the original fluxes were the only useful ones, and also to learn as much about soldering, and in particular about aluminium soldering, as I could. This exercise started in May 1976 and the first stage was completed by November.

This included a search of all the relevant books and articles I could find, and an investigation of a wide range of potential fluxes. By the end of this research one group of organic chemicals - the monocarboxylic acids, seemed to be the most promising for use as a flux.

It was decided that Serck would apply for a patent to cover this process.

The second stage of my research concentrated on finding the information for this patent. I followed up the initial literature survey by looking at past patents on soldering and some older books on the subject. The experimental work was also extended to obtain more information about the behaviour of monocarboxylic acid fluxes and to investigate the range of solder alloys and types of metal which the process could use. This work led to a provisional specification being lodged in April 1977 and I was credited as being one of three co-inventors.

Some further experimental work on fluxes was conducted in mid 1977 as a result of a patent published earlier that year. This work concerned an investigation of mixtures of natural oils, fats and waxes containing monocarboxylic acids to see if a flux with a high thermal stability could be developed, as suggested in the patent.

SECTION 2: SOLDERING THEORY

2. (a) The Action of Fluxes

A flux is a chemical which removes oxide and other impurities from the surface of the base metal and the solder so that the solder is free to flow over the metal and bond to it.

The flux must displace the layer of adsorbed gas on the metal surfaces and then remove the oxide film by chemical action. The solder can now wet the metal. The flux will promote wetting by influencing the balance of surface energies - lowering the surface tension of the molten solder. Its action is akin to that of a catalyst in promoting the reaction between the solder and base metal.

There is a number of factors which determine whether a chemical will act as a good flux.

(i) Chemical Activity

All the oxide layer and other tarnishes have to be removed before soldering. This is usually done chemically by the flux. This involves the formation of an oxide compound which is soluble in the flux, or the reduction of the oxide to the original metal.

(ii) Thermal Stability

After a chemical reaction, the flux must provide a protective coating over the clean metal to prevent reoxidation. Thus the flux must not evaporate or break down too quickly at the soldering temperature. If the flux is capable of this it can be held in a volatile carrier. If not, it is necessary to use an inert carrier to provide the coating and to aid wetting.

(iii) Activation and Deactivation temperatures

(a) Activation: The flux will become sufficiently active to remove the oxide film at a certain temperature. This must be below the soldering temperature.

(b) Deactivation: This is the temperature at which the flux decomposes, or is no longer active. If this is lower than the soldering temperature then a longer dwell time at lower temperatures is required so that the flux can remove the oxide layer. It is then necessary that either the flux or its carrier retain their surface activity at the soldering temperature.

(iv) Wetting Power

The flux must wet both metal and solder surfaces, i.e. it must be able to displace adsorbed surface gas.

(v) Spreading Activity

The flux must be able to influence the surface energy equilibrium in the direction of solder spreading, and also be easily displaced by the solder. In order to influence spreading the flux must be able to reduce the surface tension of the solder, e.g. by forming a flux/solder compound.

The flux must fulfill all these essential requirements, and it is desirable that it should have the following properties:

(a) It should be non-corrosive, or at least have low activity at normal room temperatures.

(b) The residue should be non-corrosive at operating temperatures or be easy to remove after soldering.

(c) The fumes given off while soldering should be non-corrosive or have low activity and should be non-toxic.

(d) It should be safe to use, i.e. have a high flash point, decompose slowly, not irritating, non-toxic, not react violently to other chemicals.

(e) It should act quickly

(f) It should be cheap.

2. (b) Fluxing Materials.

The two major flux groups are inorganic and organic chemicals.

Inorganic: There are three types of inorganic flux.

(i) Inorganic acids: these are highly active and corrosive and include hydrochloric acid and orthophosphoric acid. They are normally used as a part of other inorganic systems.

(ii) Inorganic salts: these are less corrosive at room temperature but become active when molten. It is often necessary to use them in weak acid solutions, e.g. Zinc chloride in weak hydrochloric acid. Combinations of salts are used to achieve a eutectic mixture with a melting point below that of the solder.

(iii) Inorganic gases: These are active at high temperatures but are dangerous, and so rarely used. Dry hydrogen and hydrogen chloride are in this group.

<u>Organic</u>: There are four main types of organic flux.

(i) Organic acids: these are of medium activity and are temperature sensitive. Acids used include Lactic, Oleic, Stearic, Glutamic, Phthalic and Citric.

(ii) Organic Halogens: these are much more active and corrosive. They are temperature sensitive and include compounds such as Aniline Hydrochloride, Glutamic Hydrochloride and Hydrazine Hydrochloride.

(iii) Amines and Amides: these are less active than the halogen derivatives, but are still corrosive and temperature sensitive. Chemicals such as Urea and Ethylene Diamine are in this group.

(iv) Rosin type: Water white gum rosin is a mixture of aromatic acids which will act as a weak, temperature sensitive flux, or as a carrier for more active fluxes. It is a good wetting and spreading agent.

2. (c) Solders

There is a wide range of solders available, and it is important to choose those with the desired properties. The factors to consider are:

(i) Temperature: Solder alloys have a wide range of melting points. The liquidus of a metal mixture can be determined from a phase diagram, and it is usually wise to work at least 30 to 40°C above this.

(ii) Intermetallic Compound Formation: Some solders combine with the base metal to form crystalline structures in the solder matrix, which is considered undesirable as it weakens the joint and hampers solder flow.

(iii) Physical Properties: these include mechanical strength and fatigue strength at the operating temperature and also ductility. They must be matched to the needs of the application.

(iv) Wetting Power: the solder should flow easily. This is determined by the balance of surface energies between the solder, the base metal and the flux.

(v) Corrosion — this is important only for those applications where the bond is in contact with an ionic liquid such as water. The solder should have an electropotential similar to that of the base metal or else the presence of the liquid, bridging the base metal and the solder, will lead to an electric cell being set up and rapid corrosion of the more electropositive metal.

(vi) Cost — solders vary considerably in cost, and it may be necessary to consider trade off's between cost and other desirable features.

2. (d) Conclusions on Theory

It is important to consider the base metal, flux and solder as a system. All the parts must be carefully chosen to match one another or the system will not work correctly. Developing the best system for a particular job may take some time. It appears that although certain broad guidelines are set out to help this choice, much of the work has to be on a trial and error basis.

As far as I am aware, there is no precise theoretical way of predicting the behaviour of a particular system or comparing it to another. It may be possible to do this experimentally by measuring bond strengths and the wetting ability of solders and fluxes.

SECTION 3. ALUMINIUM SOLDERING

3. (a) Coventional Methods

There are two types of flux normally used for aluminium - an organic flux and an inorganic flux. The inorganic flux is very active and contains a mixture of salts of heavy metals such as tin, zinc, cadmium or lead. A typical mixture would contain zinc chloride, ammonium bromide and sodium fluoride. These fluxes penetrate the oxide film so that the salts come into contact with the aluminium. This may occur when heating causes the oxide film to crack due to the different rates of expansion of the aluminium and the oxide.

At the soldering temperature the chlorides are reduced by the aluminium to form gaseous aluminium chloride and metallic zinc or tin deposits on the exposed aluminium. The gas breaks up the remaining oxide film and the zinc or tin deposit wets the solder.

The organic flux is slightly less active, although still very corrosive, and usually contains an organic fluoroborate, a heavy metal fluoroborate, an organic solvent and a "plasticiser". Its action is similar to that of the inorganic flux, leading to deposition of the heavy metal.

These fluxes and the fumes they emit when heated are toxic. The residue is highly corrosive and the fluxes temperature sensitive and expensive. There are some new organic fluxes which are claimed to leave a non-corrosive residue. These fluxes have not found favour in heat exchanger manufacture, although they are used in the electronics industry.

Aluminium solders are normally one of four types:

(a) Pure zinc or zinc and aluminium

(b) Zinc and cadmium

(c) Zinc and tin

(d) Zinc, lead and tin.

(a) and (b) are high melting point solders, usually used at 400 to 500°C with the mixture containing 90 to 95% zinc. (c) and (d) are lower melting soft solders used at or above 300°C. The relative proportions of the constituents vary and there may be small amounts of other metals such as silver or indium present to add strength or other desirable features to the solders.

The main problem when choosing a solder for aluminium where the finished product will come into contact with water, or other ionic liquids, is corrosion. Aluminium is very electropositive and so lead tin solders are not normally used. The best metals to use, in theory, are zinc, aluminium and magnesium as these all have similar electropotentials. The small amounts of other metals are present often to lower the melting point of these solders because the fluxes available cannot cope with high temperatures.

3. (b) <u>'Unibond'</u>

The new method of soldering aluminium consists primarily of a discovery that it is possible to use a range of fairly thermally stable and relatively non-corrosive fluxes. These new fluxes are easy to use, safe to handle and may not need washing off after use because they leave a non-corrosive residue. It is also possible that they may be usable at higher temperatures than conventional fluxes, thus being compatible with high zinc content solders. These are more electropositive and hence less corrosive than the more usual low temperature tin, zinc and tin, lead, zinc solders.

These fluxes consist of an organic acid which may be mixed with an inert carrier and a solvent. Initially only one acid was known to work, but it was thought that several more might do so. A series of experiments were carried out to determine which acids worked, and if possible why they worked and under what conditions.

At first, a wide range of organic acid groups were tested, choosing mainly those acids already known as fluxes. The results were largely negative, the only successes being two members of the same group of acids as the original flux.

The next step was to try some of the more promising failures with a range of inert carriers - oil, glycerol, paraffin wax, petroleum jelly and silicone grease, to add thermal stability. These did not help.

A series of high melting point acids were then tested, on the hypothesis that the temperature of deactivation might be the problem. These were also unsuccessful. Finally some more acids from the original flux group were tried and found to work. For the details of these experiments and the results see the appendix.

3. (c) Conclusions and Recommendations

In order to derive any hypothesis about the system it is necessary to look at the properties of the chemicals in relation to the requirements of a flux. A list of some of their physical properties is shown in the appendix.

The only successful chemicals are some of the monocarboxylic acids. There appears to be no single property that distinguishes a flux (for aluminium or lock seam) from a non flux. It may be that a combination of properties is important - having the right level of activity (not too strong or weak an acid), and enough thermal stability to be active before decomposing and to promote wetting when the solder is molten.

The difference between those acids which bonded the aluminium and those which only bonded the lock seam are:-

(a) The successful acids are thermally stable at the soldering temperature and have a high boiling point.

(b) The successful acids have a low density and a natural waxiness. Thus they may posses special surface properties.

The other acid groups tested may have been unsuccessful for a number of reasons. It is possible that one of the groups, the sulphonic acids, are too strong - they are hard to displace from the base metal. Conversely another group, the phenols, may be too weak. The other compounds all tend to decompose rapidly at or before the soldering temperature.

Because of a shortage of time, these experiments are not complete. More work could usefully be done in the following areas.

(a) Fluxes:

(i) Try the remaining untested Monocarboxylic acids to see if they work.

(ii) Try some comparative tests of wetting ability and bond strength. Compare fluxes, the effect of changes in concentration and the effect of different bases.
Ideally try to form a theory to account for the success or failure of chemicals to act as fluxes.

(b) Solders: Work on the range of solders - try out different combinations of zinc and tin etc.

(c) Systems: Try to find a high temperature soldering system to operate at $\simeq 500^{\circ}C$ using high zinc content solders and organic acid fluxes in an inert carrier.

We must try to optimise the flux, solder and base metal system to give as low as possible a potential difference, and as wide as possible a range of solders and soldering temperatures.

SECTION 4: LITERATURE AND PATENT SEARCH

Literature search: The first literature search had covered mainly recent work on aluminium and soldering (refs.1 to 14). However, I came across a book written in 1926 by R.J. Anderson (ref. 15), which mentioned stearic acid as an aluminium flux, although saying that it was of no use. Following up the references in this book (refs. 16 to 21) led to a U.S. Bureau of Standards report of 1919 (ref. 21). This reported tests on aluminium fluxes, including stearic acid, but did not recommend their use. I then looked at early books on aluminium and soldering (refs. 22 to 25) and discovered a reference from 1909 to patents on aluminium soldering (ref. 26). This encouraged me to search through British patents and led to some interesting and surprising finds.

The books and papers were, for the most part, not very informative. Richards in his book of 1890 (ref.16) mentions stearin in a list of fluxes, and Burgess and Hambuechen in their 1903 paper (ref.17) recommend scraping the surface of the aluminium and then applying stearic acid prior to soldering. Andrews in two 1921 papers (refs.19 and 20) contradicts himself as to whether it is necessary to scrape the surface of the aluminium before soldering or not. He recommends using stearin or lard oil as the flux. The U.S. Bureau of Standards recommend carefully cleaning the surface to be soldered with a file or emery paper and then tinning them - coating with a layer of solder, prior to joining them by heating without using a flux. They further state that "tests made at this Bureau have not shown any advantage in the use of such fluxes (as stearic acid, rosin, zinc chloride, soap, sugar or paraffin) either in the ease of application (tinning) or in the resultant adhesion of such fluxed metal."

This report was later used by Anderson in his book (ref 15) to say "In the case of aluminium, few of the fluxes recommended for soldering are of any use at all, since the principal requirement of a flux is that it shall dissolve aluminium oxide; soldering fluxes consisting of wax, grease, soap, etc., are therefore, useless" and also, later in the book - "As mentioned, fluxes are often recommended for use with the various commercial solders, and some of the more common fluxes suggested and used include the following: stearic acid, rosin, zinc chloride, soap, sugar or mixtures of these substances. The employment of such so called fluxes is totally useless, and actual tests have shown no advantage gained by applying them either in the actual tinning or in the subsequent soldering".

Anderson recommends scraping the surface and tinning prior to joining. Later books mention only the use of strong inorganic fluxes, or the fluoroborate organic type, patented in 1952, but not much used commercially.

A 1909 reference (No. 26) in a journal to "hundreds of patents having been taken out in this country, in France, in Germany and in America, all with the object of soldering aluminium" led to a patent search. I examined British patent abridgements from 1623 to 1975, concentrating on the late 1800's and early 1900's, and looked at any original patents which seemed to be relevant.

It appears that between 1890 and 1916 organic fluxes were well known - many examples were given of the use of tallow, stearin, linseed oil, olive oil, palm oil and others. The earliest patent concerning the use of these chemicals as fluxes dates from 1850. There are also many examples of these fluxes being used with aluminium - 24 relevant patents were found and are summarised below.

5 of the patents cover a soldering system similar to that of 'Unibond', four of which state that the parts to be soldered must be cleaned or thoroughly cleaned prior to applying the flux. This may mean that the inventors thought it necessary to scrape the surface of the aluminium. All cases specify a special or preferred solder. 4 patents specifically recommend scraping the surface of the aluminium before fluxing and soldering. 3 recommend tinning the aluminium before soldering, using organic fluxes such as stearic acid for the tinning and subsequent soldering. A further 12 patents contain complex flux mixture including fatty acids, sometimes for use with complex solders. There is only one mention of this type of flux after the 1920's - in 1946 G.E.C. patented a method of soldering Duralumin using palm oil as a flux, zinc plating the metal prior to soldering.

It seems therefore, that monocarboxylic acid fluxes were well known in the 19th century and early 20th century, and when aluminium was first produced in quantity these fluxes were used to solder it. The first industrial extraction process was developed in 1854, and the first industrial plant built in 1886. The new metal stimulated great excitement at the time and much research was done on it. This interest died down and between the 20's and 40's not much work was done. There was a resurgence of interest during the second world war due to its possible use in aircraft, but for some reason the organic fluxes were overlooked.

SECTION 5: FURTHER WORK ON 'UNIBOND'

5. (a) Experiments and results

The second stage of the experimental work was to explore the range of monocarboxylic acid fluxes by testing all the easily available types and also to experiment with different bases. The experimental method was the same as in the first set of tests (see appendix) using 3003 alloy aluminium strip and flat sided, lock-seam brass radiator tubes coated with 80:20 tin:zinc solder.

Experiments were also carried out to test the range of possible solders and alloys by a metallurgist at Serck, using as a guide a list of typical aluminium solders derived from the literature search.

For details of the experiments see the appendix.

As a result of the experimental work and the literature search, a provisional patent application was drafted. This was phrased in such a way as to overcome the problems of the prior art discovered during the patent search. The early patents were methods of making single joints, using special flux and solder mixtures, usually specifying cleaning prior to soldering. The 'Unibond' patent application is for "a method of making a plurality of joints simultaneously", covering a wide range of possible fluxes, solders and base metals. (see appendix)

5. (b) Work for the final specification.

After the provisional patent specification had been submitted, work continued to try and find a suitable flux mixture to operate at high temperatures (450°C+) without severe charring. This would allow the use of cheap, high zinc content solders, which in theory would be less liable to electrochemical corrosion than the low temperature, relatively expensive, high tin content solders. For details of these experiments see the appendix.

As a result of these experiments the final patent specification will include a wider range of natural oils as proven fluxes. However a high temperature flux system has still not been developed. It is possible that there is no monorcarboxylic acid mixture that will work at 450°C or more without charring. Furtner work on this will centre on speeding up the soldering process by using a high speed baking oven.

SECTION 6: CONCLUSIONS

This part of my project was an unexpected bonus arising out of a discovery during the development of the licensed process. It proved to be a most interesting and valuable exercise - both from the company's point of view and my own. The experimental work became a major part of my project and involved me directly in the process development to a far greater extent than originally seemed possible. The literature search was fascinating and taught me a valuable lesson on the usefulness of such an exercise.

Further work remains to be done on these fluxes - specifically to develop a suitable high temperature soldering system if possible, and to investigate the mechanism of the fluxes' action on aluminium to derive a theory to account for their successful use.

The impact of this discovery could be great, both on the company and on the heat exchanger and electronics industries as a whole. It seems to provide the only presently available method of joining aluminium to itself and to other metals easily without using corrosive, temperature sensitive fluxes or complicated and expensive plant.

Its technical success seems assured but commercial success depends on two factors - whether it is possible to produce an aluminium heat exchanger with as long a life as a conventional copper unit - i.e. which is reasonably corrosion resistant; and also whether the customer will accept the proposed new product, and on what terms. In the next chapter I will consider the corrosion resistance of the new product, and in the following chapter I will give the results of a market research exercise that I conducted with some of Serck's customers.

This exercise has demonstrated a number of important general principles. Firstly it has shown that in-house expertise and innovation are useful even when buying in new developments. Secondly, the need for flexibility when planning for and developing new processes can be clearly seen. Thirdly the value of looking at past research in a subject is highlighted - literature searches should be a part of any research project. Finally it seems that the theoretical background to aluminium soldering, and to soldering in general is patchy. Much more work could usefully be done in this area, particularly on the action of fluxes, and on ways of predicting the results of a particular flux, solder and base metal combination.

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CHAPTER FIVE

ENVIRONMENTAL TESTS

SECTION 1. INTRODUCTION

When I joined Serck in September 1975, my first project was to supervise and help plan an environmental test programme to assess the corrosion resistance of the new products made by the 'Unibond' process. I worked with a development engineer who had roughly planned the programme before I started. The objectives were:

(a) To selectively apply the Serck 'Unibond' process to the manufacture of test units, field trial vehicle and other such block radiator units.

(b) To evaluate the performance of these units and assess the life expectancy of various base metal materials and solders relative to their application.

It was expected that the units would be subject to electrochemical corrosion. This happens when two or more metals of dissimilar electro-potential are in contact with an electrolyte such as water. The more electro-negative element is corroded at a rate which depends on the voltage difference between the metals, the distance they are apart and the nature of the electrolyte. Aluminium in particular is open to this type of attack because it is the most electro-negative metal except for magnesium and zinc. Therefore, if a normal lead:tin solder is used with aluminium the joint is attacked at the point of contact between the aluminium and the solder where a thin fusion layer is present, which rapidly corrodes. If a zinc based solder is used, the whole surface of the solder is attacked. As there is a relatively large amount of this the effects of the corrosion are much less severe and the joint tends to last for some time. (see photographs 8, 9, 10 and 11).

There were to be two types of test. Some full size radiators were to be built and placed on field trial with customers, and at the same time a number of small units would be placed on a laboratory test rig and subjected to accelerated life tests. The aim was to be able to compare the laboratory test results with the field trials so as to be able to predict the performance of units in the field from the laboratory test results.

The planning and manufacturing of the units was expected to take a year, and then the tests would run for a year, finishing in late 1977. I started by drawing up a network diagram of the project and calculating the critical path to assist in planning and monitoring progress. (see appendix). The next stage was the design of the laboratory test rig and finding suitable customers for field trial units. Whilst the rig was being built, the plans for the laboratory tests were completed and agreement was reached on the field trial programme. This planning stage was completed by September 1976.

By the end of March 1977 the test rig had been running for two months and a number of field trial units had been made, some of which had been placed on trial. These units were proving more difficult to make than had been anticipated and so this part of the project was behind schedule. At this time the laboratory test programme was revised in the light of the two months experience, a number of new units were put on the rig and the test procedures were improved.

The rig then ran satisfactorily until September, when a further review of progress was made, resulting in a rethink of the test programme. In January 1978 the tests were stopped and the units taken off for examination.

The field trial programme continued to progress slowly. The manufacturing problems were largely solved but it became difficult to get the necessary production time at the radiator factory in Manchester. By January 1978, 14 of the planned 23 units had been made, of which 11 were out on test. 4 of these had been in service for a year, 1 for 10 months and the remainder for 6 months or less. 2 of the units made had been waiting 10 months for oil coolers to be made to complete them. However, in spite of the delay in the programme the results so far have been encouraging.

SECTION 2: OCTOBER 1975 to MARCH 1976

(a) Laboratory Tests

The first stage of planning the laboratory tests was to decide on the type of tests to conduct and the type of test unit to use so that the rig could be designed. It was decided that the test units would be 4 inch square radiator blocks, made both from the fin and tube design currently in production and also from a pack construction where corrugated fins are placed between rows of tubes. (See photograph 6). After some discussion it was agreed that the tests would involve placing the units in the front of a large box and sucking air through them by means of a fan at the rear of the box. The units would have hot water pumped through them and there would be a water spray system to give wet or dry conditions and to spray salt water on some of the units.

The air flow rate would remain constant, but the circulating hot water could be turned off to simulate cold running. A cycle was to be run which resembled normal use - e.g. cold start, running hot, stand and cool down. This could be run with or without water sprays and pollutants such as salt. Several different types of environment were to be simulated.

We decided to make 51 test models, and use several combinations of metals and solders in the models. We hoped to measure the change in performance of the models over time, and would regularly inspect them.

From this basic plan the test rig was designed and manufacture began (See photographs 1 to 5). Instructions were issued to make the experimental units using the 'Unibond' oil bath method. I was not greatly involved in the detailed design or manufacture of the rig, this being done by the development engineer with whom I worked, in conjunction with the drawing office and engineering laboratory.

(b) Field Trials

During this period a programme of field trials was set up in co-operation with the Manchester radiator manufacturing division. It was decided that normal production radiators would be re-blocked with aluminium fins and brass tubes by means of the 'Unibond' oil bath technique. Various different solders and coatings would be used to make the blocks. A list of customers who might test these units was drawn up so as to cover as wide a range of applications as possible. The customers were contacted, and in all cases agreed to test the radiators.

23 field trial units were planned, of which 11 were to be placed in cars, vans and lorries owned by Serck. The remainder were to be placed on tractors, cranes, compressors and large off-highway dump trucks. It was hoped that the units would be made by the autumn of 1976.

SECTION 3: APRIL TO SEPTEMBER 1976

(a) Laboratory Tests

The discovery of the baking process meant that the planned test units were now to be made by this process. The plans for tests and measurements were finalised during this time. These final plans are given below.

We will place 52 small blocks in a test rig and subject them to an accelerated life test in simulated operational conditions. Air will be sucked through the units and hot water pumped through the tubes.

We will be testing 10 combinations of metals and solder in each of three types of environment, and also comparing painted and unpainted units and cleaned and uncleaned units. All the units will be baked.

We will measure the water-side temperature drop across each unit periodically. These measurements will be taken at standard operating conditions and should indicate the performance of the unit. Units will be inspected for signs of corrosion and weighed before and after the experiment. The results will be analysed statistically using analysis of variance techniques which measure the differences between and within groups of results. The tests will run for about a year.

Environments

We are going to simulate three situations; highway use, off highway use and semi-continuous running.

For each of these we will run a four hour cycle twice a day to represent normal use. The cycle will contain periods of hot and cold running, water sprays, diesel fumes and salt sprays where appropriate. It will be adjusted to suit winter and summer conditions, changing every three months.

(a) Highway use:

Winter cycle:	Hour	1	2	3	4
		Cold Dry	Hot Wet	Cold Wet	Hot Dry

There will be a one minute salt spray every cycle at the end of hour 3 and diesel fumes will be added during one cycle every week.

Summer cycle: As above except that there is no salt spray and only ½ hour of water spray every cycle.

(b) Off-Highway use: As for highway but with no salt spray used in the winter.

(c) Semi-continuous running As for off-highway use except that hour 3 is hot wet running instead of cold wet

Materials

We will be testing the following combinations of metals and solder in each of the three environments. All units are to be baked and will be unpainted and uncleaned except where stated otherwise.

(i) Fin and tube units

Metals	Solder	Variant	Number off
Copper/Brass	70:30 lead:tin	A	1
Aluminium/Brass	60:40 " "	B_{10}	2
" "	70:30 " "	A	2
" "	80:20 tin:zinc	B_{30}	2
Aluminium/Alum.	" " " "	X C_{10}	1
" "	" " " "	X B_{30}	1
" "	70:30 lead:tin	X A	1
Aluminium/Brass	" " " "	A	3 *

* 1 off painted, not cleaned; 1 off painted, cleaned; 1 off unpainted, cleaned.

(ii) Packed Block Units

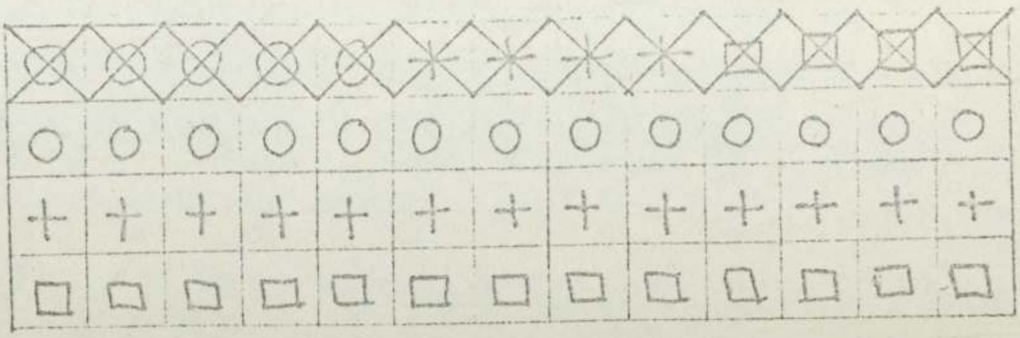
Aluminium/Aluminium	80:20 Tin:Zinc	C_{10}	1 *
Aluminium/Brass	" "	C_{20}	2
Copper/Brass	70:30 Lead:Tin	A	1

* 2 off these in semi-continuous run.

Arrangement on Test Rig

The rig has four rows of 13 spaces. Because of corrosion problems it is necessary to keep the water system of the aluminium tube units separate from that of the brass tube units. We are going to arrange the units as shown in diagram 1. The individual units will be randomly arranged within each environment.

DIAGRAM 1



KEY:

- X - Aluminium tube units
- O - Semi-continuous running
- □ - Highway use
- + - Off highway use

(b) Field Trials

Plans for the field trial programme were also finalised during this period. It was decided that the radiators would be made from brass tubes and aluminium fins using the new baking process. Each block was to be made in two vertical sections using different solders, and the lower half of each block was to be made with normal production solder - 70:30 lead:tin, and pre-treated fins. The other half would be made from untreated fins and 80:20 tin:zinc solder - corresponding to variants A and B_{30} of the 'Unibond' process.

Units were to be performance tested before and after the trials and inspected occasionally while in use. The units were to be in the field for at least a year. Details of placings were agreed and a production schedule drawn up with manufacture starting in October. This part of the programme was the responsibility of the development engineer working with the Manchester factory and the engineering laboratory. A list of the planned field trials is given below:

2 off large mobile cranes	(outside customer)
2 off small mobile cranes	(outside customer)
2 off off-highway dump trucks	(outside customer)
2 off agricultural tractors	(outside customer)
4 off compressors	(two outside customers)
3 off Bedford lorries	(Serck owned)
3 off Transit vans	(Serck owned)
5 off company cars.	

SECTION 4: OCTOBER 1976 to MARCH 1977

(a) Laboratory Tests

The test rig was completed in December 1976, moved to its present site in the engineering laboratory in January 1977 and started running on 26th January. The test units were built in November, December and January, the last seven being put on the rig in mid-February. Some manufacturing difficulties arose, but these were overcome. Only three rows of units were built - the all aluminium ones being postponed until the method of manufacture could be finalised.

I had not been greatly involved with the rig since late 1976, having been working on aluminium fluxes. When I inspected the rig in mid-March I discovered that of the 39 units in place, 18 had little or no bond remaining between the fins and the tubes. I also discovered that only 18 of the units had been weighed before being placed on the rig and that no performance tests had been conducted. Furthermore, because of inadequate heating and timers, all the units had been running on roughly the same cycle under the same conditions.

I decided to stop the rig in order to inspect some of the bad units and replace them. I also arranged for improvements to be made to the heating and timing devices, and worked out a programme of tests to be conducted when the rig recommenced running. Details of these are given in the next section. The results of the rig inspection are given in TABLE 1. When the units were examined, it was discovered that the joint had corroded at the point of contact between the fins and the solder, as expected.

TABLE 1.

RESULTS OF AN INSPECTION OF THE UNITS ON TEST RIG ON 21ST MARCH, 1977

By Manifolds

Row 3	-	5 good units;	8 bad ones
Row 4	-	10 " " ;	3 " "
Row 5	-	6 " " ;	7 " "

By variants

Fin and tube

B_{10}	(treated fin, 60:40 tin:lead solder)	-	all 6 bad
B_{30}	(untreated fin, 80:20 tin:zinc solder)	-	3 good, 3 bad
A	(treated fin, 70:30 lead:tin solder)	-	3 good, 3 bad
A	(painted, cleaned)	-	2 good, 1 bad
A	(painted, uncleaned)	-	2 good, 1 bad
A	(unpainted, uncleaned)	-	2 good, 1 bad
A	(copper fins)	-	All 3 good

Packed block

C_{20}	(untreated fin, 80:20 tin:zinc solder)	-	3 good, 3 bad
C_{20}	(copper fins)	-	All 3 good

(b) Field Trials

Manufacturing difficulties delayed the field trial programme during this period - it proved difficult to make large blocks without charring the flux on the tubes and so making it impossible to obtain a leak-free tube to tubeplate join. By January the three Ford Transit radiators, one Rover car radiator and a tractor radiator were built. The Transit and Rover radiators were out on test. (see photograph 12).

Unfortunately none of these units had been performance tested, and only 80:20 tin:zinc solder and untreated fin had been used. It was hoped that further units would incorporate treated fins and production solder, but difficulties in the pre-treatment process prevented this from happening.

By the end of March, both tractor radiators had been built and one was out on trial; all four compressor radiators had been built and were awaiting performance tests. Also five heater cores for Allegro cars had been made with aluminium fins, for British Leyland to test. Manufacturing problems were still occurring and a number of poor quality units had to be scrapped.

SECTION 5: APRIL TO JUNE 1977

(a) Laboratory Tests

The rig began running with the new cycle on 4th May. Details of this cycle and the test scheme are given below:

New Cycles and Test System

The rig is running on a 3 hour cycle, 24 hours a day. At present we are operating a winter cycle. Details are given below:

Highway use	- 34 minutes hot wet, 55 minutes cold wet and 90 minutes cold dry. One minute of 5% salt spray is added every 3 hours.
Off-highway use	- as above but with no salt spray
Semi-continuous running	- 20 minutes hot wet, 70 minutes cold wet, 55 minutes hot dry and 35 minutes cold dry.

13 new units have been added to the rig - 7 of B_{30} variant and 6 of C_{20} variant. These have replaced the bad B_{10}, C_{20} and B_{30} units.

A record is kept of all changes in the rig's operation - particularly if it is shut down for any time. Each unit on the rig has a history card which records when the new unit was made, who made it, its identification number, the method of manufacture, the weight, the date of installation on the rig and all performance test results.

Tests are carried out regularly - at present fortnightly. The tests measure the temperature drop across the units and also include a visual inspection of the bond quality and appearance. The spray system is switched off when readings are taken.

During May 3 sets of readings were made - on the 4th, 11th and 18th. The first set was only of manifold 3 and 1 unit from each of the other rows, and was made to check the cycle and the test scheme. The remaining two were sets of every unit on the rig. Also some readings were made of units with the water sprays on.

The results of the readings were encouraging, in that they were consistent - within 1°C from time to time for each unit. The average temperature drop was 6°C, and the packed block units, as expected, had a lower performance than the fin and tube units. The water sprays increased the temperature drop by between 1 and 8°C (See appendix).

Unfortunately the rig was shut down between the 9th and 16th of June because of a fire. 1 unit was removed from the rig because it was leaking at the tube to tubeplate joint (C_{20} on 5G) and was replaced by a Z_{90} unit, made using 90% zinc, 10% tin solder. Only one set of readings was taken in June, on the 23rd., and because a new thermostat had been installed with an incorrect setting, these readings were taken at high inlet water temperatures.

No trends could as yet be drawn from the results. If the new units did corrode this should be accompanied by a change in the temperature drop. The next few months should provide a good indication of whether this will happen. As the test procedure proved to be rather laborious we planned to semi-automate this using thermocouples permanently in place on the rig and a switch box. We also hoped to build 6 models of the new variant using 90% zinc solder, and 13 all aluminium units, to be completed in 2 to 3 months.

(b) <u>Field Trials</u>

Production problems were largely solved during this period and two Bedford truck radiators were made. The Transit radiators were inspected and found to be in a satisfactory condition after 6 months and up to 25,000 miles use. The tests conducted by British Leyland on the heater cores produced reasonable results.

SECTION 6: JULY TO DECEMBER 1977

(a) Laboratory Tests

Thermocouples were installed on one row of units on 4th July and performed well. The remaining two rows were wired up on 16th August and after that all readings were made using this system. A thermocouple was placed in each outlet pipe, and at each end of the inlet. There were also thermocouples to measure the tank temperature and ambient. Readings could now be taken much more quickly.

Regular measurements were made of the temperature drops, and the units were inspected visually. By mid-September nine sets of readings had been taken and I then reviewed the results to date and had four units removed from the rig for testing. These were replaced by three units made using 60:40 tin:zinc solder (Z_{40}), and one C_{20} unit. The planned Z_{90} and all aluminium units were not built because of manufacturing difficulties.

By the end of October a further 8 sets of readings had been taken and the four units taken off the rig had been examined. One further set of readings at a new pump setting was taken early in November and I then analysed the results in detail to try and draw some conclusions as to the usefulness of the exercise in order to plan the next stage.

There was a considerable variation in behaviour during the tests - as can be seen in Appendix Tables 1, 3, 4 and 5. The units tended to follow a basic pattern, set by the manifold they were on. The inlet temperatures of the manifolds tended to follow variations in ambient temperature, and accounted for some of the variation in temperature drop readings - where the inlet temperature was high, the temperature drops were also high. The average inlet temperature was lower for row 5 than for 4 or 3, which were similar.

Individual units gave a variety of results (see appendix) and some were noticeably strange - 3E is very high and 4C is high and reacts unusually to alterations in inlet temperature. Analysing the results in more depth leads to the following conclusions:

(a) There is a significant difference between the results from manifold 3 and those from 4 and 5. Units on manifold 3 tend to have higher temperature drops.

(b) There is a significant difference between the pack block units and the fin and tube units, the pack block units tending to give lower results.

(c) There are no real differences between copper fin and aluminium fin units, or between types of variant A unit, or between types of fin and tube unit (B_{30}, A, and copper)

Further to these results, Row 4 units tend to have a higher standard deviation than the other two rows, and row 5 units show less difference between pack units and fin and tube units than the other rows. Of the new units, the Z_{90} and Z_{40} fin and tube units do not seem to behave differently from the other fin and tube units. However, the Z_{40} pack block units are giving larger temperature drop readings than expected - but no conclusions can be drawn from this as so few readings are available (see appendix for details of the results and analysis).

There seems to be little difference in results between those units thought to have little or no bond left and the good units. A better analysis of these differences must wait until all the units have been taken off the rig and examined.

The four units removed for inspection were - 5D, a copper fin unit, and 5B, 3J and 3E, all B_{30} units. 3J and 3E were found to have sludge blocking the tubes, 3E being very badly effected with about 75% of flow blocked, which would account for its high readings. 3J was 30-40% blocked. 5D was unaffected by the tests and still had a 100% bond. 5B had no bond left, and some of the fins were beginning to crumble. 3J had about 30% bonding and 3E was still 100% bonded. Corrosion in 3J was mainly along the solder-aluminium boundary, as expected, and could have been encouraged by poor initial bonding. This could account for the difference in the condition of the two row 3 B_{30} units. (See photographs 8, 9, 10 and 11).

(b) Field Trials.

Only one more sound field trial unit was made during these months - the last of the Bedford truck units. There was little spare manufacturing time in which to make field trial units because a backlog of orders had arisen at the Manchester factory. All three Bedford units were put out on trial, as was the second tractor unit. The four compressor units were tested and found to be satisfactory. Two of these were delivered and two waited for oil coolers to complete them before delivery. Two large crane radiators were built but both had to be scrapped - one had no bond between the fins and tubes and one was 30% down on planned performance. 5 Allegro car radiators were made for British Leyland in the Engineering Laboratory. Both tractor radiators were inspected and found to be in good condition and all the transit radiators were still good. (See photograph 7).

SECTION 7: JANUARY TO MARCH 1978

(a) Laboratory Tests

As the results of the temperature drop changes seemed not to be yielding any useful information it was decided that tests would stop and that the units would be removed from the rig and inspected. The rig was shut down on 30th January and the units removed for examination. The rig had run for some 5,500 hours in the year since it started.

All 39 units were examined visually, and 12 of these were investigated in more detail. The condition of the bond and the fin was classified A, B or C, A being the best and C the worst. The visual inspection, when compared with the more detailed examination, tended to give an optimistic assessment of condition, and so the results have been adjusted to reflect this. A detailed analysis of the results is given in the appendix. In most cases, as expected, corrosion was present at the joint between the solder and the fins.

The results indicate that:

(a) Units on row 5 suffered the most, both on bonding and on fin condition.

(b) The copper units performed better than the aluminium units.

(c) The fins of the aluminium pack block units corroded more than those of the aluminium fin and tube units.

(d) Variant A painted, uncleaned, had slightly less fin corrosion than other variant A units.

(e) The three new pack block units were still in good condition, but the new Z_{40} fin and tube unit and the Z_{90} unit fared badly.

It seems that the temperature drop readings and visual inspection have not reflected accurately the condition of the units. Therefore a revised plan of operation for the laboratory rig is now needed. The temperature drop readings seem to be of no value, but visual inspection, if thorough, should give a reasonable guide to changes in condition. It is suggested that one row only is run under standard conditions, excluding salt spray. This row would include units from each of the variants of interest. Hopefully this would indicate the time taken before the bond corrodes.

(b) <u>Field Trials</u>

Considerable progress was made during this time. Both the large crane radiators, one of the small crane radiators and one of the off-highway dump truck radiators were made and are awaiting tests. The two compressor radiators which had been delivered have been placed on trial and the Allegro car radiators have been running satisfactorily since November. The Rover car radiators and tractor radiators have been inspected and are in good condition, as are the three Transit radiators. Two of these Transit radiators, which have covered over 50,000 miles, are to be removed and examined. The Bedford truck radiators are to be examined soon, having been in use for nearly nine months.

The remaining four company car radiators are not now going to be built, because of a shortage of aluminium. This leaves only two outstanding field trial radiators, and two compressor units awaiting oil coolers. A summary of this programme is given in Table 2.

TABLE 2

SUMMARY OF FIELD TRIAL UNITS

UNITS	DATE MADE	PERFORMANCE TESTED	DATE ON TRIAL	VISITS AND COMMENTS
3 Transit Van Radiators	December 1976 and January 1977	No	January 1977	As of February 1978, all in reasonable condition. 2 which have done over 50,000 miles to be removed and examined.
1 Rover Car Radiator	January 1977	No	January 1977	As of March 1978, in good condition
3 Bedford Truck Radiators	June & July 1977	No	August and September 1977	To be visited soon
2 Tractor Radiators	January and February 1977	No	March and July 1977	Visited January and April 1978 Both in good condition
2 Compressor Radiators	July 1977	July 1977	December and January 1977/8	-
2 Compressor Radiators	February 1977	August 1977	-	Awaiting oil coolers before being delivered.

Continued........

TABLE 2 (continued)

SUMMARY OF FIELD TRIAL UNITS

UNITS	DATE MADE	PERFORMANCE TESTED	DATE ON TRIAL	VISITS AND COMMENTS
2 Large Crane Radiators	February 1978	-	-	Awaiting Tests
2 Small Crane Radiators	One - February 1978	-	-	Awaiting Tests One more to make
2 Dump Truck Radiators	One - February 1978	-	-	Awaiting Tests One more to make
4 Company Car Radiators	-	-	-	Not now to be made

SECTION 8: CONCLUSIONS

The results of the tests show that the copper finned units are more corrosion resistant than the aluminium finned units, and that the salt spray environment was more damaging than the other environments. The results do not give a very clear indication of the life of the test units - those subjected to salt spray have probably suffered severe bond corrosion within 3 months, and the others within 9 months. The temperature drop readings did not reflect this corrosion - perhaps because the conditions were too variable, or the change in performance too small. It is also possible that the water flow rate was too low so that readings depended more on fluctuations in the flow rate than on changes in the condition of the test unit.

The field trial programme, although subject to considerable delay, has provided encouraging results. However, until a field trial unit fails there is no way of linking laboratory test results to performance in the field.

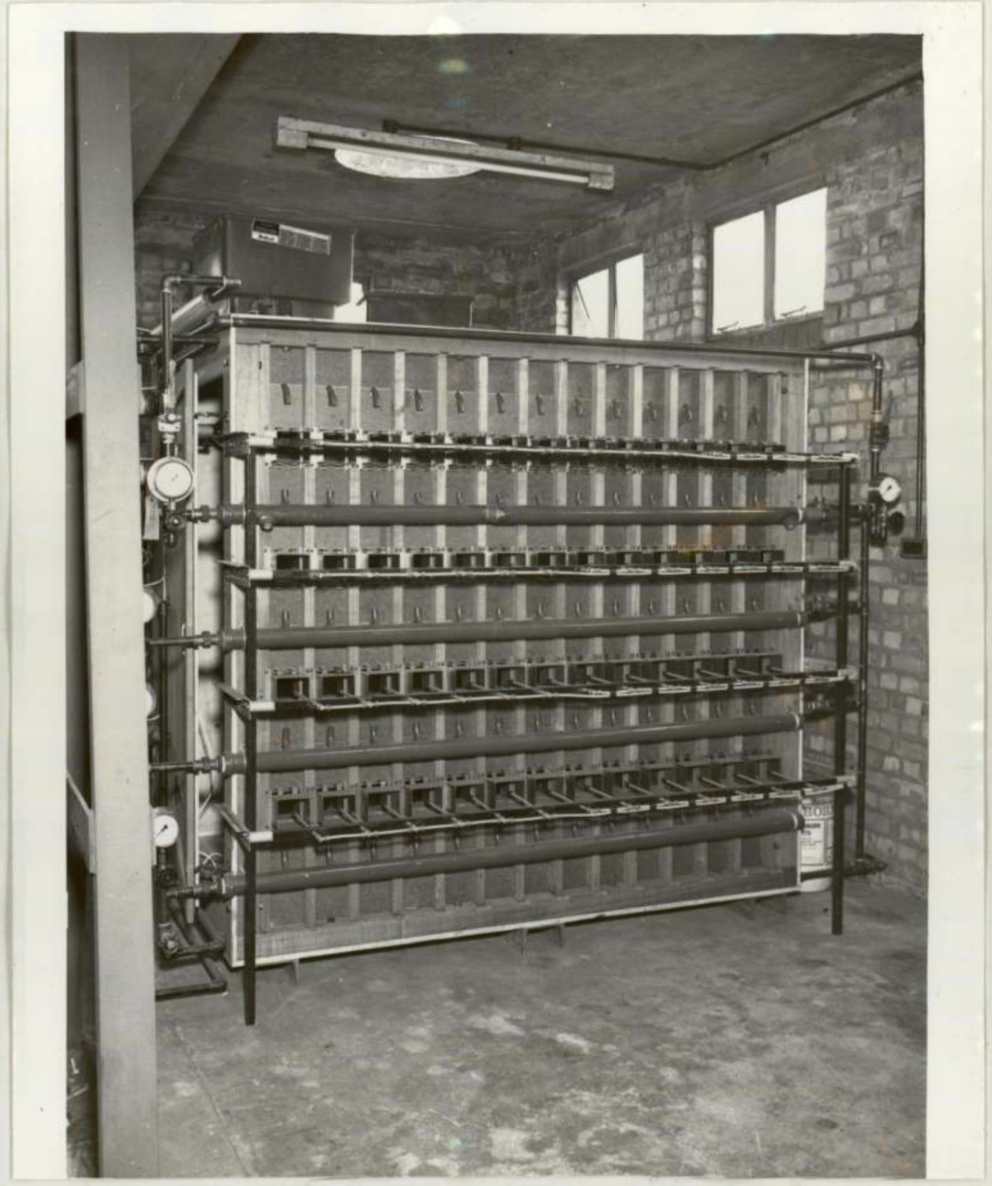
Certainly this type of test programme is a necessary pre-requisite to the manufacture and sale of aluminium finned radiators. It would seem best to start the tests as soon as possible during the development programme, but preferably after the manufacturing techniques have been worked out. Some of the delays in the field trial programme were caused by manufacturing difficulties leading to a number of poor quality units being built.

Careful planning and regular progress monitoring are needed, and there should be some definite arrangement made with the production unit to manufacture the field trial units to an agreed plan.

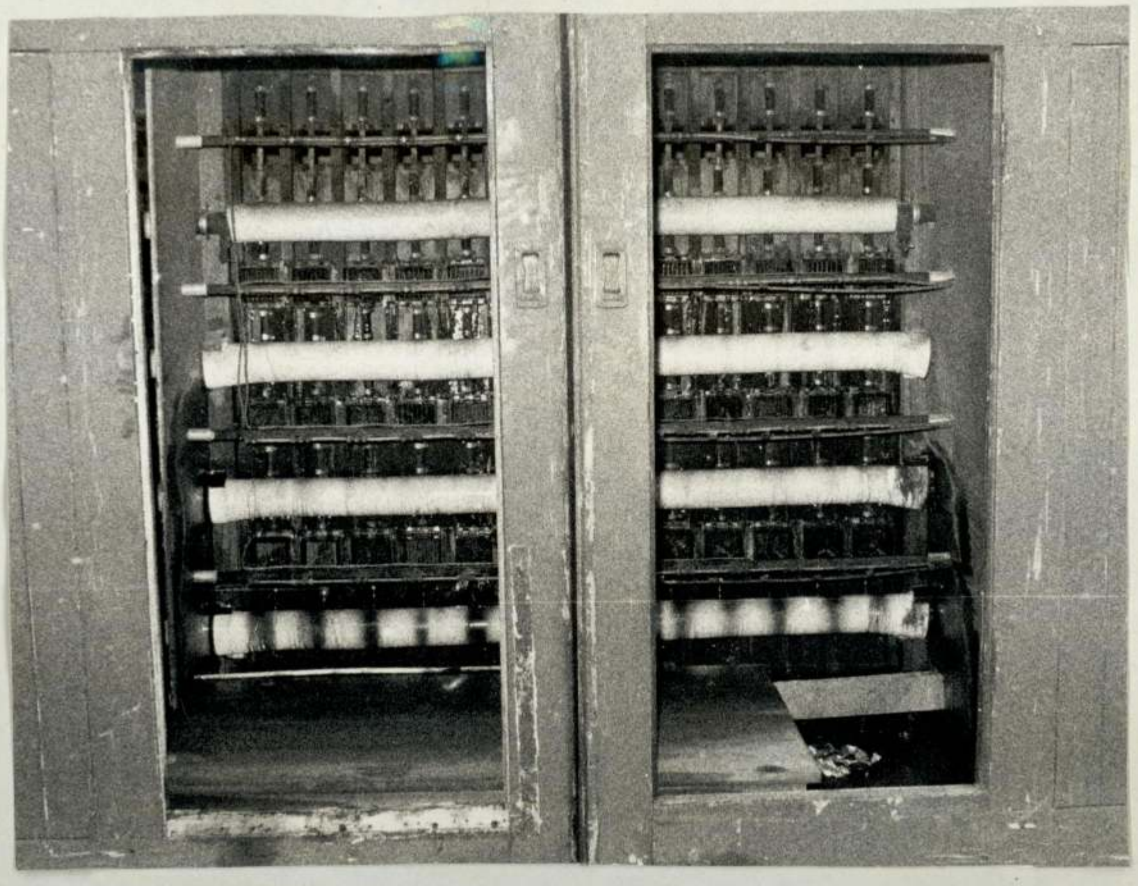
It is unfortunate that the laboratory tests didn't provide more useful results - in principle this type of test could be of great value, but the inspection and testing scheme needs further consideration.

For me this was a useful exercise in supervision and provided a good base on which to build my knowledge of the 'Unibond' process and its technology, and around which to fit the rest of my work.

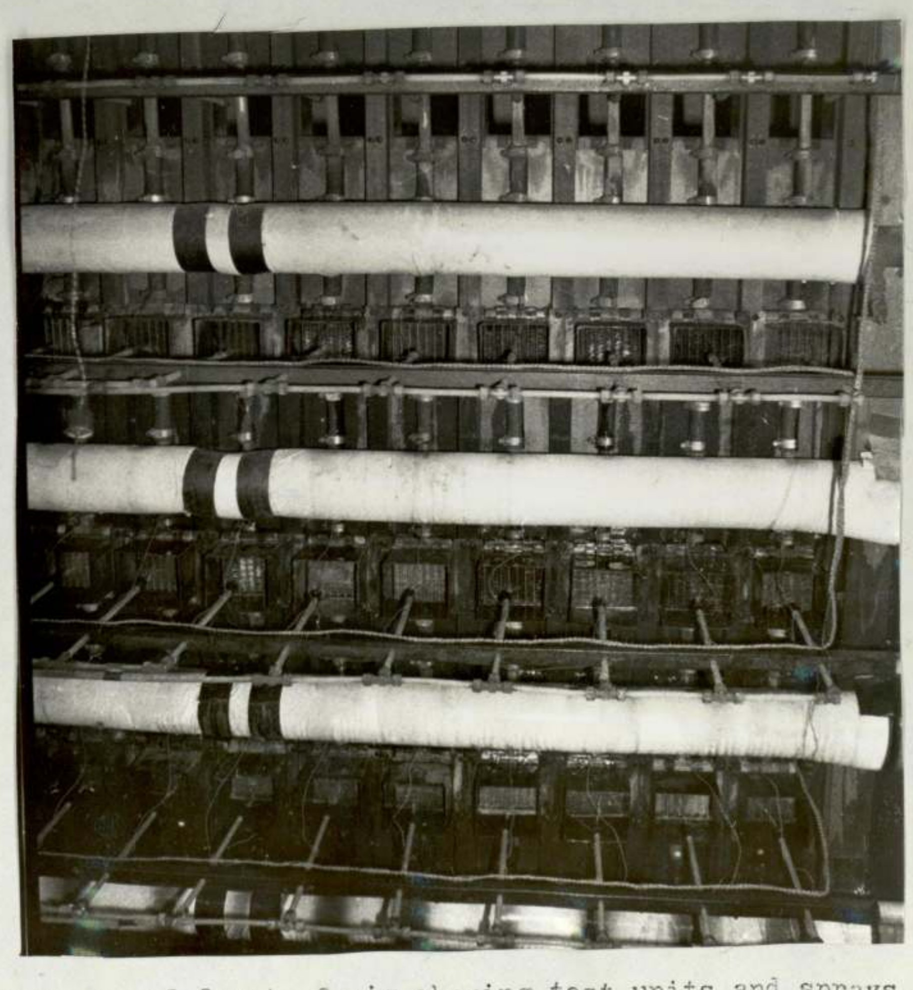
1) Laboratory rig in the first stage of construction.



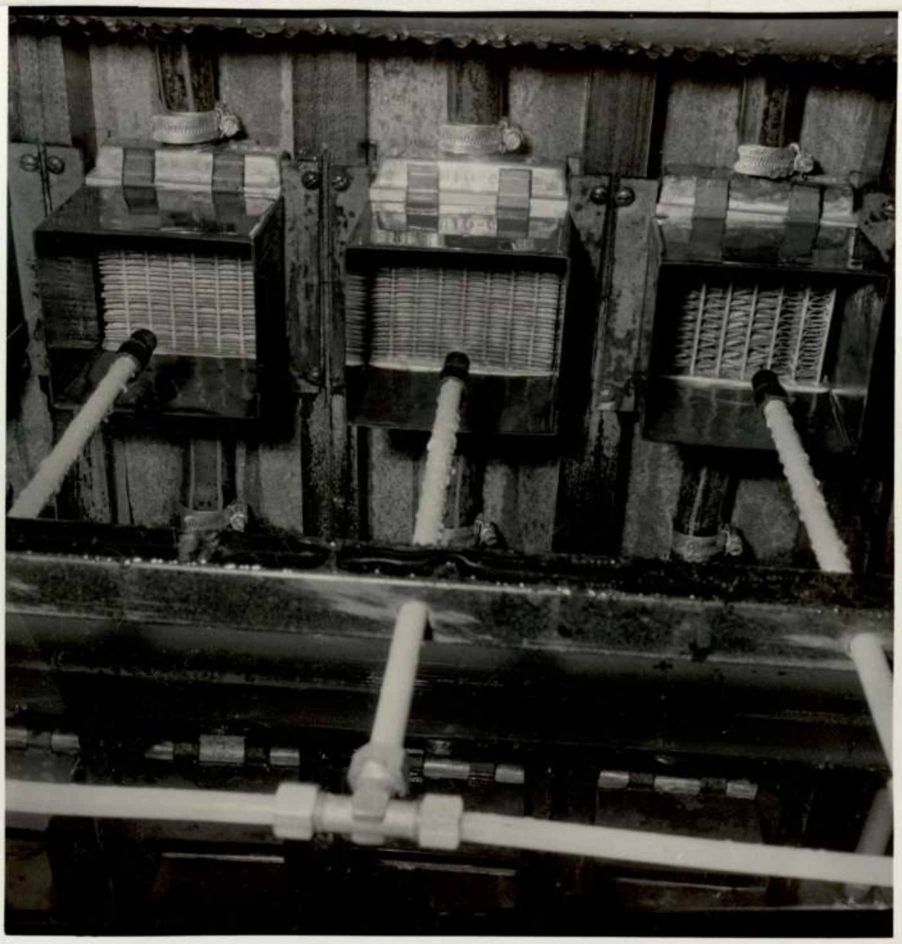
2) Laboratory rig in the second stage of construction.



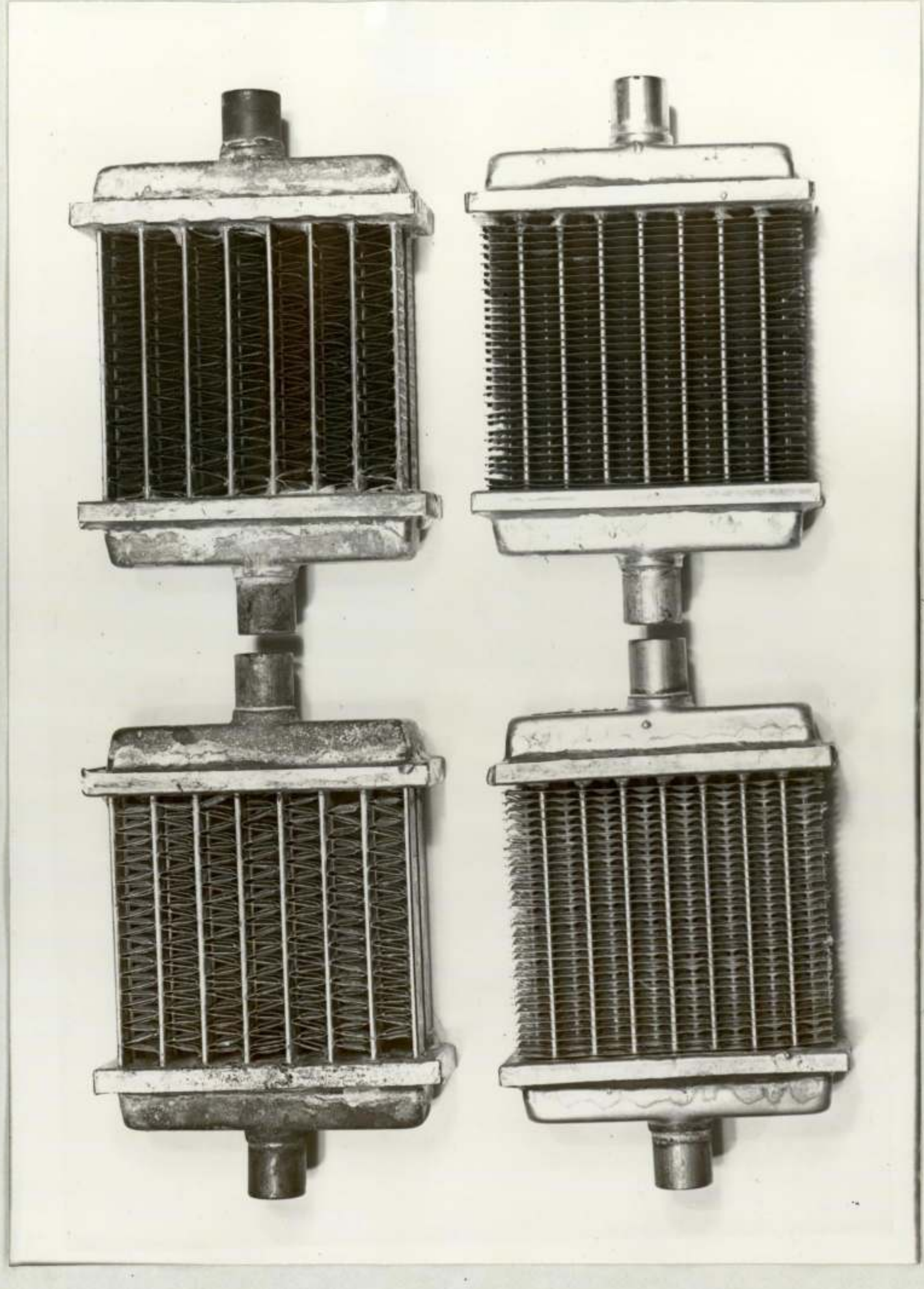
3) Front of rig exposed to the atmosphere.



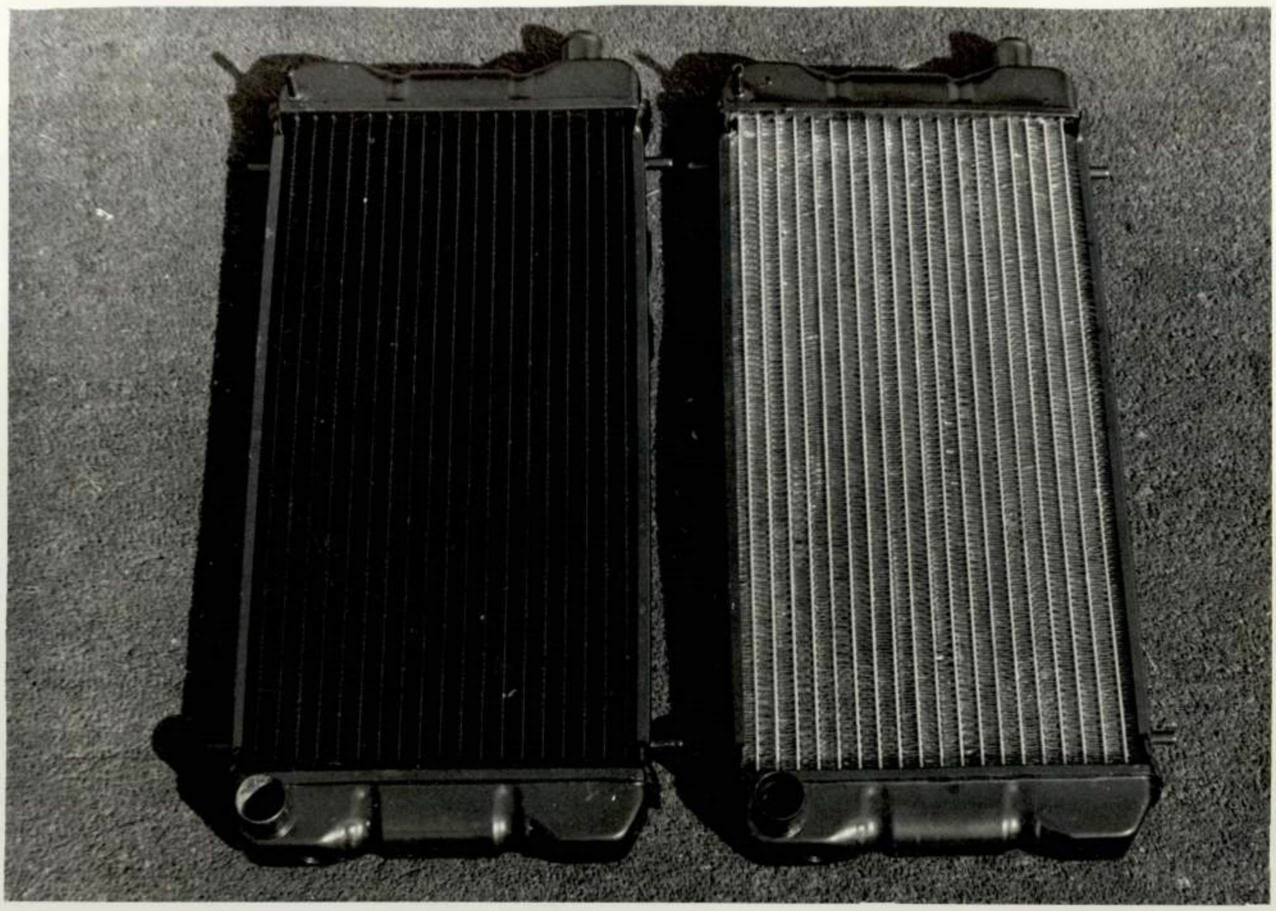
4) Close-up of front of rig showing test units and sprays.



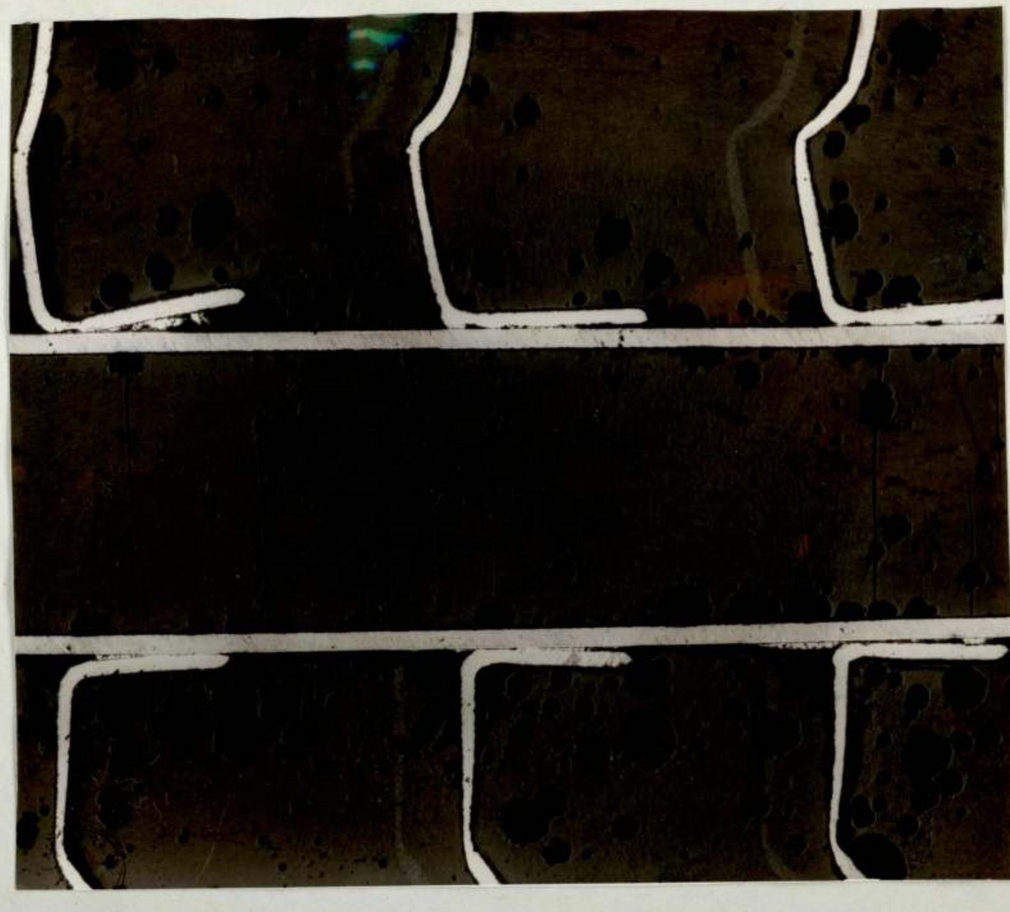
5) Close-up of test units and sprays.



6) Test units - packed block on the left and fin and tube on the right.



7) Allegro car radiators, packed block, one painted, one unpainted.

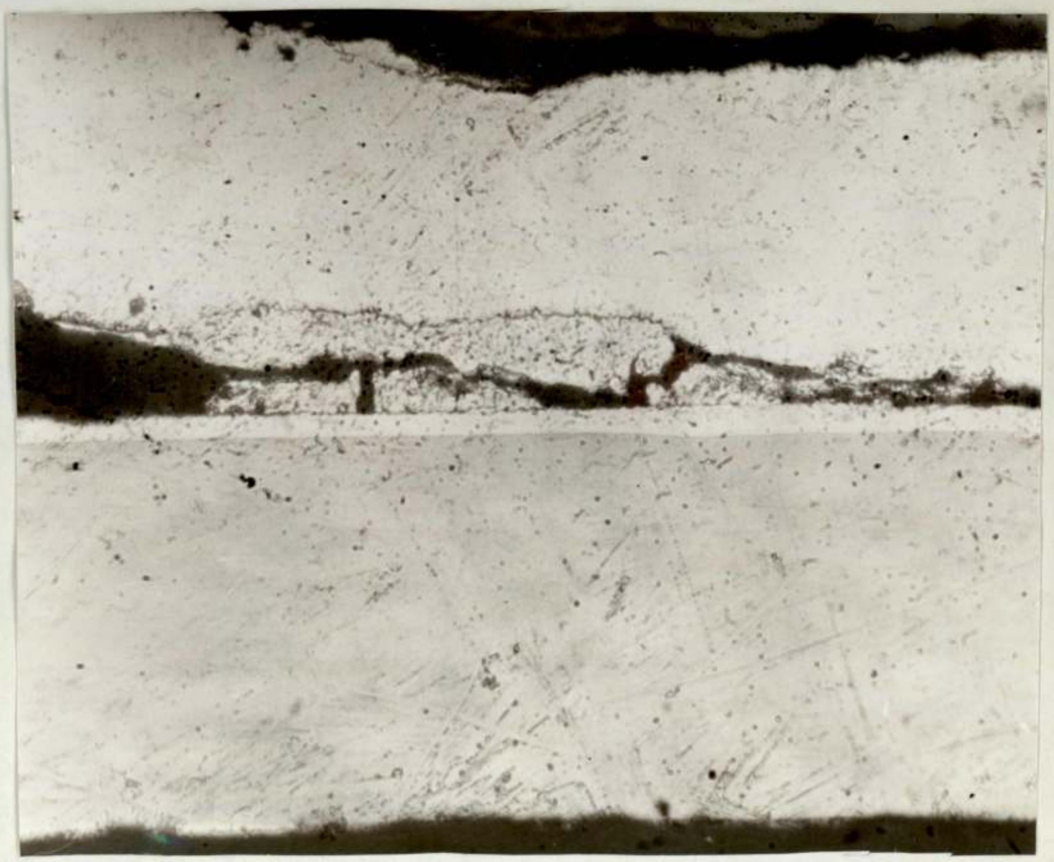


8) Unit B30 3J. Close up of a poor fin to tube bond. (x22). Fin
Solder
Tube

9) Unit B30 3E, close up of a good fin to tube bond - note the width of solder layer. (x22).

corrosion

10) Close up of a corroded joint - corrosion along the interface of the fin and the solder (x400).



11) Close up of a corroded joint - at left, corrosion of all the solder (x400).

12) Rover car radiator with aluminium fins, half painted.

CHAPTER SIX

MARKET RESEARCH

SECTION 1: INTRODUCTION AND PLANNING

This exercise formed the final piece of my practical research connected with 'Unibond'. The need for an understanding of customer reaction to the proposed new product emerged at an early stage in the project - the cost/benefit analysis (Chapter 3) indicated that market acceptance was an important factor in the economic success of 'Unibond'. In addition, as very little market research had been done by Serck Heat Transfer, the project would help to establish the value of close links between research and the market.

I started by reading a number of books about marketing and market research (see references) and also by discovering what the market position of H.O. Serck was. I then presented a paper at each of three marketing workshops run by I.H.D. at Aston. On the basis of this work and the discussions at the workshops I drew up proposals for the market research shown overleaf.
I planned to investigate the U.K. market for specialist vehicle radiators to discover - (a) what the market was and how it operated and (b) how customers would react to the use of aluminium in radiators. This would involve some background research and a series of interviews with major customers of H.O. Serck, the radiator manufacturing division.

Over the next year discussions were held with H.O. Serck, and some background research was done. By June 1977 H.O. Serck had agreed to a survey of some of their major customers and I had worked out an interview framework. By September a list of customers had been drawn up and contacts had been provided by H.O. Serck and I conducted the survey during October and November.

JUNE 1976: MARKET RESEARCH PROPOSALS

Research Area: The United Kingdom market for specialist vehicle radiators

Research Objectives: To investigate original equipment manufacturers and try to assess:-

(a) Market size, structure and trends including:-

the size of customers

how many of their units we supply

who supplies the others

who we do not supply

what determines demand

ratio of new to replacement sales

(b) Competitors' shares

Selling Methods

Pricing Policies.

(c) Customers' buying authority, practices and motives, particularly important in assessing the prospects for:-

expansion

the effects of design changes

desirable product and service features

advertising effectiveness.

(d) Product developments within the radiator industry

(e) Market opportunities and problems.

The results of the research will give a guide to:-

desirable product and service features

the reaction to the proposed design change

pricing policy

using the new product as a company advertisment.

Research Methods:

(i) The first phase of the work will involve using in-company information and published sources.

(a) Internal source-sales data, sales manager's comments and suggestions.
Previous work of other divisions.

(b) External sources - government information, trade and research associations, trade journals and company reports.

This should give much of the information on the market and product developments and some on competitors and customers.

(ii) As a follow up to this some field work will be carried out to provide the bulk of the information on competitors and customers.

The precise nature of this survey will depend on the results obtained by the desk research detailed above and at this stage only tentative suggestions can be made.

Acting on the assumption that a small number of companies will control a large section of the market, it is intended that as many as possible of these companies will be interviewed - hopefully most of them will be testing field trial units. In addition to this a postal or telephone survey of some of the smaller companies will be conducted.

A more detailed proposal for the field work will be presented after the desk research has been completed.

SECTION 2: BACKGROUND AND METHODOLOGY

H.O. Serck Division is a specialist radiator manufacturer who mainly sell small and medium sized radiators. They do not mass produce and many of their units are specially adapted to suit the customer. A breakdown of their potential U.K. Market is shown below:

Type of Application		% Proportion
(1) Industrial Engines	50 - 200 H.P.	59.2
	200 - 500 H.P.	20.3
	500 - 1000 H.P.	2.4
Diesel Engines for Rail Traction		0.7
Armoured Vehicles - Wheeled		0.2
Specialist Commercial Vehicles		10.2
(2) Agricultural Tractors		7.0

(1) This category includes engines for agricultural machines (except wheeled tractors), earth moving equipment, cranes, industrial lift trucks, generator sets, compressors, pumps etc.

(2) As H.O. Serck are equipped to produce for the smaller volume models only, this figure is 20% of the whole market for tractor radiators.

The total market is worth £9.6 million, and H.O. Serck have about a 20% share spread evenly across the group, except for Industrial Engines above 200 H.P., where they have only recently begun to compete. Their main competitors are Covrad - part of Associated Engineering, and Marston - part of I.M.I., who both have a little over 30% of the market. The remaining 15% is shared by a number of smaller companies of which 8 are listed in Kompass. Covrad do not make radiator blocks - they buy these from British Leyland and assemble the unit, and Marston concentrate on mass produced series radiators.

I surveyed H.O. Serck's top twenty British customers, excluding those in the newly entered large industrial engines market, and successfully interviewed 16 of these who accounted for about 60% of H.O.S's sales to this market - about 12½% of the total market. The customers were spread in proportion to the size of sector between industrial engines, tractors and specialist commercial vehicles - 13 in industrial engines, 1 in specialist commercial vehicles and 2 in tractors. I spoke chiefly to engineers and designers rather than purchasers because in most cases the engineers made the initial choice of unit. I used a semi-structured interview either carried out in person or by telephone. The inteérview was based on the framework shown overleaf, with questions 1(a) and 1(b) (i) and (ii) being mainly answered by desk work beforehand.

1. Why do people choose Serck radiators rather than those of another manufacturer.

(a) How large is the market, what is our share, who has the rest (What determines growth?).

(b) Who are our customers.

(i) Which companies are in the market

(ii) What is their share of it

(iii) Who do we supply and what proportion of their total demand do we meet.

(iv) Who supplies the rest (Multisourcing?)

(c) What do they want

(i) Who makes the buy decision

(ii) What is important to him/them about a radiator; e.g. Price, Performance, Service before and after sales, Reliability, Delivery, Credit, Guarantees, Size, Weight, etc. and how important are these factors relative to one another.

(iii) How important is the type of radiator as compared to other parts of the product.

(d) How do they choose (Probably depends on the type of purchase)

(e) What do they think of Serck and its product as compared to its competitors (Product feature comparison)

2. How will people accept aluminium finned and all aluminium units.

i.e. In what way could radiators be improved

e.g. size, efficiency, weight, use of aluminium fins, in tubes, reliability etc.

Try and assess:

(a) Perceived pro's and con's of our new units as compared to conventional units and other types of aluminium unit.

(b) are these important to the customer

(c) Do aluminium units have a bad reputation

(d) General resistance to change

Aim

To find a way of launching our new development which would overcome problems and prejudices about aluminium and help Serck's reputation.

Use unstructured interviews with major customers.

SERCTION 3: RESULTS: BUYING PRACTICES AND OPINIONS

(a) Buying Practices - when looking for a radiator for a new design of product the following buying pattern is typical of the customers interviewed.

(i) A request is sent out to one or more manufacturers to design a prototype unit in conjunction with the customer. If dual or multi-sourcing the customer will compare the speed of response and the quality of the design service offered. For most applications the manufacturer will be working with a tight size restraint on the unit.

(ii) The prototype is performance tested and if it is satisfactory it is specified as being acceptable for production. Some account may be taken at this stage of the manufacturer's reputation for reliability, and the after sales service.

(iii) If the customer is single sourcing, this recommendation is passed on to the buyer who will monitor price and delivery. If these are unsatisfactory either the buyer or the designer will put pressure on the supplier to improve them - to the extent of getting a competitor's quote.

If the customer is dual or multisourcing the buyer compares the recommended manufacturers' prices and deliveries and chooses a supplier for production. The supplier may be varied from time to time to take advantage of differences in price and delivery.

I found 11 of the 16 customers single sourced, but most said they kept a close watch on price and delivery. Some obtained quotes from other manufacturers which they used for comparison and as an emergency second source. 4 customers dual sourced wherever possible, the buyer having the final choice in all except one where it was policy to give each supplier half the business. One company multisourced - they were unusual in that radiators were used on only 2% of their engine output, and they were apparently not very concerned about the quality of the unit or the service provided by the manufacturer, but mainly about the price and delivery.

13 of the companies interviewed said that before sales service and the quality of the unit (reliability and performance) were the most important factors in choosing a prototype. Some mentioned after sales service and the speed of designing and building the prototype as additional factors. Price and delivery were considered at the production stage by the buyers, or checked by the designer before specifying the unit. They seemed to be less important to most of my interviewees than the service and quality. 2 companies regarded before sales service, price and delivery as the most important factors and one, mentioned earlier, was only interested in price and delivery. 12 of the companies mentioned size as a major constraint, but none regarded weight as being important.

(b) Opinions of Serck - Serck's major assets appear to be its reputation for quality and its good service, both before and after sales. 13 customers said that Serck provided good quality and service - a typical comment was that "they have a good name". 7 of these stressed the personal contact with the salesman as being important. The remaining

3 customers found little to choose between the manufacturers.

4 customers gave the impression of being loyal to Serck because of a long association with them, and 4 mentioned the fact that the company was large, not a back street set up. 3 customers thought that Serck was expensive, and 3 thought they were cheap. 2 mentioned that they considered Serck not as good at producing new ideas as Marston - "Marston have all the new ideas" and "We have occasionally tried Marston because they have offered a new, more efficient design". Marston were most often mentioned as the main competitor (4 times) 2 companies were unhappy with the quality of H.O. Serck's oil cooler.

BUYING MECHANISM

New Product

1. Prototype design
   - note speed and quality of service

2. Test Prototype
   - note quality and reliability of unit.

3. Choose one or more designs for production
   - may assess after sales service

4. (a) If single sourcing the designer will specify the unit and either he or the buyer will assess price and delivery from time to time

   (b) If dual or multi-sourcing the buyer chooses a unit for production - price and delivery are compared. After sales service may be looked at here.

Straight Replacement

(a) If single sourcing the buyer or engineer will monitor price and delivery to ensure that these are reasonable - may obtain second quotes from other companies to compare with.

(b) If dual or multi-sourcing the buyer will look at price and delivery and switch between the suppliers whenever a price or delivery advantage arises. There may be a policy of using each of two suppliers for half the business or some other similar arrangement.

SECTION 3: RESULTS: PRODUCT DEVELOPMENT.

(a) General

Most requests for product improvements arose because of the size constraint and the problem of noise. 10 customers would like to have a more efficient radiator so that the size could be reduced, and 3 others mentioned size as a major problem. Ideas for development in this area included using higher operating pressures, cross flow radiators (to reduce height) and mounting the radiator away from the engine. 4 mentioned noise as a problem. Of these, one suggested using a more efficient fan and cowl, 1 thought of mounting the radiator horizontally to enable him to duct the air away upwards and 1 is considering using an air cooled engine of the type used by Deutz of Germany.

4 companies found that blockage of the fins was a problem and 1 suggested using a higher fin pitching whereas another suggested using a lower fin pitching. 3 companies mentioned development to produce cheaper units - more efficient production techniques, using packed block type radiators and the use of aluminium being suggested. 3 companies would like to have oil coolers with the radiator, 1 of these preferring the cooler to be in the bottom tank.

(b) Using Aluminium.

3 companies would welcome the use of aluminium in radiators, because it would be cheaper. 3 would be interested in trying it - "We would try it and see how it performed", "It would depend on the price", "Interesting, but it would probably need protecting against corrosion".

9 had no reaction either for or against - they were apparently not interested in the details of the radiator as long as it performed satisfactorily. 1 company was hostile to the idea, seeing it as entailing a drop in quality.

Any saving in weight through the use of Aluminium would not be a selling feature - weight was not seen as a problem - it was associated with cost and strength. A lighter unit could suggest cheapness and a loss of strength.

The expected life of the radiator varied with the application - compressor manufacturers expected the unit to fail through abuse in about three years. Most people expected at least a five year life and 3 customers expected ten years. Blockage of the fins is expected to occur every one to two years in the construction and earthmoving industry and in agricultural machinery. From this it would appear that an aluminium radiator should have five to seven years life to satisfy most customers' expectations.

TABLE OF RESULTS

(a) Buying Practices:

11 customers single sourced, 4 dual sourced, 1 multi-sourced. 12 customers considered before sales service and quality to be the most important factors when choosing a radiator, 3 wanted before sales service, price and delivery, 1 looked for price and delivery only. (Although most customers said price and delivery were important at the production stage).

(b) Serck's Reputation:

13 customers thought that Serck had a reputation for good quality and service, 3 thought there was little to choose between manufacturers.

3 customers thought Serck expensive and 3 thought them cheap.

2 customers said that Serck was not as good at producing new ideas as their competitors.

(c) Product Development:

13 customers would like a more efficient and/or smaller radiator, 4 have a problem with noise, 4 suffer from fin blockage, 3 would like oil coolers supplied with the radiator and 3 would like cheaper radiators.

(d) Aluminium:

3 customers would welcome aluminium finned radiators, 3 would be interested in them, 9 had no reaction or were indifferent and 1 was against the idea because he thought that it would mean a loss of quality.

SECTION 4: CONCLUSIONS

There is a bias in this survey in that all the companies I contacted use Serck radiators and so must be reasonably happy with them. It is possible that if I had spoken to people who did not use Serck there would have been more criticism of the company. Also because I mainly interviewed engineers and designers it is possible that the importance of before sales service and reliability has been overstated.

The buying mechanism appears to be in two parts - firstly a prototype is designed and built. During this stage the service, speed of response and quality of unit are important. The next stage is to choose a supplier for production - here price and delivery are the important factors. The response to price changes is not likely to be very great unless the change is large - 5 to 10%. It appears to be difficult to break into the long established relationships between the engineer and the salesman except by offering a new design of product - more efficient or substantially cheaper. Serck appears to have the reputation of being good on the service and quality side, but not good on new product development. The oil coolers appear not to be a success at present, but could help sales if well made.

The main customer requirements for the future centre on more efficient, smaller radiators, and ways of reducing noise. Preventing blockage of the fins and making the radiators cheaper would also be welcomed. There does not appear to be any strong feeling against using Aluminium in radiators. It could be a useful development if allied to more efficient production techniques and sold both on the basis of price reduction and to advertise the company's concern with development of new, cheaper and more efficient radiators. The units must be reliable so as not to damage the company's reputation on this aspect, and should have at least a five year life. Because weight appears to be associated with strength Serck may need to convince the customers that a lighter unit is not necessarily weaker.

These results are similar to those suggested in the literature on industrial marketing:

(a) Purchasing mechanisms differ for "new buys" and rebuys"

(b) The decision making unit is complex, involving two or more departments.

(c) The most often involved departments are design and development and buying.

(d) The engineers tend to make the decisions about new products and the buyers have the major say in "rebuys"

(e) There is a low sensitivity to price if other factors are satisfactory.

(f) There are a small number of suppliers.

The main differences between my results and the literature were that a surprising number of companies single sourced, and that price was put lower down the list of priorities than expected.

The market research has been of value in many ways - I have gained useful information for H.O. Serck from some of the customers, and they were pleased to feel that the manufacturer was interested in their problems. It has also been useful for Advanced Development in highlighting the type of development work wanted by the customer, and indicating the reaction to Aluminium radiators. Also some impression of the company's image with its customers has emerged. Further work would involve talking to other companies in the market who do not buy Serck products, or buy only a small proportion of their total requirements from Serck to obtain a more balanced picture.

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CHAPTER SEVEN

THE FUTURE OF THE 'UNIBOND' PROJECT

SECTION 1: INTRODUCTION

I have now completed the practical work on the 'Unibond' project. In this chapter I will summarise the progress of the development programme, indicate how my work has fitted in to it and assess the future prospects of 'Unibond'. Finally I will analyse the successes and failures of the development which will provide the background to a more general assessment of the state of research, development and planning in Serck Heat Transfer in the next three chapters.

SECTION 2: THE DEVELOPMENT PROGRAMME

The development programme had two main objectives. The first was to learn the potential and limitations of the hot oil bath technique, to assist in the design of manufacturing equipment for several of Serck Heat Transfer's divisions and to investigate other applications of the process. The second objective was to investigate the possibility of substituting aluminium for copper in heat exchangers.

The first objective was to be met by four inter-related projects:-

(i) a basic data programme to investigate the process and provide standards for soldered fin and tube to tubeplate joints.

(ii) the design and installation of a production facility at H.O. Serck (radiator) division.

(iii) the development of a system for use in guided flow oil cooler manufacture in Small Engine Cooler Division.

(iv) the development of a system for use in sectional air cooler and ribbon wound tube manufacture in Air Cooling Division (See diagram 4 in chapter 2).

The second objective led to the environmental test programme described in chapter 5.

The initial plans were that the basic data programme should run for 10 months, finishing in July 1976, and the three manufacturing plant projects should take 1½, 2 and 2½ years, finishing in May 1977, January 1978 and July 1978 respectively. The environmental test programme was expected to take 3 years, being completed in October 1978 (See diagram 1).

These plans were upset by the discovery that the oil bath technique was not economically viable and that a cheaper and simpler method - the baking process, would have to be developed instead (see chapter 3). This led to the basic data programme being extended and caused delays and some confusion in the other programmes. A considerable amount of research now had to be done to make the baking process a viable production technique - the basic data programme continued until mid 1977, concentrating on the development of suitable fluxes and solders (see chapter 4).

The field trial part of the environmental test programme also suffered from the resulting confusion - many poor quality radiators were built and some of the units were a year late in completion. The delay in the H.O. Serck plant programme was partly caused by this change in the process, but was probably

The Initial Development Programme Plans

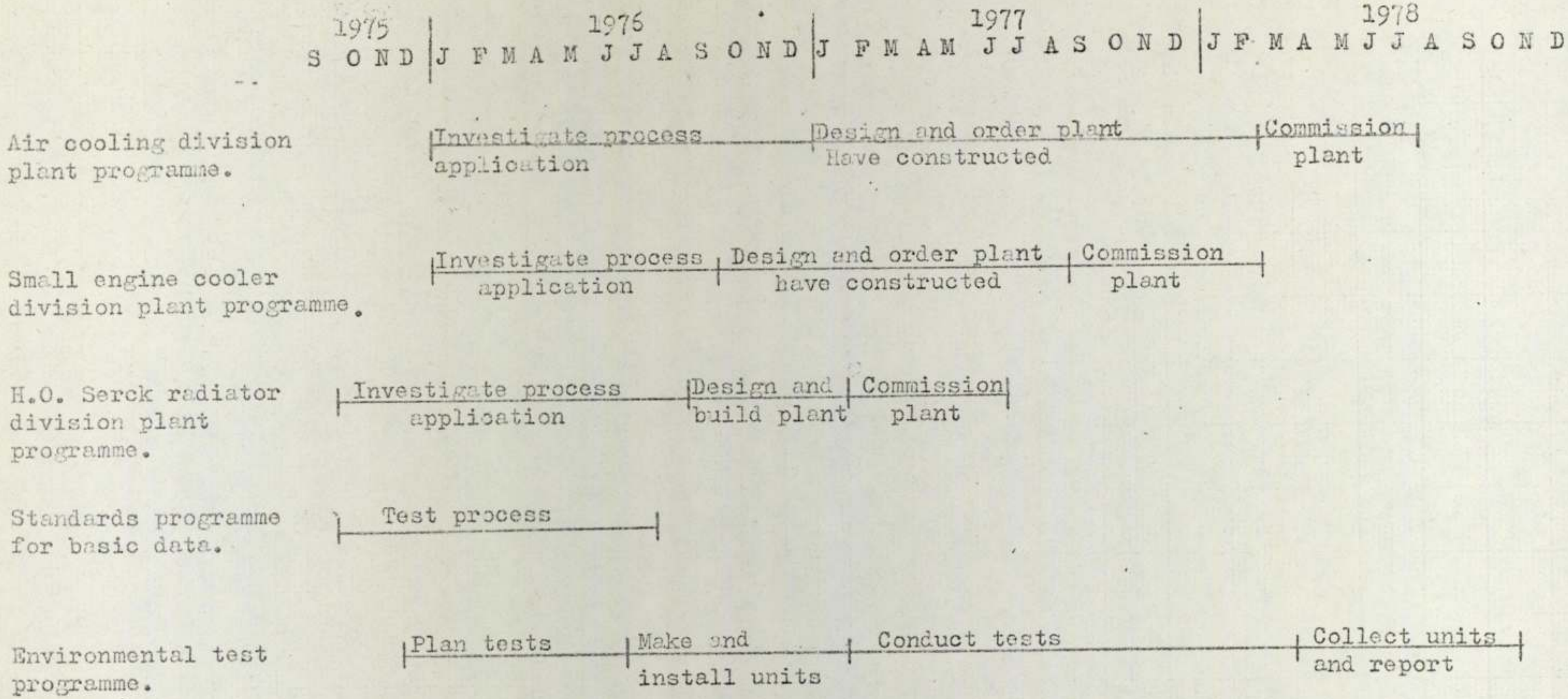


Diagram 1

mainly because of the poor economic outlook for aluminium heat exchangers due to the low price of copper.

The remaining two plant programmes were similarly delayed by the change of process, but the main causes of the slow development of these projects were economic and organisational factors. Diagram 2 indicates the actual progress of the development programme, and where my work fitted into this.

SECTION 3: FUTURE PLANS

At present, the results of the development programme have been:

(i) the installation of a quick-bake oven in H.O. Serck division which, with the use of a commercially available non-corrosive flux, saves labour and makes the production process more efficient. This baking facility enables the 'Unibond' process to be used if it becomes economically attractive.

(ii) A process for solder coating oil cooler tubes has been developed to the pilot plant stage which, if successful, will be used in the production of guided flow oil coolers with copper and aluminium fins. The aluminium finned units will be prototypes requested by a major customer.

(iii) The use of the 'Unibond' non-corrosive fluxes in the manufacture of copper finned ribbon wound tubes is being investigated by Air Cooling Division.

(iv) Some aluminium finned radiators are currently in use as field trial units.

My Work

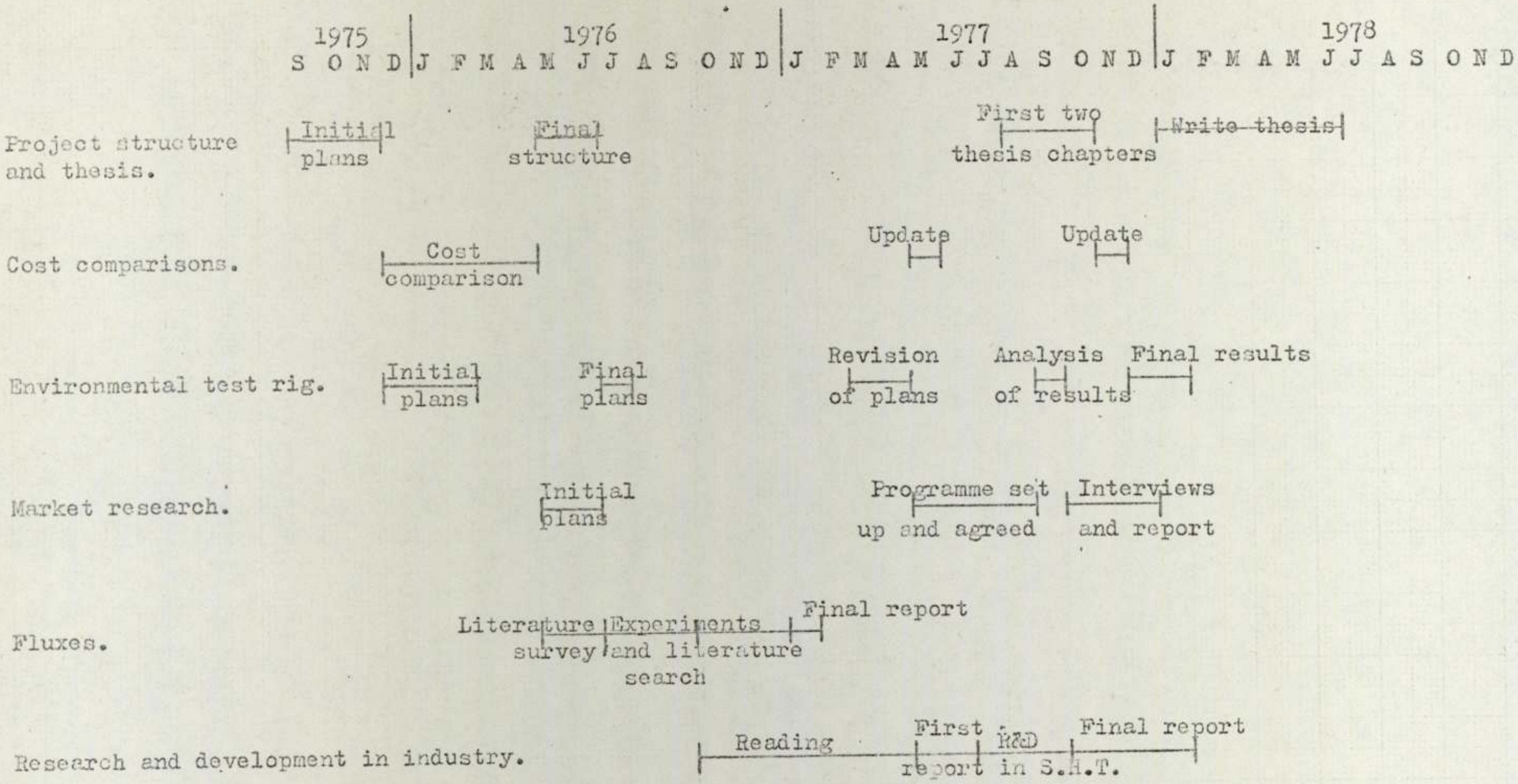


Diagram 2

Diagram 2 (cont.)

The progress of the development programme.

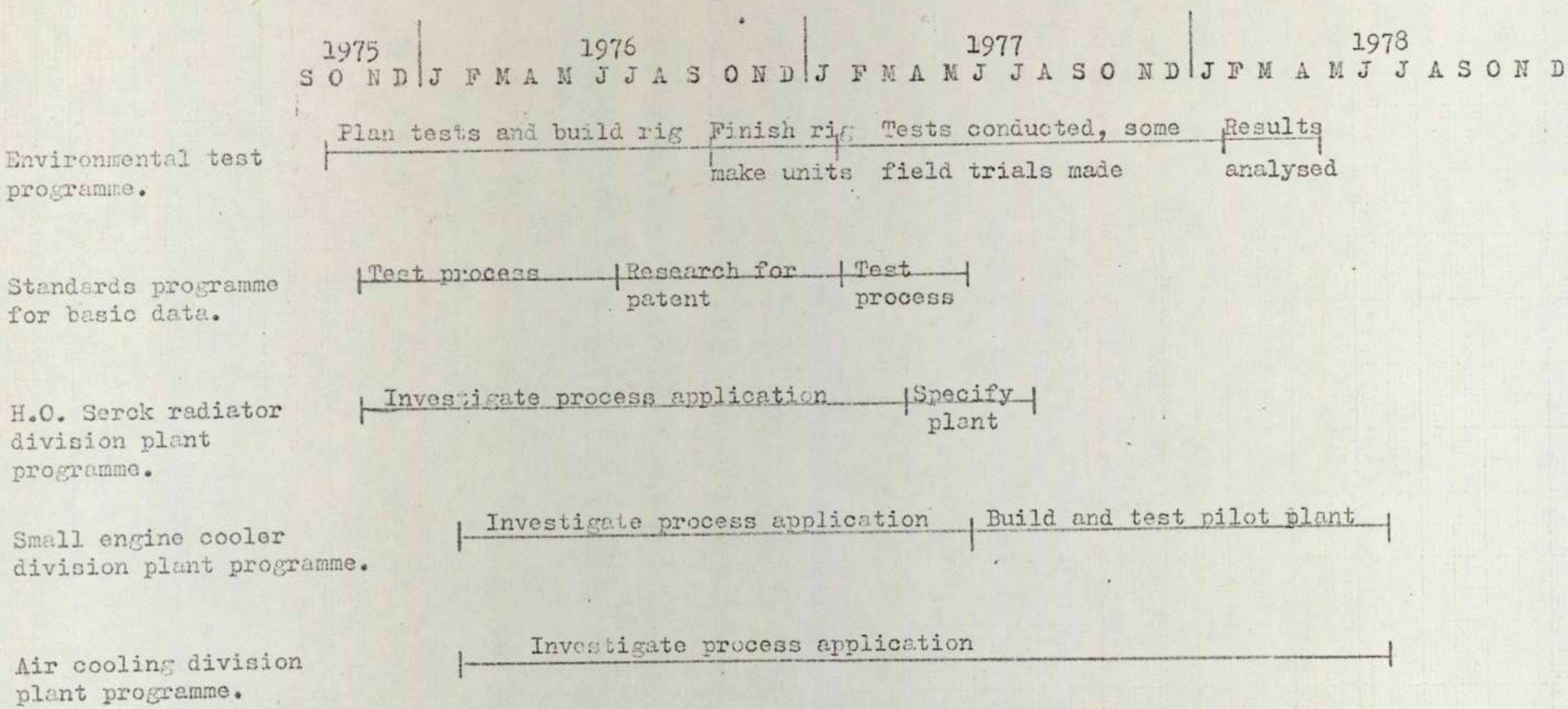
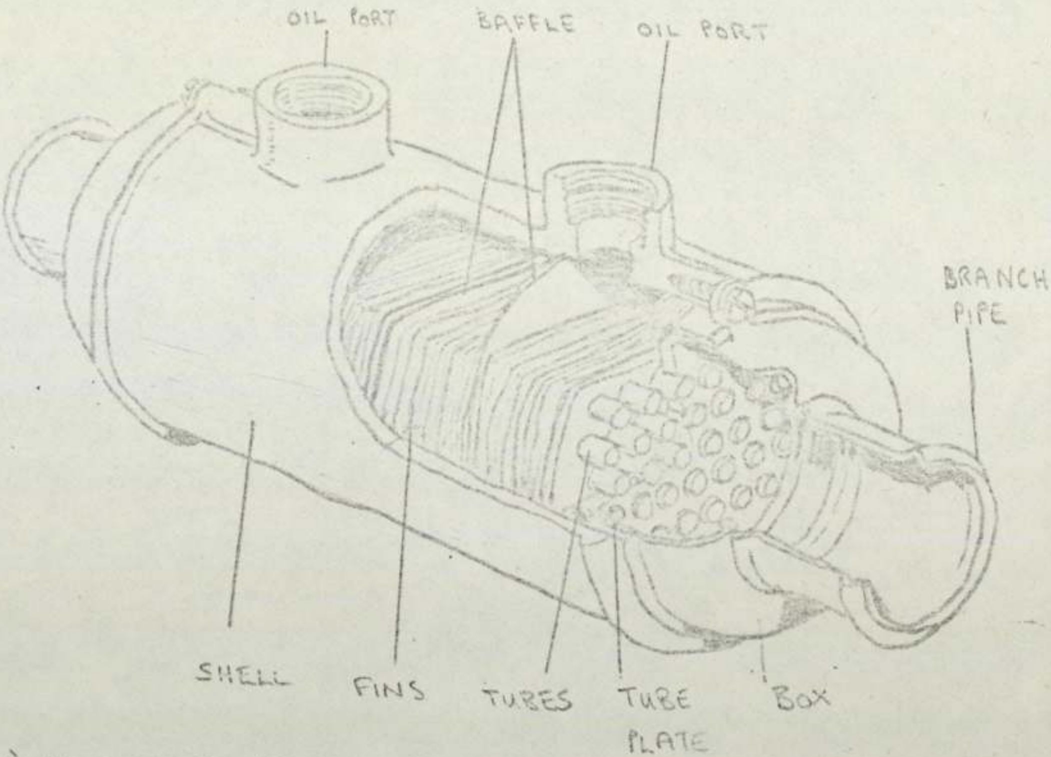
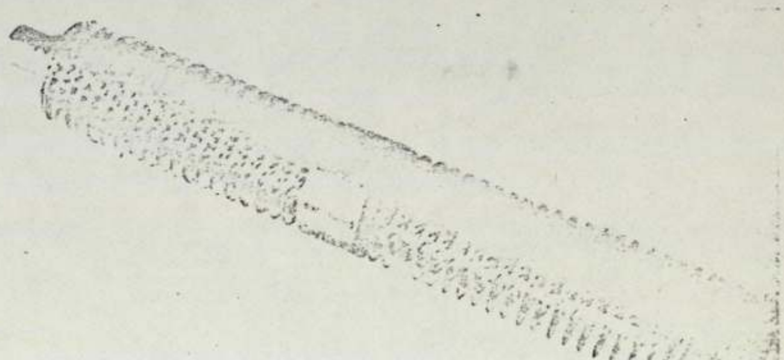


DIAGRAM 3



i) A GUIDED FLOW OIL COOLER



ii) *Ribbon wound tube*

Also, the baking process has been shown to be a technically viable production method for use in radiators and in the manufacture of a redesigned sectional air cooler. It could prove to be a useful insurance against increased material costs caused by high copper prices.

The process will probably not be used in the near future unless the cost of solder can be much reduced without affecting the quality or corrosion resistance of the product. The market research discussed in chaper 6 indicated that product quality and long life were important factors in choosing a radiator, and also that a substantial cost saving would be necessary in order to sell the product at a reduced price, unless the price of copper increases greatly (to £1400 per tonne).

Thus the future plans for 'Unibond' must centre on guided flow oil cooler manufacture and the development of cheaper solders without affecting product quality. The process could also be of use in the manufacture of a redesigned sectional air cooler.

SECTION 4: CONCLUSIONS

On the basis of the original plans and expectations the 'Unibond' development could be said to have been a failure. Certainly the oil bath technique would not have been successful - the cost of the plant was very high and the hot oil bath would have posed safety problems. The baking process successfully overcame these difficulties.

However, this new technique has not solved the remaining problems - the use of expensive solders is still necessary unless the heat exchanger is not subject to corrosion, and the low price of copper does not encourage the use of aluminium in that there is at present little, if any, price advantage in this substitution.

The development programme was hindered by shortcomings in the system of research and development management, planning and control in Serck Heat Transfer. In particular the need for a comprehensive system of project choice, involving market research, technical research and financial assessment, is clearly indicated. Also there were considerable communications problems with H.O. Serck division, which could have been alleviated by having development engineers in the divisions - either on secondment or as permanent members of staff. The research, development and planning system is discussed in the next three chapters and a section of chapter nine is devoted to the effect of the system on the 'Unibond' programme.

'Unibond' has been most successful in helping to promote cost saving procedures - tube coating in oil cooler manufacture, using a non-corrosive flux in ribbon wound tube manufacture and using a quick bake oven in radiator manufacture. These are all valuable spin offs arising from the development programme. Serck now have the ability to switch rapidly from copper to aluminium should the price of copper rise suddenly and supplies become difficult to obtain. Future work on the use of cheaper solders could make the process more attractive even if the price of copper remains low.

CHAPTER EIGHT

R. & D. MANAGEMENT IN INDUSTRY - LITERATURE SURVEY

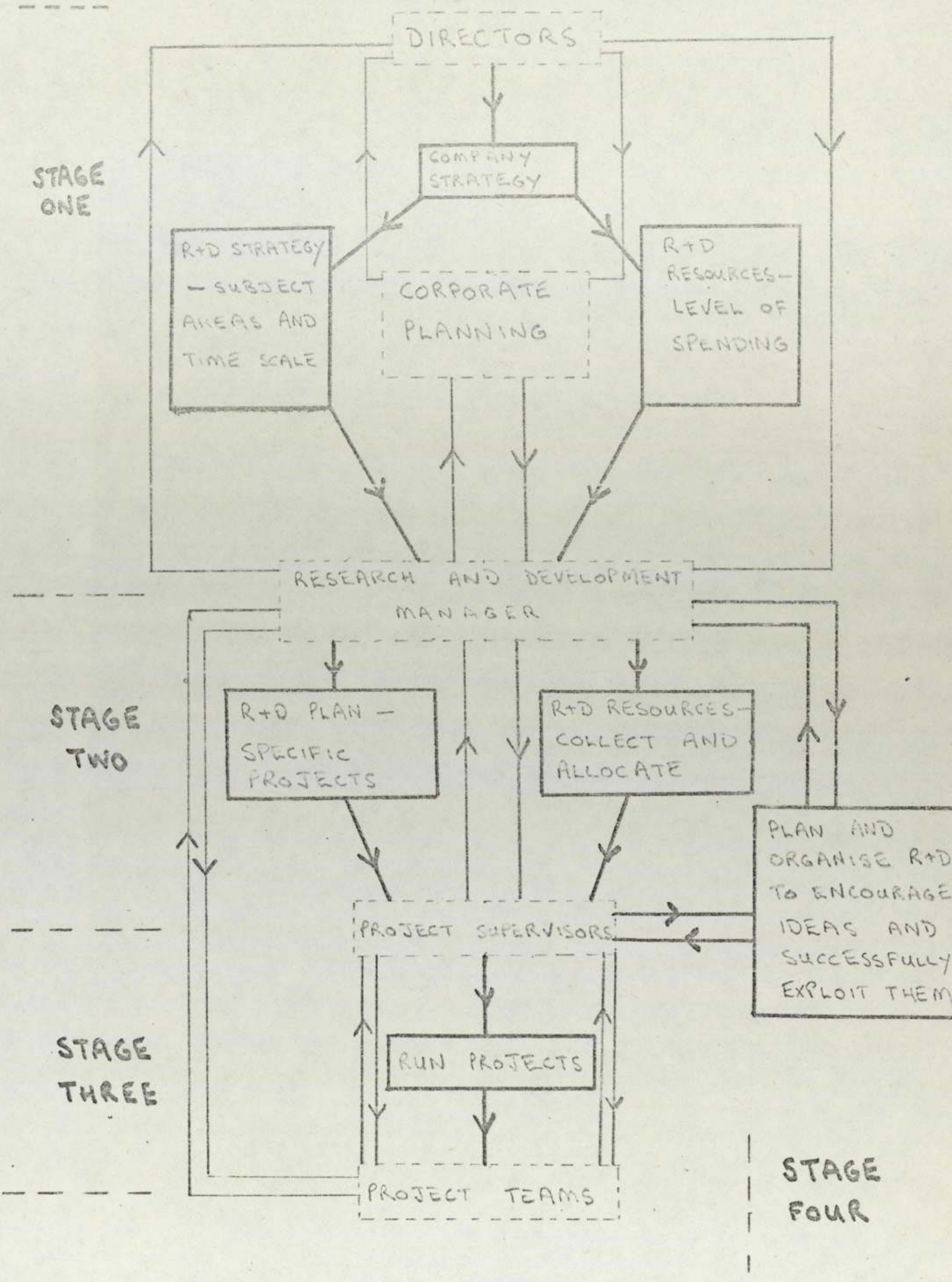
SECTION 1: INTRODUCTION

This chapter summarises the results of a literature survey on the management of research and development in industry. I have tried to pick out the main ideas in this area and fit them into a "model" of the R. & D. process, which is shown in Figure 1.

The model is in four parts - firstly the company strategy is decided which contains an allocation of money to R. & D. and an R. & D. strategy in terms of subject areas and time scales. The second stage is that of choosing specific projects and collecting the resources to run them. The third is that of running the selected programmes. Finally, in parallel to these, is a process of planning and managing R. & D. to encourage idea generation throughout the company and the successful conversion of ideas into commercially viable new products or processes.

In the chapter I consider each of these stages in turn and present a picture of the processes involved and the techniques used as described in the literature.

References 4, 5, 6.


STAGE ONE
DIRECTORS
COMPANY STRATEGY
R+D STRATEGY — SUBJECT AREAS AND TIME SCALE
CORPORATE PLANNING
R+D RESOURCES — LEVEL OF SPENDING
RESEARCH AND DEVELOPMENT MANAGER
STAGE TWO
R+D PLAN — SPECIFIC PROJECTS
R+D RESOURCES — COLLECT AND ALLOCATE
PLAN AND ORGANISE R+D TO ENCOURAGE IDEAS AND SUCCESSFULLY EXPLOIT THEM
PROJECT SUPERVISORS
STAGE THREE
RUN PROJECTS
PROJECT TEAMS
STAGE FOUR

SECTION 2: STRATEGY

The most important factor to consider when drawing up an R. & D. strategy is how well it fits in with the company strategy. Hopefully the company has a clearly defined long term plan which has been drawn up in consultation with the R. & D. Department, and other departments and is revised as necessary. The company plan may involve some technological forecasting and should certainly include a careful study of the company, its opportunities and the competition. The result would be a product-market strategy within which the role of R. & D. would be specified.

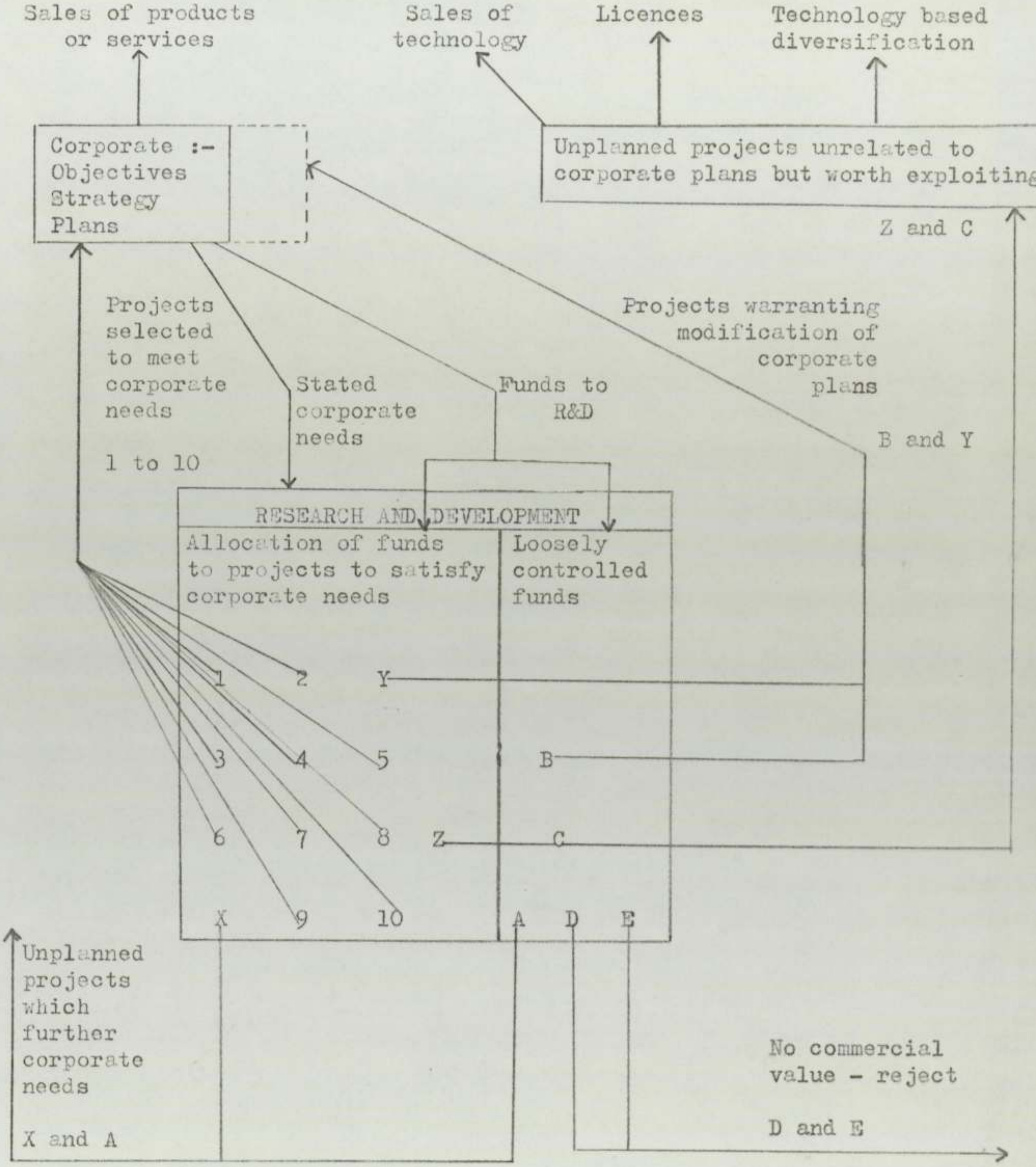
The R. & D. plan and budget are thus generated from the company plan, and there should be some allowance made for flexibility in the budget so that chance discoveries can be followed up. (See Figure 2.)

The important specifications of the R. & D. plan are a list of subject areas and an indication of the time scale to operate within. The list should contain both low risk, low pay off projects and high risk, high pay off ones, giving rise to a portfolio. The financing policy should be consistent - neither sharp cuts nor sharp increases. Different levels of resource will be required for different strategies - aggressive research is expensive, defensive research is less costly. The level of spending is also determined to some degree by the industry within which the company operates, and the size of the company.

References 1, 2, 3, 14, 30, 35, 36, 41, 46.

Figure 2

Investment in R. & D.



Projects 1 to 10 - Formal planned programme

Projects X, Y, Z - Extensions of or discoveries from planned programme

Projects A, B, C, D, E - Personal research

SECTION 3: PROJECT SELECTION AND EVALUATION

This is a two part process - firstly the ideas have to be found and this I will cover in Section 5. Secondly the projects should be evaluated to see if they are worth pursuing. The major problems are those of uncertainty and risk. The outcome, costs and returns of a project are rarely known in advance and so the selection process is based on informed guesses. The risk can be spread by using a portfolio system of project choice balancing high and low risk projects. The uncertainty should be reduced by a rigorous, and as far as possible, accurate evaluation of proposed projects.

The accuracy of estimates can be improved by training the assessors to improve their judgements, and analysing past results to try and derive an error factor. It has also been proposed to use incentive schemes to encourage accuracy. However the estimates will always remain guesses, and so no matter how complex the selection techniques are, the ultimate choice depends on the manager's judgement. Selection techniques are only an aid to this.

It is probably helpful if the review system is formal and explicit, as it provides a basis for discussion and co-operation between R. & D. and other departments. There are many suggested evaluation systems in the literature, the main types of which are set out below. For most companies and most projects the simpler systems are the best. The amount of time and effort devoted to selection should depend on the size of the projects.

Techniques

(a) Subjective ranking of projects.

(b) Review against a check list - this can be used to generate a project profile.

(c) Indices and scoring systems

(d) Discounted cash flow techniques

(e) Risk assessment - Decision trees, portfolio analysis, sensitivity analysis and others.

(f) More complex models - linear programming, utility models, computer based behavioural models and others.

The evaluation requires frequent review, and should become more thorough and quantitative as the project progresses. The simpler systems of check lists and scoring systems are useful initially. Discounting and risk assessments can be used at a later stage, where more information is available. It is best to use several different approaches to obtain as complete a picture as possible.

Resource Collection

This is dependant on the amount of money allocated to R. & D. It can act as a constraint on project choice. Resources should be chosen to match planned needs allowing some slack. Linear programming can be useful here if the R. & D. set up is large.

References 10, 14, 24, 30, 32, 37, 38, 39, 41, 44, 45, 48, 52

SECTION 4: RUNNING PROJECTS

There are two main activities involved in running projects - the initial planning of the projects, and controlling and reviewing their progress on a regular basis.

Project planning is aimed at getting a list of activities worked out so that resources can be allocated where required and any clashes between programmes in the portfolio avoided. Techniques useful in this area are research planning diagrams, which can be analysed mathematically to give times and probabilities of outcomes. Also contingency planning can be useful - potential problems and crises are looked at in advance and methods of dealing with them worked out.

Control is ongoing and should be based on the planning system. It is also useful to monitor the project selection criteria from time to time. If a project is going wrong, corrective action to modify or scrap it must be taken as soon as possible - costs escalate sharply the nearer the market launch point becomes. A formal control system ensures that all the relevant factors are considered.

The plan and control system should be based on a clear definition of the project in terms of objectives. The definition will become more precise as the project progresses and also more information will be available.

At the same time expenditure will increase rapidly. The control system must take these factors into account. The planning should be done on the basis of portfolio management, and it is a good idea to limit the number of projects in the portfolio, provided an acceptable spread of risk can be obtained.

References 17, 24, 30, 32, 56.

SECTION 5: GENERATING AND SUCCESSFULLY USING IDEAS

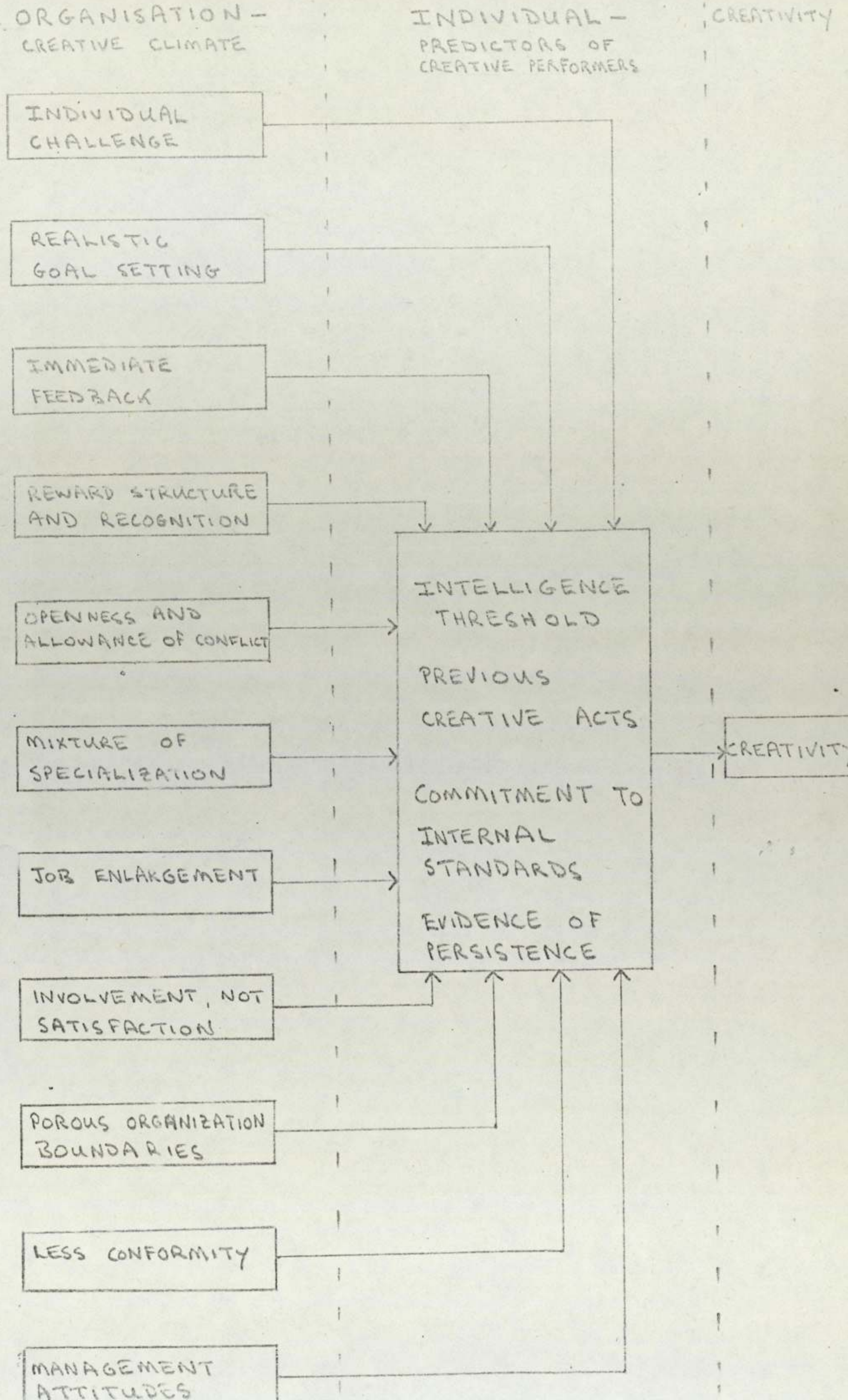
Ideas are vital to R. & D. They may come from inside or outside the company, but even if outside ideas are used it is often necessary to do some inventing to put the idea to practical use. Creativity can be encouraged by recruiting creative people, having an environment in which creativity is encouraged, and using problem solving techniques.

There are tests available which are claimed to select out creative people, but probably the best guide is the past history of the individual. The organisation's climate is vital to the encouragement of creativity - there should be some freedom for people to follow areas of interest - multidisciplinary exposure, good communications, tolerance of non-conformity and other factors. (See Figure 3). These requirements will conflict to some extent with those of the organisation, and the manager will have to minimise the detrimental effects of such conflict. There has to be some compromise between the need for planning and control, and the encouragement of creativity.

Techniques to stimulate ideas can be useful. These may be analytical - attribute analysis, morphological analysis, needs research and others; or non-analytical - breaking logical thought patterns - brainstorming, synectics, lateral thinking and others. It is important when using these techniques that the problem is carefully specified in advance. Good communications with outside academic and technical sources also help the flow of ideas into the company.

References 17, 30, 36, 42.

Figure 3


ORGANISATION - CREATIVE CLIMATE
INDIVIDUAL - PREDICTORS OF CREATIVE PERFORMERS
CREATIVITY
INDIVIDUAL CHALLENGE
REALISTIC GOAL SETTING
IMMEDIATE FEEDBACK
REWARD STRUCTURE AND RECOGNITION
OPENNESS AND ALLOWANCE OF CONFLICT
MIXTURE OF SPECIALIZATION
JOB ENLARGEMENT
INVOLVEMENT, NOT SATISFACTION
POROUS ORGANIZATION BOUNDARIES
LESS CONFORMITY
MANAGEMENT ATTITUDES
INTELLIGENCE THRESHOLD
PREVIOUS CREATIVE ACTS
COMMITMENT TO INTERNAL STANDARDS
EVIDENCE OF PERSISTENCE
CREATIVITY

SECTION 6: SUCCESS IN IMPLEMENTATION

Many studies have looked at the factors which influence success and failure in innovation. In general they have arrived at the same conclusions. The factors which help success are:

Good market analysis and an understanding of user needs.

Good communications in and outside the company

R. & D. strength

Individual commitment to the project - one or more people prepared to push for the project, who preferably have some influence in the company.

Other factors which are important are:-

A good project selection and evaluation system - the project must be of benefit to the company.

Good management and control of projects.

A source of ideas and a company receptive to innovation.

Innovation is a process of matching a need and a technology and so this requires good contacts with the market, and with development in science and technology. Also these sources of information must be linked.

References 10, 11, 14, 19, 21, 22, 27, 30, 43.

SECTION 7: ORGANISATION STRUCTURE AND MANAGEMENT

This is an important factor underlying success in innovation and it has been much discussed, mainly from a theoretical point of view. It is obviously vital that R. & D. management and top management in general are intelligent, flexible and receptive to innovation. Staff motivation and training are important as is the ability to overcome communications barriers and technology transfer problems. It is possible that the type of structure required depends on the stage of the innovation process being dealt with.

Good project selection and management is necessary, although the systems used must not be too rigid because of the uncertainties involved. The projects are best handled as a portfolio because this spreads the risk, and enables bottle-necks to be spotted in advance and dealt with. Consultation between R. & D. and other departments is helpful to the choice of good projects, and communications should continue throughout the life of the project.

The tie up between company strategy and R. & D. strategy is important if R. & D. is to usefully serve the company. The structure of the company and its policies can be related to its "technological profile". Each company has a unique set of characteristics and should organise itself around these. Many different types of structure have been tried - some of the more common include matrix organisations, new venture groups, special groups to encourage technology transfer and many others.

Probably the ideal is to use a number of structures, depending on the company, the type of research project and the stage in its development. For instance there could be a central research lab. organised by disciplines, for long term research. In addition a matrix organisation could be used to look after the majority of projects dealing with the present business and some new venture groups set up to run a few projects of major importance which could lead to diversification.

The variety is endless, and each company should from time to time examine its own structures critically to see if they are the most suitable ones for its present position. This could be incorporated into the long term planning process.

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CHAPTER NINE

R. & D. MANAGEMENT IN SERCK HEAT TRANSFER

SECTION 1: INTRODUCTION

This chapter describes the research, development and planning systems in Serck Heat Transfer. As I started this part of my project a series of changes were announced which heralded the formation of a new research and planning structure. This chapter compares the present and proposed systems with the literature based model set out in chapter 8.

The comparison is based on a series of interviews I conducted with senior managers and engineers at Serck Heat Transfer. I also visited Serck Audco Valves International to find out how their research and planning systems operated.

I begin by briefly outlining the past history of research in Serck Heat Transfer because this has had a significant impact on the present structure, and then considering the old and new structures in turn. I shall use the project I have been working on, the 'Unibond' project, as an example of the ways in which past history and the present system have affected the results and progress of development work in the division.

SECTION 2: THE HISTORY OF RESEARCH IN SERCK HEAT TRANSFER

Until the 1950's research in Serck was all product based - it was aimed at improving heat transfer performance and developing new types of fin surface and was controlled by the Chief Engineer. In 1949 the first research and development manager was appointed. He was responsible for research into surfaces and joining techniques. The development department was set up in the engineering laboratory and consisted of about 12 engineers and 12 technicians. Research was wholly centralised, was closely controlled and well run with a good information system.

Throughout the 1950's and 60's research grew in importance and is partly responsible for the growth and diversification of the company during that time. In the 1950's research was still heavily product orientated, but there was some process work done. In 1963 a small group was set up to look at product development and applied research. In 1967 Serck Heat Transfer was divisionalised along market lines with the aim of achieving high volume sales. Development was to be carried out in the divisions and so the central organisation was dismantled and the laboratory substantially cut in staff. The engineers were distributed among the divisions. The cut-back was sharp and sudden and much expertise was lost.

Also in 1967 a central research division was set up by Serck Ltd. This comprised a small central policy team, a laboratory and a computing service. The idea behind this was that there was a certain minimum effective size for research laboratories, and that there would be economies of scale. The laboratory worked for the other divisions on a repayment basis. In 1972 the laboratory was closed down because of a change in board policy - it was felt that the work generated was not relevant to the present businesses and the company's rapid expansion had caused cash flow problems. A policy of consolidation was adopted and divisional research departments were set up to replace the central facility.

Between 1967 and 1972 very little development work had been done in Serck Heat Transfer. In 1972 there was a further reorganisation into product based divisions, and the policy of aiming for high volume sales was changed. At this time the Advanced Development Department was set up as a result of the closure of Serck Ltd's. central research division. The department now has a staff of four engineers, two research students, and a manager.

SECTION 3: THE PRESENT SYSTEM

(a) Strategy

There is no explicit company strategy for new products to give long term growth or expansion. The development manager has tried to set up a research strategy but has been unable to obtain board approval for this, and so there is no long term research plan. A budget is submitted by the development manager for the resources needed and is paid for by the divisions on a percentage of turnover basis.

(b) Project selection and resource collection

Projects are selected by the development manager on an informal basis, and reviewed informally as they progress. A portfolio approach is not used - all the present projects are of the low to medium risk type, mainly cost cutting exercises either requested by the divisions or initiated by the Development Department. Resources consist of a small team of development engineers and the laboratory which acts as a central service to the whole company. The development engineers in the divisions, where present, are engaged in day to day production engineering rather than new product development.

(c) Running projects

There is an initial plan drawn up on a network. Monitoring and control are informal - meetings with the development manager and occasionally the divisions concerned with the project. A weekly meeting between the development department and laboratory staff has been set up to avoid bottlenecks and set priorities.

(d) Encouraging ideas and their successful use

The company does not at present actively encourage idea generation and creativity - contacts with outside science and engineering are not good, partly because there are few highly qualified scientists or engineers in the company to attend conferences and scientific meetings, and also little applied research is done on which to write scientific papers. The attitude of senior management has not been encouraging, partly because of history, and is reflected by a lack of development engineers in management positions. This has resulted in a falling behind in development and old fashioned products, particularly in Tubular Cooler Division, Air Cooling Division and H.O. Serck (radiator) Division.

Contact between research and the market is not good - when selecting projects, too little attention is paid to customers, and market research to find out their needs is not done.

Communications in the Company should be improved - although senior managers receive a monthly report from the development department all the general managers said that they didn't know enough about development work. This problem may be accentuated by a lack of development engineers in senior positions in the divisions - particularly H.O.S. where there are none. Communications with H.O.S. suffer also because they are geographically distant from the rest of the company.

R. & D. strength is now roughly half that of the mechanical engineering sector as a whole, and if the company is expanding it could well wish to spend more than the average. This would mean an increase of more than 100% in the present level of expenditure.

RESEARCH AND DEVELOPMENT EXPENDITURE

This is expressed as a percentage of turnover.

Figures are given for Serck Group, Serck Heat Transfer and the mechanical engineering sector of the industry.

YEAR	1964	65	66	67	68	69	70	71	72	73	74	75
Serck Group	0.9	0.9	1.2	1.5	2.3	1.5	1.0	1.1	0.9	0.8	0.6	0.5
Serck Heat Transfer	-	-	-	-	1.1	-	0.4	0.9	0.6	0.5	0.6	0.6
Mech. Eng.				2.1	2.1	1.6	-	-	1.0	-	-	1.0

Individual commitment in the development department is at present good, and at a high enough level in the company to be effective.

The financing system has a built in bias towards short term projects for the present business - some mix of central and divisional payment would be best.

The present structure in the divisions is too centralised and this leads to technology transfer problems. For example, at HOS the only liaison is with the divisional manager or the works manager but as it is the unqualified staff who actually do the work this leads to misunderstandings and mistakes.

Staff conditions need improving - particularly training and career progression.

The information recording and library system is inadequate - the system of projec files is toó skeletal to provide a useful reference document at the end of a project. There should be some system for regularly recording the progress of a project and the information gained from it. The library system needs supplementing for developmental use by having a central store of project reports, technical papers of interest, company literature on products and processes, and articles from journals, properly indexed and accessible.

Back up facilities also need supplementing - more space and manpower in the laboratory, regular management services contact, a buyer with specific responsibility for advanced development. Development engineers should control their own expenditure within the agreed budget limit.

The problems with the present system have arisen because of lack of central planning and motivation to change, and because of the history of development in the company. The short term projects are necessary and useful, but it is unwise to neglect the future of the business.

SECTION 4: THE NEW SYSTEM

(a) Strategy

A long term planning department is being set up and will report to the newly appointed marketing director who will also be responsible for development. This department will plan the company's future progress which may include growth by increasing overseas sales, by diversifying into new product areas and perhaps by acquisition of suitable companies. This plan will include an R. & D. strategy and also a centrally financed budget.

(b) Project Selection and resource collection

The development manager will select projects and collect resources. The department will be encouraged to concentrate more on long term projects. The manufacturing divisions will have small development teams to work on present products and markets.

(c) Running Projects

Projects will be run by project supervisors and the type of system used will vary with the type of project.

(d) Encouraging ideas and their successful use

Experts in the fields of heat transfer, materials and joining may be recruited to help raise the level of technical awareness in the company and foster links with outside science and technology. Transfer of staff between the centre and the divisions will also be used to help this. One of the aims of the new system is to change the attitude of the company to innovation.

The contact between research and the market should improve, as should communications in the company, aided by the transfer of staff, development departments in the divisions and a formal communications system that is to be set up between the centre and the divisions.

R. & D. strength should increase, but individual commitment may be at too low a level in the management structure of the company to aid progress. The financing system will help long term research, but it is perhaps too one sided. Some divisionalised financing would help maintain contact between development and the divisions.

The structure of project management may vary with the project. Some projects may be treated as new ventures or joint ventures, with people from the centre moving into the new business, some may be handled entirely in the divisions and others may be initiated in the centre and moved into the divisions, again involving a transfer of staff. The central facility is necessary to do the initial research on most projects, to act as a source of expertise and to co-ordinate divisional development. However it should not be used to control divisional development.

This system closely resembles the literature model. The details are not yet clear but the aims seem to be good. The greatest problem is likely to be persuading people to accept change and co-operate with the new systems.

Some areas appear to be neglected, and others need more consideration - these are discussed in detail in the next chapter.

SECTION 5: 'UNIBOND'

The 'Unibond' process was developed in Romania, and patents applied for in the U.K. in 1970. It was first heard of by Serck in March 1972, by the staff office for development and technology - part of the central research division. Some experiments were conducted on the process in late 1972, and when the results of these proved satisfactory, negotiations for a licence were started. In May 1974, representatives from S.H.T. saw the pilot plant operating in Romania, and in October 1974 an initial agreement was signed. The final agreement was signed in September 1975, and the technical details received in January 1976. In May and June 1976, a new method of bonding was developed from the Romanian process by S.H.T.

The licence negotiations took much longer than expected because the Romanians were initially very slow to respond, and later proved difficult to satisfy over the details of royalty payments in the licence. The initial experiments in 1972 were not followed up until 1975, and the development programme began in October 1975. It was planned to continue until 1978 by which time three plants would have been installed in S.H.T. and a programme of environmental tests would have indicated whether aluminium could successfully be used instead of copper in radiators.

It was soon discovered that the process as bought was probably not commercially viable because the plant was expensive, the combinations of materials best at resisting corrosion were expensive, and also the hot oil posed safety problems. Luckily, the development programme led to a much simpler, cheaper process which used standard plant, cheaper materials, and was not hazardous. This new process was commercially attractive.

The change in approach has resulted in much more research work being done, and has delayed the development programme. This delay has been increased by the problems of finding time at H.O.S. to make field trials, and coated tubes, and also communication problems with H.O.S., which resulted in a large number of bad units being built. Also, the present prices of metals, with copper being very low, have slowed the implementation of the new system. These three factors have led to a delay of at least a year in the programme.

The history of this project provides some useful examples of the faults of the present system of R. & D at S.H.T.

(a) The initial experiments, if continued as part of a basic research programme on aluminium soldering, could have led to the present 'Unibond' process without having to buy the Romanian process.

(b) The development programme's progress indicates the necessity of having a sound base of in-house expertise when ~~when~~ buying in knowledge.

(c) The need for a comprehensive system of project choice is clearly indicated - this should involve market research, technical research, and a financial assessment.

(d) A formal planning and monitoring system could have helped to avoid delays and bottlenecks - more research could have been planned initially, before plant development and field trials were started. It is also clear that this system needs to be flexible, with regular updating of the plan.

(e) The communications problems with H.O.S. could have been alleviated by having development engineers in the division in senior positions. Meetings with the divisions concerned, when held regularly, were a useful way of keeping everyone informed of progress.
More manpower back-up in the engineering laboratory might have speeded up the development programme.
A good information recording system would have saved some confusion over the experimental work.
Some formal arrangements to use production facilities for making experimental units would have saved time.
The best project management structure for this type of development would be where the initial work is done in the centre and then the project is transferred to the divisions concerned at the plant specification stage. This would involve continuing liaison with the divisions throughout the later stages of the development and possibly a transfer of staff from the centre to the divisions.

The project has helped to initiate some improvements in the present R. & D. system:-

(a) There have been regular meetings with the divisions concerned with the process

(b) The development has helped re-establish the position of development at S.H.T.

(c) A regular series of meetings with laboratory staff has been started to help plan the development work.

(d) There has been some valuable spin off from the project, both in terms of cost cutting in the manufacture of some heat exchangers, and by establishing the need for market liaison, field trials and some basic research.

SECTION 6: CONCLUSIONS

I think the new system is better for the future of the company than the present one, although this may have been an essential first step in re-establishing the credibility of research and development in the company. There are a number of areas in the new system which will need careful consideration and I think there are some important factors not yet included. The next chapter sets out my suggestions for the organisation of the research and planning system.

One factor of great importance underlying what has happened at Serck Heat Transfer is that of stability. Too much sudden change is extremely damaging to the morale and progress of departments and companies. If the company is to grow successfully in the future, the senior management must be prepared to make a long term commitment to the planning and research system. It is essential that it is given ten years to prove itself and is not cut back sharply at the first hint of a cash shortage.

CHAPTER TEN

RECOMMENDATIONS FOR R. & D. MANAGEMENT IN S.H.T.

A. STRATEGY

The coporate plan should consist of a set of objectives and the strategies to be used to reach them. The objectives could be product and market based with quantified targets and specific time-scales for such factors as market share, turnover and profit.

The choice of strategy should be based on an inspection of the company's environment, leading to a forecast of what the company might do; an analysis of the company's capabilities - what the company can do, and finally a choice of what the company should do. This is obviously an iterative process which must involve all levsls of management in the company.

The plan will need to be reassessed frequently, and the planners will need good contacts with the company to ensure a sufficient input of information, and to monitor the company's progress. It is particularly important that R. & D. is involved in the planning process.

From the plan there should emerge an R. & D. strategy. This would include well defined subject areas, an indication of the time scale desired and an idea of the acceptable level of risk. This strategy should be based on a portfolio approach where some mix of low and high risk projects is undertaken. The precise strategy will depend on the capability of the company and on the markets it is in.

I think that, in its present markets, the company should concentrate on a defensive and licensing in strategy with the emphasis being on product and process improvements to cut manufacturing costs, using existing technologies and short to medium term projects. At the same time, the company should keep an eye open for possible future threats and opportunities. As the new research structure becomes established in the company and the company's attitude to change improves, research could become more aggressive, looking for new products and new technologies, both in the existing markets and in new markets.

A suggested breakdown of the central research department's budget would be to spend 5% on applied research, 20% on new products or processes, 50% on major improvements to present products and processes, 20% on minor improvements and 5% on technical services. The divisional development departments would spend most of their time on product and process improvements and on technical services - 5% on new products and processes, 20% on major improvements, 50% on minor improvements and 25% on technical services.

The research and development budget should be based on the company's long term needs for new products and improvements to present products. It is important to maintain stability in research - no sudden cuts or increases. Ideally the budget would be split between the centre and the divisions. The company would provide the centre with money to support applied research, new product work, and the initial stages of major improvement work. The divisions should be allowed some minimum figure when their targets are set to spend on R. & D., both in the division and bought from the centre. They may spend more or less than their allowance on their own department and paying the centre for minor product improvements, technical services and the later work on major product improvements.

This would provide a way of monitoring the centre's success in doing useful work for the present business and also the use the divisions make of research and development - both central and divisional. Ratios such as R. & D. expenditure vs Production expenditure, Sales expenditure and turnover could be used for comparison.

B. PROJECT CHOICE

Projects should be chosen to conform with the company plan, and their effect on current programmes must be assessed. The amount of time and effort devoted to selection should depend on the cost and importance of the project.

Where a high degree of uncertainty surrounds the outcome of a project - particularly in the early stages of longer term research, I would recommend the use of a comprehensive checklist leading to a project profile. (See Fig.1). This system ensures that all the relevant factors are explicitly considered. The choice will involve a considerable element of judgement.

Where the level of uncertainty is low - in development and shorter term research, and in the later stages of all projects, the assessment can be more quantitative and rigorous. The checklist will still be useful, with the factors considered more thoroughly. The financial analysis can be supplemented by a detailed cash flow statement, DCF

Figure 1

Check list of project evaluation criteria

A. *Corporate objectives, strategy, policies, and values*

1. Is it compatible with the company's current strategy and long range plan?
2. Is its potential such that a change in the current strategy is warranted?
3. Is it consistent with the company 'image'?
4. Is it consistent with the corporate attitude to risk?
5. Is it consistent with the corporate attitude to innovation?
6. Does it meet the corporate needs for time-gearing?

B. *Marketing criteria*

1. Does it meet a clearly defined market need?
2. Estimated total market size.
3. Estimated market share.
4. Estimated product life.
5. Probability of commercial success.
6. Likely sales volume (based on items 2 to 5).
7. Time scale and relationship to the market plan.
8. Effect upon current products.
9. Pricing and customer acceptance.
10. Competitive position.
11. Compatibility with existing distribution channels.
12. Estimated launching costs.

C. *Research and development criteria*

1. Is it consistent with the company's R & D strategy?
2. Does its potential warrant a change to the R & D strategy?
3. Probability of technical success.
4. Development cost and time.
5. Patent position.
6. Availability of R & D resources.
7. Possible future developments of the product and future applications of the new technology generated.
8. Effect upon other projects.
9. Environmental effects.

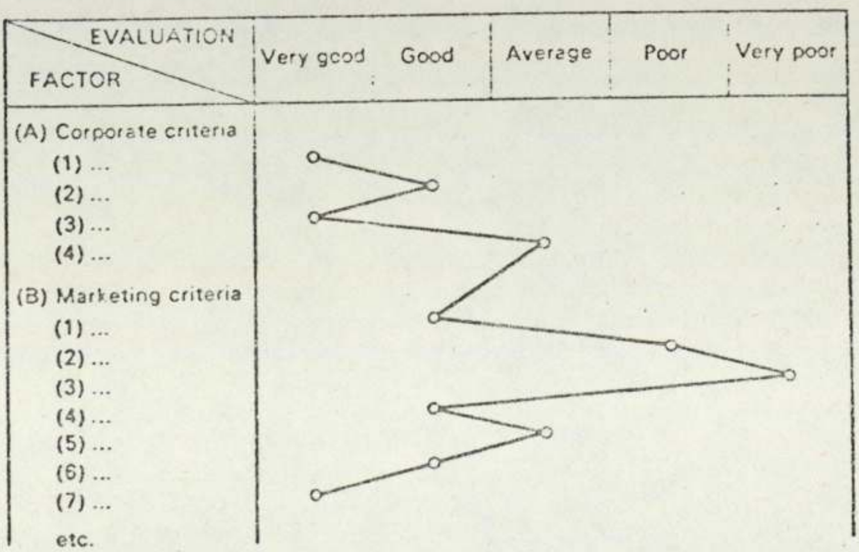
D. *Financial criteria*

1. Research and development cost:
   (*a*) capital
   (*b*) revenue.
2. Manufacturing investment.
3. Marketing investment.
4. Availability of finance related to time scale.
5. Effect upon other projects requiring finance.
6. Time to break-even and maximum negative cash flow.
7. Potential annual benefit and time scale.
8. Expected profit margin.
9. Does it meet the company's investment criteria?

E. *Production criteria*

1. New processes involved.
2. Availability of manufacturing personnel—numbers and skills.
3. Compatability with existing capability.
4. Cost and availability of raw material.
5. Cost of manufacture.
6. Requirements for additional facilities.
7. Manufacturing safety.
8. Value added in production.

Project profile

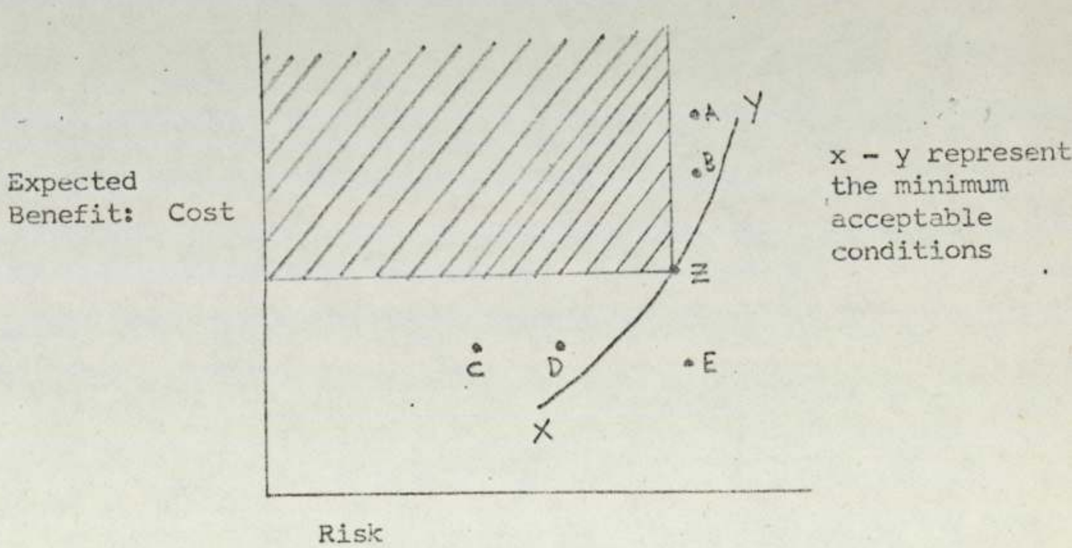


From - B.C. Twiss; reference 30.

analysis, risk analysis and sensitivity analysis to give as complete as possible a picture of the likely outcome (see below). It is very important that all projects are carefully assessed in this way so that bad projects can be terminated as soon as possible.

(i) Qualitative risk analysis - the two types of risk involved in R. & D. projects can be expressed as the probability of technical success P_t, and the probability of commercial success P_c. The risk that a project will fail is then $1 - P_t \times P_c$.

The results of risk analysis can be used to compare the desirability of projects both in relation to each other and in relation to the portfolio as a whole. In the diagram below it can be seen that project A is preferable to B, C is preferable to D and E is rejected.



The shaded area represents the set of acceptable outcomes for the portfolio, with Z being the minimum acceptable benefit:cost ratio. Thus a choice of projects A and C would lead to an acceptable overall position, whereas a choice of A and B, whilst giving a higher benefit cost:ratio, leads to an unnaceptably high risk level.

Obviously this is only a rough comparison but it is a suitable means of identifying those projects which can be readily rejected. The selection of others will depend on further analysis.

(ii) Sensitivity Analaysis - this is simply identifying areas where the estimate of business success of a project is sensitive to errors in the figures used. Resources should be allocated to obtain better information in the sensitive areas, and then decisions made on the strength of the better estimates.

Some simple indices can also be useful when choosing between development projects (see fig.2).

The accuracy of estimating during project choice could be improved by feedback of eventual results, and an analysis of any major variations from the estimates. An intensive effort by the R. & D. department in the early stages of a project can help to provide more certain information at an early stage for little extra cost - this would help the early identification of potential failures.

Small projects can be easily assessed by the R. & D. manager in consultation with other parts of the company concerned.

Larger projects concerning one or more divisions could be assessed and monitored by a committee of 6 or 7 people including the development manager, the project supervisor (central or divisional) and representatives from the division or divisions concerned, including people from sales, production and accountancy. Other interested parties could be kept in touch by being sent the committee's papers and being briefed by the project leader or committee chairman.

As an extension of this system it would be useful to have a permanantly established committee to choose and monitor all large projects which do not directly concern the present business. This could be composed of the development manager, a representative from marketing and the general managers of the operating divisions or their representatives, This committee would meet every three months to consider major new project proposals suggested by any member of the committee, and to review the progress of the existing major research projects. This would be one way of involving the whole of the company in the central research effort.

Some arrangements should be made for the centre to use divisional equipment for model building and trials, or pilot plant equipment should be provided for the centre. The arrangement could be negotiated at the start of a project, based on the plan, and revised as necessary.

FIGURE 2.

There are many project ranking indices, most of which are useful if the data is accurate. An example of one of the simpler types of index is shown below.

RATING SYSTEM

Criterion	Question	Range of answers	Numerical rating
Promise of success (*P*)	What is the best estimate of the promise of technical success consistent with known economics and the state of the art?	Unforeseeable	1
		Fair	2
		High	3
Time to completion (*T*)	How long will it take to complete the research effort from this time forward?	Greater than 3 years	1
		1 to 3 years	2
		Less than 1 year	3
Cost of project (*C*)	How much will it cost to complete the research effort from this time forward?	Greater than $1 million	1
		$100,000 to $1 million	2
		Less than $100,000	3
Strategic need (*N*)	To what extent is successful research needed from a market standpoint?	No apparent market application; must be developed	1
		Desirable to maintain, reinforce, or expand position within market applications currently served	2
		Essential in relation to current or projected markets within market applications not currently served	3
Market gain (*M*)	What is the net market gain potential for the company after taking into account losses through product replacement?	Less than $1 million/yr.	1
		$1 to $10 million/yr.	2
		Greater than $10 million/yr.	3

The Index = P x T x C x N x M

The best score possible is 243 and the worst is 1. Using the project scores, the research manager can arrange his programme in relation to various budget amounts. The values for the different criteria can also be shown in two-way tables to illustrate various features of the programme such as success versus market gain in relation to budget request.

(See Mottley and Newton, reference 44)

C. RUNNING PROJECTS

The project must be carefully defined , and its objectives specified. This information will need to be revised as the project progresses. The next step is to allocate resources, bearing in mind the effect of this programme on the rest of the portfolio. It is usually better to concentrate resources on a few projects at a time, with priorities determined by their cash flow characteristics. A project team and project manager should be assigned to each project.

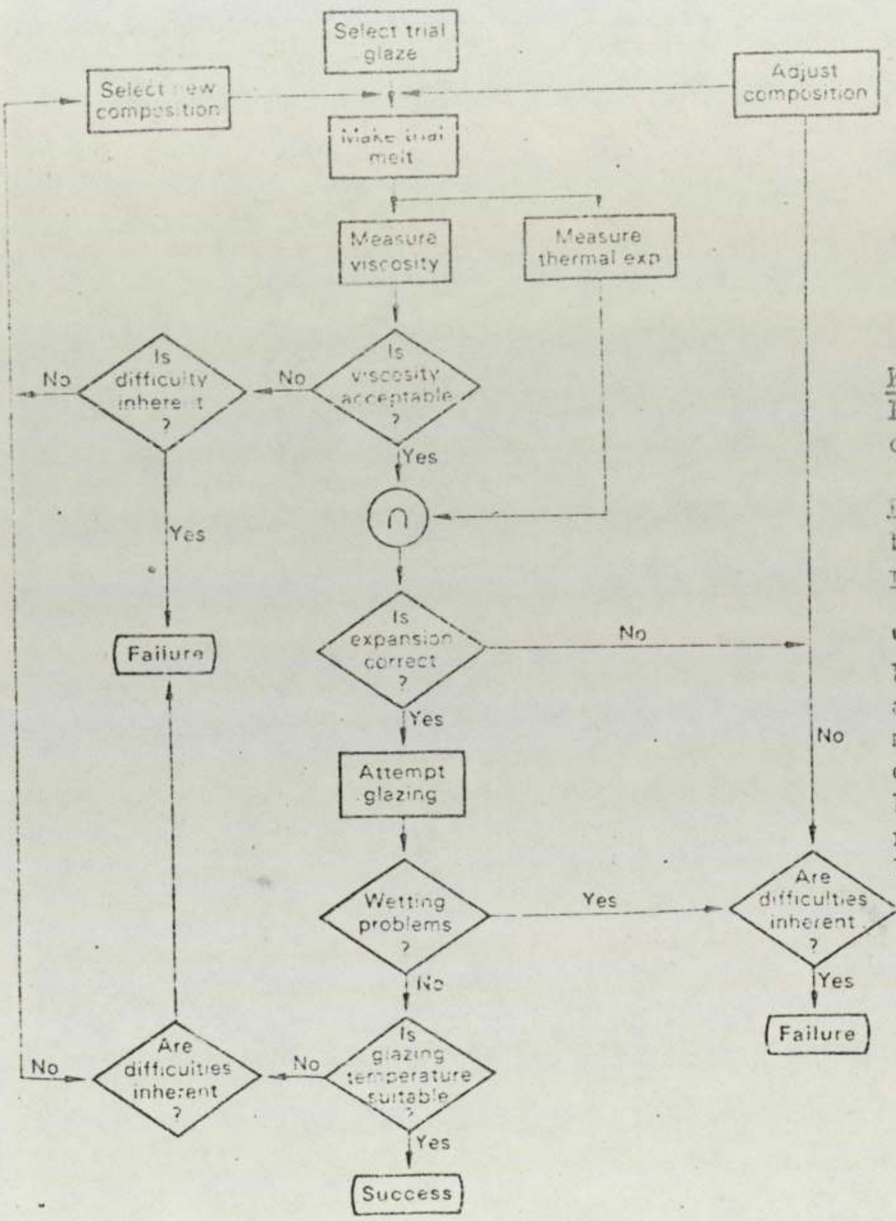
It is important to plan projects carefully at the outset - the best way of doing this is to use a network diagram. Where there is a little uncertainty as to outcomes and times, a critical path analysis can be used. This gives an indication of the time the project will take, the critical parts of the programme affecting this time and how a crash programme will cut the time and alter the cost.

Where there is some uncertainty surrounding a project, a system of research planning diagrams is more useful. They are more flexible and subjective probabilities can be applied, permitting quantitative anyalses of the costs and time probabilities to be made (see Fig.3).

The main purpose of these planning systems is to aid effective project control. They must identify critical events at which major reviews of the project are desirable, and provide a basis for regular monitoring of progress. The plan, along with the project definition and objectives, and the original selection criteria are the standards which provide the basis of control. The assessment should become more rigorous and quantitative as the project proceeds. Feedback of the results of projects compared to the estimates could help to improve the accuracy of forecasting.

Figure 3

Example of a research planning diagram

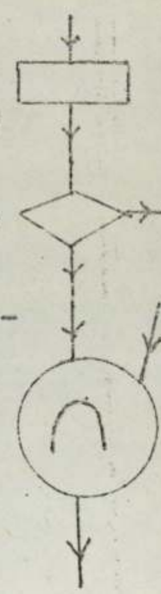


Key

Process or activity

Decision between two paths

"And" gate - both prior activities must be complete before the next one begins



Source: D.G.S. Davies, 'Research Planning Diagrams', *R & D Management* Vol 1 No 1 Oct 1970

There should be regular monitoring of costs, times, and the progress of the work using a standard recording system.

A record of the trends in these figures provides a useful picture of the project's progress. (See Figs.4 and 5). The necessary information for this could be more easily collected if all development staff kept a notebook in which project work was recorded on a daily basis, supplementing the present working files system. Also it should be possible to discover how much has been spent on each project every month.

At major review points the project's progress should be thoroughly reviewed, the selection criteria reassessed, and if necessary, the project objectives and plan altered. A decision must be taken at these points whether to proceed with the project or to stop it.

The project plans, objectives, and selection data should be incorporated into the project files and the monthly progress reports, major review documents, and any other relevant papers added. The proposed laboratory notebook and present working files would provide all the necessary data.

D. ENCOURAGING IDEAS AND THEIR SUCCESSFUL USE.

There are several ways in which idea generation could be encouraged in S.H.T.:-

(a) Recruit creative people

(b) Conduct some basic research

(c) Recruit experts in fields of interest to S.H.T. to act as consultants.

Figure 4

Date of review :	Reviewed by :	
Project title :		Project no. :
Objectives :		
Time of completion :	Estimated cost :	Start date :
Technical progress in this period :		
	Technical feasibility index : *	
% Completion :	Projected completion date :	

Cost of programme :	This period	To date	Future
Labour Materials Laboratory and tests Outside (Divisional)			

% of original cost estimate now spent :

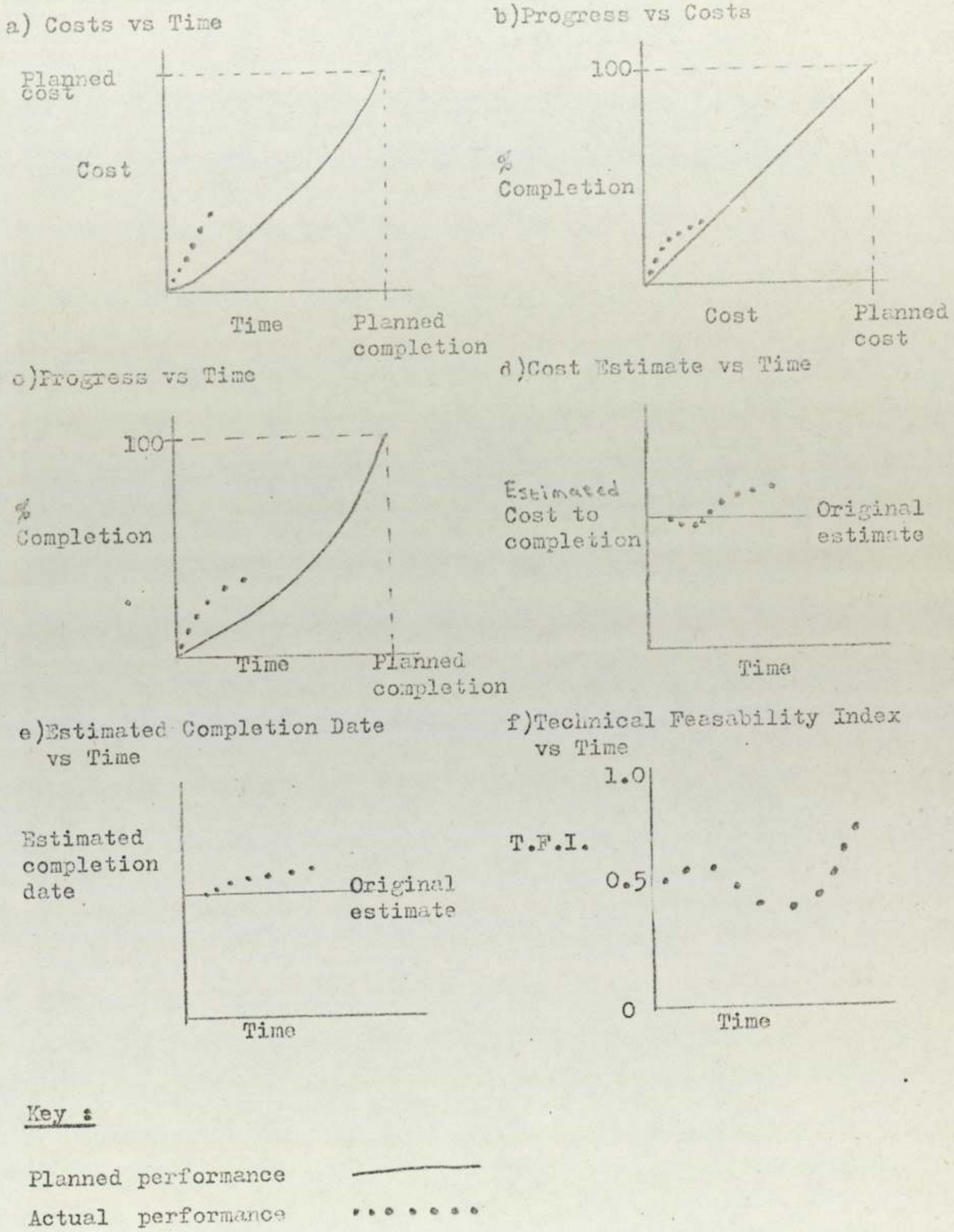
Any recommended changes in programme plan or objectives :

Main factors causing any delay or unexpected expense :

* The technical feasibility index starts at 0.5, and is increased towards 1 if difficulties are being overcome, or decreased towards 0 if unexpected difficulties arise. It serves as a measure of the project leader's technical pessimism or optimism and its movements with time are a useful guide to a project's progress.

Figure 5

Trend Analysis of Review Data



(d) Improve the information storage and retrieval system

(e) Use creativity stimulating techniques.

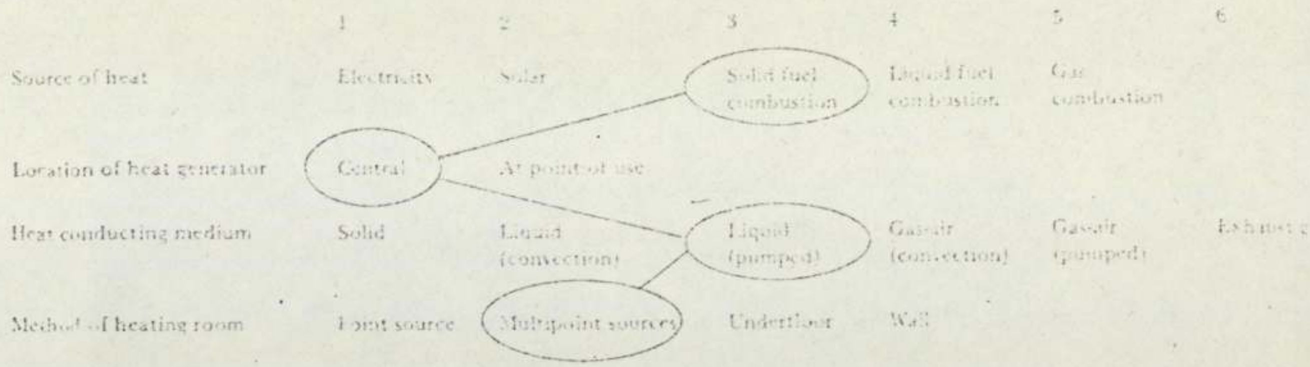
A good information storage and retrieval system would not only be of use to R. & D.,but also to corporate planning and the company as a whole. This would include project files, papers of interest, patents, text books, notes on useful techniques, reference sources, literature from other companies and internally generated data and reports on such areas as markets, product costs, manufacturing methods and historical sales data. There would need to be a good indexing system, and it might be necessary to restrict access to some of the information.

Some of the techniques for encouraging idea generation could be of use to the company - in particular the analytical methods such as attribute analaysis, morphological analysis and technology monitoring.

(a) Attribute analysis: this system uses a matrix to examine the possible relationships between two lists of parameters. For instance, a list of the attributes of a technological advance can be related to a list of possible practical applications. The parameters in the list must be of the same type, and should be exhaustive.

(b) Morphological analysis: in this, the main features of a problem are identified, together with ways of achieving each of them. All possible combinations of alternative solutions can then be considered. In the example below the ringed path would represent a coal-fired central heating system using pumped hot-water and radiators.

Partial morphological table for room heating



From B.C. Twiss; reference 30

(c) Technology monitoring: this is a rigorous examination of the environment as represented by information reaching an individual. A storage and cross-indexing system are used to suggest areas where a new development, combined with existing knowledge, makes possible an innovation. This technique also provides a possible spin-off from the random association of pieces of information during the review and indexing process. A suggested scheme is where items are recorded in a 'Journal' under four headings - date, event and technical economic data, possible significance, and things to consider. The list is then subjected to frequent evaluation and review to monitor the speed and direction of progress of new technologies.

There should be a much greater inflow of ideas from the divisions - particularly sales and marketing. Typically only ¼ to ⅓ of ideas would come from R. & D., these being mainly the more radical and innovative ones.

Communications within the company could be improved if formal systems were set up such as the proposed project selection committee which could meet monthly or quarterly to monitor the progress of large projects and consider major new project proposals. The monthly report system, staff transfers and development departments in the divisions will also help.

Individual commitment to a project is an important factor in its success - particularly at the level of the "business innovator", the individual who is responsible within the management structure for the overall progress of the project. This emphasises the need for development supervisors in positions of influence within the management structure of the company.

The staff need a career progression and performance assessment scheme, including facilities for further training and salary increments, particularly if it is intended to move people in and out of the centre regularly. At present senior technical staff have few promotion prospects in S.H.T. and a narrow salary structure.

The structure of development and project management needs careful consideration. Different types of project require different structures which should be tailored to help technology transfer and communications. There will be four main classes of project:

(i) New products or processes which lie outside the present business could be developed in the centre to the pilot plant stage. The subsequent work could be done on a new venture or joint venture system where people from the centre might move into the new business with the project.

(ii) New products or processes which will be placed in one of the present divisions could be developed in the centre, possibly using some of the divisional staff. The project team would then supervise the installation of the project in the division - again, staff could be transferred or seconded to the division to sort out any initial problems.

(iii) Major changes in existing products or processes could be developed by both the centre and the divisions concerned on a matrix basis, with the centre controlling the project - particularly when several divisions are affected.

(iv) Minor changes in existing products or processes could be carried out entirely in the division concerned with the centre providing advice, if needed, and co-ordination if several divisions are involved.

It is important that research and development is not over-centralised, resulting in communications problems and potential isolation from the existing business. Also it should not be completely decentralised, because this leads to a neglect of the future of the company.

CHAPTER ELEVEN

CONCLUSIONS

SECTION 1: INTRODUCTION

In this chapter I will examine the effect of the new manufacturing process on the industrial organisation, summarising the work discussed in the preceding chapters and giving my conclusions on the project.

The research has involved both practical exercises such as the cost comparisons, experiments on fluxes, environmental testing and market research; and a more general look at the organisation - in particular a comparison of the theory and practice of R. & D. management and planning.

The new process has affected the organisation at both these levels. In a practical sense it has led to the alteration of production methods, and it has highlighted some of the strengths and weaknesses of the organisation of R. & D. in Serck Heat Transfer.

I will start by examining the new process - what it is, the history of its development and the results. I will then look at the industrial organisation and how it has changed during the project. I shall continue by discussing the effect the new process has had on the organisation and conclude with a discussion on the future of the process including an analysis of the benefits gained from this project.

SECTION 2: THE NEW MANUFACTURING PROCESS

The 'Unibond' process is a method of soldering which provides the ability to join aluminium to itself and other metals easily in air, using non-corrosive fluxes and low melting point solders. The novelty of the process lies in its use of a group of weak organic fluxes not normally considered suitable for soldering aluminium.

The oil bath process, on which the licence was bought, was not commercially viable. It used expensive plant and was potentially hazardous. The baking process that was developed from this uses cheaper plant and poses no safety problems. The major difficulty with this process is that it seems to be necessary to use expensive solders to obtain a corrosion resistant product. The use of cheaper solder leads to a high risk of corrosion at the point where the aluminium touches the solder. This problem has to be resolved in any method of manufacturing aluminium heat exchangers. It seems that there is an inevitable link between product cost and quality in terms of corrosion resistance. A further factor which has impeded the success of the process has been the very low price of copper which has meant that the use of aluminium as a substitute has not been economically attractive.

The technical development of the process has been successful, although at first the change from the oil bath method to baking caused some confusion and delay. The project was no longer concerned only with developing plant to use a well defined process. It was now necessary to develop the process, involving research into the use of different fluxes, solders and aluminium alloys as well as the parameters of soldering such as temperature and time. Some of the problems experienced during this stage of the development programme were caused by faults in the organisation. For example, communications between the central development team and the radiator manufacturing division were not good enough, and there were many misunderstandings.

The process development was completed by mid 1977, having taken 1½ years - almost twice as long as originally planned. Plant design programmes are continuing - a system for radiator manufacture has been completed and some new plant installed, a technique for oil cooler production is at the pilot plant stage, and some other applications are being investigated. Aluminium is not in use in heat exchangers at present, however, because the low price of copper makes it unnecessary.

The development has led to small cost savings in radiator manufacture and may give some cost savings in oil cooler manufacture even if aluminium is not used. The ability to switch easily from copper to aluminium may prove to be very useful as copper prices tend to rise very sharply from time to time. Also, the field trial programme is a valuable exercise and may give some interesting results. The future of the 'Unibond' process would be more assured if cheaper solders could be used without endangering the corrosion resistance of the product. This would probably mean the development of a higher temperature soldering system which used cheap high zinc content solders.

SECTION 3: THE INDUSTRIAL ORGANISATION

Serck Heat Transfer is an operating division of Serck Industries Ltd., the British holding company for Serck Ltd. It is organised into semi-autonomous manufacturing groups and a central service group which includes the development department. The structure of Serck Heat Transfer given in chapter one has been altered recently. There are now only three manufacturing groups - Air cooling division, Tubular cooler division and a new Engine equipment division incorporating H.O. Serck (radiator) division, Aircraft equipment division and Small engine cooler division. These three divisions are run by general manager/directors who sit on the board of Serck Heat Transfer, and are of roughly equal size. Some parts of the central services group, including the after sales division, have been transferred into the divisions in order to increase their autonomy.

Earlier changes in the structure of the central services group included the appointment of a marketing director who is also responsible for overseas sales, long term planning and research and development. A long term product planning manager was appointed at the same time. The aim of these changes was to draw up and implement a long term plan for the future growth of the company and establish a corporate planning system.

There are probably some further rearrangements yet to be made within the company - in particular the structure of research and development is likely to be reassessed in the light of the increased decentralisation of the company. It is possible that small development departments will be established in the divisions to deal with short term projects and product improvements liaising with the central R. & D. group. This group would then be free to concentrate on longer term research projects which will arise from the company plan.

Because these changes in the structure of the industrial organisation are so recent, and incomplete, it is not possible to judge the effect they will have. The corporate planning function will be a valuable addition to the company and is long overdue. It should have good links with research and marketing but will need to ensure the maintenance of close contacts with the manufacturing divisions. I think that the central functions of marketing, research and planning will need to grow in the near future - at present they are too small to cater for the needs of a growing company.

There is a possibility of the manufacturing divisions becoming too independant - extreme decentralisation is as bad for a company as too much central control.

Some form of central co-ordination is needed to avoid duplication of effort and to encourage good communications within the company. This is particularly so if an effective career progression scheme is to be established and the movement of staff within the company is to be encouraged.

Finally there is a danger that the directors of the company will become over involved with the day to day business, thinking too little of the long term future of the company. General manager/directors will inevitably attach a greater urgency to the short term problems of their divisions than to the longer term prospects of the whole company.

SECTION 4: THE EFFECT OF THE NEW PROCESS ON THE INDUSTRIAL ORGANISATION

The effect of the new process on the industrial organisation has not been as great as was hoped. There have been some alterations in the method of radiator manufacture, e.g. cost saving by using a quick bake oven and a commercially available non-corrosive flux. A tube coating plant for the manufacture of guided flow oil coolers using the 'Unibond' fluxes is at the pilot plant stage. This will cut product costs by using less solder than the present dipping process. Also, the benefits of using the 'Unibond' fluxes in the manufacture of ribbon wound tubes are being investigated.

These effects are by-products of the development of the 'Unibond' process. The environmental test programme and my market research exercise have been useful to the company, although having no immediate effect. A further potential benefit is that the company can now switch fairly easily from using copper to using aluminium if the price of copper rises. This may have a significant effect on the profitability and market position of the company in the future.

The development of the new process has also played some part in re-establishing research and development in Serck Heat Transfer. In particular it has helped in the formation of contacts with the manufacturing divisions and in setting up procedures such as the regular planning meeting with the laboratory manager. In addition, the progress of the development project may have an effect on the future shape and organisation of research and development in the company. It has highlighted the weaknesses of the present system and could provide some useful lessons for any future reorganisation.

SECTION 5: DISCUSSION

The development of the new process has had little direct effect on the organisation, although this may change if the price of copper rises sharply. This is a distinct possibility because of the unstable political situation in the major copper producing countries - Zaire, Zambia, Chile and Peru. The project has had some effect on the structure of the organisation - in particular in the research and development department. Again this may increase in the future as lessons are learnt about the weaknesses of the present system. Although the project has not been an immediate success, it may prove to be a useful experience for the company.

The project has, however, been a success for me. This is at least partly due to its failure to achieve its objectives. If all had gone smoothly I would have learned much less. During the course of the project I have looked at soldering, accountancy, market research, metallurgy, management science and the theory of organisations. This breadth of interests has been, for me, one of the most exciting features of the work.

In conclusion I would like to make two general comments. Firstly, there is a very great gap between much that is written about organisations and management in the journals and the actual practice in industry. This is unfortunate because although much of the theorising is of little practical value, some of the work could be of great use to managers and could improve the efficiency and profitability of industry.

Secondly, it is counter-productive for an organisation to concentrate too much on the short term problems of making and selling its products, neglecting its future, both in terms of new product research and manpower development. This leads to a situation of stagnation, and ultimately to the death of the organisation. It is a difficult and lengthy process to repair the damage this neglect causes.

THE EFFECT OF A NEW MANUFACTURING PROCESS ON AN INDUSTRIAL ORGANISATION

DAVID JOHN SAUNDERS

DOCTOR OF PHILOSOPHY

JULY 1978

APPENDICES

APPENDIX TO CHAPTER TWO

CRITICAL PATH ANALYSIS

Section One : Introduction

One of my first jobs at Serck was to help plan the development programme. Each of the five projects had been set out in some detail and rough times allocated to them. I divided the projects into a series of activities and estimated a time for each of them. I then drew networks for all five and analysed these using a critical path analysis computer programme supplied by Honeywell. The resulting print out listed the activities and their durations and gave the earliest and latest start and finish dates for each activity. It also indicated the critical activities and the amount of free time or "float" available on the others.

I compared these analyses to see if resources in the engineering laboratory or drawing office were likely to be over-stretched at any time and drew up a chart to help monitor the progress of the projects.

Section Two : An Example

As an example I shall show how the environmental test programme was analysed. The initial plan is shown on pages 2 to 4. This was divided into activities and an estimated duration given to each - these are shown on page 5. A network was drawn (page 6) and the figures analysed by computer. The resulting print out is shown on pages 7 to 9.

PROGRAMME FOR THE PRODUCTION OF ENVIRONMENTAL TEST UNITS AND FIELD TRIAL UNITS.

PROGRAMME OBJECTIVES.

1. Selectively apply the Serck 'Unibond' process to the manufacture of test units, field trial vehicle and other such block radiator units.

2. Evaluate the performance of these units and assess the life expectancy of various base metal materials and solders relative to their application.

OBJECTIVES FOR EACH ACTIVITY.

Activity.

1-2 Specify applications:-

With the help of the operating Divisions concerned select product applications for the development programme.
Have provisional discussions with Manufacturing Divisions on availability of component parts. Obtain estimates of labour involvement from each Division including Engineering Laboratory.

2-3 Specify products:-

Obtain a full set of engineering drawings and specifications for each selected product. Confirm standard frame components are available. Specify performance requirements of experimental units. Specify materials.

3-4 Specify tests.

Define test specifications with operating Divisions. Prepare detailed test programme for field trials and lab. tests. Discuss programmes with operating Divisions. Obtain agreement. Discuss test programme with Technical Manager. Draw-up schedule for installation programme.

4-5 Test Rig Specification:-

Specify what is required of the rig.
Design test rig.

5-6 Engineering drawings:-

Drawing Office is to prepare detailed drawings of the rig and apparatus. Discuss and resolve any problems which may arise during this phase. Examine drawings.

6-7 Obtain estimates:-

Select contractors to make parts for test rig. Discuss specification with contractors, await estimates. Compare quotations, prepare recommendations for placing orders.

7-8 Order test rig.

Raise paperwork, obtain approval, place orders for made-out parts.

8-9 Manufacture.

Visit Contractors to review progress
Report on progress.

9-10 Prepare site:-

Arrange with Engineering Laboratory to make space available for test rig.

10-11 Install.

Assemble test rig on arrival. Install and connect services.

11-12 Design Radiators.

Drawing Office is to prepare design drawings for each test unit.
Obtain approval.

12-13 Engineering drawings:-

Drawing Office is to prepare detailed drawings for production.
Examine drawings.

13-14 Obtain materials.

Arrange for materials to be ordered and raise paper work for the production of experimental units, installation and test programme.

14-15 Manufacture sub-units:-

Produce coated tubes
Manufacture fins
Assemble sub-units
Assemble sub-units to tubeplates
Degrease
Arrange shipment to Engineering Laboratory.
Solder
Clean
Inspect
Arrange shipment back to Manufacturing Division.

15-16 Assemble radiators:-

Solder tubeplates
Fit headers, frame etc.
Arrange shipment to Engineering Laboratory.

16-17 Performance test:-

Uniquely identify each radiator.
Engineering Laboratory is to conduct performance test on selected units.
Obtain test results.

17-18 Install:-

Engineering Laboratory are to carry out environmental test programme
Laboratory Technicians are to install radiators in vehicles etc.

18-19 Environmental Test 'A'.

Field trial units under test.
Continually monitor performance of units.
Engineering Laboratory are to hold original units and provide a replacement in case of failure.

19-20 Environmental Test 'B'.

Remainder of test units are installed in test rig and subjected to simulated environmental conditions.
Continually monitor performance of units.

20-21 Analyse data:-

Collect information together, interpret. Look for trends.
Make predictions.

21-22 Interim Report:-

Write progress report on experimental work to date.

22-23 Remove radiators:-

Laboractory Technicians are to remove radiators from vehicles etc.
re-install original radiators. Arrange for shipment to Engineering Laboratory.

23-24 Performance Test:-

Engineering Laboratory are to performance test selected units a second time.
Obtain results.

24-25 Analyse data.

(as activity 20-21)

25-26 Write report:-

Write final report, summarising findings of experimental work.

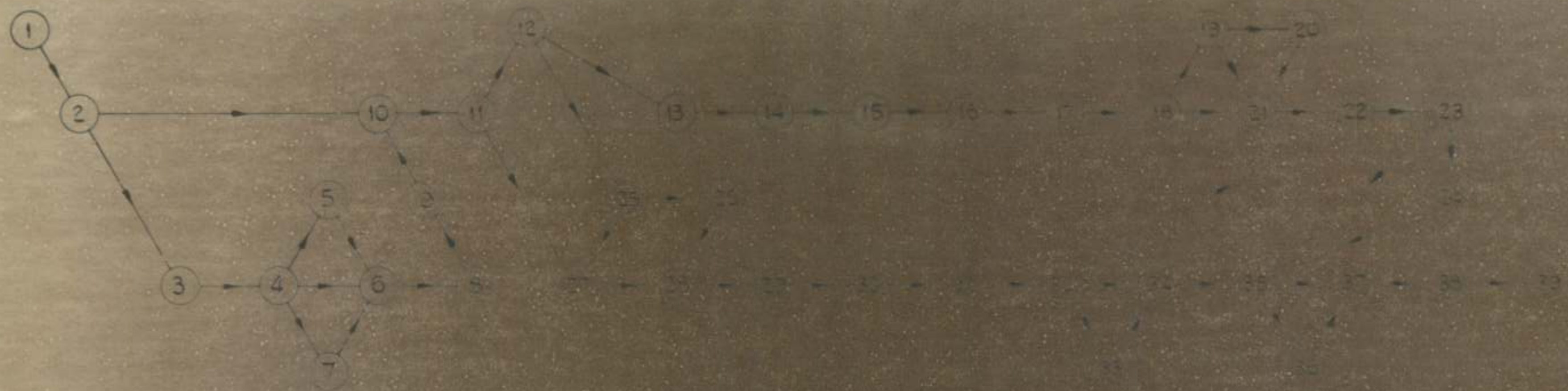
Activity No.	C.P.A. No.	Duration	Description
1 - 2	1 - 2	2	Select product applications.
	2 - 3	2	Discuss availability of parts.
	2 - 10	2	Obtain estimates of labour involvement.
2 - 3	3 - 4	3	Obtain engineering drawings and specifications for each product.
	4 - 5	1	Confirm components are available.
	4 - 6	1	Specify performance requirements.
	4 - 7	1	Specify materials.
3 - 4	6 - 8	1	Define test specifications.
	8 - 9	1	Prepare test programme.
	9 - 10	1	Discuss with division and get agreement.
	10 - 11	½	Discuss with Technical Manager.
	11 - 27	1	Draw up schedule for installation.
4 - 5	12 - 13	1	Specify requirements of test rig.
	13 - 14	2	Design test rig.
5 - 6	14 - 15	6	Get drawings of test rig and examine.
6 - 7	15 - 16	2	Select contractors, discuss specification and get estimate.
	16 - 17	1	Compare quotes and recommend order placing.
7 - 8	17 - 18	1	Raise paperwork and obtain approval.
	18 - 19	½	Place orders for made out parts.
	18 - 21	16	Manufacture.
8 - 9	19 - 20	1	Visit contractors to review progress.
	20 - 21	1	Report on progress.
9 - 10	19 - 21	1	Prepare site.
10 - 11	21 - 22	4	Install test rig.
11 - 12	11 - 12	6	Design drawings for test units.
	12 - 25	1	Get approval.
12 - 13	25 - 26	10	Detailed drawings for production.
	26 - 28	2	Get approval.
13 - 14	25 - 27	10	Order materials.
	27 - 28	2	Raise paperwork.
14 - 15	28 - 29	6	Manufacture units and ship to Engineering Laboratory.
	29 - 30	1	Solder and inspect.
	30 - 31	1	Ship to Manufacturing Division.
15 - 16	31 - 32	2	Assemble radiators and ship to Engineering Laboratory.
16 - 17	32 - 34	24	Performance test units.
17 - 18	32 - 33	6	Install radiators in vehicles.
18 - 19	34 - 35	52	Monitor Test A.
19 - 20	22 - 23	1	Install units in test rig.
	23 - 35	52	Monitor Test B.
20 - 21	23 - 24	4	Collect information and analyse.
21 - 22	24 - 35	6	Write interim progress report.
22 - 23	35 - 36	6	Remove radiators from vehicles.
	36 - 37	2	Ship to Engineering Laboratory.
23 - 24	35 - 37	20	Performance test selected units again.
24 - 25	37 - 38	2	Collect and analyse data.
25 - 26	38 - 39	10	Write final report.

107-1

PROJECTION

ALL DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE STATED

DO NOT SCALE



FINISH	
WEIGHT	
SCALE	
TITLE	
ORDER No	

Serck Heat Transfer
PO BOX 598 B. WARWICK RD.
BIRMINGHAM B11 2QY, ENGLAND

A2

DRAWING No
107-1

C P M NETWORK ANALYSIS

107-1 ENVIRONMENTAL TEST PROGRAMME

PAGE 1

Activity	S	E	D	SORT	ES	LS	EF	LF	F **
SELECT PRODUCTS	1	2	20	0	3/11/75	3/11/75	14/11/75	14/11/75	0 **
AVAILABILITY OF PARTS	2	3	20	0	17/11/75	17/11/75	28/11/75	28/11/75	0 **
LABOUR INVOLVEMENT	2	10	20	0	17/11/75	8/ 1/76	28/11/75	21/ 1/76	70
DRAWINGS AND SPECS.	3	4	30	0	1/12/75	1/12/75	19/12/75	19/12/75	0 **
COMPONENTS AVAILABLE	4	5	10	0	22/12/75	22/12/75	30/12/75	30/12/75	0 **
SPECIFY PERFORMANCE	4	6	10	0	22/12/75	22/12/75	30/12/75	30/12/75	0 **
SPECIFY MATERIALS	4	7	10	0	22/12/75	22/12/75	30/12/75	30/12/75	0 **
DUMMY ACTIVITY	5	6	0	0	31/12/75	31/12/75	31/12/75	31/12/75	0 **
DUMMY ACTIVITY	7	6	0	0	31/12/75	31/12/75	31/12/75	31/12/75	0 **
TEST SPECIFICATIONS	6	8	10	0	31/12/75	31/12/75	7/ 1/76	7/ 1/76	0 **
PREPARE TEST PROG.	8	9	10	0	8/ 1/76	8/ 1/76	14/ 1/76	14/ 1/76	0 **
DISCUSS WITH DIVS.	9	10	10	0	15/ 1/76	15/ 1/76	21/ 1/76	21/ 1/76	0 **
DISCUSS WITH TECH MGR	10	11	5	0	22/ 1/76	22/ 1/76	26/ 1/76	26/ 1/76	0 **
DRAWINGS FOR TEST RIG	11	12	60	0	26/ 1/76	26/ 1/76	8/ 3/76	8/ 3/76	0 **
SCHEDULE FOR INSTALL.	11	27	10	0	26/ 1/76	20/ 5/76	2/ 2/76	27/ 5/76	160
REQUIREMENTS OF RIG	12	13	10	0	8/ 3/76	14/ 6/76	15/ 3/76	21/ 6/76	130

C P M NETWORK ANALYSIS

107-1 ENVIRONMENTAL TEST PROGRAMME

Activity	S	E	D	SORT	ES	LS	EF	LF	F	**
APPROVAL OF DESIGNS	12	25	10	0	8/ 3/76	8/ 3/76	15/ 3/76	15/ 3/76	0	**
DESIGN TEST RIG	13	14	20	0	15/ 3/76	21/ 6/76	29/ 3/76	5/ 7/76	130	
ORDER MATERIALS	25	27	100	0	15/ 3/76	15/ 3/76	27/ 5/76	27/ 5/76	0	**
PRODUCTION DRAWINGS	25	26	100	0	15/ 3/76	15/ 3/76	27/ 5/76	27/ 5/76	0	**
DRAW TEST RIG	14	15	60	0	29/ 3/76	5/ 7/76	13/ 5/76	16/ 8/76	130	
RAISE PAPERWORK	27	28	20	0	27/ 5/76	27/ 5/76	14/ 6/76	14/ 6/76	0	*
APPROVAL OF DRAWINGS	26	28	20	0	27/ 5/76	27/ 5/76	14/ 6/76	14/ 6/76	0	*
OBTAIN ESTIMATES	15	16	20	0	13/ 5/76	16/ 8/76	27/ 5/76	1/ 9/76	130	
MANUFACTURE UNITS	28	29	60	0	14/ 6/76	14/ 6/76	26/ 7/76	26/ 7/76	0	*
COMPARE AND ORDER	16	17	10	0	27/ 5/76	1/ 9/76	7/ 6/76	8/ 9/76	130	
SOLDER AND INSPECT	29	30	10	0	26/ 7/76	26/ 7/76	2/ 8/76	2/ 8/76	0	*
OBTAIN APPROVAL	17	18	10	0	7/ 6/76	8/ 9/76	14/ 6/76	15/ 9/76	130	
SHIP TO MANUF. DIV.	30	31	10	0	2/ 8/76	2/ 8/76	9/ 8/76	9/ 8/76	0	*
PLACE ORDERS	18	19	5	0	14/ 6/76	20/12/76	16/ 6/76	22/12/76	265	
MANUFACTURE TEST RIG	18	21	160	0	14/ 6/76	15/ 9/76	6/10/76	10/ 1/77	130	
ASSEMBLE AND LABEL	31	32	20	0	9/ 8/76	9/ 8/76	23/ 8/76	23/ 8/76	0	*

C P M NETWORK ANALYSIS

107-1 ENVIRONMENTAL TEST PROGRAMME

S	E	D	SORT	ES	LS	EF	LF	F	*
VISIT CONTRACTORS									
19	20	10	0	17/ 6/76	22/12/76	23/ 6/76	31/12/76	265	
PREPARE SITE									
19	21	10	0	17/ 6/76	31/12/76	23/ 6/76	10/ 1/77	275	
PERFORMANCE TESTING									
32	34	240	0	23/ 8/76	23/ 8/76	14/ 2/77	14/ 2/77	0	*
INSTALL RADIATORS									
32	33	60	0	23/ 8/76	31/12/76	6/10/76	14/ 2/77	180	
DUMMY ACTIVITY									
32	22	0	0	23/ 8/76	7/ 2/77	23/ 8/76	7/ 2/77	230	
REPORT ON PROGRESS									
20	21	10	0	24/ 6/76	31/12/76	30/ 6/76	10/ 1/77	265	
DUMMY ACTIVITY									
33	34	0	0	6/10/76	14/ 2/77	6/10/76	14/ 2/77	180	
INSTALL TEST RIG									
21	22	40	0	6/10/76	10/ 1/77	3/11/76	7/ 2/77	130	
ENVIRONMENTAL TEST A									
34	35	520	0	14/ 2/77	14/ 2/77	27/ 2/78	27/ 2/78	0	*
INSTALL UNITS IN RIG									
22	23	10	0	3/11/76	7/ 2/77	10/11/76	14/ 2/77	130	
ENVIRONMENTAL TEST B									
23	35	520	0	10/11/76	14/ 2/77	23/11/77	27/ 2/78	130	
GET AND ANALYSE INFO.									
23	24	40	0	10/11/76	14/12/77	8/12/76	16/ 1/78	550	
INTERIM REPORT									
24	35	60	0	8/12/76	16/ 1/78	24/ 1/77	27/ 2/78	550	
PERFORMANCE TESTING									
35	37	200	0	27/ 2/78	27/ 2/78	24/ 7/78	24/ 7/78	0	*
REMOVE RADIATORS									
35	36	60	0	27/ 2/78	25/ 5/78	13/ 4/78	10/ 7/78	120	
RADS. TO ENG. LAB.									
36	37	20	0	13/ 4/78	10/ 7/78	27/ 4/78	24/ 7/78	120	
COLLECT DATA									
37	38	20	0	24/ 7/78	24/ 7/78	7/ 8/78	7/ 8/78	0	
WRITE FINAL REPORT									
38	39	100	0	7/ 8/78	7/ 8/78	18/10/78	18/10/78	0	

APPENDIX TO CHAPTER 3

Section One : This supplements parts 4,5 and 6 of chapter three and includes the detailed figures and results used in these sections.

SECTION ONE

TABLE ONE

The values used for metals were extrapolated (See section two)
They are given below in £ per metric ton :-

Aluminium	£600
Tin	£4,000
Zinc	£425
Lead	£290

It is assumed that the coversion cost of aluminium is £400 per ton and that of copper is £270 per ton for series 200 and 500 units and £220 per ton for series 700 units. All prices quoted are L.M.E. values, but costs include conversion costs.

(a) Cost of the fin material

The calculations assume that the aluminium fins are twice as thick as the copper fins and hence that 60% as much aluminium is used by weight as copper. The double thickness of aluminium is used because of its poorer heat conductivity and strength. The variation factors used for copper fins are:-

Series 200	£0.01
Series 500	£0.03
Series 700	£0.08

The variation factor for aluminium is:-

for a £100 change in the aluminium price,

Series 200	£.06
Series 500	£.18
Series 700	£.48

Cost of aluminium fin = cost of copper fin x0.6x (Price of aluminium / price of copper)

where prices include conversion costs.

TABLE ONE cont.

Series	200	500	700
Cost of copper fins at £600	.87	2.60	6.50
Cost of aluminium fins	.60	1.79	4.75
Saving in cost per unit	.27	.81	1.75
Cost of copper fins at £1000	1.27	3.80	9.70
Cost of aluminium fins	.60	1.79	4.75
Saving in cost per unit	.67	2.01	4.95
Cost of copper fin at £1400	1.67	5.00	12.90
Cost of aluminium fin	.60	1.79	4.75
Saving in cost per unit	1.07	3.21	8.15

(b) Solder use

This is an estimate of block solder used assuming that an average coating thickness of .0005"is applied to both sides of the tubes in all units.

Series	200	500	700
Solder used in grammes	213	680	1700
Cost of using 70:30 lead:tin solder in £'s	.30	.95	2.38
Cost of using 40:60 lead:tin solder in £'s	.49	1.55	3.88
Difference in cost	.19	.60	1.50

Series	200	500	700
Cost of using 80:20 tin:zinc solder in £'s	.54	1.71	4.28
Difference in cost	.24	.76	1.90

TABLE ONE cont.

The variation factors in these results for a £200 change in the price of tin are approx:-

Series	200	500	700
Variation factor for 40:60 solder in £'s	.01	.04	.11
Variation factor for 80:20 solder in £'s	.02	.05	.12

(c) Labour Cost.

A rate of £60 per man week is used.

Present labour use:-

Output (units per week)	Labour use in men		
	Block soldering	End Dipping	Washing
400	1	2	1
700	2	3	1
1000	3	4	1
1400	4	5	1

The new process only requires 1 man for block soldering whatever the output.

∴

Men saved	Output	£'s saved per week
0	400	0
1	700	60
2	1000	120
3	1400	180

If a tube to tubeplate bond is possible, end dipping and washing are unnecessary, but one extra man may be required to preplace solder

∴

Men saved(in total)	Output	£'s saved per week
2	400	120
4	700	240
6	1000	360
8	1400	480

TABLE ONE cont.

(d) Cost of Chemicals. - usage figures are estimates.

Chemical	Cost per litre in £'s
DP_{10}	.55
DP_{10a}	.59
M_{25}	1.15
D_3Z	.40

Series	DP_{10} use	DP_{10} cost	DP_{10a} use	DP_{10a} cost	M_{25}* use	M_{25}* cost	D_3Z cost
200	20 mls	.01	20 mls	.01	50 mls	.06	.005
500	30 "	.02	30 "	.02	140 "	.16	.005
700	40 "	.02	40 "	.02	240 "	.28	.005

* It is assumed that a coating of .001 inches is applied to one side of the fins only.

(e) Cost of Power

Present cost of heating baking ovens is about £6.00 per week

Estimated cost of electric power for new plant is about £14.00 per week

∴ Cost of extra power used is about £.02 per unit.

ANALYSIS OF COSTS OF VARIANTS.

In the following analyses the costs or savings introduced by using the new process and substituting aluminium for copper are considered. The results are expressed in two forms, taking each type of unit in isolation. Firstly the savings achievable are expressed as a percentage of total present materials and labour cost, and secondly the results are expressed as pounds saved per week. Both sets of figures are copper price and output dependant.

All figures are in pounds.

TABLE 2: Copper fin and brass tube units.

In this first section the effect of using the new process to solder units with copper fins is assessed.

All savings are in labour, and there is a small extra power cost. Three situations are considered:-

1. Using the new process
2. Using the new process and a non-corrosive flux for end dipping, thus eliminating washing.
3. One shot soldering of tubes to tubeplate as well as the block.

Savings expressed as a % of total materials and labour cost at an output of 1000 units a week.

Copper price in £ per ton	600	800	1000	1200	1400
New Process					
Series 200	.96	.87	.80	.74	.69
500	.55	.49	.44	.40	.37
700	.27	.24	.22	.20	.18
No Washing					
Series 200	1.53	1.40	1.29	1.19	1.11
500	.87	.78	.70	.64	.59
700	.44	.39	.35	.32	.29

Copper price in £ per ton	600	800	1000	1200	1400
One Shot					
Series 200	3.25	2.97	2.73	2.53	2.35
500	1.85	1.66	1.50	1.36	1.25
700	.93	.83	.74	.67	.61

Savings expressed in £ per week.,

Output - units per week	£ saved per week		
	New Process	No washing	One shot
400	- 10	50	110
700	46	106	226
1000	100	160	340
1400	150	210	450

TABLE 3: Aluminium fin and brass tube units using variant 'A'

In the following three sections the effect of using the new process to solder units with aluminium fins is assessed, looking at each of the three variants in turn.

Copper price in £ per ton	600	800	1000	1200	1400
Series 200					
fin saving	.27	.47	.67	.87	1.07
Cost DP_{10} + power (.01 each)	.02	.02	.02	.02	.02
∴ Saving at output 400	.25	.45	.65	.85	1.05
∴ Saving at ouput 1000 (+ .12 per unit labour)	.37	.57	.77	.97	1.17
Total material and labour cost	10.45	11.45	12.45	13.45	14.45
∴ % saving (400)	2.39	3.93	5.22	6.32	7.27
(1000)	3.54	4.98	6.18	7.21	8.10
£ per week saved (400)	100	180	260	340	420
(1000)	370	570	770	970	1170

Copper price in £ per ton	600	800	1000	1200	1400
Series 500					
fin saving	.81	1.41	2.01	2.61	3.21
Cost of DP_{10}+ power(.02 + .02)	.04	.04	.04	.04	.04
∴ Saving (400)	.77	1.37	1.97	2.57	3.17
Saving (1000)	.89	1.49	2.09	2.69	3.29
Total material & labour cost	18.34	20.54	22.74	24.94	27.14
∴ % Saving (400)	4.20	6.67	8.66	10.30	11.68
(1000)	4.85	7.25	9.19	10.79	12.12
£ saving (400)	308	548	788	1028	1268
(1000)	890	1490	2090	2690	3290

Copper price in £ per ton	600	800	1000	1200	1400
Series 700					
fin saving	1.75	3.35	4.95	6.55	8.15
Cost of DP_{10}+ power(.02 + .02)	.04	.04	.04	.04	.04
∴ Saving (400)	1.71	3.31	4.91	6.51	8.11
Saving (1000)	1.83	3.43	5.03	6.63	8.23
Total material & labour cost	36.40	41.20	46.00	50.80	55.60
∴ %Saving (400)	4.70	8.03	10.67	12.81	14.59
(1000)	5.03	8.33	10.93	13.05	14.80
£ Saving (400)	684	1324	1964	2604	3244
(1000)	1830	3430	5030	6630	8230

TABLE 4: Aluminium fin and brass tube units using variant B_{10}

Fin savings and total material and labour costs are as in Variant 'A'

Copper price in £ per ton	600	800	1000	1200	1400

Series 200

Costs are DP_{10a} + solder + power
= .01 + .19 + .01 = .21 per unit

	600	800	1000	1200	1400
∴ Saving (400)	.06	.26	.46	.66	.86
Saving (1000)	.18	.38	.58	.78	.98
% Saving (400)	0.57	2.27	3.69	4.91	5.95
(1000)	1.72	3.32	4.66	5.80	6.78
£ Saving (400)	24	104	184	264	344
(1000)	180	380	580	780	980

Series 500

Costs as above = .02 + .60 +.02
= .64 per unit

	600	800	1000	1200	1400
∴ Saving (400)	.17	.77	1.37	1.97	2.57
Saving (1000)	.29	.89	1.49	2.09	2.69
% Saving (400)	.93	3.75	6.02	7.90	9.47
(1000)	1.58	4.33	6.55	8.38	9.91
£ Saving (400)	68	308	548	788	1028
(1000)	290	890	1490	2090	2690

Series 700

Costs as above = .02 + 1.50 + .02
= 1.54 per unit

	600	800	1000	1200	1400
∴ Saving (400)	.21	1.81	3.41	5.01	6.61
Saving (1000)	.33	1.93	3.53	5.13	6.73
% Saving (400)	.58	4.39	7.41	9.86	11.89
(1000)	.91	4.68	7.67	10.10	12.10
£ Saving (400)	84	724	1364	2004	2644
(1000)	330	1930	3530	5130	6730

TABLE 5: Aluminium fin and brass tube units using variant B_{30}

Fin savings and total material and labour costs are as in variant 'A'

Copper price in £ per ton	600	800	1000	1200	1400
Series 200					
Costs are M_{25} + solder + power					
= .06 + .24 + .01 = .31 per unit					
∴ Saving (400)	- .04	.16	.36	.56	.76
Saving (1000)	.08	.28	.48	.68	.88
% Saving (400)	- .38	1.40	2.89	4.16	5.26
% Saving (1000)	.77	2.45	3.86	5.06	6.09
£ Saving (400)	- 16	64	144	224	304
(1000)	80	280	480	680	880
Series 500					
Costs as above = .16 + .76 + .02					
= .94 per unit					
∴ Saving (400)	- .13	.47	1.07	1.67	2.27
Saving (1000)	- .01	.59	1.19	1.79	2.39
% Saving (400)	- .71	2.29	4.71	6.70	8.36
(1000)	- .05	2.87	5.23	7.18	8.81
£ Saving (400)	- 52	188	428	668	908
(1000)	- 10	590	1190	1790	2390
Series 700					
Costs as above = .28 + 1.90 + .02					
= 2.20 per unit					
∴ Saving (400)	- .45	1.15	2.75	4.35	5.95
Saving (1000)	- .33	1.27	2.87	4.47	6.07
% Saving (400)	- 1.24	2.79	5.98	8.56	10.70
(1000)	- .91	3.08	6.24	8.80	10.92
£ Saving (400)	- 180	460	1100	1740	2380
(1000)	- 330	1270	2870	4470	6070

TABLE 6: One shot soldering and elimination of washing

In this section an assessment is made of the effect of being able to solder tubes to tubeplate at the same time as the block is soldered.

The results are expressed as an increment in % saving, this figure being the same for all variants. The amount saved is the labour saving as set out in section c of table one.

Output per week	£ saved per week	Saving per unit
400	120	.30
1000	240	.24

Increment in % saving

Copper price in £ per ton		600	800	1000	1200	1400
Series 200 output	400	2.87	2.62	2.41	2.23	2.08
	1000	2.30	2.10	1.93	1.78	1.66
Series 500 "	400	1.64	1.46	1.32	1.20	1.11
	1000	1.31	1.17	1.06	.96	.88
Series 700 "	400	.82	.73	.65	.59	.54
	1000	.66	.58	.52	.47	.43

The elimination of washing by using a non-corrosive flux for end dipping saves 1 man, i.e. £60 per week at all levels of output.

The effect of aluminium price variations.

These are shown for a change in price of £100 assuming the price of copper remains constant.

Change in % saving

Copper Price	600	800	1000	1200	1400
Series 200	.57	.52	.48	.45	.42
500	.98	.88	.79	.72	.66
700	1.32	1.17	1.04	.94	.86

Change in £ saving per week

	Series 200	500	700
Output 400	24	72	192
1000	60	180	480

TABLE 7 : OIL BATH PROCESS

a) OUTPUT IN UNITS PER WEEK

Year O (1976-77)	S Shaped Growth Total Output	S Shaped Growth Aluminium Fin Units	15% Growth Total Output	15% Growth Aluminium Fin Units	5% Growth Total Output	5% Growth Aluminium Fin Units
1	700	123	580	102	525	92
2	1100	303	660	182	550	151
3	1650	677	760	312	580	238
4	2100	1103	880	462	600	315
5	2400	1560	1000	600	640	384
6	2600	1690	1160	754	670	436
7	2700	1823	1330	898	700	473
8	2800	1960	1530	1071	740	518
9	2900	2103	1760	1276	780	566
10	3000	2250	2020	1515	820	615

b) RATES OF RETURN ON INVESTMENT :

Comparison of variants and output growth rates.

Variant	Copper price £/ton	% Rates of Return: High Growth	15% Growth	5% Growth
A	800	20	7	-
A	1000	26	14	3
A	1200	32	17	7
A	1400	37	20	10
B_{10}	1000	20	7	-
B_{10}	1200	26	14	3
B_{10}	1400	32	17	7
B_{10}	1600	37	20	10
B_{30}	1000	16	4	-
B_{30}	1200	24	10	1
B_{30}	1400	29	15	5

TABLE 8 : BAKING PROCESS

a) Effect on the costs of using the baking process.

The M_{25} solution used in baking costs £1.06 a litre, and a coating of .0001 inches is applied to the tubes. The cost of this is :-

Series	Use of M_{25} in mls.	Cost per unit
200	3	0
500	10	.01
700	20	.02

The changes in the costs of the variants are :-

Variant "A"	Series	200	500	700
Extra saving in £ per unit		.02	.03	.02
∴ Extra saving in £ per week	(400)	8	12	8
	(1000)	20	30	20

This is an increase of about .2% in % savings.

Variant B_{10} - as in variant A, giving an increase of about .1% in % savings.

Variant B_{30}

		200	500	700
Extra saving in £ per unit		.07	.17	.28
∴ Extra saving in £ per week	(400)	28	68	112
	(1000)	70	170	280
Average increase in % savings		.6	.75	.65

b) Rate of return on investment of the baking process.

		% Rates of Return		
Variant	Copper price £/ton	High Growth	15% Growth	5% Growth
A	800	34	18	7
A	1000	42	24	14
A	1200	49	29	19
A	1400	55	34	23
B_{10}	1000	34	18	7
B_{10}	1200	42	24	14
B_{10}	1400	49	29	19
B_{10}	1600	55	34	23
B_{30}	1000	32	16	6
B_{30}	1200	40	23	13
B_{30}	1400	45	28	18

SECTION TWO

METAL PRICE FORECASTS.

As stated earlier in this report the metal prices used were extrapolated from a comparison of London Metal Exchange annual average prices with the Index of Basic Materials and Fuels Purchased by Manufacturing Industries issued by the Department of Industry.

The annual averages for the last ten years were adjusted by dividing the average by the index figure for that year, taking 1970 as a base year, thus removing general inflationary effects from the price trend and the resulting figures were plotted on a graph both on normal and semi-log paper.

From these plots a likely value of the metal to use as 1976/77 average was determined.

ANNUAL AVERAGE METAL PRICES IN £ PER METRIC TONNE.

	1965	66	67	68	69	70	71	72	73	74	75	76 Jan.	Feb.	Mar.	Apr.	May
ALUMINIUM	196	196	200	234	249	256	257	235	244	325	389	420	420	420	-	520
LEAD	115	95	84	102	123	127	104	121	175	254	186	166	172	197	-	265
COPPER	468	555	418.	525	621	590	444	428	727	912	556	588	601	684	-	850
ZINC	113	102	100	111	121	123	127	151	347	543	336	341	340	374	-	425
TIN	1412	1297	1223	1324	1451	1531	1438	1506	1967	3498	3090	3074	3205	3552	-	4400

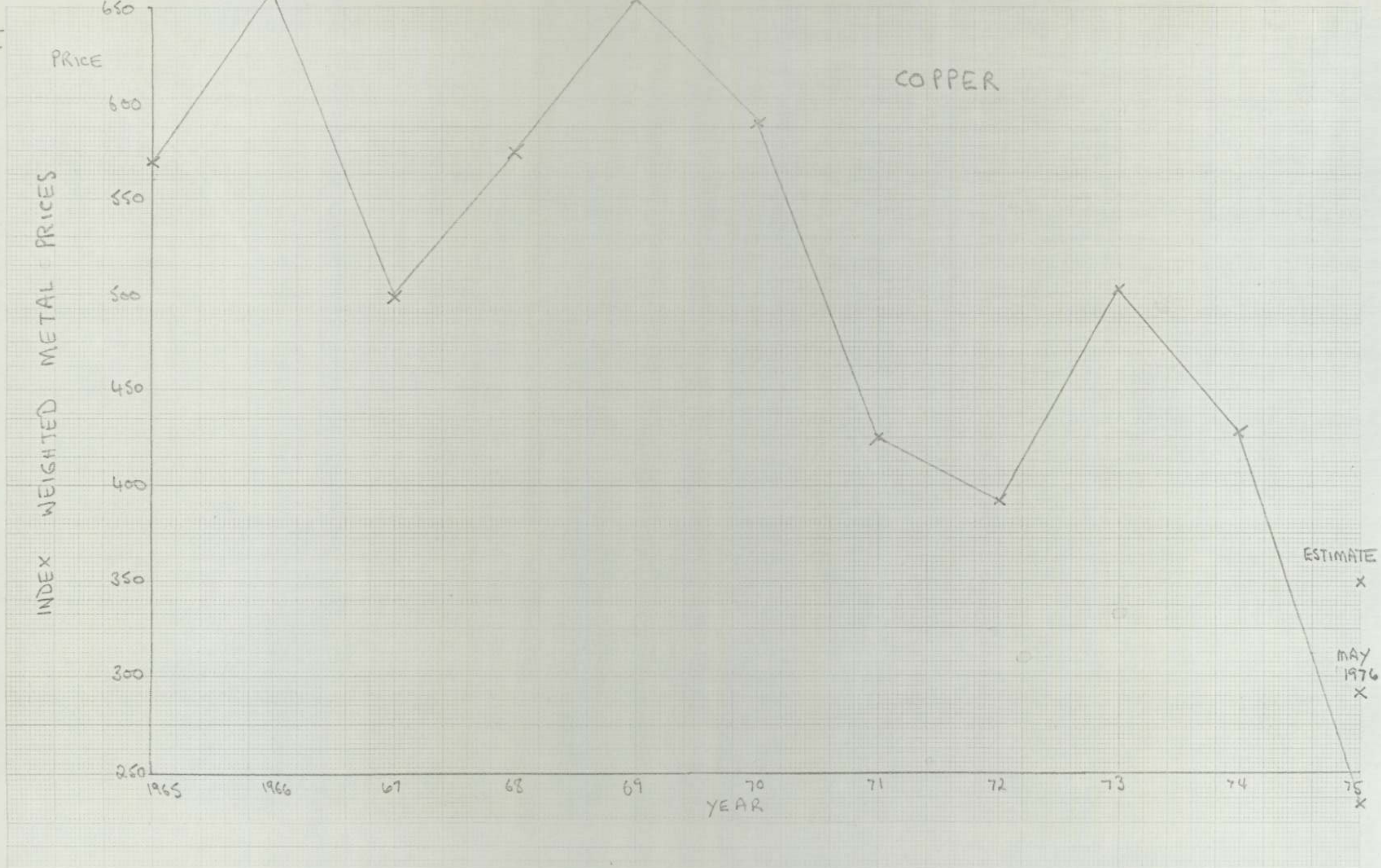
INDEX WEIGHTED METAL PRICES.

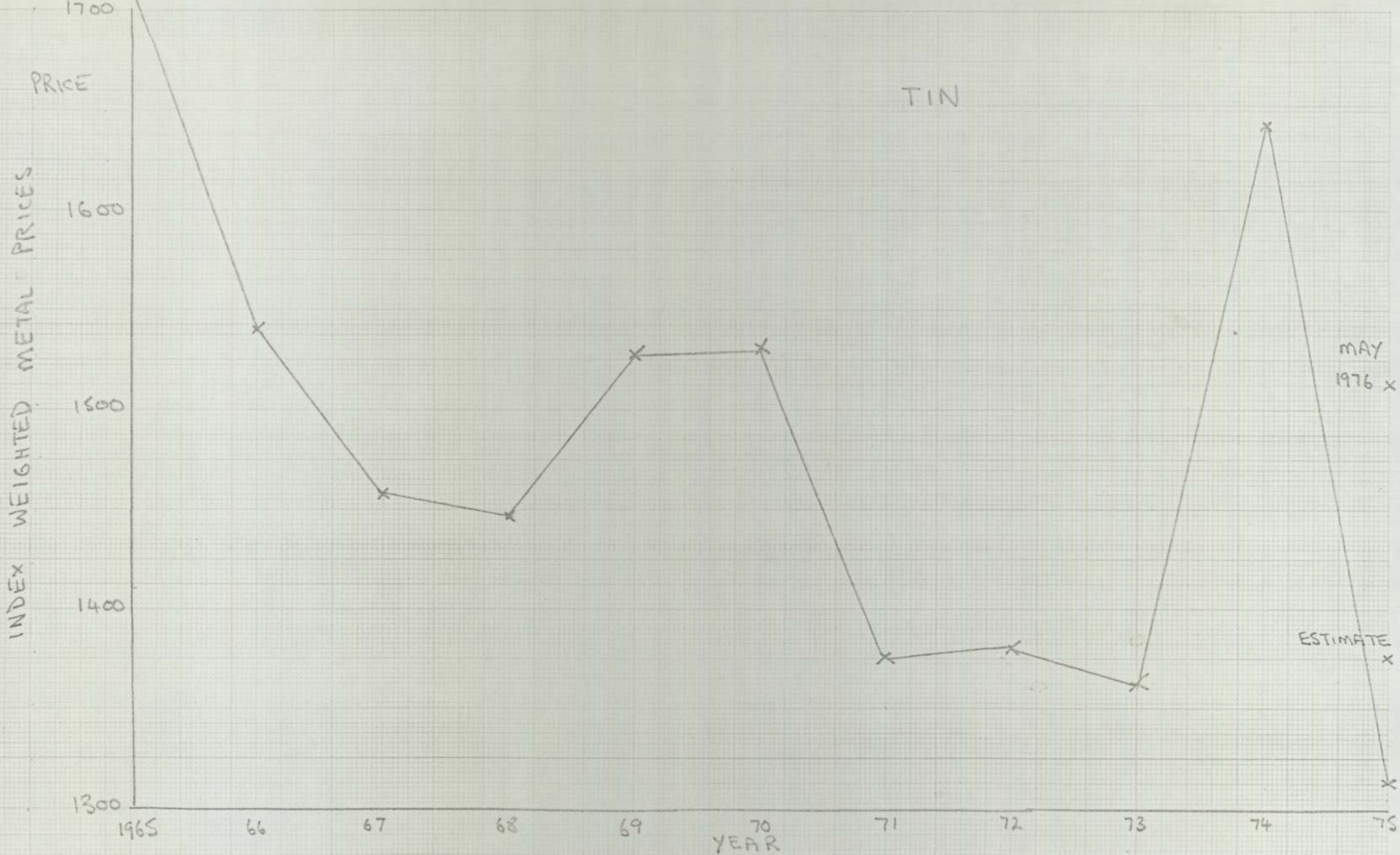
	1965	66	67	68	69	70	71	72	73	74	75	76 Jan.	Feb.	Mar.	Apr.	May
INDEX	82.21	82.24	83.86	91.5	95	100	104.6	109.2	144.5	213	235.4	260.9	263.5	273.8	285.1	290.7
ALUMINIUM	238	233	239	256	262	256	246	215	169	153	165	161	159	153	-	179
COPPER	569	659	499	574	654	590	425	392	503	428	236	225	228	250	-	292
TIN	1718	1540	1458	1447	1527	1531	1375	1379	1361	1642	1313	1178	1216	1297	-	1514
ZINC	138	121	119	121	127	123	121	138	240	255	143	131	129	137	-	146
LEAD	140	113	100	112	130	127	99	111	121	119	79	64	65	72	-	91

The prices decided upon were are follows:-

	Index Weighted Price	L.M.E. price £ per tonne.
Aluminium	205	600
Tin	1375	4000
Zinc	146	425
Lead	100	290
* Copper	350	1018

* The copper price used in the report is for the most part not a fixed one.


INDEX WEIGHTED METAL PRICES
PRICE
COPPER
650
600
550
500
450
400
350
300
250
1965
1966
67
68
69
70
71
72
73
74
75
YEAR
ESTIMATE
MAY 1976


TIN
PRICE
INDEX WEIGHTED METAL PRICES
1700
1600
1500
1400
1300
1965
66
67
68
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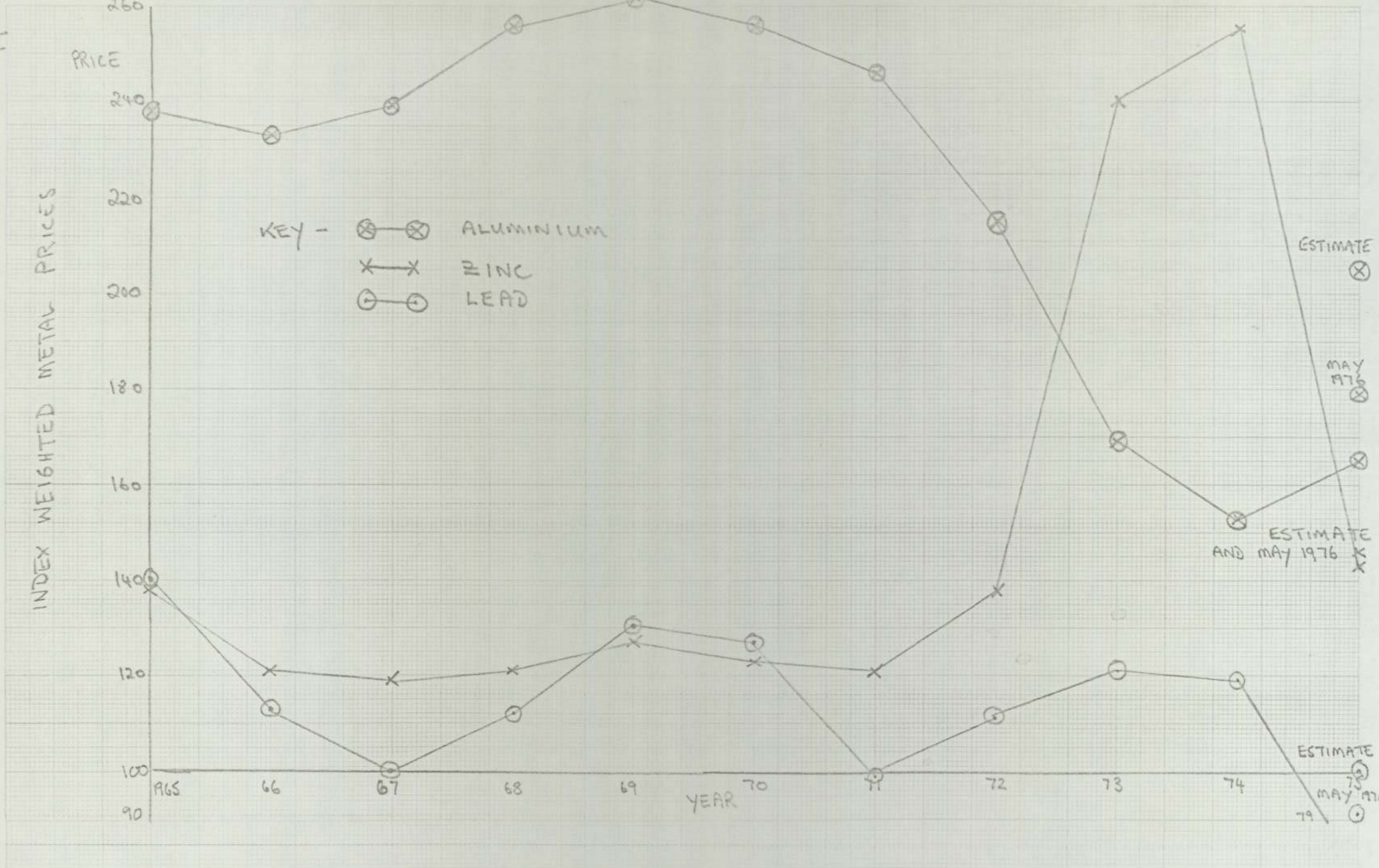
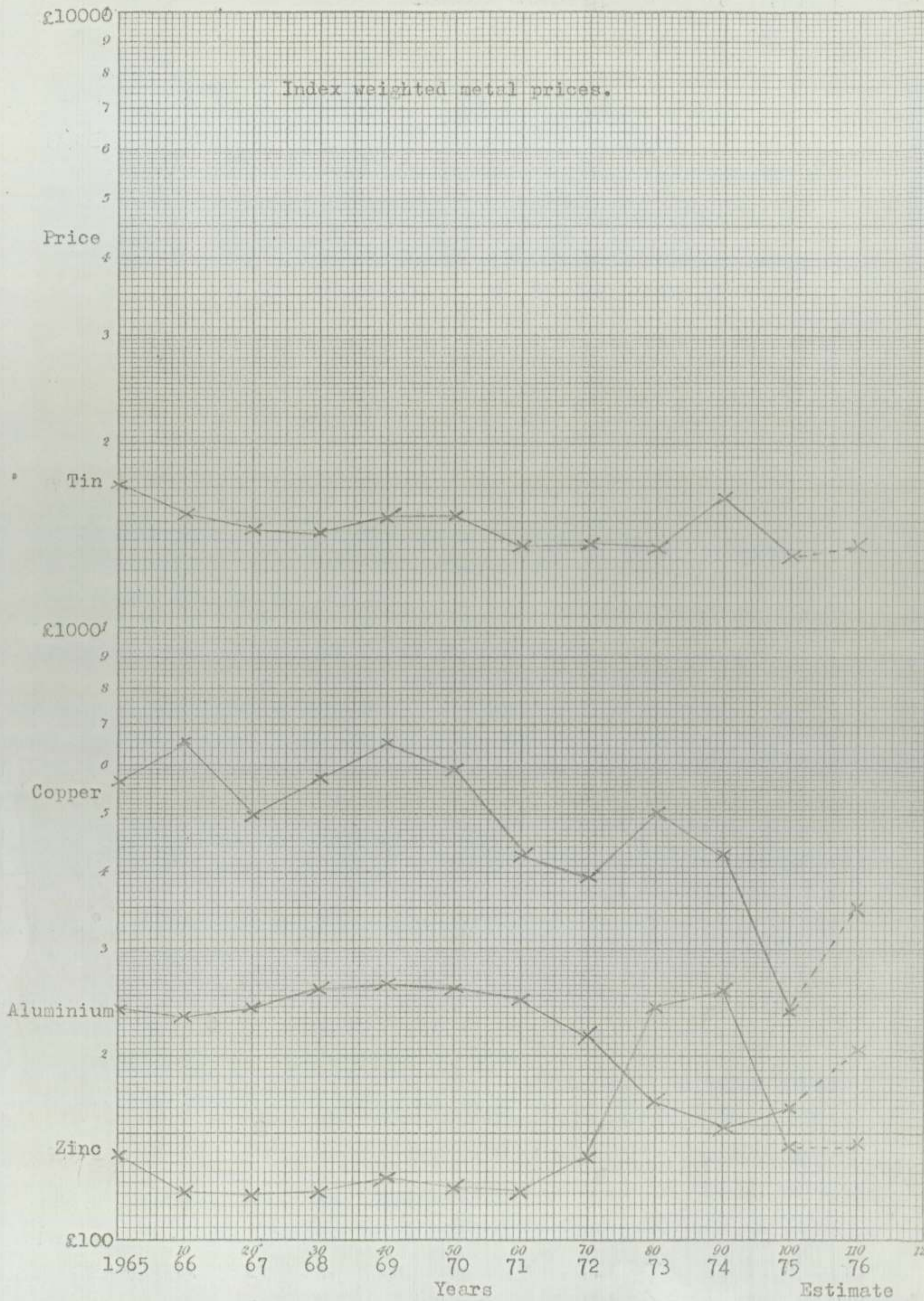
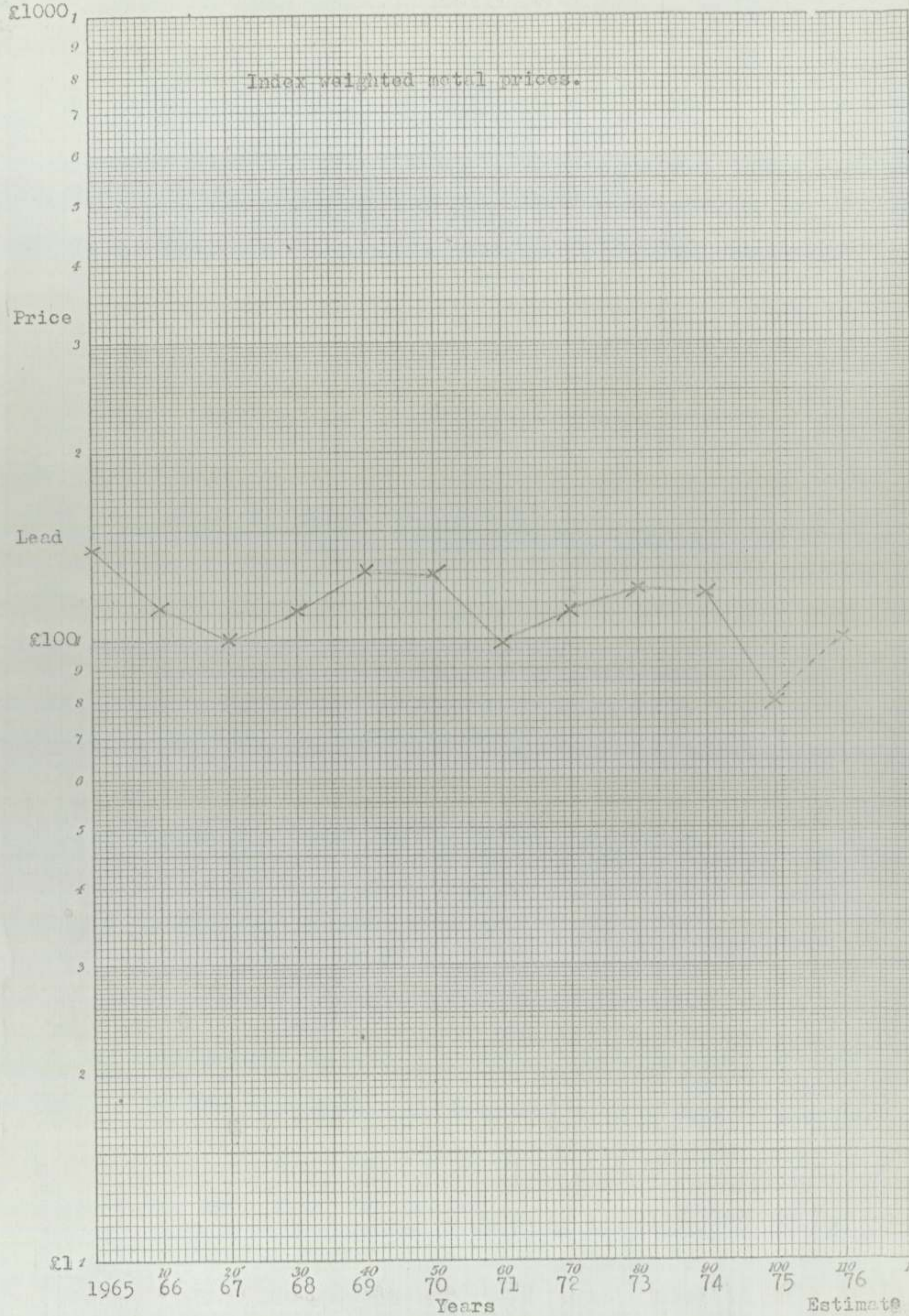
70
71
72
73
74
75
YEAR
MAY
1976
ESTIMATE


INDEX WEIGHTED METAL PRICES
PRICE
260
240
220
200
180
160
140
120
100
90
KEY -
ALUMINIUM
ZINC
LEAD
1965
66
67
68
69
70
71
72
73
74
75
YEAR
ESTIMATE
MAY 1976
ESTIMATE AND MAY 1976
ESTIMATE
MAY 1976
79


Index weighted metal prices.
£10000
9
8
7
6
5
Price
4
3
2
Tin
£1000
9
8
7
6
Copper
5
4
3
Aluminium
2
Zinc
£100
10
20
30
40
50
60
70
80
90
100
110
1965
66
67
68
69
70
71
72
73
74
75
76
Years
Estimate



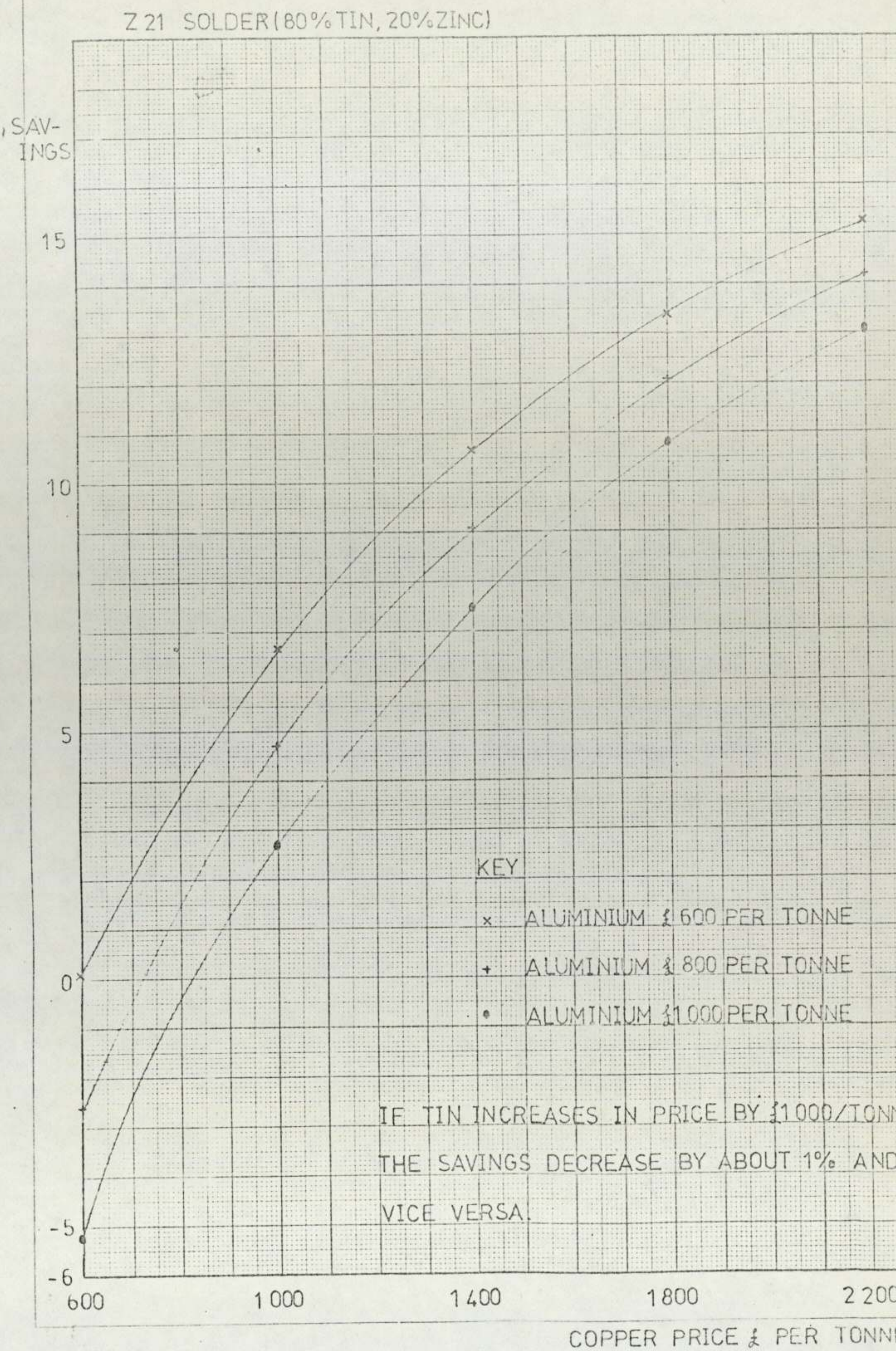
Index weighted metal prices.
£1000
Price
Lead
£100
£1
1965
66
67
68
69
70
71
72
73
74
75
76
Years
Estimate

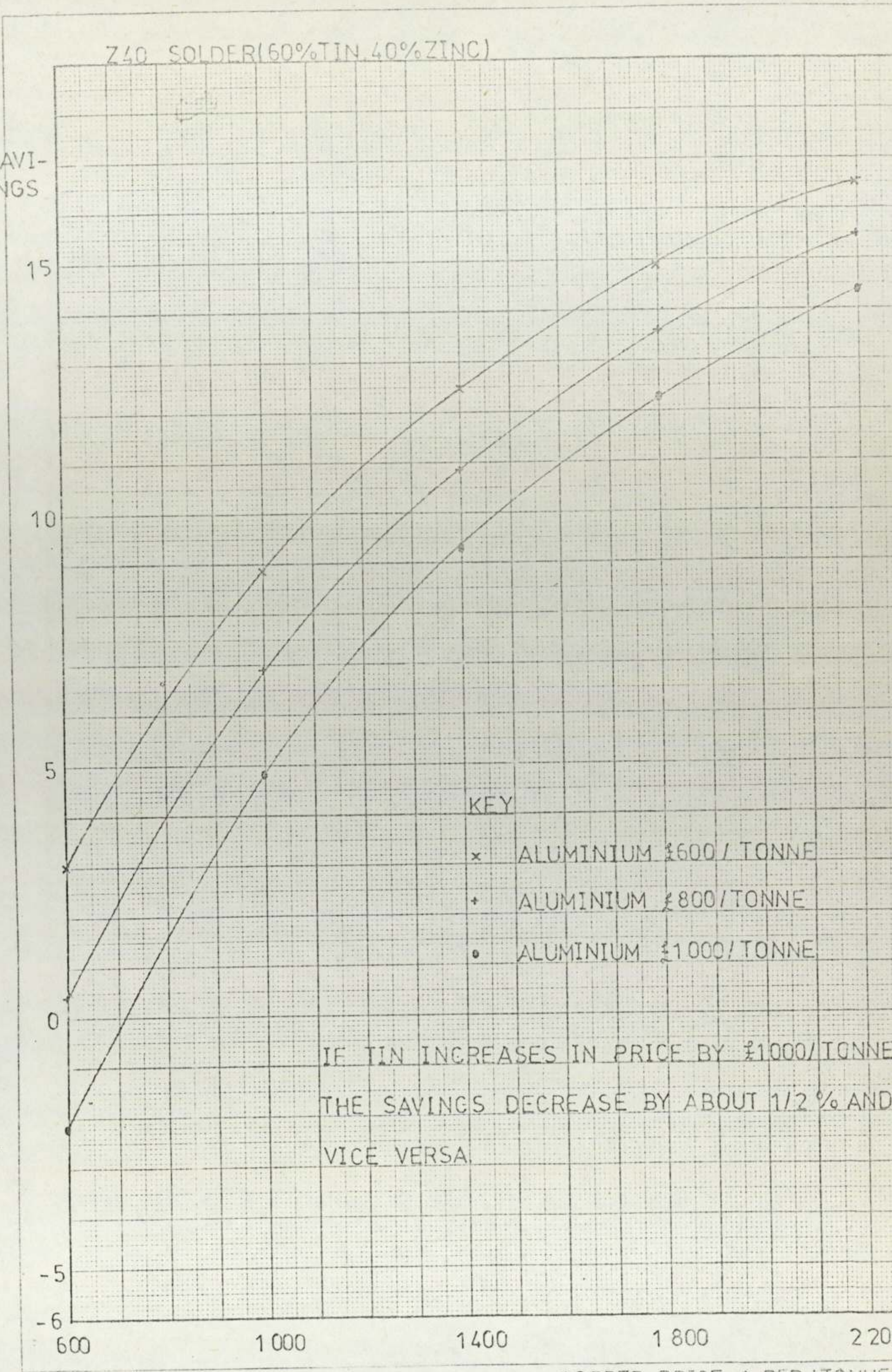
SECTION THREE

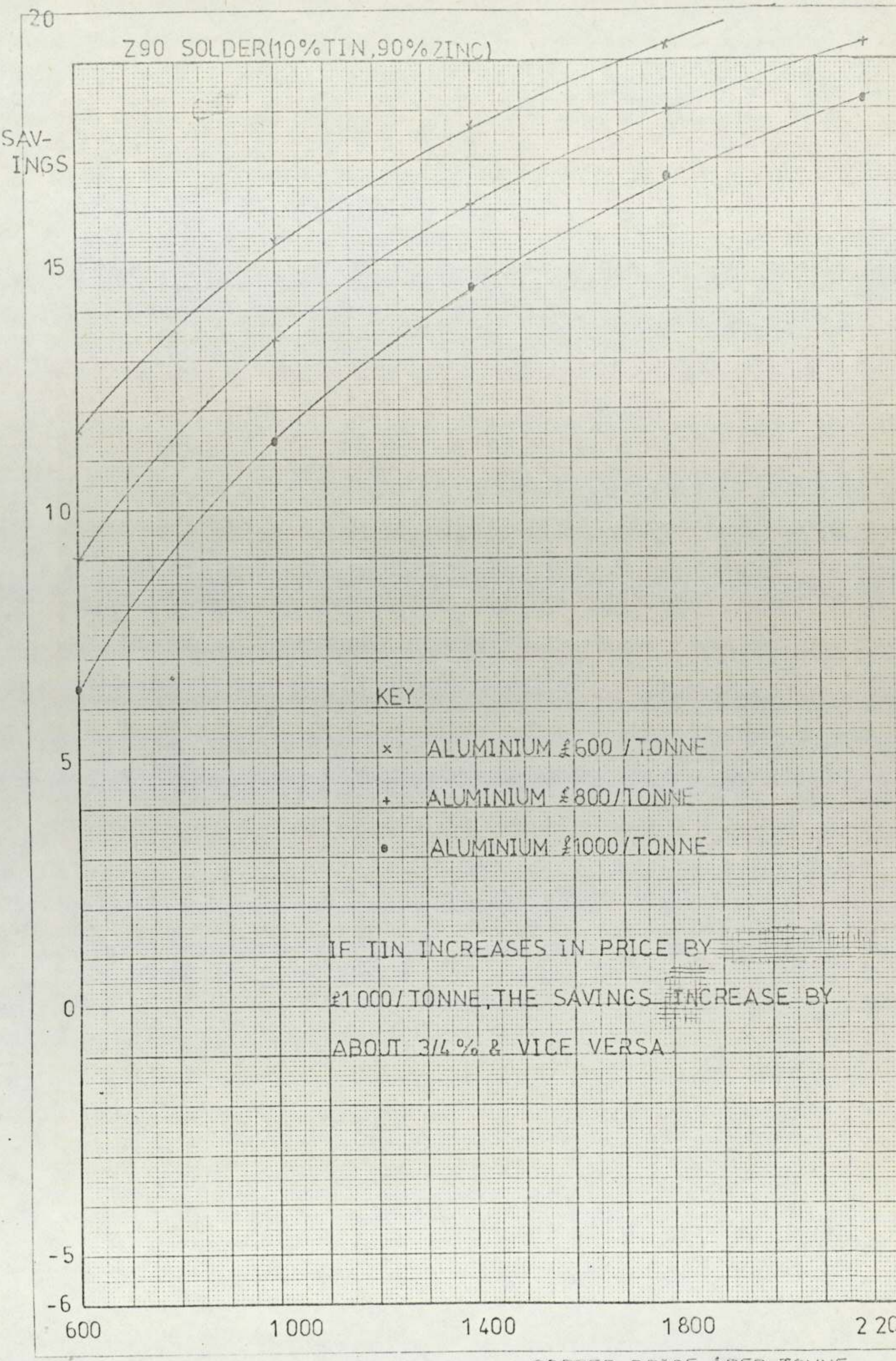
Savings associated with using Unibond to make radiators with aluminium fins

The three graphs attached show the savings possible if the Unibond process is used to make radiators with aluminium fins. The savings are expressed as a percentage of the total material cost of a medium sized radiator, using a H.C. Serck series 500 unit as an average. The savings will increase slightly if a larger unit is considered and decrease slightly if a smaller unit is considered. The graphs show the variation in savings with changes in the L.M.E. prices of copper and aluminium, and also state the effect of the price of tin on the figures. Each graph represents the results for one solder. We have used the Z21 solder to make our field trial units, and intend to use the Z40 solder as soon as the high speed baking oven is installed. The Z90 is our objective - we hope, eventually, to be able to use a solder of this type.

It has been assumed in calculating the savings that the prices of lead and zinc remain constant at £375 per tonne each, that the conversion costs of copper and aluminium are £270 and £400 per tonne respectively, that the price of tin is £6000 per tonne, that an average coating of .0005" of 75% lead, 25% tin solder is used on each side of radiator tubes at present and that the aluminium fins are twice as thick as present copper ones.


Z 21 SOLDER (80% TIN, 20% ZINC)
SAVINGS
15
10
5
0
-5
-6
600
1 000
1 400
1 800
2 200
COPPER PRICE £ PER TONNE
KEY
× ALUMINIUM £ 600 PER TONNE
+ ALUMINIUM £ 800 PER TONNE
• ALUMINIUM £1 000 PER TONNE
IF TIN INCREASES IN PRICE BY £1 000/TONNE
THE SAVINGS DECREASE BY ABOUT 1% AND
VICE VERSA.


Z40 SOLDER(60%TIN 40%ZINC)
SAVI-
NGS
15
10
5
0
-5
-6
600
1000
1400
1800
220
COPPER PRICE £ PER TONNE
KEY
× ALUMINIUM £600 / TONNE
+ ALUMINIUM £800 / TONNE
• ALUMINIUM £1000 / TONNE
IF TIN INCREASES IN PRICE BY £1000/TONNE
THE SAVINGS DECREASE BY ABOUT 1/2 % AND
VICE VERSA


Z90 SOLDER(10%TIN,90%ZINC)
SAV-
INGS
20
15
10
5
0
-5
-6
600
1000
1400
1800
2 20
COPPER PRICE £ PER TONNE
KEY
× ALUMINIUM £600 /TONNE
+ ALUMINIUM £800/TONNE
• ALUMINIUM £1000/TONNE
IF TIN INCREASES IN PRICE BY
£1000/TONNE,THE SAVINGS INCREASE BY
ABOUT 3/4% & VICE VERSA.

Savings Associated with using Unibond to make Guided-flow oil coolers with aluminium fins.

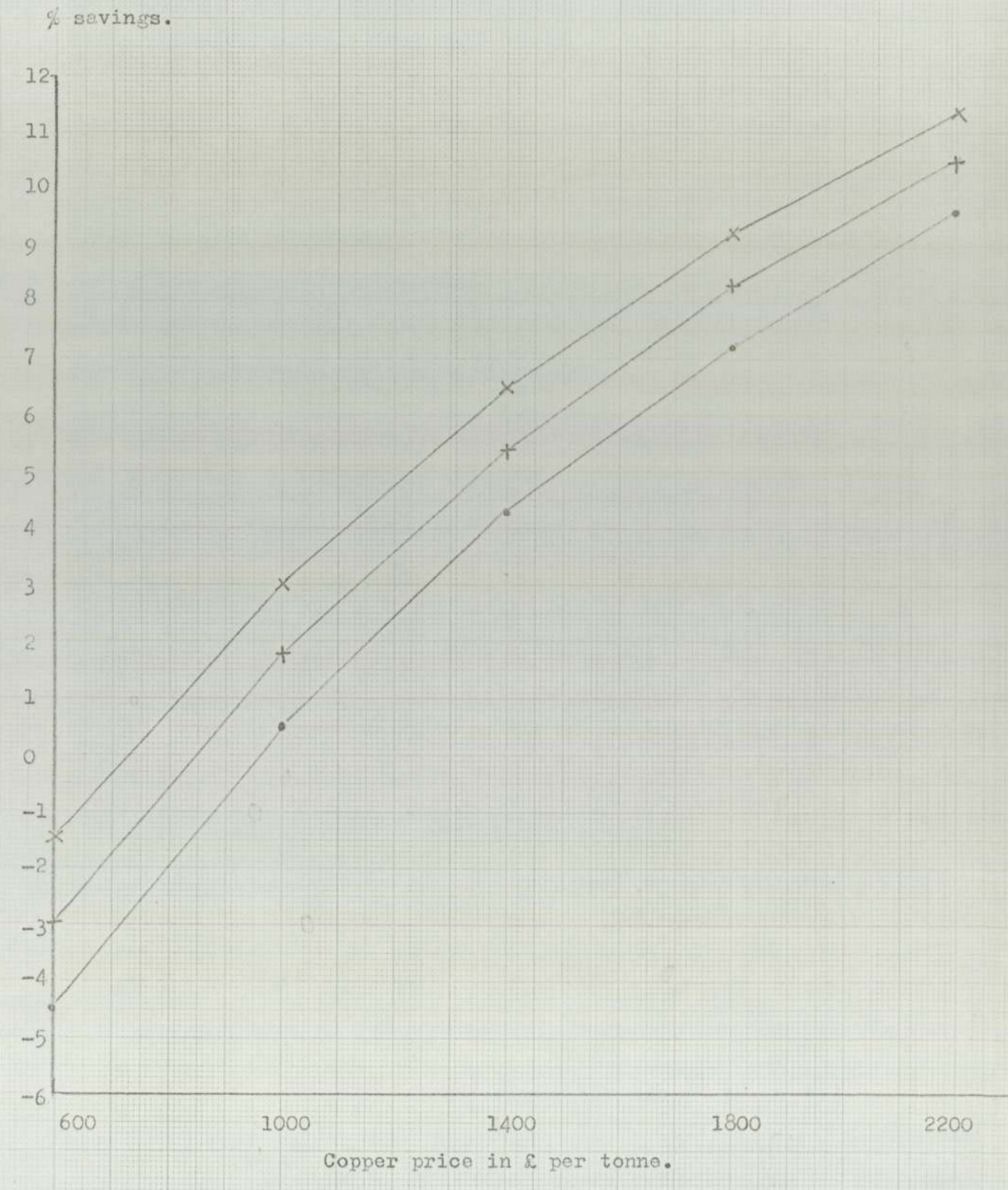
The four graphs attached show the savings possible if the Unibond process is used to make guided-flow oil coolers with aluminium fins. The savings are expresse as a percentage of the total material cost of a fin and tube matrix of a type now being developed. The graphs show the variation in savings with changes in the L.M.E. prices of copper and aluminium, and also state the effect of the price of ti on the figures. Each graph represents the results for one solder. The B10 variant uses a lead tin solder; we have used the Z21 solder to make our field trial units at H.O.S., and intend to use the Z40 solder as soon as a high speed baking facility is intalled. The Z90 is our objective - we hope, eventually, to be able to use a solder of this type.

The matrix used to calculate the savings is 19.78" long, has 134 copper tubes o 3/16" O.D. and .01" thick, and has 4.2" by 3.3" fins of .005" copper, 12 fins per inch. This is equivalent in performance to an AM10 'J' type cooler 35½" long. The results are approximately the same for the new and old designs except for variant B10 where the new design gives about 2% higher savings. The savings do not vary greatly with changes in size of unit.

It has been assumed in calculating the savings that the prices of lead and zin remain constant at £375 per tonne each, that the conversion costs of copper and aluminium are £370 and £650 per tonne respectively, that the price of tin is £6,00 tonne, that an average coating of .0015" of 75% lead, 25% tin solder is used on t tubes, the aluminium fins are twice as thick as present copper ones and that for variant B10 a .00025" coating of zinc is put on both sides of the fin.

B_{10} (75% Lead, 25% Tin solder; Pre-treated fin)

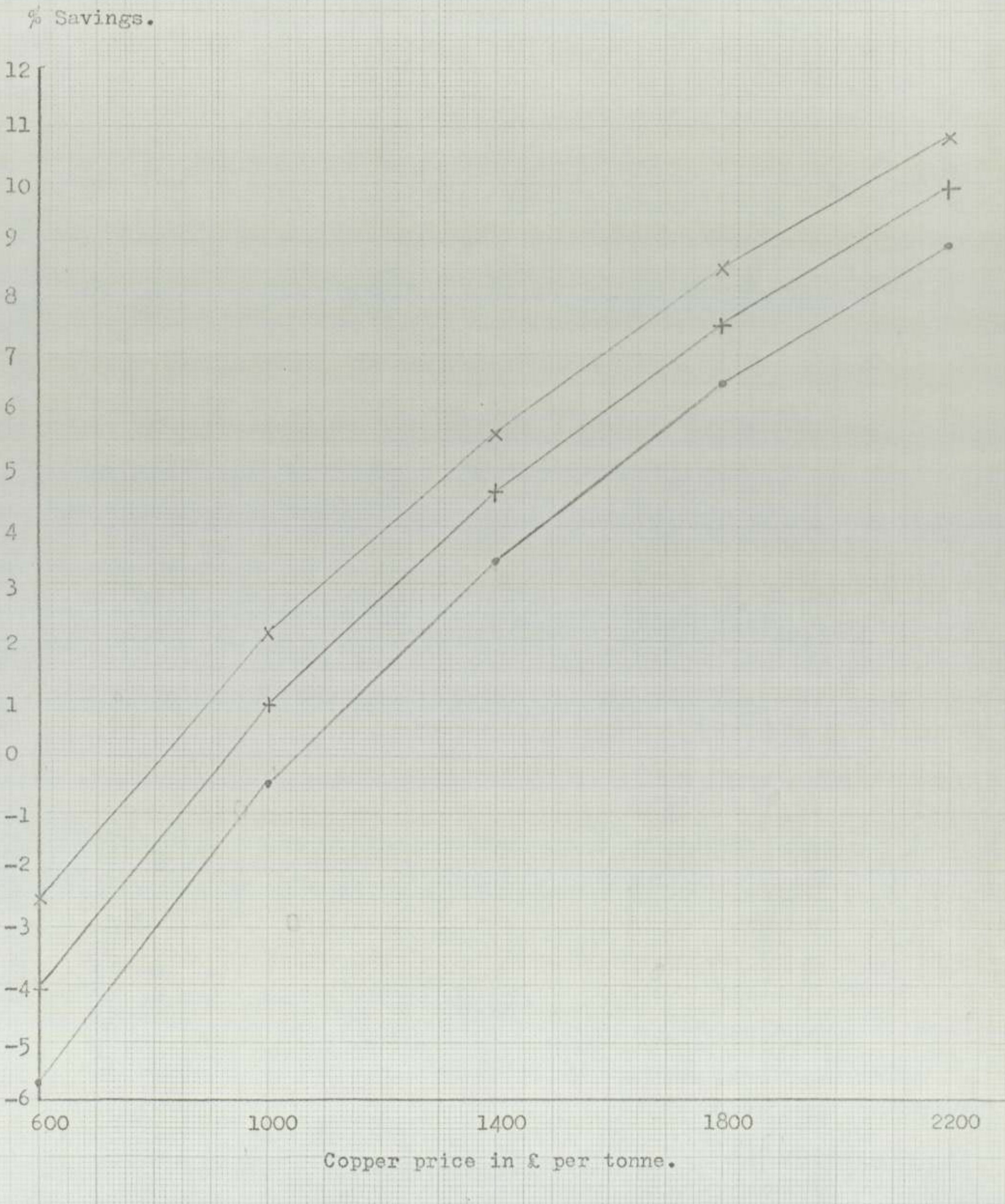
KEY: Aluminium £600 per tonne ×——×
Aluminium £800 per tonne +——+
Aluminium £1000 per tonne •——•



Z_{21} (20% Zinc, 80% Tin solder)

KEY: Aluminium £600 per tonne ×——×
Aluminium £800 per tonne +——+
Aluminium £1000 per tonne •——•

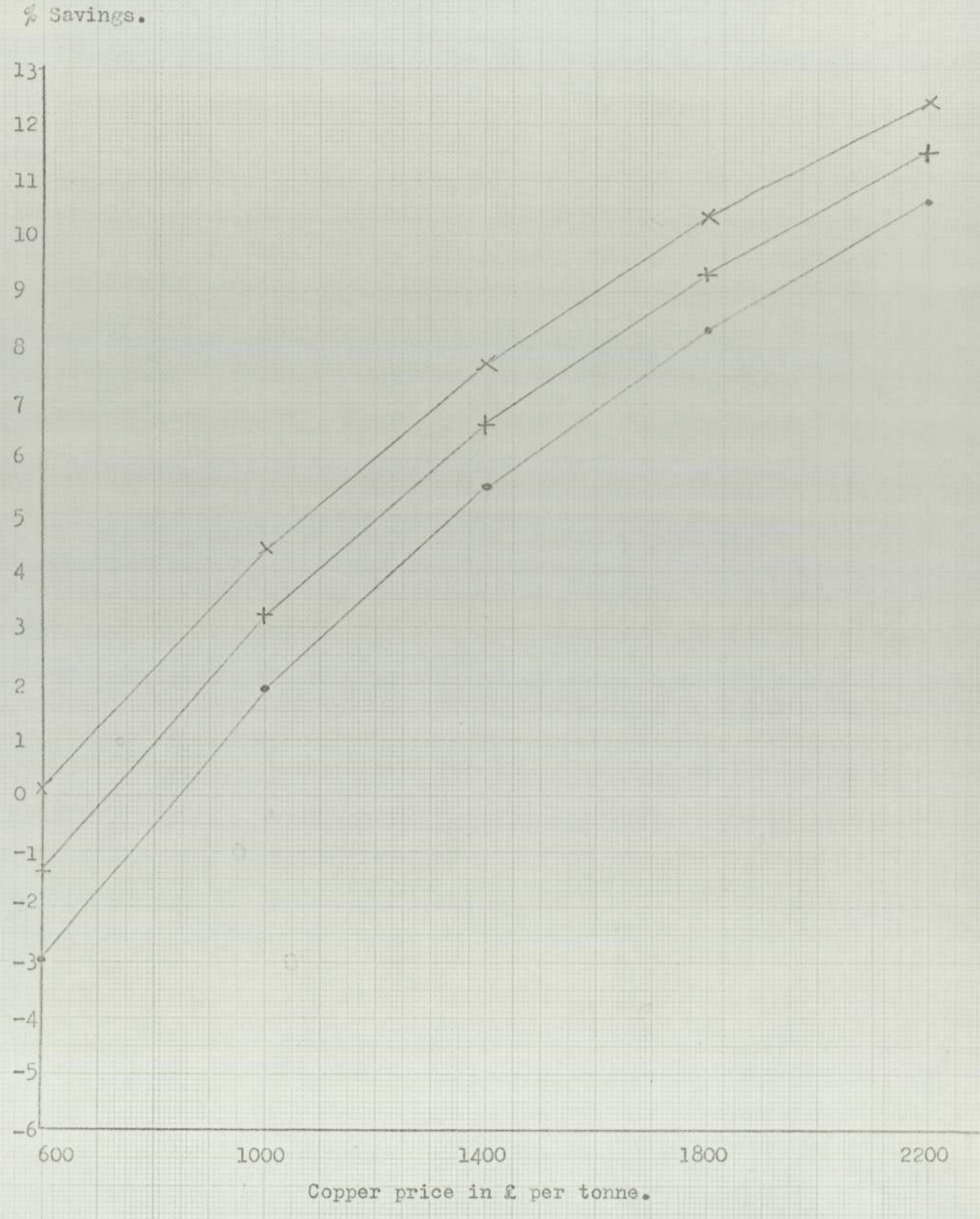
If tin increases in price by £1000 a tonne the savings decrease by about 0.8% and vice versa.



Z_{40} (40% Zinc, 60% Tin solder)

KEY: Aluminium £600 per tonne x——x
Aluminium £800 per tonne +——+
Aluminium £1000 per tonne •——•

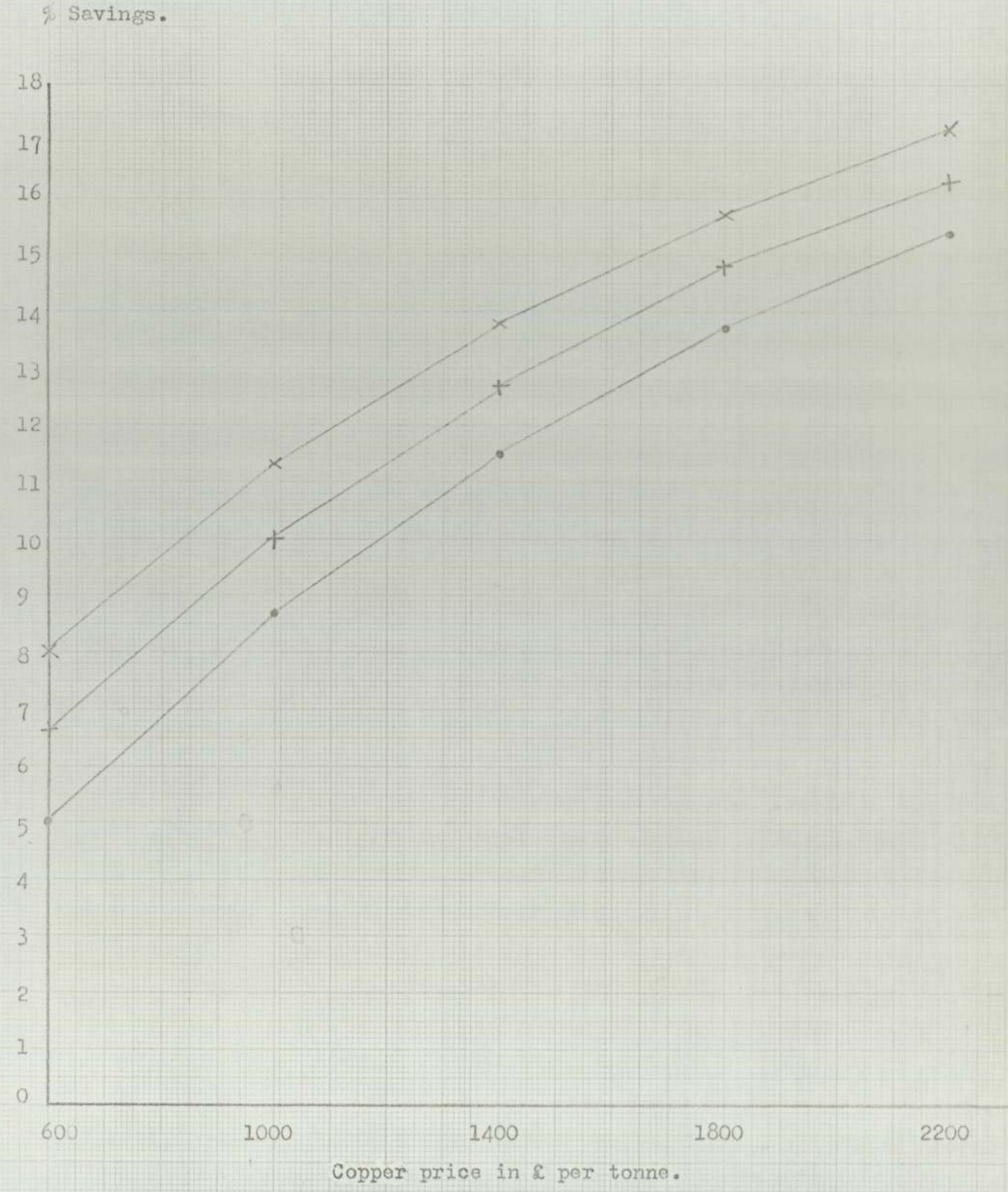
If tin increases in price by £1000 a tonne the savings decrease by about 0.5% and vice versa.



Z_{90} (90% Zinc, 10% Tin solder)

KEY: Aluminium £600 per tonne ×——×
Aluminium £800 per tonne +——+
Aluminium £1000 per tonne •——•

If tin increases in price by £1000 a tonne the savings increase by about 0.65% and vice versa.



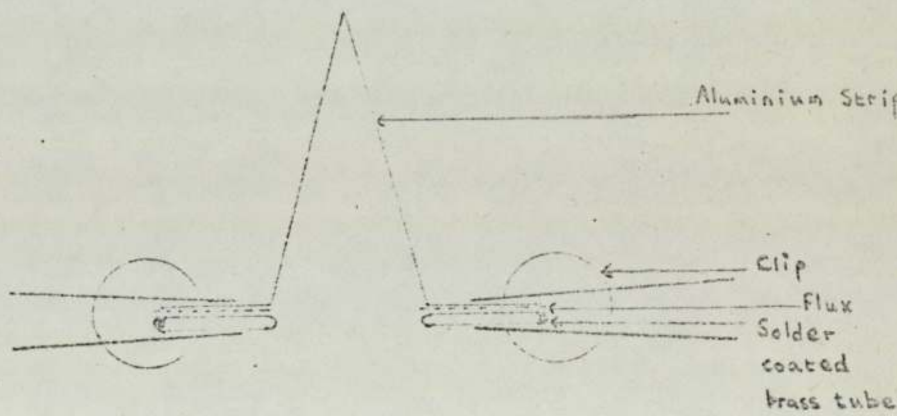
APPENDIX TO CHAPTER FOUR

Organic groups tested as fluxes include :

Monocarboxylic Acids	eg. Formic, Acetic, Capric, Palmitic, Stearic.
Dicarboxylic Acids	eg. Oxalic, Adipic, Maleic.
Hydroxy Acids	eg. Citric, Tartaric, Lactic.
Amino Acids	eg. Glutamic
Aromatic Acids	eg. Benzoic, Phthalic, Abietic, Cholic.
Sulphonic Acids	eg. Benzenesulphonic.
Phenols	eg. Phenol, Quinole.

Experimental Method ; The experiments were carried out using 80 :20 tin: zinc solder coated, flat sided brass radiator tubes and shaped aluminium 3003 alloy strip. The tube was fluxed and the strip then attached and held in place by bulldog clips. The assembly was placed in an oven at 300°C for one minute. This test showed whether the flux soldered the tube to the aluminium and also whether it soldered the lock seam on the tube.

Test Piece Assembly :



Results : Some of the chemicals succeeded in bonding both the aluminium to the tube and the lock seam of the tube. Others only bonded the lock seam and the rest didn't bond either and so did not appear to act as fluxes even for conventional materials.

The details are given overleaf.

RESULTS OF EXPERIMENTS TO TEST FLUXES.

Bonded Alumiumium and Lock Seam.	Bonded Lock Seam Only.	No Bonding At All.
Capric acid	Acetic acid	Formic acid
Palmitic acid	Glutamic acid	Maleic acid
Stearic acid	Lactic acid	Phenol
Oleic acid	Oxalic acid	Adipic Acid
Linoleic acid	Benzoic acid	Benzenesulphonic acid (b)
Tallow (a)	Abietic acid	Quinole (b)
	Tartaric acid	Cholic acid (b)
	Citric acid	
	Phthalic acid	

(a) Perhaps effective because of acid impurities

(b) High melting point chemicals

Almost all of the unsuccessful fluxes have been tested with one or more of the inert carriers in various mixtures to no avail. Stearic acid has been tested successfully with all the carriers - so although they have not been shown to promote bonding, they do not hinder it.

TABLE 1. PROPERTIES OF CHEMICALS.

Chemical	Melting point - °C	(1) Boiling point - °C	(2) Dissociation constant	Density
Capric acid	31.5	270	Between 10^{-4} and 10^{-5}	.8850
Palmitic acid	63	354		.8527
Stearic acid	71.5	370		.9408
Oleic acid	16	286^{100}		.8930
Linoleic acid	-5	230^{16}		.9022
Acetic acid	16.6	117.9	1.75×10^{-5}	1.049
Lactic acid	50	119^{12} d	1.40×10^{-4}	1.2060
Citric acid	153	- d	7.45×10^{-4}	
Tartaric acid	170	-	1.10×10^{-3}	1.7600
Oxalic acid	190	- s	5.0×10^{-2}	1.90
Glutamic acid	213	- d	7.4×10^{-3}	1.538
Benzoic acid	122.4	249	6.3×10^{-5}	1.30
Phthalic acid	206	- d	1.26×10^{-3}	1.60
Formic acid	8.4	100.5		1.22
Maleic acid	140	-	1.5×10^{-2}	1.59
Adipic acid	153	265^{100} s	3.71×10^{-5}	1.36
Phenol	41	181.7	1.3×10^{-10}	1.072
Quinole	173	285^{730}	2×10^{-10}	1.32
Benzenesulphonic acid	65.6	-	Strong	

(1) Normally at 1 atmosphere (760 mm Hg) unless stated in superscript.

(2) A measure of acidity. A strong mineral such as Hydrochloric acid would have a measure of 10^{10} or more.

d Decomposes

s Sublimes.

A number of monocarboxylic acids were tested to see if they would act as fluxes.

Chemicals which succeeded included :

n Butyric acid, n Valeric acid, n Hexanoic (Caproic) acid
n Heptanoic (Enanthic) acid , n Octanoic (Caprylic) acid,
n Nonanoic (Pelargonic) acid, n Decanoic (Capric) acid,
Palmitic acid Stearic acid, Oleic acid, Undecenoic acid,
Linoleic acid, Docosanoic (Behenic) acid, Cyclohexanecarboxylic acid,
2 Ethylhexanoic acid, Olive Oil, tallow.

Chemicals which did not succeed included :

Formic acid, Acetic acid, Propionic acid, Glycollic acid
Glyoxylic acid Benzoic acid, Phthalic acid.

Monocarboxylic acids can be divided into several categories (ref. 27)

Each category is now considered in the light of the above results and some conclusions drawn as to which types of acid are likely to be successful as fluxes.

1. Straight chain saturated acids.

Formic, Acetic, Propionic, Butyric, Valeric, Caproic, Enanthic, Caprylic, Pelargonic, Capric, Palmitic, Stearic and Behenic acids from this group were tested.

It is probable that every acid with a chain length greater than three (Propionic) will act as a flux.

2. Straight chain unsaturated.

(i) Monounsaturated - Undecenoic and Oleic acids from this group were tested.

It is probable that all the acids in this group will act as fluxes.

(ii) Non-conjugated polyunsaturated - Linoleic from this group was tested.

It is probable that all the acids in this group will act as fluxes.

(iii) Conjugated polyunsaturated - No acids from this group were tested. Most have a chain length of 18 and many contain O or OH groups.

It is possible that some or all of this group may act as fluxes.

3. Branched Chain.

These contain methyl, ethyl or other similar groups.
2 Ethylhexanoic acid from this group was tested.

It is probable that many of this group will act as fluxes.

4. Alicyclic acids.

Cyclohexanecarboxylic acid from this group was tested.
It is possible that many of this group will act as fluxes.

5. Aromatic acids.

Benzoic and Phthalic acids from this group were tested.
It appears that this group do not act as fluxes.

6. Other derivatives.

These include Hydroxy, Keto, Epoxy, Methoxy, Halogens and others.
Tests were conducted on an Hydroxy and a Keto acid - i.e. Glycollic and Glyoxylic. These are both derived from Acetic acid.
It is hard to say which, if any, of these acids will act as fluxes.

7. Natural oils, fats and waxes.
Glycerides.

Tests were conducted on tallow and olive oil from this group.

It seems that many of the oils, fats and waxes could act as fluxes, probably because of free acids present in them.

It does not appear that pure glycerides will act as fluxes, although as they have not been tested this is not a firm conclusion.

It therefore seems that there are 300 or more possible fluxes.

CONCENTRATION OF FLUX IN BASE

3 Monocarboxylic acids were tested in an "inert" base by trying to bond 3003 alloy aluminium strip to flat sided, lock-seam brass radiator tubes coated with 80 : 20 tin : zinc solder at about 400°C. The tests started with a high concentration of the flux in the base and this was reduced successively until no bond was obtained.

RESULTS.

(a) Methanol base : Stearic, Oleic and Linoleic bonded until a concentration of 1% was reached.

(b) Glycerol base : Linoleic bonded until a concentration of 30% was reached.

Oleic bonded until a concentration of 10% was reached.

Stearic is not miscible with glycerol.

(c) Silicone grease base : Stearic bonded until a concentration of 5% was reached.

(d) Oil base : Stearic bonded until a concentration of 1% was reached.

Linoleic bonded until a concentration of 1% was reached.

(% is % by weight).

CONCLUSIONS

The oil acts as a base better than either the glycerol or the silicone grease do at this temperature.

As all 3 acids tested have similar molecular weights, they would be expected to act in a similar way when added to a base.

It is possible that natural oils, fats and waxes provide the best base.

The amount of acid present (COOH) group) is probably the most important factor, although unsaturation and the presence of other functional groups w have an effect on the acid strength.

Thus one would expect an acid such as Caprylic with a molecular weight roughly half that of the three tested, to be successful as a flux at about half the % concentration by weight of the three tested.

The surface properties of the individual acids may also affect the results.

Section 3

A recent patent on the use of monocarboxylic acid mixtures for soldering tin plate was discovered which claimed that a suitable flux mixture, having a good thermal stability, could be composed of :

1) A dimerised or trimerised acid with a low degree of unsaturation, the monomer having at least 10 carbon atoms. The preferred compound was an oleic acid dimer.

2) In addition, an aliphatic monocarboxylic acid and/or acid organic phosphate having between seven and eleven carbon atoms. The preferred compound in this case was "Versatic Acid", manufactured by Shell - a trialkyl acid having ten carbon atoms with the structure $CR_1R_2R_3COOH$ where R is an alkyl group, at least one of which is a methyl group.

The experiments covered this type of mixture as well as others and used a range of fatty acids compounds drawn from natural oils, fats and waxes. These included : "Versatic acid", Safflower oil, Soya Bean oil, Palm Kernel oil, Linseed oil, Coconut oil, Fish oil. a linoleic and linolenic acid mixture, and "Dimac" - a proprietary dimerised acid mixture similar to that described in the patent. The compositions of these mixtures are shown in table two. They range from the largely saturated coconut and palm kernel oils to the highly unsaturated linseed and fish oils.

All except 'Dimac' and 'Versatic Acid' were successful as fluxes. None of the compounds were good at high temperatures - they all charred more or less badly. The mixture suggested in the patent fared no better than any of the other compounds.

TABLE 2

AVERAGE FATTY ACID COMPOSITION AND CONSTANTS OF FATS AND OILS

	CHEMICAL FORMULA	COCONUT	PALM KERNEL	BABASSU	MURUMURU	PALM	TALLOW – BEEF	LARD	RAPE SEED	MUSTARD SEED	OLIVE	GROUNDNUT
	SATURATED ACIDS											
CAPROIC	$C_6H_{12}O_2$	0.2	Trace	0.1								
CAPRYLIC	$C_8H_{16}O_2$	8.0	2.7	6.5	1.1							
CAPRIC	$C_{10}H_{20}O_2$	7.0	7.0	2.7	1.6							
LAURIC	$C_{12}H_{24}O_2$	48.0	46.9	45.8	42.6							
MYRISTIC	$C_{14}H_{28}O_2$	17.5	14.1	19.9	36.8	1.0	3.0	2.0			Trace	
PALMITIC	$C_{16}H_{32}O_2$	8.8	8.8	[illegible]	4.5	42.5	29.0	25.5	1.5	[illegible]	[illegible]	[illegible]
STEARIC	$C_{18}H_{36}O_2$	2.0	1.3	Trace	2.2	4.0	18.5	11.4	0.5	Trace	2.3	5.0
ARACHIDIC	$C_{20}H_{40}O_2$									0.5	0.2	4.0
BEHENIC	$C_{22}H_{44}O_2$								0.5			
LIGNOCERIC	$C_{24}H_{48}O_2$					Trace			1.0	1.5		3.0
	UNSATURATED ACIDS											
MYRISTOLEIC	$C_{18}H_{26}O_2$											
PALMITOLEIC	$C_{18}H_{30}O_2$											
OLEIC	$C_{13}H_{34}O_2$	6.0	18.5	18.1	10.8	43.0	46.5	51.5	23.9	25.0	82.5	60.0
LINOLEIC	$C_{18}H_{32}O_2$	2.5	0.7		0.4	9.5	3.0	11.6	19.8	19.5	6.0	21.0
LINOLENIC	$C_{18}H_{30}O_2$								1.8			
ELAEOSTEARIC	$C_{18}H_{30}O_2$											
LICANIC	$C_{18}H_{28}O_3$											
RICINOLEIC	$C_{18}H_{34}O_3$											
ERUCIC	$C_{22}H_{42}O_2$								51.0	51.5		
C_{20} UNSATURATED	$C_{20}H_{2(20-x)}O_2$											
C_{22} UNSATURATED	$C_{22}H_{2(22-x)}O_2$											
	CONSTANTS											
SAPONIFICATION VALUE		250-264	245-255	247-251	237-247	195-205	196-200	190-200	170-180	178-184	195-200	183-1[illegible]
IODINE NUMBER		7.5-10.5	14-22	14-16	10-13	44-58	40-50	50-70	97-108	94-106	74-94	84-10[illegible]
TITRE °C		20-24°	20-25°	22-23°	–	40-47°	40-45°	34-42°	11.5-15°	–	18-25°	26-32

	LINOLEIC/LINOLENIC	"DIMAC"	"VERSATIC"	SAFFLOWER	SOYBEAN	SUNFLOWER	WALNUT	LINSEED	PERILLA	CASTOR	TUNG	OITICICA	WHALE	MENHADEN	SARDINE	HERRING
SATURATED ACIDS																
CAPROIC																
CAPRYLIC																
CAPRIC			100													
LAURIC																
MYRISTIC							Trace	0.2					8.0	7.0	5.0	7.0
PALMITIC				4	6.5	3.5	4.8	5.5	7.5		4.0	6.5	11.0	16.0	14.0	8.0
STEARIC	15			5	4.5	3.0	1.0	3.5	Trace	2.0	1.5	5.5	2.5	1.0	3.0	Trace
ARACHIDIC					0.7	0.6	Trace	0.6								
BEHENIC																
LIGNOCERIC					Trace	0.4		0.1								
UNSATURATED ACIDS																
MYRISTOLEIC													1.5	Trace	Trace	Trace
PALMITOLEIC													17.0	17.0	12.0	18.0
OLEIC	45	100		14	33.5	34.0	17.8	21.0	8.0	8.6	15.0	5.0	34.0	27.0	10.0	9.0
LINOLEIC	35			77	52.5	58.5	73.3	24.0	38.0	3.5			9.0	Trace	15.0	13.0
LINOLENIC	5				2.3		3.3	45.0	46.5				Trace			
ELAEOSTEARIC											79.5	5.0				
LICANIC												78.0				
RICINOLEIC										85.9						
ERUCIC																
C_{20} UNSATURATED													5.0	20.0	22.0	20.0
C_{22} UNSATURATED													12.0	12.0	19.0	25.0
CONSTANTS																
SAPONIFICATION VALUE		192-198		198-204	[illegible]	183-194	190-197	188-196	188-197	176-187	189-195	186-195	185-195	189-193	189-193	179-1[illegible]
IODINE NUMBER		85-95		145-155	120-141	125-136	154-162	170-204	193-208	81-91	160-175	140-152	110-136	148-185	170-190	130-1[illegible]
TITRE °C		–		14-16°	20-21°	16-20°	14-16°	19-21°	12-17°	–	37-38°	44-47°	22-24°	31-33°	28-34°	23-2[illegible]

Many factors such as soil, climate, variety, feeding, season when produced, etc. affect the composition and constants of fats and oils, and for this reason individual samples may show a considerable variation from the above averages.

SECTION FOUR

P.F. No. 2

PATENTS ACT 1949 to 1961

APPLICANTS REF.

No:

Date:

PROVISIONAL SPECIFICATION

"METHOD OF SOLDERING"

We, SERCK INDUSTRIES LIMITED, a British company of P.O. Box 598B, Warwick Road, Birmingham B11 2QY do hereby declare this invention to be described in the following statement:-

This invention relates to a method of forming a plurality of separate joints simultaneously between at least two parts of which at least one part has an aluminium or aluminium alloy surface and is more particularly, though not exclusively, concerned with the manufacture of a finned heat exchanger tube assembly in which a plurality of strips of aluminium or aluminium alloy foil are soldered to a plurality of tubes formed of, for example, brass, in a single soldering operation.

To form soldered joints it is generally necessary to employ a flux which protects the metal surfaces to be joined against oxidation at the soldering temperature which, in most cases, also serves to remove any oxide layer so that the solder can wet and bond to the metal surfaces. Various types of fluxes can be employed and the type chosen depends upon the types of metal to be soldered and the type of solder employed. In the case where an aluminium part is to be soldered, a so-called reactive flux which reacts with the strongly adherent oxide coating on the aluminium to expose the aluminium metal can be employed. Alternatively, a so-called organic flux which releases the oxide layer and deposits a metal onto the bare aluminium so that the solder wets and bonds to the deposited metal can be employed. One example of such an organic flux is one which contains (1) an organic fluoroborate, such as borontrifluoride-monoethanolamine to remove the aluminium oxide layer, (2) a heavy metal fluoroborate such as cadmium fluoroborate [$Cd(BF_4)_2$] to coat the bare aluminium and (3) a base e.g. methyl alcohol and stearic acid, to give the mixture body and to plasticise. Both of these types of fluxes have problems associated with their use. The reaction fluxes (generally heavy metal halides) are unpleasant to use in view of the toxic nature of the fumes generated during the soldering operation and tend to be very hygroscopic and therefore require careful storage to avoid the formation of undesirable oxychlorides. The so-called organic fluxes also produce extremely toxic fumes due to the presence of fluorine and cadmium and are relatively expensive. Both types of flux leave a deposit behind which requires to be removed so as to prevent corrosion of the joint in service.

It has been proposed many years ago to use fluxes consisting of or containing an organic acid, e.g. stearic acid, as the active fluxing ingredient in making a soldered joint between two aluminium parts. Such fluxes fall within the group of so-called intermediate fluxes which are generally considered to be not as powerful as the commonly used inorganic fluxes and it has been accepted that thorough cleaning of the surfaces to be soldered is necessary in such cases, especially when the two parts to be soldered are aluminium parts. Thus, to form a plurality of separate joints simultaneously between at least two parts of which at least one part has an aluminium or aluminium alloy surface, one would expect to use either a very strong flux such as an inorganic flux or the fluoroborate organic flux described hereinabove to avoid having to clean the surfaces, with all the concomitant disadvantages of the use of such fluxes.

It has also been proposed to use a method which involves immersing the two parts in an oil bath which ensures not only even heating but also excludes air so that further oxidation of the aluminium or aluminium alloy surfaces is avoided. However, such a method is expensive in that it requires expensive equipment and subsequent cleaning of the soldered parts in order to remove adherent oil, and its application is limited to low melting point solders as it is unsafe to operate the oil bath at temperatures above about 300°C.

An object of the present invention is to provide a simple process wherein a plurality of separate joints can be formed simultaneously between at least two parts of which at least one part has an aluminium or aluminium alloy surface wherein the process can be effected in air or an inert gas, i.e. without requiring an oil bath, and without the need to effect a prior cleaning operation and which requires little or no subsequent cleaning operations.

Suprisingly, it has been found that the process can be effected by using certain organic acid fluxes. This is totally unexpected in view of the inherent difficulties in forming a plurality of joints simultaneously with such materials and ensuring consistently reliable joints.

Accordingly, the present invention provides a method of forming a plurality of separate joints simultaneously between at least two parts of which at least one part has an aluminium or aluminium alloy surface, wherein the bond between the solder and the aluminium or aluminium alloy surface is effected in air or an inert gas using a flux consisting of, or containing as an active fluxing ingredient, at least one substituted or unsubstituted aliphatic alicyclic or aromatic monocarboxylic not being benzoic acid, phthalic acid, formic acid, acetic acid, propionic acid, glycolic acid or glyoxylic acid.

Preferably, the monocarboxylic acid has the formula R-COOH, wherein R is a straight or branched chain substituted or unsubstituted alkyl group having a chain of at least three carbon atoms, a straight or branched chain, conjugated or unconjugated, unsaturated aliphatic group, an alicyclic group, or an aromatic containing group wherein the bond to the carboxyl group is not on the aromatic ring.

The following fluxes were found to be suitable in bonding 3003 aluminium alloy strip to flat-sided, lock-seam brass radiator tubes coated with 80:20 tin:zinc solder at about 300°C:-

n-Butyric acid, n-Valeric acid, n-Hexanoic (Caproic) acid, n-Heptanoic (Enanthic) acid, n-Octanoic (Caprylic) acid, n-Nonanoic (Pelargonic) acid, n-Decanoic (Capric) acid, Palmitic acid, Stearic and Oleic acid, Undecenoic acid, Linoleic acid, Docosanoic (Behenic) acid, Cyclohexanecarboxylic acid, 2-Ethylhexanoic acid, Olive oil, Tallow, Safflower oil, Soya bean oil, Palm Kernal oil, Coconut oil, Fish oil, Linseed oil.

The following materials were found not to be satisfactory for such a soldering operation:-

Formic acid, Acetic acid, Propionic acid, Glycolic acid, Glyoxylic acid, Benzoic acid, Phthalic acid, Versatic 10*, Dimac 'S'÷.

* Shell Chemicals Ltd.
÷ Victor Wolf Ltd.

The active fluxing ingredient may, if desired, be employed in a suitable base to assist in application of the flux to the tubes. By heating in air at 300°C.3003 aluminium alloy strip was bonded satisfactorily to flat-sided, lock-seam brass radiator tubes coated with 80:20:tin:zinc solder at about 400°C, using stearic acid, oleic acid and linoleic acid in a methanol base down to a concentration of 1% by weight of the total weight of flux. Linoleic acid in a glycerol base was satisfactory down to a concentration of 30% by weight of the total weight of the flux whilst oleic acid was satisfactory down to a concentration of 10% by weight. Stearic acid bonded down to a concentration of 5% by weight of the total weight of flux when a silicone grease base was employed. When a mineral oil base was employed, stearic acid and linoleic acid were found to be satisfactory down to a concentration of 1% by weight of the total weight of flux.

A suitable solder for use in the method of the present invention wherein the flux employed is a 10% stearic acid/silicone grease mixture wherein the temperature is about 100°C above the liquidus of the solder and wherein the two parts to be joined is a solder-coated brass tube fluxed and sandwiched between a folded piece of 3003 aluminium alloy foil is tin, zinc, any tin-zinc alloy, a tin-lead solder containing down to 20% by weight of tin, a zinc-cadmium or tin-cadmium alloy containing up to 40% cadmium, a tin-aluminium alloy containing down to 85% tin. Zinc-aluminium solder alloys are found not to be satisfactory in the above-described soldering operation.

It has been found that the following materials can be satisfactorily soldered using a 95% zinc-5% tin solder and 10% stearic acid in a silicone grease base as a flux:-

99.99% Pure Aluminium, Al 1200,

Al 3003, Al 3005, Al 3103, Al 5005,

Al 8079, and Duralumin.

In effecting the method of the present invention, it is possible either to pre-tin the aluminium or aluminium alloy surface with the solder using the flux before effecting the jointing operation with the other part using any suitable flux. Alternatively, the two parts may be joined together without pre-tinning the aluminium or aluminium alloy surface.

In a preferred embodiment of the present invention, a plurality of strips of aluminium or aluminium alloy foil are soldered simultaneously, in air or inert gas, to a plurality of tubes formed of e.g. brass.

In such a method, it is preferred for the tubes to be pre-tinned with the solder using any suitable flux and to effect the joints between the pre-tinned tubes and the strips using the method of the invention.

Embodiments of the present invention will now be described in the following Examples.

Example 1

In making a radiator matrix of the "fin-and-tube" type, fins are stamped out of 3003 aluminium alloy foil;

using conventional tooling in a press. Lock-seam flat-sided tubes made from brass strip in the manner usual in radiator manufacture, the brass strip being passed through a bath of a suitable conventional flux, then through a bath containing molten 80:20 tin:zinc solder and formed into the required shape by means of sequential forming rolls, then cut off in suitable lengths. Before cutting, a layer of flux in applied to the tube by brushing, the flux comprising a liquid solution of 5% stearic acid, 50% methanol and 45% mineral oil by weight, the solution being maintained at 60°C.

The fins are held equally spaced in a suitable jig and the fluxed tubes inserted into the holes in the fins in the manner usual in the assembly of radiator matrices of the "fin-and-tube" type. The matrix is then placed in a forced air circulation oven at 300°C, after which it is removed and allowed to cool. In the resultant radiator matrix, the fins are securely soldered to the tubes.

Example 2

In making a radiator matrix of the "pack-construction" type, a corrugated fin strip is produced from 7072 aluminium alloy foil, using forming rolls usual in the construction of this type of radiator, cut off to appropriate lengths in the usual manner. Fluxed tubes are produced in the same manner as in Example 1 but using a flux mixture of 25% tallow, 25% methanol and 50% oil.

The radiator matrix is assembled by placing, in a suitable jig, two lock-seam flat-sided tubes side by side, parallel to one another, laying a length of corrugated fin above them, then a further pair of tubes and so on until the required width of radiator matrix is obtained. The assembly is then clamped and placed in a forced air circulation oven at 300°C, as in Example 1. The fins are securely soldered to the tubes in the resultant matrix.

Example 3

Example 2 is repeated except that the tubes are of 18:8 stainless steel coated with 90:10 zinc:cadmium solder and the flux mixture is 20% palmitic acid in silicone grease and the temperature of the oven is 500°C.

Example 4

Example 3 is repeated except that the solder is 40:60 tin:lead solder, the corrugated fin is made from 3003 aluminium foil the flux is oleic acid and the oven temperature is 350°C.

Example 5

In the soldering of copper wires attached to electronic components, to a printed circuit board comprising a 99.99% pure aluminium foil bonded to an epoxy glass cloth substrate, a flux comprising a solution of 70% linoleic acid dissolved in 30% meth is applied to the surface of the printed circuit board by brushing after the wires to be soldered to the aluminium foil have been placed in their appropriate positions, and the aforesaid surface of the printed circuit board is then passed over and in contact with a wave of 60:40 tin:lead solder at ~~200~~ 250°C. The copper wires are securely soldered to the aluminium foil with a good electrical connection therebetween.

Example 6

Example 1 was repeated using cyclohexanecarboxcylic acid as the flux to produce a radiator matrix in which the fins are securely soldered to the tubes.

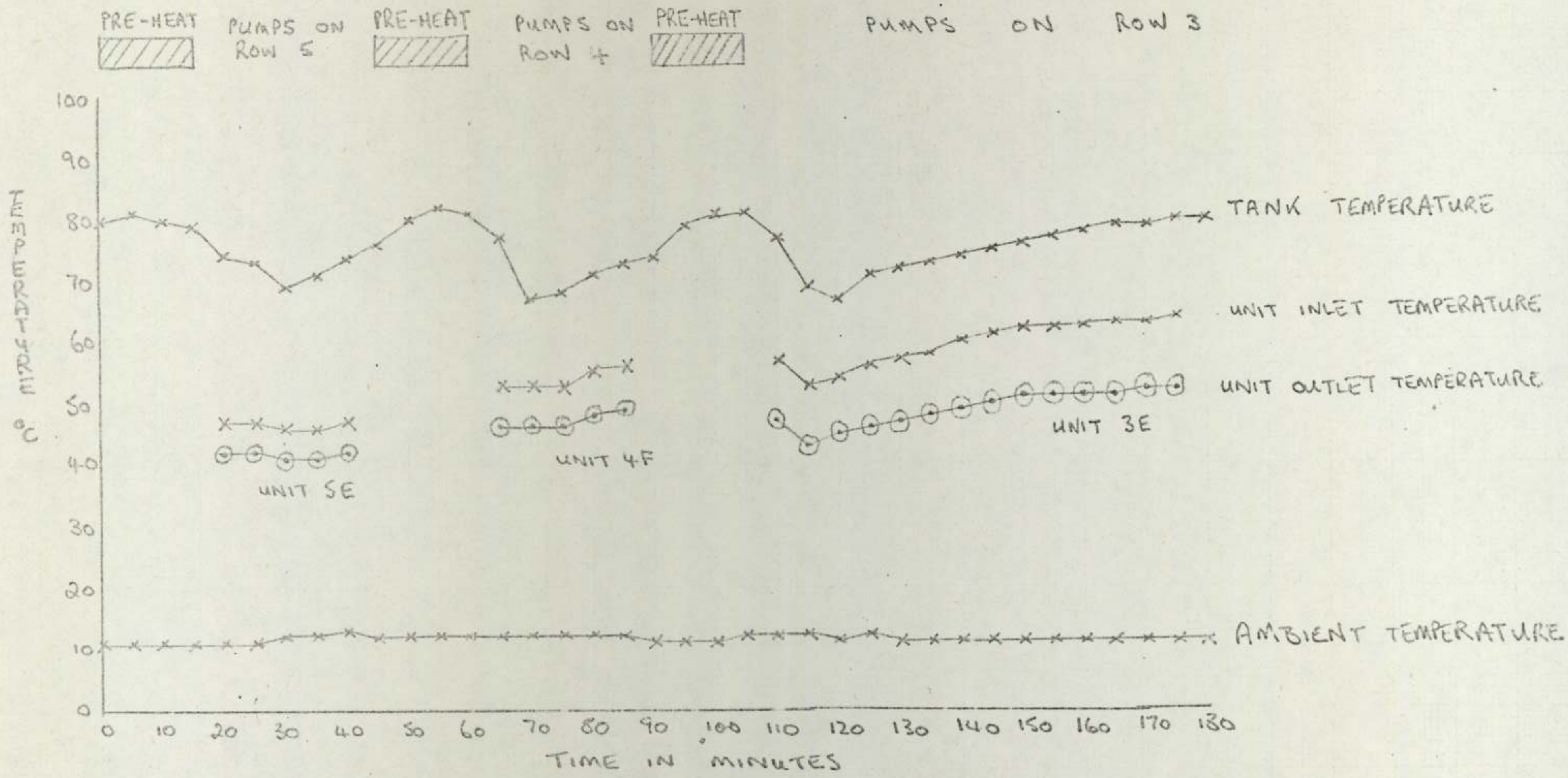
APPENDIX TO CHAPTER FIVE

Graphs 1 and 2 show the new laboratory test rig cycle. (See part five of chapter 5). Graph one is of a cycle with the water sprays turned off so that readings can be taken and graph two is of a cycle with the sprays on.

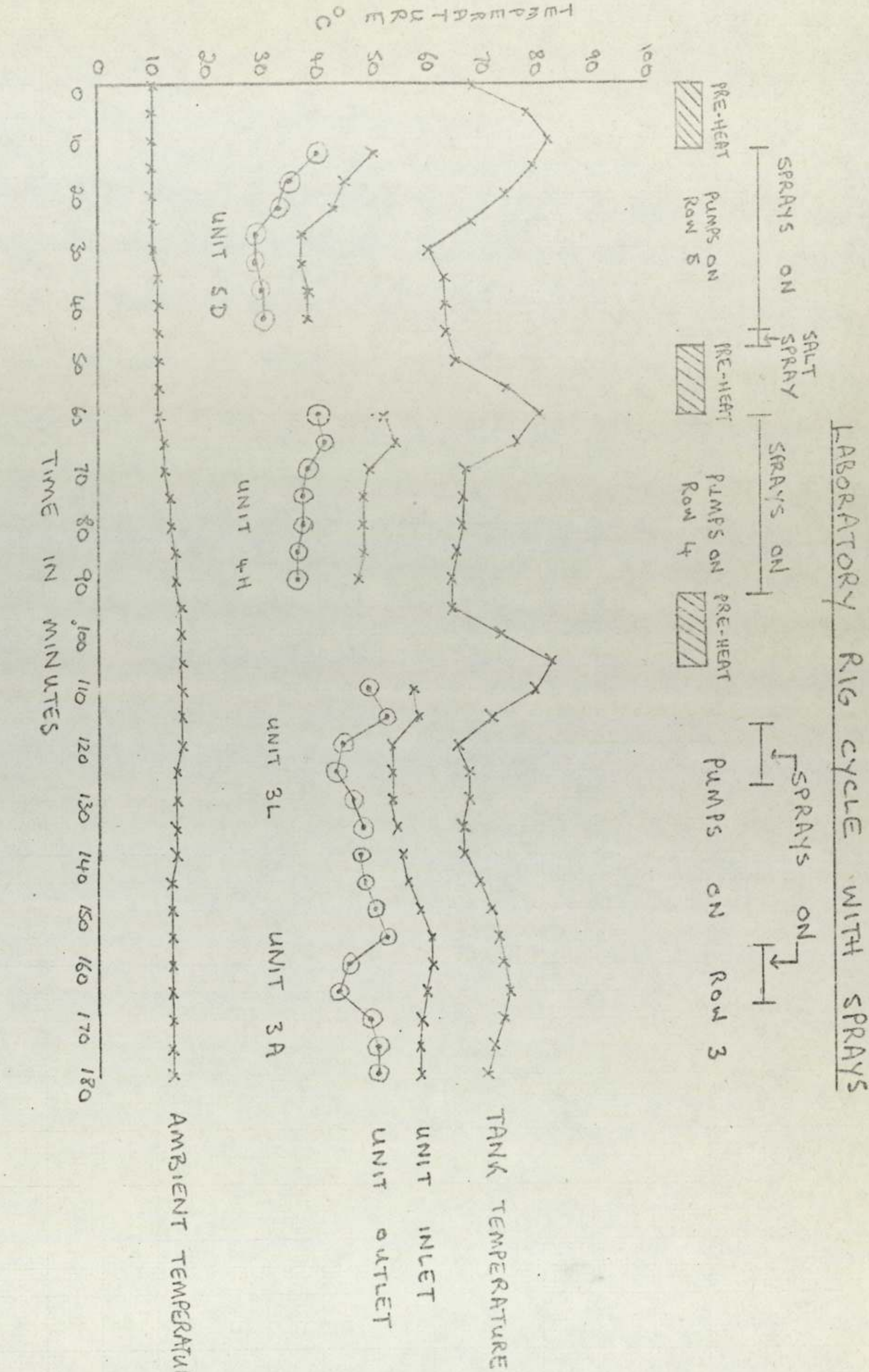
Tables 1 to 10 contain the results summarised in part six of chapter five. Table 11 gives the analysis of results referred to in part seven of chapter five.

GRAPH 1

LABORATORY RIG CYCLE WITHOUT SPRAYS



GRAPH 2


LABORATORY RIG CYCLE WITH SPRAYS
SPRAYS ON
SALT SPRAY
SPRAYS ON
SPRAYS ON
PRE-HEAT
PUMPS ON ROW 5
PRE-HEAT
PUMPS ON ROW 4
PRE-HEAT
PUMPS ON ROW 3
TEMPERATURE °C
TIME IN MINUTES
TANK TEMPERATURE
UNIT INLET
UNIT OUTLET
AMBIENT TEMPERATURE
UNIT 5D
UNIT 4H
UNIT 3L
UNIT 3A

TEMPERATURE DROP MEASUREMENTS

Table 1

1977

Unit No.	Type	4/5	11/5	18/5	23/6	6/7	15/7	18/8	24/8	5/9	13/9	24/9	30/9	3/10	4/10	5/10	6/10	7/10	20/10	2/11
Row 3A	A up.c.	9	10	11	14		12	9	8	7	6	10	8	9	9	9	10	8	9	6
B	A p.c.	8	8	9	11		10	9	9	8	8	12	9	9	9	9	10	9	9	7
C	C_{20}	5	5	5	9		10	5	5	5	5	6	5	5	5	5	6	5	5	4
D	C_{20}	[7]	7	7	7		8	6	6	6	5	7	5	6	6	6	7	6	6	5
E	B_{30} ∂$_{40}$	[11]	12	11	14		15	11	15	13	13	13	[10]	12	11	11	12	11	11	8
F	C_{20}	[7]	7	7	7		7	7	6	6	6	8	7	7	7	6	7	6	7	5
G	A copper fin	8	8	8	11		10	9	7	7	7	11	8	8	8	8	9	8	8	7
H	A p.uc.	8	7	8	8		8	7	6	6	5	9	7	7	7	7	7	6	7	6
J	$B_{30}C_{20}$	[9]	8	8	9		8	7	6	6	5	9	[7]	7	7	7	7	6	7	5
K	A	8	7	7	7		8	8	7	7	6	10	8	8	7	8	8	7	8	6
L	A	7	7	7	9		8	8	7	7	6	9	8	8	8	8	8	7	8	6
M	A copper pack	7	7	7	8		7	6	6	6	6	6	6	6	6	6	6	6	6	4
N	B_{30}	[7]	7	6	7		6	9	8	8	8	9	8	9	8	8	8	8	8	6
Inlet		60	54	63	70		68	63	63	66	68	67	67	63	66	66	65	67	68	62
Ambient		12	13	13	14		18	12	13	16	18	14	16	11	15	14	13	15	17	-
Tank		-	-	-	-		-	89	-	-	-	89	80	77	79	79	79	81	81	-

Key :
- [ ] (box) - New Unit
- up. - Unpainted
- p. - Painted
- uc. - Uncleaned
- c. - Cleaned

∂$_{40}$'s on 3E and 5B are pack blocks.

The one on 5D is fin and tube.

The ∂$_{90}$ on 5G is fin and tube.

5

TEMPERATURE DROP READINGS

1977

Date of Reading	Type	4/5	11/5	18/5	23/6	6/7	15/7	18/8	24/8	5/9	13/9	24/9	30/9	3/10	4/10	5/10	6/10	7/10	20/10	2/1
Row 4A	C_{20}		6	6	6		6	7	4	3	2	2	6	4	4	4	4	4	3	2
B	A p.uc.		9	8	10		9	10	6	6	4	5	9	6	5	6	6	5	5	4
C	B_{30}		9	9	13		10	15	9	9	8	9	18	10	10	10	10	10	10	8
D	A copper pack		6	7	10		6	9	5	5	3	4	8	5	5	5	5	5	5	3
E	A up.c.		7	7	9		8	9	5	5	3	4	8	5	5	5	5	5	5	3
F	B_{30}	7	7	7	10		8	9	5	5	3	4	8	6	6	6	6	5	5	3
G	C_{20}		5	5	6		6	8	4	3	2	3	5	3	3	4	3	3	3	2
H	A		7	7	10		7	8	6	6	4	6	10	6	6	6	6	6	6	4
J	B_{30}		5	5	7		7	5	4	4	3	3	6	4	4	4	4	5	4	3
K	A p.c.		6	6	10		6	6	5	4	4	4	8	5	5	5	5	5	4	3
L	A		6	6	8		6	6	5	5	4	4	8	5	5	5	5	5	5	4
M	A copper fin		6	7	8		6	6	5	5	4	4	8	5	5	5	5	5	5	4
N	C_{20}		6	6	6		5	4	3	3	2	2	5	3	3	3	3	3	3	2
Inlet			55	57	71		62	61	61	63	64	60	75	60	63	61	62	63	65	60
Ambient			13	13	14		16	12	13	15	18	13	16	10	15	14	13	15	17	-
Tank			-	-	-		-	89	-	-	-	89	83	78	80	79	80	81	83	-
Row 5A	C_{20}		5	5	7	4	4	5	4	4	4	4	5	4	4	4	4	4	4	3
B	B_{30} a_{40}		6	5	8	4	4	5	4	4	3	4	10	8	7	7	8	8	8	5
C	A		6	6	6	6	6	7	6	6	5	6	8	6	5	5	6	6	6	4
D	A copper fin a_{40}		6	7	8	5	5	7	6	5	6	5	8	5	5	6	5	6	5	4
E	B_{30}	5	5	5	6	4	4	5	4	4	4	4	6	5	4	4	5	5	4	3
F	A up. c.		6	5	6	4	4	6	5	4	5	4	6	4	4	4	4	4	4	3
G	C_{20} a_{90}		7	7	7	5	5	7	5	5	5	5	7	5	5	5	5	5	5	4
H	A p.uc.		6	5	8	4	4	6	5	4	5	5	6	5	4	5	5	4	5	3
J	A		5	6	10	4	3	5	4	4	4	4	5	4	4	4	4	4	4	2
K	B_{30}	6	5	5	6	5	5	7	5	5	5	5	8	6	5	6	5	5	6	4
L	C_{20}		4	4	7	4	3	5	3	4	3	3	5	4	3	3	3	3	3	2
M	Ap.c.		4	4	9	4	3	5	4	4	3	3	5	4	4	4	4	4	4	2
N	A copper pack		4	4	6	5	4	5	4	4	4	4	5	4	4	4	4	4	4	2
Inlet			48	48	63	59	55	51	51	54	54	50	67	51	53	53	53	53	57	52
Ambient			13	13	14	26	20	12	13	15	16	12	16	10	15	14	13	13	17	-
Tank			-	-	-	83	81	89	-	-	-	88	80	77	78	78	79	79	82	-

NOTES TO TABLE 1

Notes on Readings

4.5.77	This set was taken to test the new operating cycle.
11.5.77) 18.5.77)	Both these sets of readings were taken at a low inlet temperature.
23.6.77	This set of readings was taken at a high inlet temperature.
6.7.77	This set of readings was taken to test the thermocouples installed on manifold 5.
18.8.77	This set of readings was taken using thermocouples on all manifolds.
24.8.77) 5.9.77) 13.9.77)	These readings were taken by a different person.
30.9.77	For some unknown reason the inlet temperature on manifolds 4 and 5 was high during this set of readings.
2.11.77	Pumps were operating at an increased water flow rate for this set of readings.

RESULTS OF VISUAL INSPECTION

Date of inspection :

Unit No.	17/3	4/5	11/5	23/6	15/7	13/9	24/10 *	1977
Row 3A	5	5	5	5	5	5		
B	3	3	3	3	4	4		
C	1	3	3	2	3	5		
D	5	[1]	1	2	1	1		
E	5	[1]	1	1	1	1	1	
F	4	[1]	1	1	1	1		
G	1	1	1	1	1	1		
H	3	3	3	3	2	3		
J	5	[3]	2	3	2	3	4	
K	1	4	4	2	3	2		
L	4	5	5	5	5	5		
M	1	1	1	1	1	1		
N	5	[3]	2	1	1	1		
Row 4A	5		[1]	2	2	1		
B	1		1	1	1	1		
C	5		[1]	1	1	1		
D	1		1	1	1	1		
E	1		1	1	1	1		
F	4		[1]	1	1	1		
G	2		2	1	2	1		
H	1		1	1	1	1		
J	1		3	3	2	2		
K	1		3	1	1	1		
L	1		1	2	2	1		
M	1		1	1	1	1		
N	1		2	1	1	2		
Row 5A	5		[1]	1	1	1		
B	1		1	1	5	2	5	
C	5		4	3	3	5		
D	1		1	1	1	1	1	
E	5	[1]	1	1	2	1		
F	1		1	1	3	1		
G	4		[1]	[1]	1	1		
H	1		1	1	1	1		
J	3		2	1	3	2		
K	5	[1]	1	1	1	1		
L	4		[1]	1	1	1		
M	1		1	1	1	1		
N	1		1	1	1	1		

Key :
1. Good Bond (75% or more)
2. Quite good bond
3. 50% bonded
4. Not much bond
5. Little or no bond

[ ] New unit

* Examination of units taken off rig.

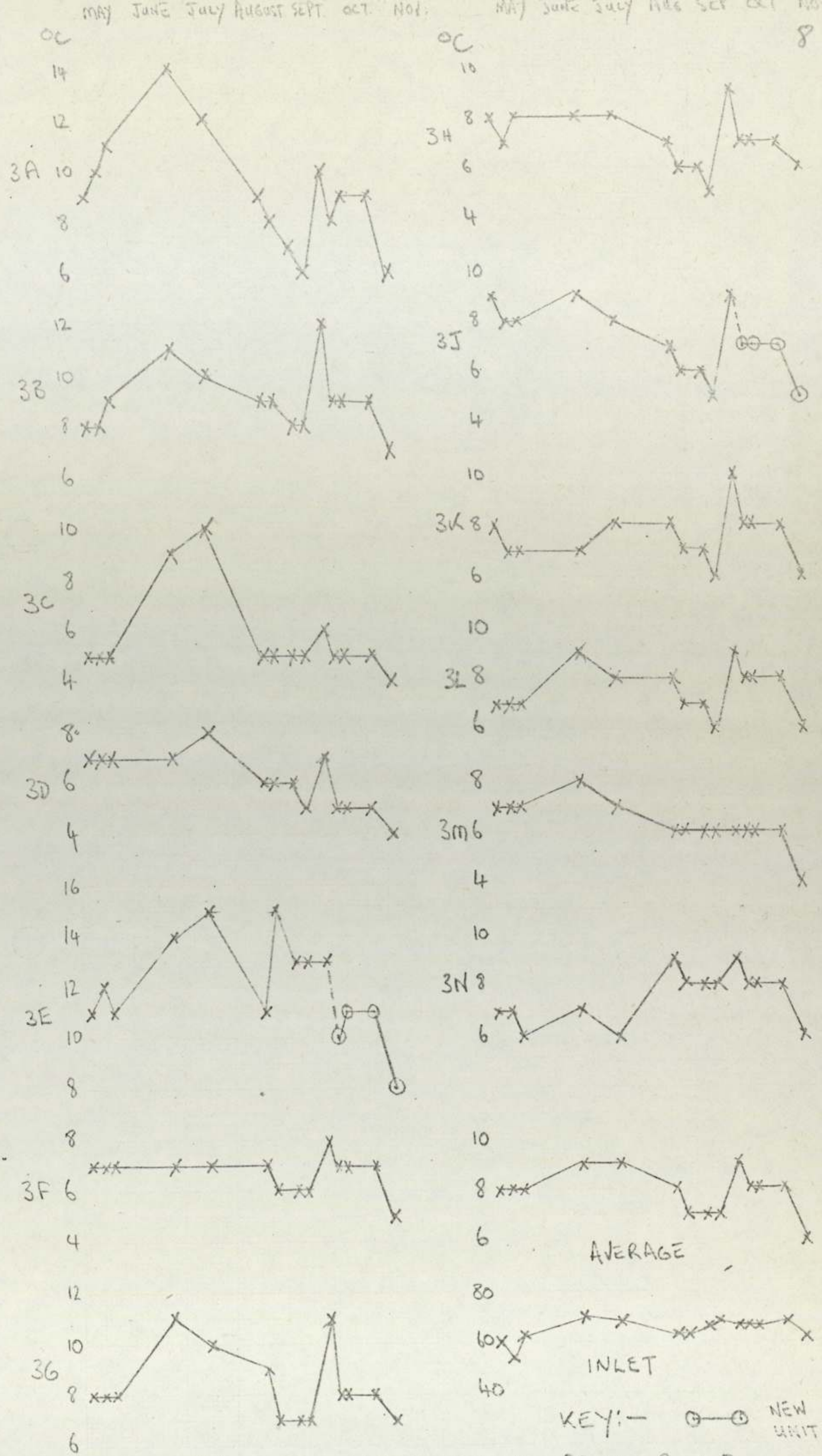


TABLE 3 – TEMPERATURE DROPS ROW 3

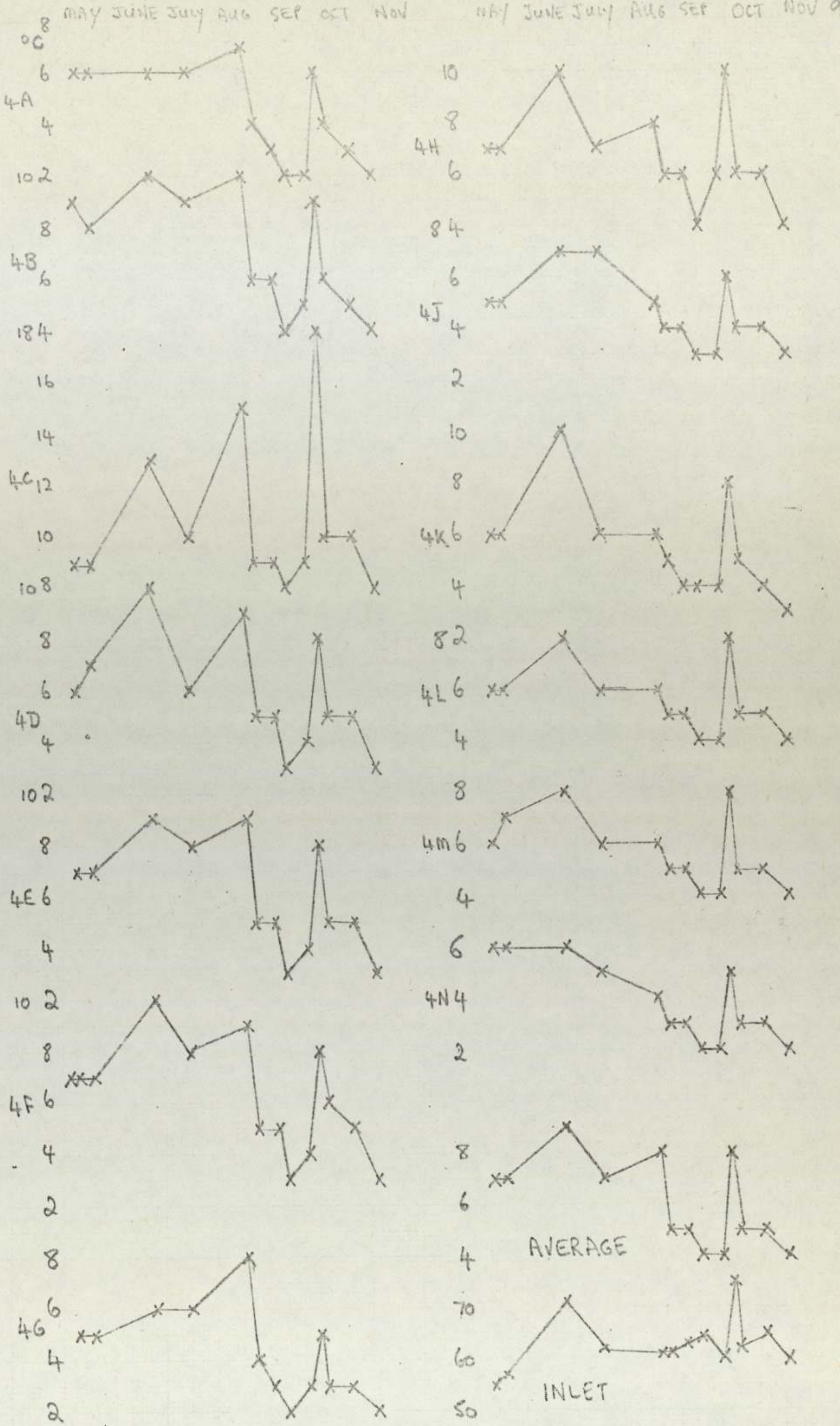


TABLE 4 - TEMPERATURE DROPS ROW 4

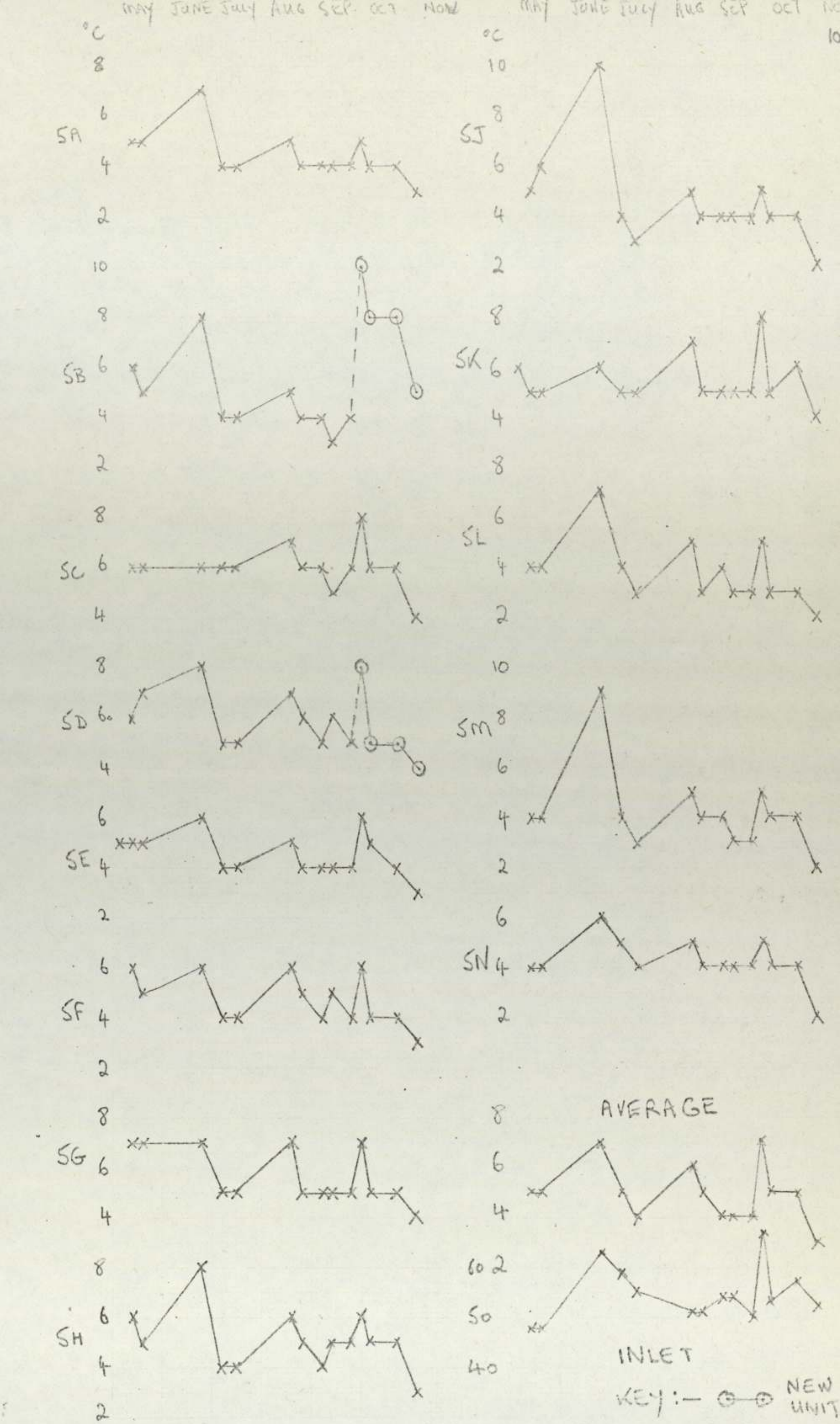


TABLE 5 - TEMPERATURE DROPS ROW 5

TABLE 6

Correlations between the inlet temperatures and ambient.

Row 3 - considering 13 inlet readings, discounting the first four and the last one.

Correlation of 79%

Equation is $y = -53.89 + 1.04x$
where y is ambient and x is inlet temperature

Row 4 - considering 12 readings, discounting the first three, the last one and the reading on 30.9.77.

Correlation of 74%

Equation is $y = -61.42 + 1.22x$

Row 5 - considering 11 readings, discounting the first five, the last one and the reading on 30.9.77

Correlation of 77%

Equation is $y = -33.98 + .9x$

AVERAGES AND STANDARD DEVIATIONS

	Av.	St.Dev.		Av.	St.Dev.		Av.	St.Dev. (1)	Av.	St.Dev. (2)	Av.	St.Dev. (3)
3A	9	1.4	new units	9.3	1.8	4A	4.2	1.5	4	1.3	4.4	1.5
B	9.1	1.0	(from 30/9)	9.2	1.0	B	6.4	1.8	6.2	1.5	6.8	1.9
C	5.4	1.2		5.7	1.5	C	9.9	1.6	9.5	.6	10.6	2.5
D	6.3	.8		6.4	.8	D	5.4	1.3	5.1	.9	5.8	1.8
E	12.7	1.5/11.1 .6		12.8	1.5(old)	E	5.6	1.6	5.3	1.3	5.9	1.8
F	6.8	.6		6.7	.6	F	5.9	1.5	5.6	1.3	6.3	1.8
G	8.3	1.0		8.4	1.2	G	3.9	1.6	3.5	1.2	4.1	1.6
H	7.0	.9		7.1	.9	H	6.2	.9	6.1	.7	6.7	1.5
J	7.3	1.3/6.9 .4		7.5	1.4(old)	J	4.4	1.0	4.3	1.0	4.6	1.2
K	7.6	.9		7.6	.8	K	5.0	.8	4.9	.7	5.5	1.6
L	7.6	.7		7.7	.8	L	5.1	.6	5.1	.6	5.5	1.1
M	6.3	.4		6.4	.6	M	5.2	.8	5.2	.8	5.6	1.2
N	7.8	.9		7.8	.9	N	3.6	1.2	3.5	1.3	3.8	1.4

(not including 23.6.77)   All results   (1)(not including 23/6 or 30/9)
(2)(Also not 18/8) (3)All results

Inlet 65 3.6 — 63 4.5
Ambient 14 2.0 — 14 2.1

	Av.	St.Dev.		Av.	St.Dev.		Av.	St.Dev.	
5A	4.2	.4	new units	4.1	.4		4.4	.8	new units
B	4.3	.8/7.6 .5		4.3	.8	(old)	4.7	1.4 /8 .92	
C	5.9	.5		5.8	.4		6	.7	
D	5.8	.8/5.3 .5		5.6	.7	(old)	6	1.0 /5.7 1.0	
E	4.4	.5		4.4	.5		4.6	.7	
F	4.5	.7		4.4	.6		4.7	.8	
G	5.4	.8		5.3	.7		5.4	.8	
H	4.8	.7		4.7	.6		5.1	1.0	
J	4.2	.7		4.1	.6		4.6	1.5	
K	5.3	.6		5.2	.4		5.5	.9	
L	3.5	.6		3.4	.5		3.8	1.1	
M	3.9	.5		3.8	.4		4.2	1.3	
N	4.1	.3		4.1	.3		4.3	.6	

(not including 23/6 or 30/9)   (also not 18/8)   All results

Inlet 54 4.8
Ambient 15 3.6

ANALYSIS OF MEANS AND STANDARD DEVIATIONS

Pack Block Units

C_{20} -	3c	5.7	1.5
	D	6.4	.8
	F	6.7	.6
	J	6.9	.4
	4A	4.4	1.5
	G	4.1	1.6
	N	3.8	1.4
	5A	4.4	.8
	L	3.8	1.1
Average		5.1	1.1

copper fin -	3M	6.4	.6
	4D	5.8	1.8
	5N	4.3	.6
Average		5.5	1.0

a_{40}	3E	11.1	.6
	5B	7.6	.5
		9.4	.6

Fin and Tube Units

Variant A -	3K	7.6	.8
	3L	7.7	.8
	4H	6.7	1.5
	4L	5.5	1.1
	5C	6.0	.7
	5J	4.6	1.5
Average		6.4	1.1

unpainted -	3A	9.3	1.8
cleaned	4E	5.9	1.8
	5F	4.7	.8
Average		6.6	1.5
painted	3H	7.1	.9
uncleaned	4B	6.8	1.9
	5H	5.1	1.0
Average		6.3	1.3

ptd.	3B	9.2	1.0
clnd	4K	5.5	1.6
	5M	4.2	1.3
Avg.		6.3	1.3

All A's -	Average	6.4	1.2
Variant B_{30}	3E	12.8	1.5
	3J	7.5	1.4
	3N	7.8	.9
	4C	10.6	2.5
	4F	6.3	1.8
	4J	4.6	1.2
	5B	4.7	1.4
	5E	4.6	.7
	5K	5.5	.9
	Average	7.2	1.4
without 3E & 4C		5.9	1.2

copper fin -	3G	8.4	1.2
	4M	5.6	1.2
	5D	6.0	1.0
Average		6.7	1.1
a_{90} -	5G	5.4	.8
a_{40} -	5D	5.7	1.0

	Pack		Fin and Tube		All Units		
3	6.4	.8	7.2	1.1	3	6.9	1.0
	(7.2 with E)		(8.6 with E)			(7.6 with E)	
					4	5.4	1.6
						(5.8 with C)	
4	4.5	1.6	5.9	1.5			
			(6.4	1.6 with C)	5	5.3	.9
5	5.0	.8	5.4	.9			
All	5.4	1.0	6.1	1.2			
	(not 3E)		(not 3E or 4C)				

Bad Units

3C pack	5.7	1.5	)	Slightly high standard deviations
3J B_{30}	7.5	1.4	)	
5B "	4.7	1.4	)	
3A A	9.3	1.8	)	
3B "	9.2	1.0	)	All the row 3 variant A units. Do not
3H "	7.1	.9	)	differ noticeably from copper fin or B_{30}.
3K "	7.6	.8	)	
3L "	7.7	.8	)	
5C "	6	.7	)	
5F "	4.7	.8	)	Do not differ much from other row 5
5J "	4.6	1.5	)	variant A units.

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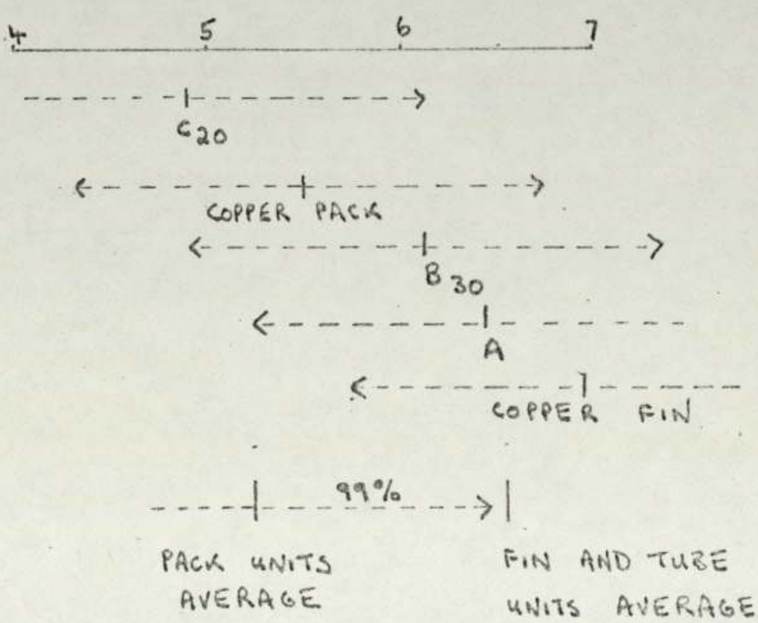
ANALYSIS OF VARIANCE

Manifold	3	4	5	mean
C_{20} Pack	6.5	4.1	4.1	4.9
Copper Pack	6.4	5.8	4.3	5.5
Variant A	8.2	6.1	5.0	6.4
Variant B_{30}	7.7	5.5	5.1	6.1
Copper Fin	8.4	5.6	6.7	6.9
Mean	7.5	5.4	5.0	6.0

Source	Variation	d.f.	Variance	Ratio	Prob. value H^{0}
Between manifolds	18.05	2	9.03	45.15	pr $< .001$
Between units	7.32	4	1.83	9.15	pr $< .01$
Unexplained	1.60	8	.2		
Total	26.97	14			

Row 3 differs from rows 4 and 5 significantly up to 99.9%.
Pack block units differ from fin and tube up to 99% (C_{30} more than Cu)
Otherwise no significant differences.



Means with 90% confidence interval. (± 1.2)

Variant	A	A up/c	A p/c	A p/uc	A copper	Mean
Row 3	7.7	9.3	9.2	7.1	8.4	8.3
4	6.1	5.9	5.5	6.8	5.6	6.0
5	5.3	4.7	4.2	5.1	6.0	5.1
Mean	6.4	6.6	6.3	6.3	6.7	6.5

Source	Variation	d.f.	Variance	F ratio	Prob.Value H^{O}
Between rows	25.9	2	12.95	22.3	$<.01$
Between units	.78	4	.2	.35	$>.25$
Unexplained	4.65	8	.58		
Total	31.33	14			

There is no significant difference between units, but a 99% significant difference between manifolds 3 and 4 and 5.

TEMPERATURE DROP READINGS WITH SPRAYS ON

11, 12th and 18th May.

Unit	Type	No Spray	Spray
3A	A up/c	8	16
B	A p/c	7	13
C	C_{20}	5	10
H	A p/uc	7	12
J	B_{30}	7	10
L	A	7	10
M	Copper pack	7	10
	Average	6.9	11.6
	(67% increase)		

4G	C_{20}	5	12
H	A	7	11
N	C_{20}	6	9
	Average	6	10.7

5 D	Copper fin	6	8
H	A puc	6	8
K	B_{30}	5	7
L	C_{20}	4	7
M	Apc	6	7
N	copper pack	4	7
	Average	5.2	7.4
	(42% increase)		

6th June

5A	C_{20}	4	7
B	B_{30}	4	7
C	A	6	9
D	Copper fin	5	8
E	B_{30}	4	8
F	A upc	4	8
G	2 90	5	8
H	A puc	4	7
J	A	4	7
K	B_{30}	5	7
L	C_{20}	4	6
M	A pc	4	6
N	Copper pack	5	7
	Average	4.5	7.4
	(67% increase)		

23rd June

4G	C_{20}	6	13

13th September

4G	C_{20}	2	9
5C	A	5	10

Table 11

ANALYSIS OF INSPECTION RESULTS

	Bond				Fin Condition		
Row 3	9C	1B	3A		OC	3B	10A
	(no new units - 10c 1B 2A)						
Row 4	7C	4B	2A		2C	5B	6A
Row 5	11C	2B	OA		6C	5B	2A
Pack Units	8C	3B	3A		3C	6B	5A
Fin and Tube	19C	4B	2A		5C	7B	13A
C_{20}	8C	-	-		3C	5B	-
New pack units	-	2B	1A		-	-	3A
Copper pack	-	1B	2A		-	1B	2A
B_{30}	4C	2B	-	)	1C	2B	3A
A	5C	1B	-	) All B's on row 4	2C	1B	3A
A up,c	2C	1B	-	)	1C	1B	1A
A p,uc	3C	-	-		-	-	3A
A p,c	3C	-	-		-	2B	1A
2_{90}	1C	-	-		-	1B	-
2_{40}	1C	-	-		1C	-	-
Copper fin	-	-	2A		-	-	2A

A grade bonds 3G copper fin 3M copper pack 3J new C20 pack
4D copper pack 4M copper fin

B grade bonds 3E 2_{40} pack
4C B_{30} 4E A up,c 4F B_{30} 4 H A
5B 2_{40} pack 5N copper pack

ANALYSIS OF INSPECTION RESULTS

Alloting a value of 5 to C, 3 to B and 1 to A; and correcting manifold 3 results to allow for the presence of the new units.

Analysis of Variance

Bond

Row	3	4	5	Mean
C_{20}	5	5	5	5
Copper pack	1	1	3	1.7
A	5	4.2	5	4.7
B_{30}	4.3	3.7	5	4.3
Copper fin	1	1	3	1.7
Mean	3.3	3.0	4.2	3.5

Source	Variation	d.f.	Variance	F. Ratio	Prob.Value H_o
Between manifolds	3.9	2	2	4.2	$<.05$
Between units	32.43	4	8.11	16.9	$<.001$
Unexplained	3.84	8	.48		
Total	40.17	14			

Row 5 differs from 3 and 4 significantly at the 95% level.
Copper units differ from the others at the 95% level.

ANALYSIS OF INSPECTION RESULTS

Fin Condition

Row	3	4	5	Mean
C_{20}	3	4.3	4	3.8
Copper pack	1	1	3	1.7
A	1	2.2	3.8	2.3
B_{30}	1	1.7	4.3	2.3
Copper fin	1	1	3	1.7
Mean	1.4	2.0	3.6	2.3

Source	Variation	d.f.	Variance	F. Ratio	Prob.Value H^o
Between manifolds	12.95	2	6.5	5.0	$<.001$
Between units	8.91	4	2.2	16.9	$<.001$
Unexplained	1.01	8	.13		
Total	22.87	14			

Copper units differ from the others significantly at the 99% level.
C_{20} units differ from the A and B_{30} significantly at the 99% level.
Manifold 5 differs from 4 and 3 significantly at the 99.9% level.

	A	A up,c	A pc	A p,uc	Mean
3	1	1	1	1	1
4	2	3	3	1	2.3
5	5	5	3	1	3.5
Mean	2.7	3	2.3	1	2.3

Source	Variation	d.f.	Variance	F.Ratio	Prob.Value H^o
Between manifolds	12.52	2	6.3	6.3	$<.05$
Between units	7.02	3	2.3	2.3	$<.25$
Unexplained	6.25	6	1.0		
Total	25.79	11			

Manifold 5 differs from 3 and 4 at the 90% level.
A p,uc differs from the others at the 75% level.

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