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Council, in the Chair.

COTTON-POWDER FOR MILITARY AND NAVAL PURPOSES.

By S. J. MACKIE, Esq., C.E.

THE works of which I have charge at Faversham are now fully occupied in making powder for commercial purposes: they are indeed, although the site is an extensive one—only the first instalment of factory-works put up to assure the foundation of a manufacture, which, as these works are extended, will increase into a national industry. Consequently, although from time to time various trials have been made and various experiments carried out, in view of military and naval applications of cotton-powder, yet experiments in this direction have not been pushed forward actively, and the present state of results is imperfect in a large degree, although enough has been accomplished and still more indicated, to make the subject one of interest to this audience.

We have now had three years' experience of cotton-powder in the very considerable quantities which have been used for mining, tunnelling, and quarrying, as well as for submarine operations in the clearance of wrecks. We know, too, from numerous operations on trees, timber, boulders, masonry, and iron, steel, slag, and cinder, its capacities for demolition: and we have at least one example of its success in practical military work in the recent experiments at Eastbourne.

The cotton-powder, therefore, is an actual fact: it is *not* a theoretical idea: nor an untried novelty. It was not born like gun-cotton and nitro-glycerine in the early days of the age of explosives, when the untilled fields of the whole world were open: but it has had to fight for existence from the day it went into the market against most powerful established rivals famous everywhere—gun-cotton and dynamite: and against this latter, its strongest competitor, in all places where it has been introduced it has been firmly winning a superior position. Its quality of power, therefore, has had tangible

demonstration. Again, in the various samples which have been abroad to different parts of the world, undergoing temperature every variety, there is actual proof of its stability under changes: and, finally, up to the present time we have not had a single accident attributable to cotton-powder: and only five in any directly and indirectly, connected with its employment.

This short summary of its commercial career is sufficient to show that cotton-powder is a marked, special, and extraordinary explosive.

Cotton-powder consists of the purest gun-cotton crushed to an impalpable dust, and purified from all bastard products due to combinations of nitric acid with the starches, gums, oils, resins, and other impurities of the cotton: and intimately mixed with an oxidizing substance, by incorporation like ordinary gunpowder, in such proportions as to produce the highest possible effects in the explosion.¹

The qualifications properly looked for in an explosive are 1, Safety; 2, Power; 3, Handiness in Use; 4, Cheapness.

I. On the first head "Safety": it is that the most important progress has been made in cotton-powder. Twenty years ago gun-cotton took a month to wash; and even with double that period of immersion in running water was never thoroughly freed from acids and injurious nitrous impurities. Vast as was the improvement made by Mr. Abel in pulping the gun-cotton, and so by dividing fibre into very minute lengths to facilitate the washing process—it was reduced from six weeks to two or three days—yet the mechanical ablution in the poacher never entirely frees the gun-cotton from the bye-products of resins, starches, oils, and so forth, with nitric acid: hence the various spontaneous decompositions and accidents which have from time to time occurred; for these products decay at far lower temperatures than the gun-cotton proper, or nitro-cellulose. In this one branch alone, if nothing else had been done, the process of purification would have given character to Faversham Cotton-Powder Works; for, in two hours the gun-cotton made there is rendered absolutely pure and free from all deleterious substances. This is attained by air-washing and steam-boiling. About a ton of pulverized gun-cotton is put in a large volume of water in a vat of inverted pyramidal shape, and a current of air is injected which agitates thoroughly the fluid. The boiling by means of steam similarly injected eliminates by actual chemical decomposition, under gaseous conditions those nitrous compounds which have been hitherto the source of so much mischief in ordinary gun-cotton: and is important still by the use of carbonate of ammonia, the "red fumes" or nitrous oxide, are in this way thoroughly destroyed.

The purity of the gun-cotton in the cotton-powder is the basis of its safety. It is this quality of purity which puts cotton-powder at the front of all other explosives, and will give it sooner or later the command of the market.

This quality above all others is needful in any explosive employed for military and naval purposes, particularly the latter, for on:

¹ Samples of the raw and manufactured materials were here shown to the audience.

board it is the one condition of safety, which is everything; indeed, where the very existence of officers and crew depends on the integrity of the vessel, none other than a thoroughly reliable explosive can be permitted at all. It is the absence of this perfect purity which renders it needful to store ordinary gun-cotton in a wet state, and makes it dangerous to store inferior gun-cotton in any state whatever. It is the absence of this perfect purity that gives to nitro-glycerine and its compounds some of their most serious defects.

To obtain this perfect purity nothing is left undone at the Faversham Works, for, although two hours suffice for the boiling, yet it is continued for from twelve to twenty-four hours, so great is the stress laid upon the value of perfection of manufacture.

In short, if one wanted to lay down an axiom, one would say no explosive is any good that will not stand boiling.

II. The next point in the manufacture of cotton-powder is the incorporation of the purified gun-cotton with an oxidizing substance—the source of its superior power.

In blasting in quarries, so in military demolitions, in submarine mines and torpedoes, in the bursting charges of projectiles from guns, the utmost amount of disruption is expected. In all these purposes, therefore, the full force of the “explosive” is required to be instantaneously exerted—the total possible destruction being attainable only through the absolute instantaneity of evolution of the destroying force.

This instantaneous production of the full extent of power is commonly obtained by detonation, or the instantaneous chemical disruption locally effected by a fulminate, and which once initiated is carried equally instantaneously through the mass of the susceptible explosive.

The admixture of an absorbent earth with the explosive oil nitro-glycerine, for the convenience of use in practical operations adds nothing to its strength, but on the contrary, there is diminution of power proportionate to the extent of the adulteration. The admixture of gun-cotton with an oxidizing substance—preferably in cotton-powder, the nitrate of baryta—on the contrary most materially adds force to the primitive explosive.

If we look at any tabulated statement of the “heat” given out on explosion by various substances and compounds, we are struck with the poor appearance made by gun-cotton.

Nitro-glycerine, for example, disengages 1,320 units;¹ whilst Abel’s gun-cotton yields only 590 units, or actually less than common gun-powder, which stands at 600 units.

When we seek for the reason, we find that the glycerine has combined chemically with a larger proportion of gas or nitric oxide from the bath than the cotton, and consequently there are better chemical relations in the nitro-glycerine than in the gun-cotton.

III. It is, therefore, by satisfying more fully the carbon base of the gun-cotton, that we have to look for an increase of power. And this

¹ The unit is the quantity of heat required to raise one kilogramme of water one degree centigrade, and the figures given correspond to one kilogramme of the explosive burnt or exploded.—S. J. M.

we find to be the case. Thus it is, that by incorporating the oxygen materials in the proper combining and most efficient proportion that we attain the highest power in the compound, cotton-powder well as the most satisfactory results in the comparative absence of noxious emanations from the explosion.

The saturation of gun-cotton by saltpetre was unsatisfactory; the nitre being soluble, the influence of various degrees of moisture left the due explosion of the charge always doubtful; and on the other hand, the crystallization of the nitre caused the product when dried to crumble. Nitrate of baryta was thus a far preferable material because of its insolubility, and because of the less amount of energy required to evolve its gases in explosion. In fact, taking everything into consideration in the composition of cotton-powder, we have more stored up and available than in any other explosive mixture.

If we take common gunpowder and satisfy the carbon in it with oxygen from chlorate of potash, we have the yield of heat increased to nearly double, or as 1,000 to 600 units; and a similar effect is produced with gun-cotton, the development of heat in chlorated gun-cotton reaching the highest point of 1,420 units, or 40 units in excess of nitro-glycerine itself.

IV. The chlorate of potash, from the readiness with which it gives up its oxygen, is commonly regarded as a dangerous substance. It is well known that gunpowder, with chlorate of potash substituted for the nitre, is neither safe to make nor use. The first essays that were made to produce a blasting compound from the pulverized cotton were with the chlorate of potash, but an accident—happily of a fatal character—led to the substitution of the nitrate of baryta as the oxidizer; and from the very outset of this second compound, no cotton-powder, it has been a veritable success.

The incorporation of this oxidizer with the pulverulent gun-cotton gives to the compound a great deal of the nature and character of ordinary gunpowder—the carbon of the cotton taking the place of charcoal, and the nitrate of baryta of the saltpetre—the substitution being unnecessary because the gun-cotton itself is rapidly ignited. But the characteristic of gunpowder, namely, explosion by rapid combustion, is so far reduced by the high density of cotton-powder without the detonator it is simply a *combustible*. By mere ignition it does not explode, but burns with an intense greenish flame. Nevertheless, like gun-cotton and nitro-glycerine, it is susceptible of detonation, only in a less ready degree, and therein further demonstrating its superiority of safety over those and all other known explosives.

The detonation being effected, the cotton-powder is equally remarkable for its superiority of *power*. Slight confinement or a small load facilitates the detonation; or the rather more inertness of cotton-powder can be got over equally well by an increase in the quantity of the initiating fulminate—the proportion practically adopted being as 3 to 1 in respect to dynamite, which can even be fired with caps containing $2\frac{1}{2}$ grains of the fulminate of mercury; whereas caps containing 15 grains are regularly sent out with blasting charges of cotton-powder. This marked difference in

strength of the caps is also an accurate measure of the relative safety of the two compounds in their everyday use and employment.

V. The stability of cotton-powder is also superior, not only to other explosives, but even to that of gunpowder itself. In gunpowder the sulphur may be a source of deterioration; and in the old books instances of spontaneous explosion are recorded, being probably of not infrequent occurrence when the art of gunpowder-making was not so skilful, nor the care of manipulation so great as in the present day.

It is well to bear in mind, too, that the materials of the cotton-powder are first tested for purity before manufacture, and the article itself again tested after manufacture, thus giving guarantees for its perfection. Whereas even now there is no guarantee for gunpowder—which is never tested at all.

VI. The form into which cotton-powder is made up for blasting and general use is undoubtedly the most convenient and the safest ever devised.

In the early stage of manufacture, the meal was dried and then after being weighed to the charge required, was poured through a funnel into a paper shell and rammed into it around a central paper tube, the whole being choked with a double-ended wire. The detonator being firmly nipped on to a Bickford or Branton fuze, was inserted in the central tube, and the wire-tags being bound round the fuze in opposite directions, and their ends twisted, the fuze and cartridge were closely fixed together, and could not be pulled apart, or separated in the act of loading the charge, or afterwards by stemming over it, as is always liable when the capped fuze is merely put into a perforation, as in Abel's discs, without anything to hold it there.

When a detachment of this kind occurs in a mine, there is of course a miss-fire—always a source of danger—and there might be an unintended explosion by the ramming down of stones upon the cap, or by striking or forcing it crosswise on the charge. The primers of dynamite, soft putty-like substance that it is, are always more or less subject to similar accidents; whereas in the cotton-powder the cap is securely packed in the centre of the charge, and the tighter the stemming and the closer the ramming, the better the protection given to the detonator.

These first cartridges were made by hand, but now very powerful machinery is employed, and they are pressed up *wet* with a pressure of some five tons on the square inch, calculated to give a density of 1.6 to the powder when subsequently dried.

The improvement effected by this mechanical compression is very important; and as the cartridges are produced with far greater rapidity, they are consequently cheaper as well as better.

Finally, these cartridges are waterproofed in a composition of paraffin to enable them to be used in wet holes and under water. For great depths—as in the open sea—the tenacity of the waterproofing is increased to keep the charge dry, as against the increase of hydrostatic pressure.

VII. A few remarks may here be well made in respect to the quality of strength in the cotton-powder.

We have seen that chemically the power indicated for the stor explosives is only about double that of ordinary gunpowder, w their evident effects are from at least three to five or six times of gunpowder, and often even very much more. The quality of power exerted is therefore clearly attributable to the nature of explosion and of the explosive.

First, the higher the density of the explosive (or in o words the greater quantity within a given space) the greater force therein located. Secondly, the closer in contact the part of the explosive are, the more powerful and the quicker is detonation; and thirdly, the more rapid the detonation the gre the force exerted by the explosive in consequence of the higher sion of the gases evolved. The density therefore of this explosiv another indication of its power, and in this respect cotton-pow shows off most favourably against its compeers. The density of g cotton is 1.0, or the like density as water; dynamite is given Nobel as 1.50, while cotton-powder is pressed to 1.6, and can be j duced with a density as high as 2.0.

Amongst the samples exhibited is a 1-lb. cube of cotton-pow compacted under such a pressure as to put the powder into a space only about two-thirds of that occupied by the Service gun-cott One essential element in obtaining the superior compactness of cott powder is the fineness of its particles—compression being difficult : dangerous in proportion to the coarseness of the gun-cotton and amount of fibre left in it. That rough kind of gun-cotton or tri-nit cellulose made from wood by Mr. Muschamp and called "*Patent G powder*,"—a very different article from *Cotton Powder*—is notable this respect, as the cartridges in which it is turned out for min purposes are the least compressed of anything in the market; : possibly their fibrous condition would not allow of more compress without considerable risk.

VIII. The comparative freedom of an explosive from noxious ga and poisonous emanations is a very important matter for the conside tion at least of those who pass their lives in the daily occupation of bla ing in mines and tunnels. It is of less moment in military and na work other than gunnery. For out-door operations a very lar amount of fumes may be mingled with the atmosphere and so dilut as to be practically harmless. The fumes of dynamite and of litt fracteur may be smelt at distances of over half a mile from the exp sion; and similarly gun-cotton gives off considerable volumes carbonic oxide; and those who are acquainted with the use of the lat explosive for earth-mines and lodgments will have often seen a crack ling-cloud of fiery gas blazing three or four feet above the recen disturbed and fissured soil, and will have heard successions of sm reports amongst the clods which have fallen back into the crater. T extent of the emanations of nitrous-oxide from dynamite may often well observed in subaqueous operations such as those of clearing aw of submerged rocks in the bed of the Tees navigation, where t Diamond Rock Drill Company put down by the drill-barge as ma: as twenty-four or twenty-six holes at a time; and when these charg

are fired, the distinctions between the perfect detonations and the partial explosions are manifested most distinctly by the clear white foam rings of the former, and the huge bubbles of "red fumes," which come up from the latter—sometimes as many as half the shots belching forth the copper-coloured nitrous oxide in this manner.

The cotton-powder seems to be free from any dangerous noxious after-gases when properly detonated. When burnt, there is a pungent odour, but I have never experienced inconvenience from it even in close places; nevertheless the presence of any odour is a hint to be cautious, which it would be well always to pay a little attention to; but from charges effectually detonated, as all charges ought to be, with the strong caps supplied with the cotton-powder, there is absolutely nothing to prevent immediate entry after the blasts. There is a small amount of smoke after firing, consisting chiefly of heavy dust, for the nitrate of baryta—which is made from the carbonate, a natural earthy mineral called "Wetherite," by chemical treatment—is decomposed by the heat of the explosion, and re-formed by combination with the carbonic acid into carbonate of baryta. This dust-cloud quickly falls to the ground, especially if there be any moisture in the workings, leaving the atmosphere clear and wholesome. The other products of explosion are the vapour of water and some free nitrogen. Altogether the products of explosion of cotton-powder are then as little noxious as they well can be, and in this respect beyond any other explosive, and indeed far less injurious to health than the smoke of common gunpowder.

I have, myself, had very considerable experience of cotton-powder under all circumstances—often those of extreme closeness—and have never suffered in the least degree, although I have made it a practice to rush in instantly after firing.

In military mines this element of comparative freedom from smoke is of much consideration, as time is almost always of importance in such work; and the rapidity with which a military mine can be entered after the blast may in many instances be a vital gain to the operators.

IX. The final qualification of cotton-powder for military and naval purposes—as well as for general favour—appears to me to be its *cheapness*. This is the conclusive consideration in commercial transactions when two or more articles are of equal utility; and it is always a decisive ground for adoption when an article is superior to its competitors in most other respects.

The production of gun-cotton in the customary way is not a cheap manufacture. The cotton is far dearer than the charcoal of gunpowder, and indeed is a more expensive condition of carbon; each pound of cotton requires to be steeped in $10\frac{1}{2}$ lbs. of mixed nitric and sulphuric acids of the value of 1s. 9d., of which three-quarters of a pound only is actually combined with the cotton—the produce being $1\frac{3}{4}$ lb., theoretically, of gun-cotton; but practically with the waste in the different operations it is really not much more than $1\frac{1}{2}$ lb. The remainder of the mixed acids not absorbed by the gun-cotton have always been regarded as "waste," and returned to the chemical

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factory at a price of about a halfpenny per lb. If to this cost we labour in manufacture, and wear and tear of machinery, and buildings, packages, and so forth, and the total cost of the gun-cotton mounts up to 2s. per lb. If, however, we add 1 lb. of nitrate of baryta at 1s., we have 2 lbs. of powder for 3s., or cotton-powder 1s. 6d. per lb.

Now, if I had strong commercial proclivities, I might be disposed to improve this occasion by showing that gun-cotton being sold *wet*, 25 per cent. of moisture in it for "safety," is practically sold at 2s. per lb.; but then it would be retaliated that cotton-powder is sold at 2s. per lb., and therefore we have 25 per cent. of profit also. So do; but we do not keep all that to ourselves when we get our customers. Nevertheless, without wishing to dwell on commercial topics, I would only add that it would be a great economy to the State, and a profitable engagement for our Company to convert Government stores of excellent gun-cotton into still better cotton-powder; and I shall be very pleased indeed whenever the Chemist to the War Department and the Government authorities are of the same opinion.

X. Further progress in the direction of cheapness has been made by the introduction of charcoal into the cotton-powder; and a very good article (No. 3) has been produced in this manner. This brand possesses some very important qualities, and its safety and stability are singularly high. It will not indeed detonate alone, but requires a primer of the No. 2 cotton-powder (or of gun-cotton) to produce explosion. Its combustion is even more brilliant than that of No. 2, or the cotton-powder proper, and is peculiarly suitable for night signals, the light being visible for long distances, whilst the report from its explosion is very loud and sharp, and large cartridges can be heard for miles.

For open-air work it will in due time command an extensive application, and just as No. 2 brand is the rival of dynamite, so No. 3 brand will become the competitor with common gunpowder.

Shooting Powder.

XI. The first manufacture attempted at the Faversham Works was that of shooting-powder or cotton-gunpowder; and having introduced the subject of modifications of cotton-powder, it will be well not to pass over this notable one, which some day will in all likelihood again come forward. Any way, it is a topic not to be ignored in military and naval considerations.

A true gunpowder should not be susceptible of detonation, or, in other words of instantaneous chemical disruption; but the explosion of a gunpowder should be a combustion of very considerable rapidity for the force required is a pushing force exerting itself upon the projectile as long as it remains in the barrel; and it should be a force increasing in direct ratio with the motion of the shot, if such be practicable. These effects we have seen of late years attained by variations in the dimensions of the "grains," or broken fragments of powder cake—a form necessary for the free circulation of fire throughout the charge. The intention in gunpowder is to furnish a propellant

force which shall not burst the gun, which is required to be preserved intact for the repetition of innumerable discharges. The practical purpose of gunpowder is thus diametrically opposite to that of blasting-powder.

To form a *gun-powder* from *gun-cotton* we have to substitute for the *baryta* another substance as the oxidizer, and to make further modifications in the composition and materials.

On the table are samples of very good small-arms and sporting powders made more than two years since, but the manufacture of which is for the time being suspended on account of the demand for blasting cartridges, which taxes the utmost resources of our present works. One fact of importance has been gained by our experience in this direction, namely, that very small quantities of fulminate must be used in the percussion-caps employed to fire the charges in guns; otherwise detonation will intervene to the destruction of the weapon; and doubtless this has been a cause of many of those accidents which have happened with *gun-cotton*, *gun-sawdust*, and similar *nitro-cellulose* products in the hands of sportsmen. The tendency to detonation was diminished in *cotton-gunpowder* also by its excessively high density—pressures of from 30 to 50 tons being put upon the “cake”—which, like black gunpowder, was similarly broken up into “grains.” The *cotton-gunpowder* gives off very little smoke, which can be clearly seen through; whilst there is no fouling, but only a slight dusting of dry carbon on the interior of the barrel. The recoil, too, is easy, and the strain lighter than with ordinary sporting powder. There seems no reason why cubes of considerable sizes for cannon should not be in due time produced, whenever the subject is again taken up at the Faversham Works.

XII. Having given a tolerably full sketch of cotton-powder in its present stage as a commercial industry, it becomes my next duty to deal, as best I am able, with those topics which relate more particularly to its application to military and naval purposes.

Most of what might be primarily urged is of course what might be generally said in favour of the use of explosives for certain purposes in preference to gunpowder; but on this occasion I have no intention of being diffuse. We have not yet all the requisite accurate experiments, nor the means and apparatus requisite for a masterly discourse on the subject. Much of what we have done is crude, although the knowledge obtained is satisfactory. Again, over some of our details I am obliged to hold the veil of reticence until they are further advanced.

The first public experiments with cotton-powder were made at the Company's works in February, 1875, and of these some may be mentioned as demonstrating the superior properties of cotton-powder in a few of the more familiar requirements of military operations.

The first series of those experiments were illustrative of safety in transport, storage, and the loading with charges of cotton-powder. Some loose cartridges were burnt in the hand like torches, and two barrels—of the best possible make, and service gunpowder-barrel pattern, and materials without fissure, crack, or blemish, tightly coopered up, and containing 40 lbs. of powder each, one of No. 2 (white) and

one of No. 3 (black) cotton-powder—were placed over huge bonfires and roasted for six and seven minutes respectively when the powder took fire, and burnt in splendid globes of yellowish fire of intense brilliancy. Of course the executives were well up to the usual doctrine in burning explosives; but we did not select boxes with screws easily drawn, and made of wood that would easily split; nor did we put packages in the midst of the faggots, that the flames might lap at and light the powder on the top. But we wanted—for we had a great purpose—to show that we had an article which the railway authorities might safely permit to be carried over the lines committed to their care. So we built brick piers and put iron bars across, the barrels of cotton-powder being rested on them, and the faggots piled well on the windward side, that the barrels might have a good scorching before the powder in them ignited. So by manly, honest daring, we succeeded in our object, and the railways all over the United Kingdom and Ireland carry cotton-powder without fear or hesitation, and at higher freights than ordinary gunpowder.

Since then we have had an accidental ignition of over 400 lbs of cotton-powder, and no tendency to explosion was shown. Of course I am well enough aware—for I was the first to inculcate the doctrine—that every explosive may be, to a greater or less extent, burnt harmlessly; but that it is a matter of certainty that the residual portion of a very large mass in conflagration will be sooner or later heated up to explosion point, and then explosion will follow. This point, however, is reached in very different periods, according to the nature of the explosive. In wet gun-cotton it takes some time and long-continued heating to effect this explosion, but in dynamite and nitro-glycerine compounds, the conduction of heat by the fluid oil quickly raises the temperature of the mass and explosion follows in a short time after ignition when the pile of explosive is close-packed and of any magnitude. It is thus easier to burn fifty 5-lb. boxes of dynamite than a 50-lb. barrel.

There is scarcely any conduction of heat in cotton-powder, and cartridges burn very slowly, being at the rate of 1 to 5 inches of Abney gun-cotton. The cartridges of No. 3 (black) burn still more slowly, and soon after ignition the fire can be easily cut out with a knife. I have had other and ample evidence that explosion will not follow the conflagration of considerable quantities, and that even charges may be ignited by friction in bore-holes, and yet burn away harmlessly. It would, however, be most improper to encourage or permit trifling with “safety” in any explosive—all ought to be dealt with according to the most prudent rules, for a mistake cannot be retrieved, and a bad example may have improper imitations. It is different where one gains experience for the sake of others at the risk of one’s self.

Another experiment was made at our works to show the non-liability of cotton-powder to explode under ordinary violent blows, namely, to fall from the height of 15 feet, of a half-ton pile-driver, upon 10 lbs. of cotton-powder, in a box placed on a 12-inch pile driven into the mass. Neither explosion, nor even ignition, followed on the blow.

But the most telling experiment, in the 1875 series, was the cutting

of four steel ingots, each over 4 feet long by 11 inches by 11 inches, in dimensions at the median portion (or 121 square inches of sectional area), by a charge of $2\frac{1}{2}$ lbs. of cotton-powder placed between them and packed with clay. These ingots, of the finest and toughest steel for submarine cable-wire, were cut as clean as by a hatchet, and the half pieces, weighing as much as 8 cwt., were hurled 40, 60, and even 90 yards away.

Illustrations of land mines and submarine mines were also given on that occasion, two being 30 lbs. charges; also a box, containing 20 lbs. wetted with 20 per cent. of moisture, and in an unflammable condition was exploded unconfined, and so successfully that its report was the source of a considerable glazier's bill for the destruction of window-glass in our store shed.

A submarine mine of 50 lbs. was fired and threw up a magnificent fountain in the waters of the Swale, the arm of sea which separates the Isle of Sheppey from the Kent shores of the cotton-powder works.

All these experiments have been confirmed by our subsequent experiences, and their testimony is undoubtedly valid.

XIII. The effects of cotton-powder in very large blasts was most satisfactorily tested in May, 1875, at South Shields, where gun-cotton, it is stated, had previously failed on two occasions, and where, subsequently, a trial of the "Patent Gunpowder" (Muschamp's) proved otherwise than remarkable, if the statements I have received be correct. Indeed, it seems difficult to make large blasts successful, in commercial operations, with limited charges, for the high prices of explosives restrict the quantities employed, and the only terms obtainable are those of "cost for cost," with common gunpowder, for so many thousands of tons of rock shifted; as was done in the case of the Trow Rock Quarry, referred to. The blast was an excellent one, the line of pegs indicating the area estimated to be disturbed by 3,000 lbs. of gunpowder being exceeded all round by about 10 to 15 feet, and a quantity of rock was shifted of over 25,000 tons. The work, too, was of good quality, for the purpose intended, the ground being riven and fissured in all directions, without being too much broken up.

Some blasts of smaller dimensions have been made in the great limestone quarries at Buxton, in which the cotton-powder was used with ordinary gunpowder, in the manner known provincially as "chirping," that is, the main charge was of common gunpowder, and this was fired by the cotton-powder charge put on the top of it, the work done being reported as very effective.

XIV. Reference has already been made to the usefulness of cotton-powder for signal purposes. Soon after the loss of the "Deutschland" I made some highly satisfactory trials in the Lledr Valley, in North Wales. The station selected was the high ground opposite the noble mountain, Moel Siabod. Men, with return-signal cartridges, were sent out to distances of one, two, four, and six miles, and, when the night was quite dark, 1-lb. charges of cotton-powder, of both brands, were alternately lighted and exploded, the light signals and the sound signals being returned, in all cases, by the observers up to the most distant. The light is quite as powerful as the lime-light, and the

report equal to that of a 40-pounder gun. The object of the experiments was to show that, whilst frequently in the case of wrecks at sea, roughness of the weather and the spray, by wetting the powder, prevents the firing of the signal gun, the cotton-powder could be always used, either as a light or instead of a gun, and cotton-powder would receive no injury from the water, and whilst the signal gun is limited in capacity of sound, the report of the cotton-powder could be increased to any requirement by the use of additional cartridges. All that would be required would be to run the cotton-powder charge up by a halyard a few feet clear of surrounding objects, with its Bickford fuze burning, and let it explode in the mid air.

The clearness with which surrounding objects were brought out of the darkness by the burning of a 1-lb. cube of the cotton-powder was remarkable, the whole immediate mountain side being illuminated some fifty yards by fifty yards, and every object of any size being distinctly visible. Its qualities in this respect, as a most handy discovery of light, will be thoroughly recognized whenever its applicability in any way is properly investigated. At night, ashore, for discovering at night parties, and afloat, for the look-out for boats and torpedo vessels and in other sudden emergencies, its readiness to hand and the requirement of apparatus—a bit of deal board or a spade making a sufficient expedient for a reflector—will be points of very practical service.

XV. Another application of cotton-powder for military purposes would be in the disabling or destruction of cannon. On a recent visit to South Wales, I was asked to break up some old and some latest cast tuyères, at the Ogmore Iron Works. These nozzles for the blasts of the furnaces are, as is well known, kept cool by circulating water in a coil of wrought-iron pipes within the shell of cast-iron. This wrought-iron pipe strengthens the construction immensely, and as these objects are of considerable size, 24 inches in diameter, 14 inches in length, and the walls 4 inches thick, they are not easily demolished by ordinary means, and it was thus, with a smile, that the manufacturer brought them forward for operation. Having the broad ends tamped down upon a pad of clay, laid on a thick bed of "old horse," or cinder, I had the tuyère filled with water, like a bucket, and put into it a small cartridge, suspended by its fuze, the explosion took place in the water, and the nozzle was split easily into four unequal pieces, which were thrown apart only about four or five feet.

This principle might be applied to the breaking up of guns, the medium of water effects great advantage over the use of explosives to act directly in breaking up metal, for fragments are commonly thrown to great distances, involving dangers which the care of the operator can guard against. A single cartridge, with water-tamping, would be ample for each operation, and if water could not be had in an emergency, plastic clay would make a passable substitute.

XVI. Another useful although simple application would be the cracking of blind shells, such as those falling into trenches or recesses, which it would be objectionable to leave, and yet would

more dangerous to unscrew or unload. A small charge of cotton-powder, applied externally and covered with a heavy pad of soft clay, will split the cast-iron shell without exploding its bursting charge. The minimum effective charge should not be exceeded in this operation.

XVII. In the various *submarine* operations which have been undertaken with cotton-powder for the removal of wrecks by various operators, reports have been received crediting it with very superior power for such duties. Indeed, for torpedoes and submarine mines, it possesses superior qualities. Over dynamite it has the advantage of never requiring thawing, and is free from the defects of deterioration by any exudation of its materials. Over compressed gun-cotton it has the advantage that much more in weight, and consequently much more of power can be got into the same space; thus, as much as 640 lbs. of cotton-meal-powder could be got into a Service torpedo intended for 500 lbs. of gun-cotton; and, compacted as it might be, more even than this might be got in.

For loading torpedoes and submarine mines, the *form* into which the cotton-powder is made up, is suitably varied. As a general rule, it is pressed into cubes of various sizes; but it has also been formed into grains for the purpose of loading through the loading-holes of torpedoes and mine-cases originally intended for gunpowder.

These cubes and grains are interpacked with *melted paraffin* run in between them in such a way that a waterproof walled chamber or cell is formed for each, and thus damage from the leakage or breaking of the mine or torpedo case will be limited to a portion, and will not extend to the whole of the charge. If the main mass of the charge remains in an effective state, it is capable of exploding the wetted portion. According to some experiments we have made, it would appear that it takes a weight of dry cotton-powder equal to the weight of water in a saturated charge to effect its proper explosion. The cubes of cotton-powder are usually 1 lb. and $\frac{1}{2}$ lb., but some as small as 1 oz. have been made.

II.—Shells.

XVIII. The cotton-powder *grains* are also useful for *filling shells* to be fired from guns; and this leads me to another subject well worthy the attention of Officers of both Services.

Most members of this Institution well know the interest I have long taken in the official experiments; and the lengthened series, in October and November last, at Eastbourne, would naturally have attractions for me. Seeing there round after round of heavy shells with gunpowder bursters fired against the fortification structures without producing any effective results on the masonry and concrete, I requested permission to try some shells loaded with cotton-powder, which was graciously accorded.

The result was exceedingly satisfactory. Three shells—a 64-pounder, 180-pounder, and 350-pounder—were loaded with the Government gun-cotton, and three similar ones with cotton-powder.

The Service gunpowder bursting-charges of these shells are relatively 7 lbs., 14 lbs., and 27 lbs. The bursting-charges of Abel's cotton put into them were $4\frac{1}{2}$ lbs., 10 lbs., and 21 lbs., the last by tight and careful loading. Of cotton-powder, the bursting-charges were 7 lbs., 14 lbs., and 24 lbs., the last shell (the 350-pounder) loaded with broken fragments of small cartridges with paper wrapped on them, and the chamber of the shell not being completely filled. Want of time, the approach of twilight necessitating the performance of the trials. However, its load proved ample for the work before which it performed with a completeness which left nothing to be desired.

The six shells were laid in pairs, side by side, on various sections of the target—these sections representing various styles of permanent fortification—the termination of the target being a large Monmouth gun-pit.

The two 64-pounder shells were laid on the upper surface of the overhanging crest of the gun-pit, and the two 180-pounder gun-cotton shells on the concrete roof of the opposite extremity of the target, the gun-cotton shell being on the roof, which was formed of half iron arch plate 7' 2" span, resting on iron girders (18 feet span) with $13\frac{1}{2}$ inches of brickwork, and from 2' to 3' 6" of concrete over it.

The 180-pounder cotton-powder shell was on an adjoining position similar in construction, except that there was no brickwork, but the whole thickness of roof was of concrete, varying from 3' 2" to 4' 6".

The two 350-pounder shells were placed on the thickest part of the roof, where the vertical section of the structure gives:—Brick 2' 8" thick and 14 feet span, with from 1' 7 $\frac{1}{2}$ " to 2' 6" of concrete at top, the concrete thickening with the incline of the upper surface of the roof.

The whole series of six were fired simultaneously by battery, the ordinary Service electrical fuzes being employed for the ignition of the charges. Only the 350-pounder cotton-powder shell with its bursting charge of 24 lbs. effected penetration of the massive roof. The other shells all made "scoops" in the concrete of greater or less dimensions proportionate to their bursters; the largest gun-cotton shell not making a crater of more than about 3 feet in diameter and some 15 inches deep.

The break-through of the roof by the 10-inch (350-pounder) cotton-powder shell was singularly complete, the quantity effect being of exact character so valuable in experiments, and so seldom obtained. Above was a wide crater, some 6 feet in diameter, and below was an inverted crater about 5' 9" across, a hole of over 2 feet in diameter being punched clean through at the intersection of the two craters.

XIX. This first essay of cotton-powder in the military world, before the public for military purposes, was so good a beginning, I confess I have been hoping to be invited to further trials, and this is still within me, a lingering trace of "hope deferred." Of course I knew when I made these trials, the first words which would rise to the artilleryman's lips:—"Oh, you put your cotton-powder shells on the c

"mate; the thing is to get them there." Of course it is; and my reply was as prompt: "If you will let me have the guns, I will send them there."

I am ready, whenever the opportunity is given me.

XX. In the present circumstances of cotton-powder, any further details of interest to put before you do not occur to me; and I think I cannot do better than conclude this necessarily imperfect essay with the wish that, if the storm of hostilities which has been so long lowering over the political atmosphere should burst upon the world, that the Executive of the Cotton-Powder Works may be found to be *not* the least useful nor the least *active* of Her Majesty's subjects; and that long before such events, the War Office will have recognized at least some of the merits claimed for cotton-powder, and have given it fair opportunities of demonstrating that superiority which is now claimed on its behalf.

The CHAIRMAN: I dare say there are some gentlemen present who will favour us with their remarks on this subject in its various sections—civil, military, and naval. For myself, I should very much like to hear a little more as to its applicability to naval warfare; first, as to its perfect safety below, and in handling it, next as to the certainty of ignition and the utmost power of elastic propulsion while in the gun, without any chance of bursting it, and then as to making certain that in the hands of men more or less skilled in handling these things we may never have a mistake; because in these matters a mistake on board a ship is a very fatal thing.

Mr. J. POXSONBY CUNDILL, R.A.: There are one or two questions I should like to ask. Did I understand the lecturer to say that the detonators are sent out with the powder?

Mr. MACKIE: No, certainly not.

Mr. CUNDILL: As I understand, the cartridges can be kept wet on board ship, or elsewhere, and those cartridges, or the powder itself, can be detonated in the same way that the Service gun-cotton can with the help of a certain proportion of dry. Then there is what is perhaps a minor point; the lecturer said that on the occasion of explosions there was a sort of dust-cloud in the air, which was probably some compound of baryta. From my slight knowledge of it, I should say he is right. Now that is not a dust-powder I should care much to go into and breathe, because it is rather a poisonous substance. Two or three months ago I was up at some carbonate of baryta mines near Keswick, and I found that some of the men complained of suffering a good deal from the dust of baryta in its various compounds, especially when roasted with carbon. They complained a good deal both in the mine and in the roasting of the fumes of this baryta. Of course, it is a minor question, but the lecturer seemed to insist upon its being innocuous, although those who have had practical experience of it, say that it is not. A great deal of stress was laid on the question of density. We must all admit that if you press a given explosive tightly, you get more force out of the tight compression than out of the loose compression. But the density, as I understand it, is equivalent to the weight; that is to say, supposing two equal blocks, one of gun-cotton and the other of cotton-powder, the cotton-powder will be the heavier one, and very naturally it should, because it has got that extremely heavy stuff, nitrate of baryta, in it. I do not see that the actual density is a proof that it is more powerful; it may be so, but I do not follow the reasoning that it is more powerful because it weighs heavier. And the same question comes in with regard to the cost. Of course you get more absolute bulk of gun-cotton in a pound than of cotton-powder, so that it is hardly fair to compare the price of three shillings for two pounds of cotton-powder, with the two shillings and sixpence for the gun-cotton. With regard to sporting purposes, gun-cotton has often been tried, as regards its use in rifles, down at Woolwich ranges. I have frequently heard say that it went on shooting beautifully for a time, and then perhaps a cap had accidentally some slight degree more of composition in it, and

irregularities took place. It was always subject to irregularity of shooting, and then the rifle burst. As regards the recoil, the lecturer said the recoil was as I understood him to mean there was less recoil. Now, we do not want to get the recoil in the gun. The large gunpowder gives more recoil than the *poudre brut* which we used to use, and we argue it is better for the gun to get pushed back than to have all the blow absorbed by the metal, and no recoil at all.

M. GUSTAVE CANET: I should like to offer a few remarks, more especially as I had recently the opportunity of witnessing the manufacture of cotton-powder at Faversham. The general features which struck me on seeing the works were these: firstly, ingenious process of crushing the fibres of the gun-cotton into very fine powder then the washing, or rather purifying, of the same; and, lastly, the addition to gun-cotton of an equal quantity of nitrate of baryta to obtain the cotton-powder. Mr. Mackie, in his able lecture, has fully explained this, so that I shall not say much about it. A great deal is being said and written every day about the relative merits of gun-cotton and cotton-powder. It seems to me it would be much easier to settle that important question by experiments similar to those carried on in France some time ago by MM. L. Roux, directeur, and E. Sarrau, ingénieur du Depot Central Poudreries. These gentlemen wished to test the relative strength of several explosives. They found out experimentally—1st, the charge of each explosive necessary to burst shells as nearly identical as possible; 2ndly, the amount of heat disengaged on explosion; and, 3rdly, the relative proportion of permanent gases produced by the explosion. They found that nitro-glycerine, gun-cotton, picric acid, and picrates of potash and strontium followed the law given by M. Berthelot, viz., the strength of explosives is nearly proportionate to the amount of heat disengaged on explosion; but fulminate of mercury and picrates of baryta and lead did not follow the law. It is very highly probable that the law will apply to cotton-powder; consequently we must expect, according to the figures given by Mr. Mackie, that with cotton-powder we shall get half as much strength again as with ordinary gun-cotton. There is another point I should like to refer to. MM. Roux and Sarrau found that there is a greater probability of obtaining an explosion of what they call the first order when there is a greater mechanical resistance to overcome. For instance, they found that to burst a shell, 12 grammes (that is a little over half ounce) of dynamite were required when the dynamite was put loosely into the shell; but that if the dynamite was put into a piece of paper, 3 grammes only were required in order to produce the same effect, showing that the simple resistance of a piece of paper would determine an explosion of quite another order in dynamite. They found exactly the same thing in gun-cotton, which they could hardly explode in its natural state, but they could obtain its explosion when packed tightly in a piece of paper, or in its compressed state, or when it is introduced into an insubstance which is afterwards crystallized, such as chloride of potash, and also when wet pressed gun-cotton was frozen. It seems to me that the mechanical resistance offered by cotton-powder is much greater than that by gun-cotton; consequently should say the advantage would be again with the cotton-powder. All this could easily be settled by experiments, and it is highly important that such experiments should be made. It has been stated by a former speaker that the recoil of guns is greater with a slow-burning powder than with a "brisant" powder. I saw some time since several eminent officers of a French experimental commission, and I asked them they had remarked such a fact in their practice. They replied that the idea was quite new to them, and that in their experiments they found no difference at all in the recoil.

M. C. A. FAURE: I should like to say a few words on the stability of gun-cotton because that is the point we are to look to. We have the "fact" staring us in the face that gun-cotton is "*thoroughly stable*," but no Government will believe it. The English Government do not believe in gun-cotton; they use it, but dip it in water, to make sure of its safety. The French Government will not look at it, and therefore there appears to be very great difficulty in establishing the stability of cotton-powder for naval purposes. This will warrant, I think, a few more words on the stability of cotton-powder, and the way it is purified at Faversham. Since gun-cotton has been introduced, there have been a great many accidents, which have burnt nearly as much gun-cotton as has ever been made use of, and no one w

therefore, believe in gun-cotton unless it is kept wet. Now I am sure wet gun-cotton is almost useless practically, and we at Faversham have really started a new era in its manufacture, and claim to have removed this uneasiness on account of safety. Those who are initiated in the controversies that have taken place on the stability of gun-cotton will know well what I mean, and why it is necessary that there should be more proof before you ask the Navy to carry tons of dry gun-cotton in their ships. The impurities in gun-cotton are impurities that cannot be washed away; that is really the fact. The Company have spared no means for facilitating the investigation of the properties of gun-cotton, in order to get at the bottom of it. Mr. Mackie himself has been untiring in his endeavour to get at the inner properties of the material, and we have really come to this, that the impurities in the gun-cotton are impurities that cannot be washed away, and any process of washing them out is wrong. They must be decomposed within the cellule of the gun-cotton itself, and there is nothing but boiling it with ammonia that will do this, because this boiling destroys all the nitro-starch, nitro-sugar, and anything injurious that is within. If you boil it with ammonia, you reduce them all to water and nitrogen, &c. That is the principle of the performance, and to my mind it is the only thing that need trouble you. We have established a new way of doing the thing, which was not done before, and whether this produce will obtain a large success, will of course depend upon its own merit. As something has been said about carbonate of baryta, I should like to say, it is very likely that those who are in carbonate of baryta mines must be thoroughly saturated with the stuff. When they go for their food, they must have heaps of it about their hands, and they must eat it with their food. Carbonate of baryta, if taken inside the digestive apparatus in considerable quantities would be injurious; but if we merely breathe a few particles in the air, it is a very different thing, and one need not be much concerned about that. I should think gun-cotton with its carbonic oxide emanations is much more dangerous than that little carbonate of baryta in suspension in the air, because it takes very little carbonic oxide in the air to make it poisonous, but it will take a good deal of the particles of carbonate of baryta to make it poisonous if you merely inhale it. As to nitrate of baryta being not quite suitable from a chemical point of view, I for myself should have opposed the idea of putting nitrate of baryta in powder, instead of other nitrates apparently better suited, but we are bound to use it, because the nitrate of baryta for the same amount of oxygen, occupies the smaller volume. It does not matter to the miner exactly what is the weight of the powder he puts in the hole; what he wants to do, is to have the smallest hole possible. Often a very small bore-hole costs a great deal of money to make, and if you can reduce the holes only three inches in depth, those three inches are worth sometimes a shilling, and the powder is worth only threepence. That is an advantage. And then with regard to shells, if you can put more into a shell you have so much more effect. That is the reason why nitrate of baryta is valuable, and experiments have shown it to be so quite sufficiently, I think, to warrant the Company keeping to what they have got.

MR. MACKIE: I should have been pleased to have heard some opinions from Naval Officers present as to the use of explosives in a variety of ways, but, under the circumstances, I am very happy to deal with the questions which have been brought forward. The practice of sending out detonators with the powder is one which is totally objected to on every ground both by myself and by the Company. It is utterly useless to make a powder that is absolutely safe in itself if you are going to destroy that safety which you have made, by sending out the very thing with it which causes the explosion. I always recommend railways to send the detonators which are consigned with orders, in a separate van from the powder itself. As long as this powder is left by itself, it will stand any amount of ordinary blows or heat, but to mix up detonators with powder of a quality so safe as this, would be a very great piece of folly. Then again the powder can be exploded wet, but there is no use in keeping the powder wet. I think the saying of Cromwell, "Trust in Providence, and keep your powder dry," is as good a maxim with regard to cotton-powder as it was of old, especially when you know that water takes away from the capability of the powder being immediately detonated, and that there is a risk in wet substances of their not being exploded at the time they are wanted; and the very fact that failure of detonation can arise from wetness, is a very proper barrier

to the use of wet powder. There is no doubt whatever that the Service gun often fails to explode at the right moment, through its wetness, or some cause connected with the system of damping it. Powder, to be serviceable on board ship on land, ought always to be available in the dry state, and the mixture of nitro-baryta is as complete a dilutant to the gun-cotton as any amount of water that be put there. It is just the same thing in its mechanical action as the gun-sand with gunpowder; and therefore, the cotton-powder, as you saw, was per open to ignition without any chance whatever of explosion. With regard to nitro-baryta dust, we know very little indeed about the poisonous effects of baryta, especially the carbonate of baryta. There are instances on record of people I have been poisoned by taking carbonate of baryta into the stomach; and it is by absorption into the digestive organs only, so far as is known that baryta is injurious. In the mines where baryta is raised, and particularly when water from the veins of baryta mines is drunk, cases of poisoning from baryta would take place not from the effects of explosions of baryta in the cotton-powder. I have been present, when heavy charges have been fired, for days and nights together close headings, and have fired as much as 30 lbs. at a time below ground; and on occasion in a very close lead mine, without a particle of ventilation, we were charged from eleven o'clock in the morning to five in the afternoon, and I suffered at all; and in no other case whatever have I ever experienced the effect from the slight dust which comes from the cotton-powder. In fact, the portion of the dust after an explosion arises from the limestone dust, or steam driven out from the disrupted rock. If you fire a charge in the open, you see little result, except a mass of white steam. If you take the quantity of nitro-baryta which there is in an ordinary mining charge of cotton-powder, and mix with the atmosphere of even a small heading, you will find it is diluted down to a very small percentage indeed, and that but next to nothing could be got in the stomach. In a dry heading, the dust very soon falls to the ground; and in a heading be damp, the dust is gone almost immediately. The smoke ordinarily vanishes away in less than a minute. It is not at all an unusual thing in a shaft any depth to send down a fire-brazier to burn away the fumes of gunpowder. Certainly I would much rather work in mines in the smoke of cotton-powder for a whole day than I would for half that time in the smoke of gunpowder. The proof is, that ever since we have been manufacturing the cotton-powder, the London and North-Western Railway Company have been using very large quantities for the tunnel in North Wales. They have 500 men employed there, and we have not a single complaint. With regard to the density of cotton-powder, of course the addition of any merely heavy material would be of no value in the explosion; weight added would take off from the value of the density, the value of which is in representing, as I intended it should, the weight of the actual available of gas and carbon got into a given space, and which should be the indication of the power of the powder. But Mr. Faure has explained that baryta takes up oxygen in the same space than any other substance that can be used, and that has the advantage in that way of giving more force to the gun-cotton; and I agree with him that the system which has been adopted in our works—and for very great credit is to be given to Mr. Faure himself, who for three years has been my colleague, and whose services I am very proud to acknowledge—I agree with Mr. Faure, too, that nothing has ever been done for gun-cotton in the way of purification that approaches the system of destroying utterly by boiling with carbonate of ammonia the noxious qualities which were the bane of the old gun-cotton. I quite agree also in the necessity which M. Canet has suggested, that it is no more lecturers' arguments or theoretical talk that questions of the superiority of an explosive can be settled, and as I ended my essay with the expression that the matter will have further attention, so I do most sincerely hope the opportunity may be given to us to show that the cotton-powder is what it is stated to be the road we have started on at any rate we can maintain; and if any one can show us in it, we shall be very pleased to try our utmost to get again to the front.

The CHAIRMAN: May I ask whether you can see your way to producing a powder which would answer for great guns on board ship as well as on shore—on

would give the greatest amount of propelling power, but gradually burning, and also igniting without the danger of an explosion?

Mr. MACKIE: I am much obliged to you for reminding me of those points. Gun-cotton, we all know, is sensitive to detonation, and however you may attempt to conceal it, a stronger cap than usual is liable to cause the destruction of the gun. What we have tried is to avoid detonation in the gun, and our trials have had in view to produce a gunpowder which would be a true gunpowder, and would give only a pushing force in the gun. In that direction we have succeeded in a very marked degree. Where the gun-cotton is reduced to an exceedingly fine powder, as it is with us, there is no degree of incorporation with other substances that cannot be effected, and I believe myself we could produce powder fit for any service whatever, from the smallest pistol up to the largest cannon. I do not say we could do it instantly, but we are on the right road to do it. It is simply a question of experiment and elaboration, but with such works as we have at Faversham, which are commercial works, the first consideration is earning a dividend for the shareholders. Therefore we are obliged to go on the road of blasting-powder because Governments are only single customers, and we cannot afford to spend the shareholders' money to produce a thing which has no general market. But there is no doubt whatever that if we are put to the test by any Government, we will do it. In that case I fully understand what you want is a gunpowder made from gun-cotton, which can be put into the hands of gunners to fire with perfect security, and that the guns shall not be exposed to risk of destruction.

The CHAIRMAN: I think the meeting will join with me in thanking Mr. Mackie for a very interesting lecture on a subject which concerns us all as naval or military men, not only at present, but for the future. We are, of course, much more interested with its Service-possibilities for the future than simply in the present commercial question. But we are still more concerned in the apparent prospect that there is of its great utility for our guns, both on shore and afloat.