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ROYAL AIRCRAFT ESTABLISHMENT

(FARNBOROUGH)

REPORT No. PBW. 2

EXPLOSION OF A TITANIUM FURNACE AT THE JESSOP-SAVILLE WORKS, SHEFFIELD

by

P. B. Walker, C.B.E., M.A., Ph.D.

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MINISTRY OF AVIATION

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SUMMARY

An investigation into the explosion of a titanium arc-furnace is briefly described, and photographs of the more important pieces of wreckage are given.

The accident is attributed to insufficient cooling of the copper base of the crucible and there is clear evidence of penetration. The main damage is attributed to chemical action between molten titanium and some of the cooling water.

Comparisons with steel melting are also made and there is a brief discussion of other potential hazards. It is suggested that most of the essential precautions here recommended are being taken in more modern designs of equipment.

1 INTRODUCTION

On 12th April 1963, a titanium melting furnace at the Jessop-Saville Works, Sheffield, exploded. The Director R.A.E. was asked for help, and at his request the writer visited the firm with Mr. F.H. Jones on 29th April, 1963.

The furnace, which had seen many years service, operated on the principle of the electric arc at about 400 kilowatts of power. In this design, a cylindrical block of titanium, weighing initially about a ton, drips molten metal along a downward moving arc into a copper crucible. This crucible is cooled on the outside by a steady circulation of water enclosed in a steel jacket. The system is illustrated diagrammatically in Fig.1.

The explosion occurred shortly after the "melt" had been started, and there would have been about 100 lb of titanium in the bottom of the crucible. About three tons of control gear together with the block of titanium (Fig.2) were projected upwards through several feet. Hundreds of square feet of glass and panelling were removed from the roof and walls of the building. The water jacket, made of quarter inch steel, was blown apart (Fig.3).

Despite the evidence of violence, injuries to personnel were minor, and caused mainly by falling debris and flying dust. After a preliminary examination, the complete wreckage was sent to Farnborough for investigation. A most significant item in the wreckage was the bottom of the crucible. This was made of copper two inches thick, and had clearly been melted right through (Fig.4).

The conclusion reached is that the explosion is primarily attributable to imperfections in the cooling system as described in Section 2 below. The investigation called for review of the melting process and some further comments are given in Section 3, with a few notes on other potential hazards in Section 4. Finally, recommendations for future design and operation are given in Section 5.

Several of these recommendations are thought to have already been incorporated in more modern equipment, such as the Heraeus plant which the firm already possesses. With suitable precautions the arc type of titanium furnace does not appear unduly dangerous as judged by normal standards in the metallurgical industries.

This brief report is based mainly on work done by the following people:

Mr. F.H. Jones Mr. J.I.M. Forsyth	Wreckage Analysis Section of Structures Department, R.A.E.
Mr. A.R.G. Brown Mr. K.S. Jepson	Metallurgy Division of C.P.M. Department, R.A.E.
Dr. R.E. Miller	General Chemistry Division of C.P.M. Department, R.A.E.

These specialists may later produce detailed reports for scientific record.

2 CAUSE OF THE ACCIDENT

The primary cause of the explosion is considered to be defective circulation of cooling-water immediately underneath the bottom of the copper crucible. It is probable that a bubble of steam or air collected there and allowed the copper to reach an excessively high temperature.

It is believed that the electric arc, in the early stages of melting, pushed aside the molten titanium and penetrated the copper base. The evidence of such penetration (Fig.4) is regarded as conclusive.

The overall supply of water is thought to have been adequate and to have been properly circulated everywhere except at the bottom of the crucible. Failure to protect the bottom is attributed to some modifications to the original equipment, and in particular to the use of a "spider" guide-vane system (Fig.5) without the water jets appropriate to it. The spider as fitted must inevitably have checked the flow of water in the critical region, and caused this to be by-passed. Furthermore, the geometry was such that the rim of the spider and the bottom of the crucible formed a shallow inverted bowl calculated to produce a steam or air lock.

The primary purpose of the spider was to give mechanical support to the copper bottom of the crucible, but it had originally been designed to do so without prejudicing the essential cooling. In this respect it would have been successful if water had been injected directly between the radial vanes. In this particular assembly, however, the entry holes or jets were not opposite the spider and so were relatively ineffective in the critical region.

The main explosive energy was provided by the chemical action between molten titanium and water (steam). This action is violently exothermic and is thought to account for virtually all the damage that was done. About 100 lb of titanium was missing after the explosion and it is estimated that most of this had been converted into titanium-dioxide (TiO_2).

The precautions that had been taken in the way of providing blast walls and having the furnace in a pit appear to have been fully effective in directing the blast away from personnel, and there are grounds for satisfaction in the minor character of the injuries that were caused.

The titanium-water reaction produces hydrogen, which even acting as a chemically inert gas tends to increase the explosive forces that are generated. If mixed with air, however, it becomes potentially an additional explosive on its own account. It is significant that the balance of the evidence indicates that the hydrogen did not explode, anddid not even catch fire. This absence of a hydrogen fire or explosion may have been partly fortuitous, and it has to be noted that had either occurred the injuries and damage could have been more serious.

3 FURTHER CONSIDERATIONS

The investigation brought out a number of additional points that have some bearing upon this particular accident.

The melting of steel has received much attention because the same furnaces are used for steel as for titanium, and the melting processes are basically identical. Major differences arise, however, if water enters the furnace. While the titanium-water reaction is highly exothermic, the steel-water reaction is virtually thermo-neutral. In this connection it it important to note that the heat given out in the formation of titanium-dioxide does more than provide the main supply of explosive energy, significant though this be. It also produces violent thermo-mechanical agitation which greatly accelerates the chemical processes and intensifies their explosive character.

On these grounds it could clearly be misleading to draw deductions from experience with steel melting and apply them directly to titanium. The point is important because there appear to have been innumerable steel melts in all parts of the world without explosion. On the other hand, there appear to have been minor troubles with steel in a few cases and it is not unlikely that similar conditions would sometimes have caused an explosion if titanium had been in the furnace instead of steel.

There is another difference between steel and titanium that may have a more direct bearing on the accident under investigation. Steel requires a temperature for melting about 200°C lower than titanium, say 1600°C instead of 1800°C. Under normal conditions this difference raises no major issue. It could become significant, however, under marginal conditions such as are believed to have existed in this accident; and the plant in the form last used for titanium had been operated several times for steel without any trouble.

Mention should perhaps also be made of the atmosphere within the crucible. Normally a high vacuum (about one thousandth of a millimetre of mercury) is maintained. For some titanium alloys, however, it is more usual to have argon in the crucible, and argon was used in this case at a pressure of about a quarter of an atmosphere. The main known effect of argon is to concentrate the arc to some extent and to make it more intense. Normally it would be a minor consideration, but this also could have significance under marginal conditions.

4 OTHER POTENTIAL HAZARDS

Apart from penetration of the crucible wall caused by inadequate cooling, the further hazards to a furnace of this type are water leakage and hydrogen fire or explosion. None of these is deemed to have occurred in this case, but they have received some consideration and a few remarks may be worthwhile from the standpoint of safety.

It is not possible always to be certain that there will be no leak from the water jacket into the crucible at the joint between the base and the sides. A water leak is not necessarily catastrophic, however, but it is considered important that there should be a sensitive pressure relief valve operating at a few lb/sq.in. outward differential pressure. If practicable this valve should be linked to a switch cutting off the supply of current.

The diaphragm type of release as fitted in this case does not meet this requirement, since it needs to have considerable strength to resist the reversed vacuum loading. It is estimated that a differential pressure of about 70 lb/sq.in. would be required to burst the diaphragm actually used. Whether a suitable valve could act quickly enough to prevent an explosion in the event of penetration as first discussed is uncertain, but it is reasonably certain that an explosion could not be avoided if molten titanium were forced by a pressure of several atmospheres into water.

A disastrous hydrogen explosion might occur if pressure release were followed by air intake. The valve already mentioned must therefore be designed to close before there is a pressure reversal. A diaphragm is unsuitable from this standpoint, not only because it leaves a hole for the entry of air, but also because the high pressure required for rupture is likely to be followed by suction.

5 RECOMMENDATIONS FOR FUTURE SAFETY

It is possible to make a number of recommendations for future guidance primarily as matters of principle. Practical considerations might necessitate some modification in detail before they can be implemented.

(a) The water circulation must clearly cover all parts of the outside of the crucible, with water specially directed to the centre of the base.

(b) Failure or impairment of the supply of cooling water should automatically switch-off the electric current.

(c) Special care should be taken in design, manufacture and assembly of the joints in the crucible.

(d) The crucible should be provided with a substantial escape route for hydrogen and steam, with a valve that opens at a small excess pressure and closes again before air can enter the crucible.

(e) If practicable, opening of the release valve or abnormal rise in internal pressure should automatically switch-off the current. In any event a warning signal should be given to the operator.

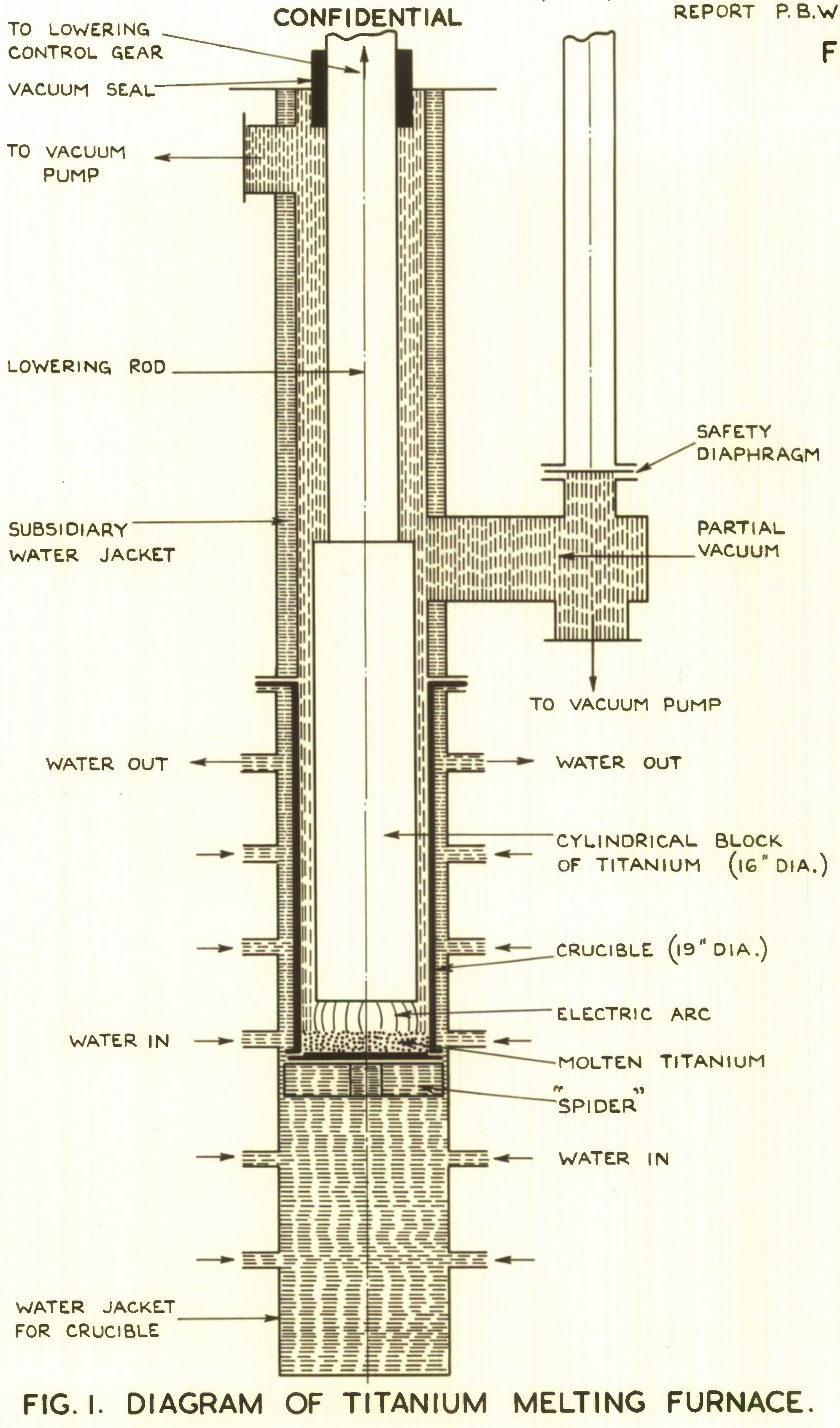

FIG. 1. DIAGRAM OF TITANIUM MELTING FURNACE.

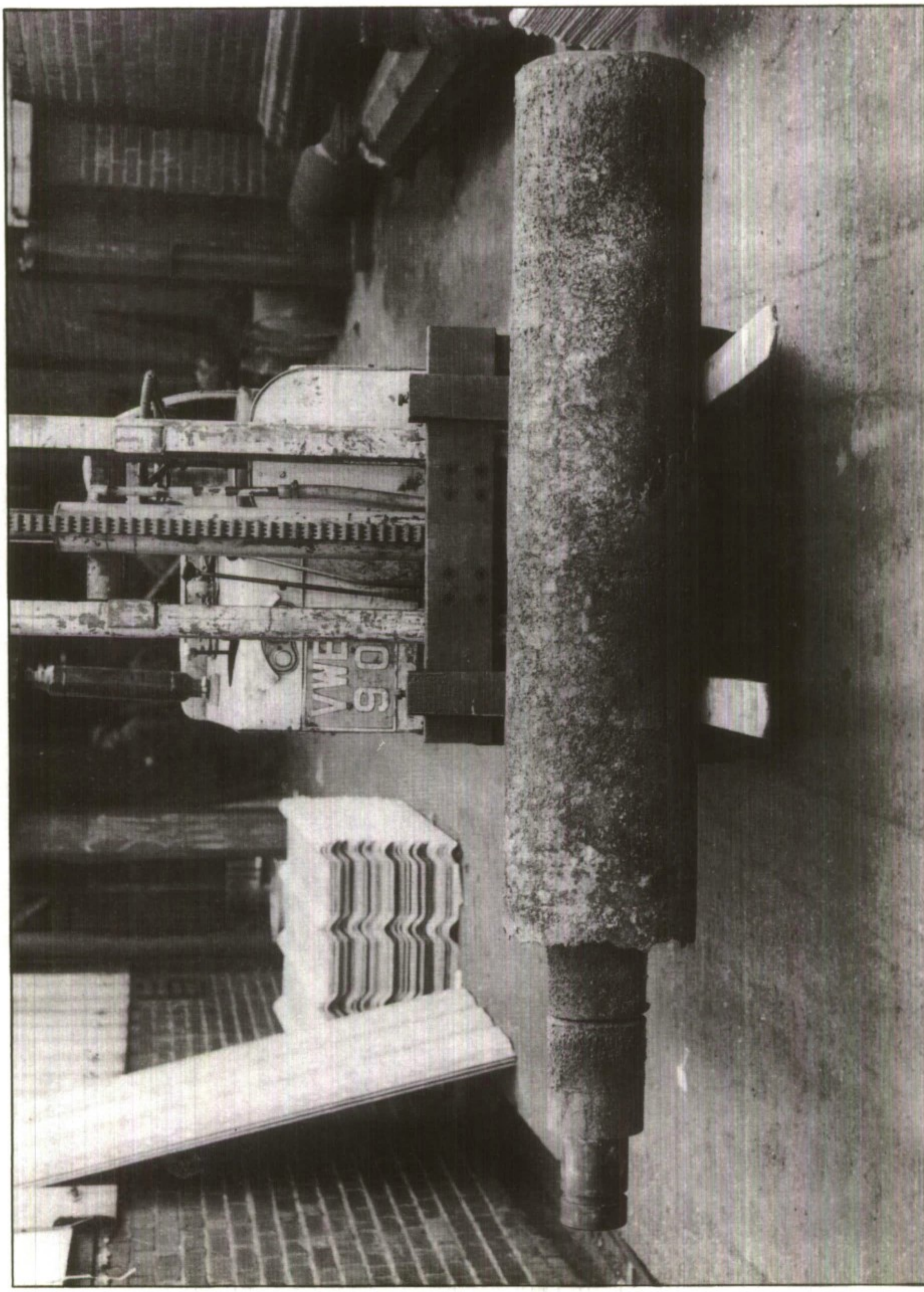

FIG.2. TITANIUM BILLET WITH ITS ELECTRICAL COUPLING

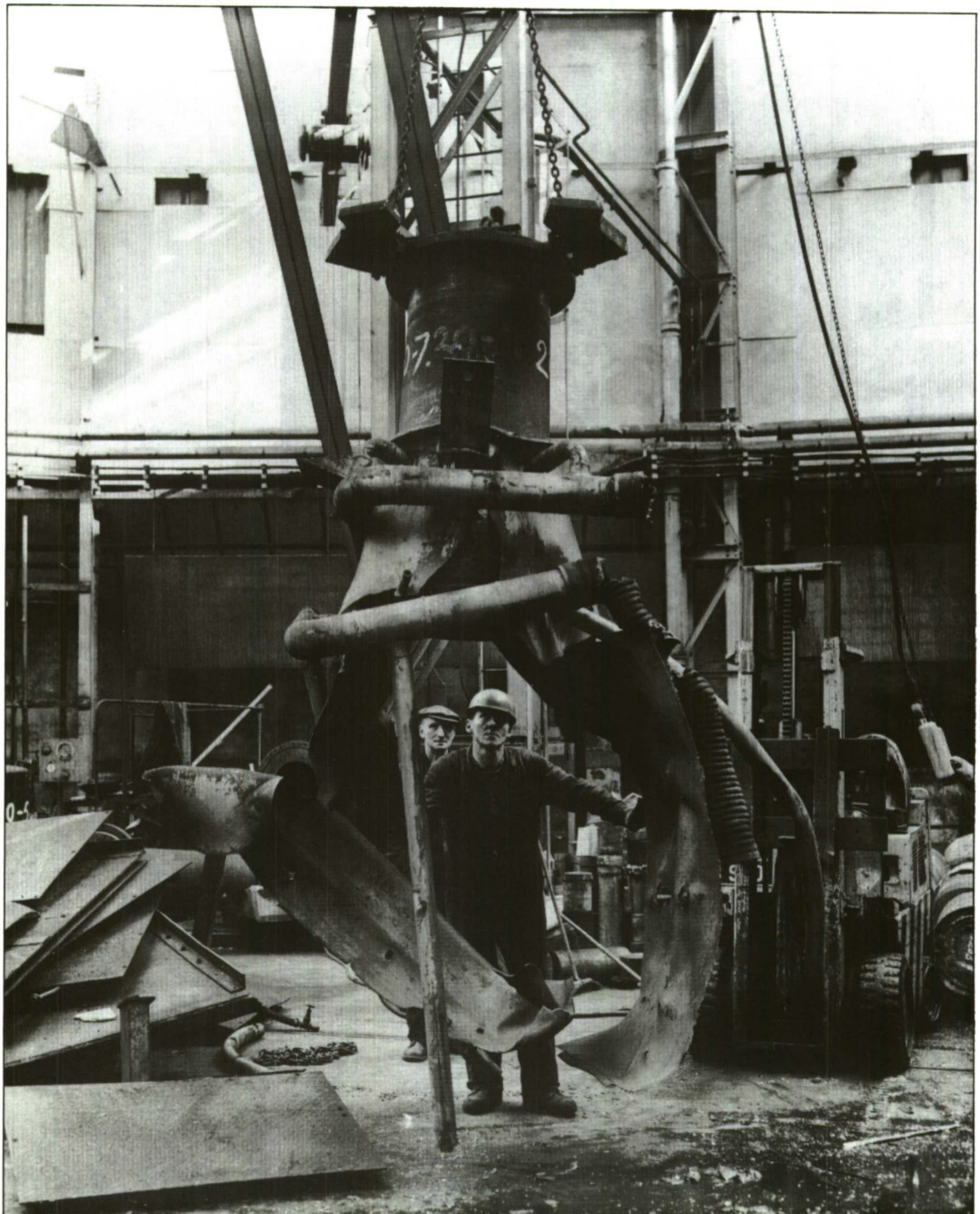

FIG.3. THE EXPLODED WATER JACKET

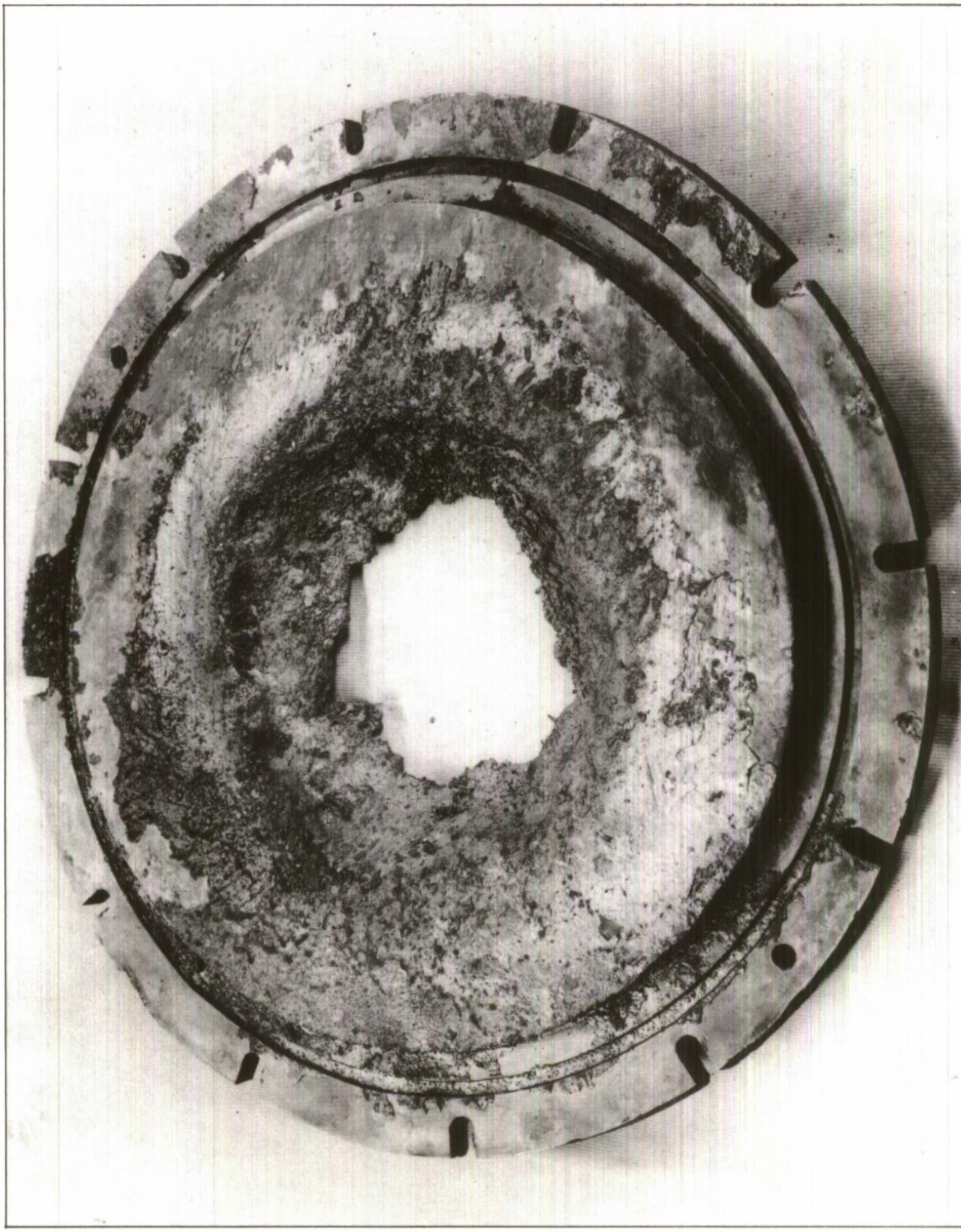

FIG.4. DETACHABLE BOTTOM OF CRUCIBLE

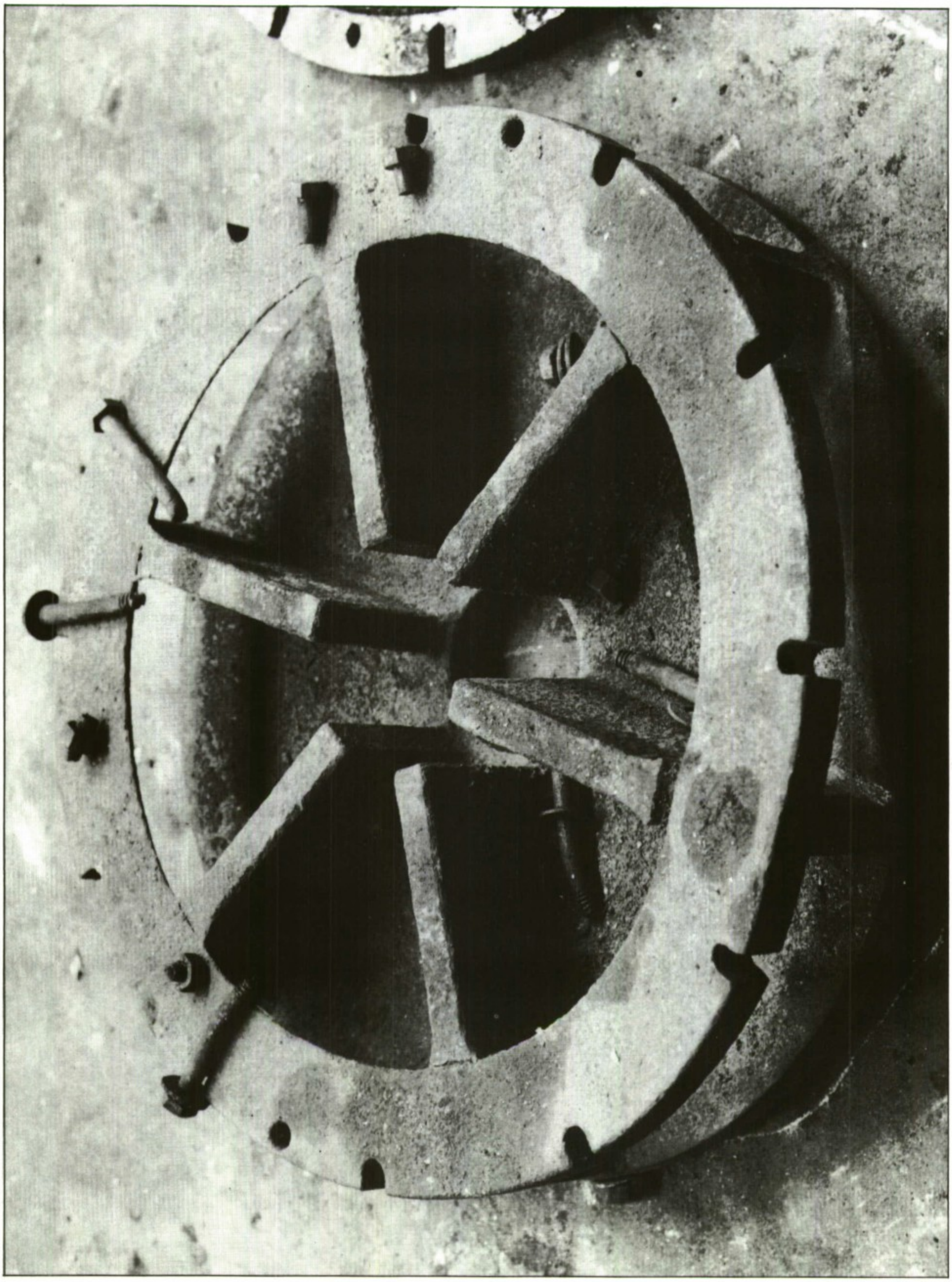

FIG.5. SPIDER GUIDE-VANE UNIT SUPPORT FOR THE CRUCIBLE BOTTOM

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