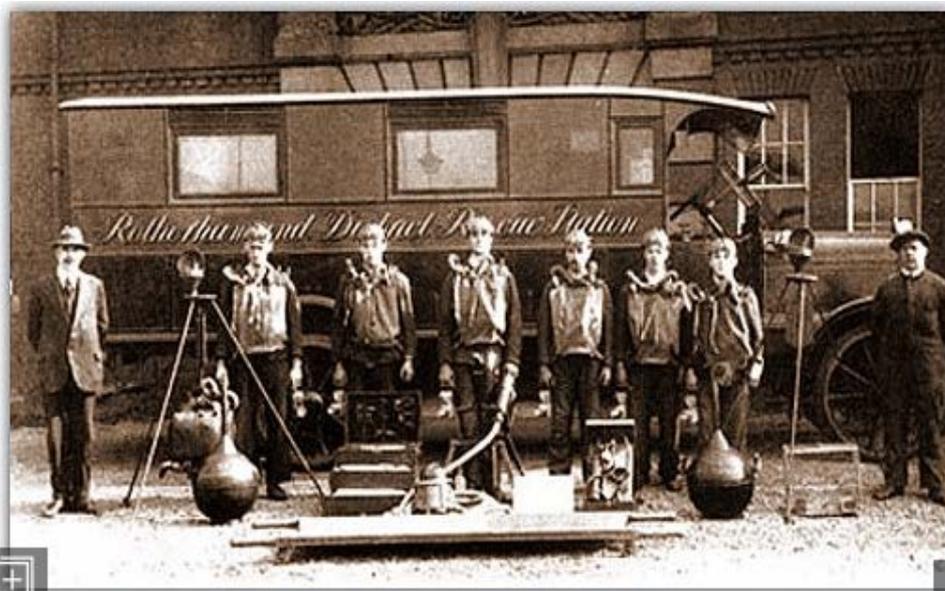


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**Baking a New Technology:  
Breathing Apparatus for Mine Rescue in Britain, c. 1890 - c. 1930**

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**Fig 1.** Rescue team and kit from the Rotherham and District Rescue Station, early 1920s. Source: <http://www.healeyhero.co.uk/rescue/pits/Maltby/Maltby-1.html> accessed 20 December 2017

In 1908, George Blake Walker, a prominent mining engineer based at Wharncliffe Silkstone Colliery near Barnsley, stated that money spent by collieries on mine rescue breathing apparatus was 'of the nature of an insurance fund' in relation to the

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threat of explosions to life and property.<sup>2</sup> Although relatively infrequent, serious explosions could cause hundreds of fatalities and wreck parts of collieries for months or even permanently. Several types of breathing apparatus for use in irrespirable conditions in coal mines were developed in the late nineteenth and early twentieth centuries. Such apparatus was employed in rescue operations (albeit it with limited success), the retrieval of corpses, and work to restore damaged mines to production. It could also be used in fire-fighting and the isolation of districts deemed to be in danger of explosion. Under legislation in 1910 and 1911 it was compulsory for the vast majority of British collieries to have access to breathing apparatus. Employers in each district were encouraged to build central rescue stations to hold sets of apparatus and train rescuers. By 1921 there were 49 rescue stations, and 1758 sets of approved breathing apparatus, most kept at the stations but some at the colliery.<sup>3</sup>

Many ingredients go into the development of a new technology, hence the title's baking metaphor. The ingredients of our cake are not the tubes and mouthpieces and breathing bags worn by rescue men, but rather the individuals and groups, from tinkerers to academic scientists to commercial companies that contributed in various ways to the design and testing of effective breathing apparatus. Relationships between the parties were complex and shifting, but on the whole they complemented one another. The key role in mixing and baking the ingredients was played by the Institution of Mining Engineers (IME), its journal *Transactions*, and regional groups of mining engineers.<sup>4</sup> The literature on collective invention, open source invention and user innovation is deployed to help organize and interpret of the evidence.

The first section outlines the conceptual framework underpinning the paper. Section 2 provides historical context, especially on explosions. The origins and design of breathing apparatus are discussed in section 3. Section 4, the longest, examines the ingredients - the individuals and groups that made up the community

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<sup>2</sup> George Blake Walker (1908-1909), 'On the practical use and value of colliery rescue-apparatus, and the organization of rescue-corps', *Transactions of the Institution of Mining Engineers*, Vol. 36, p. 537.

<sup>3</sup> Mines Department (1922), *First Annual Report of the Secretary of State for Mines for the Year Ending 32st December 1921 and the Annual Report of H.M. Chief Inspector of Mines*, London: HMSO, pp. 132-133.

<sup>4</sup> The contribution of the mining engineering institutions and the *Transactions* to the circulation and testing of new methods and technologies is discussed by Peter Scott (2006), 'Path dependence, fragmented property rights and the slow diffusion of high throughput technologies in inter-war British coal mining', *Business History*, Vol. 48, No. 1, pp. 25-26.

working to improve breathing technology. Section 5 considers their interaction, which was facilitated in large measure by the IME and its *Transactions*. The focus of Section 6 is the Rotherham and District Rescue Station, how it selected a type of breathing apparatus, and then proceeded to modify it through a process akin to tinkering.

## 1 Conceptual framework

The current paper does not offer a direct test of the validity of existing theories of collective invention, open source invention, and user innovation. It seeks, rather, to use them to interpret the development of breathing apparatus. Robert Allen, Peter Meyer, and Eric von Hippel are the authors whose research seems most relevant in this context.

According to Allen, inventive activity may be conducted by (a) commercial enterprises, (b) individual inventors, (c) non-profit entities including universities and governments, or (d) networks of practitioners who swap ideas and technical information free of charge. It is the fourth option that Allen classifies as collective invention. For collective invention to proceed, it is necessary for there to be a mechanism to facilitate the exchange of technical information, not necessarily every detail but enough to spur other members of the network to take the technology further. Allen argues that collective invention is most likely to occur in situations where technical change cannot easily be patented. He investigates the ironworks of Cleveland in north-east England in the nineteenth century, focussing on competition to increase the height and temperature of blast furnaces. Little was known of the underlying science behind the design of blast furnaces and incremental improvements could not be patented. Ironworks owners boasted about their achievements in the trade and technical press, such as the *Journal of the Iron and Steel Institute*, prompting efforts to match or surpass their achievements.<sup>5</sup> Of course, there is no reason why all four sources of inventive activity should not be present simultaneously, and we shall argue that that was the case with breathing apparatus.

Nuvolari reinforces the collective invention thesis with an article on pumping engines in Cornish mines during the Industrial Revolution. Having been tormented until 1800 by Watt's patent, Cornish engineers were inclined to favour the sharing of

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<sup>5</sup> Robert C. Allen (1983), 'Collective invention', *Journal of Economic Behavior and Organization*, 4, pp. 1-24.

technical information. Collective invention was stimulated by a monthly publication, *Lean's Engine Reporter*, founded by a group of mine managers in 1811. This journal recorded the technical specifications, method of operation, and fuel efficiency of each new pumping engine. Nuvolari contends that this exchange of engineering information accelerated development of pumping technology.<sup>6</sup>

Open source technology is technology that is not patented. Meyer points out that, in the early stages of the development of new technologies, opportunities for profit are not yet available to inventors, and they may be willing to share technical information. The origins of personal computing may be traced back to such an environment. Meyer is particularly interested in the motivation of inventors when great uncertainty exists over the route to commercial viability, and the only apparent certainty is that success is a distant prospect. Inventive endeavour will continue if inventors have at least some non-financial goals. Intrinsic motivations encompass a delight in tinkering in the garden shed or taking up an intellectual challenge, as well as the desire for fame and honours (and possibly fortune); extrinsic motivations include a desire to make the world a better or safer place. Patents, argues Meyer, may be used less to deter imitators than to broadcast technical advances. In order to demonstrate commitment to an international network devoted to solving an important problem, inventors may be prepared to share their secrets. Some may become information brokers, publishing textbooks or bibliographies. Meyer illustrates open source invention by examining collaboration between inventors working on powered flight before the emergence of a viable technology after 1900. Although some were individual tinkerers, others could call on help from related organizations: Otto Lilienthal had a steam engine manufacturing company, whilst Samuel Langley was director of the Smithsonian Institution.<sup>7</sup>

In an investigation of the obstacles to the full mechanization of British coal mines between the wars, Peter Scott refers to the 'collective learning' facilitated by exchanges of information at meetings of the IME and its regional constituents and through the pages of the Transactions, albeit without exploring this avenue in detail.<sup>8</sup>

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<sup>6</sup> Alessandro Nuvolari (2004), 'Collective invention during the British Industrial Revolution: the case of the Cornish pumping engine', *Cambridge Journal of Economics*, 28, pp. 347-363.

<sup>7</sup> Peter B. Meyer (2013), 'The airplane as an open-source invention', *Revue économique*, 64, 1, pp. 115-132; idem (2007), 'Networks of tinkerers: a model of open-source technology innovation', Bureau of Labor Statistics Working Papers, No. 413.

<sup>8</sup> Scott, 'Path dependence', pp. 25-26.

Von Hippel's work, which is less historical, complements Meyer's on the prehistory of the aircraft. According to von Hippel, the users of a technology often modify and improve it, sometimes working in cooperation with the manufacturers, and sometimes sharing their results freely with other users. User innovation, as we shall see, was present during the early stages of the development of breathing apparatus for work in mines.<sup>9</sup>

In short, Allen, Meyer, and von Hippel provide intellectual tools that promise to be of considerable use when explaining the development of mine rescue apparatus.

## 2. Historical context

Fatality rates in coal mining in Britain and other countries fell in the late nineteenth century, either because of technical changes, such as the adoption of better methods of ventilation, or stronger regulation, or a combination of those factors.<sup>10</sup> Nevertheless, at the start of the twentieth century, coal miners continued to face multiple hazards. Most deaths and injuries underground were caused by falls of rock and coal and haulage accidents. Although relatively uncommon, large firedamp and/or coal dust explosions attracted the most public and political attention.<sup>11</sup>

**Table 1** Coal mine disasters with over 100 fatalities in the UK, 1900-1939

Date	Colliery	County	Fatalities
11 July 1905	National	Glamorgan	119
16 February 1909	West Stanley	Durham	168
11 May 1910	Wellington	Cumberland	137
21 December 1910	Hulton	Lancashire	344
14 October 1913	Senghenydd	Glamorgan	439
12 January 1918	Podmore Hall	Staffordshire	155
22 September 1934	Gresford	Denbighshire	265

Source: Durham Mining Museum, 'In Memoriam', [http://www.dmm.org.uk/names/index\\_19.htm](http://www.dmm.org.uk/names/index_19.htm)

<sup>9</sup> Eric von Hippel (2006), *Democratizing Innovation*, Cambridge, MA: MIT Press.

<sup>10</sup> John E. Murray and Javier Silvestre (2015), 'Small-scale technologies and European coal mine safety, 1850-1900', *Economic History Review*, 68 (3), pp. 887-910.

<sup>11</sup> On Senghenydd, see John Singleton (2016), *Economic and Natural Disasters since 1900*, Cheltenham: Edward Elgar, pp. 108-123; on Gresford, see Stanley Williamson (1999), *Gresford: The Anatomy of a Disaster*, Liverpool: Liverpool University Press. Other disasters

For much of the nineteenth century, it was assumed that the ignition of firedamp (methane) was the principal cause of explosions. But there was also a growing acceptance that firedamp explosions could dislodge and ignite accumulations of coal dust at the face or in the roadways. Coal dust, moreover, could be ignited in the absence of firedamp. The force of the explosion and the initial fire would account for some fatalities, but most victims succumbed to the afterdamp (carbon monoxide) circulated by burning coal, coal dust and wood.<sup>12</sup> Although worker error was a factor in many explosions, the disaster investigations of H.M. Mines Inspectorate often criticised management for tolerating or encouraging risk taking in order to boost production.<sup>13</sup> Other factors included the adoption of mechanical coal cutters that created more coal dust, the use of electrical equipment, including signalling devices, which could emit sparks, and the spontaneous combustion of coal and waste material.<sup>14</sup> Not until the First World War was it established beyond doubt that the best means of preventing the ignition of coal dust was to coat it liberally with stone dust. Other methods, including sprinkling water and removing coal dust manually, were problematical, but stone dusting worked if carried out systematically. From 1920 onwards, all coal mines, except those producing anthracite (which was not dusty), were required to apply stone dust.<sup>15</sup>

Interest in breathing apparatus was fuelled by a mixture of humanitarianism, technophilia, and self-interest. Not all coal owners were ogres, at least not all of the time. In parts of South Wales, for example, they contributed generously to the cost of new hospitals for their communities.<sup>16</sup> The management side of the mining industry

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<sup>12</sup> Trevor Boyns (1986), 'Technical change and colliery explosions in the South Wales coalfield, c. 1870-1914', *Welsh History Review*, 13 (2), 155-77.

<sup>13</sup> James Reveley and John Singleton (2018), 'Carbon copy: the mock bureaucratic setting of colliery explosions in early twentieth century Britain and at Pike River, New Zealand', *Journal of Management History*, forthcoming.

<sup>14</sup> Alan Victor Jones (2006), 'Towards safer working: the hazards and the risks of introducing electrical equipment in British coal mines up to about 1930', *Transactions of the Newcomen Society*, 76, 115-26; Baron Evelyn Rockley (1938), *Royal Commission on Safety in Coal Mines: Report*, Cmd. 5890, London: HMSO, p. 23.

<sup>15</sup> Stone dust cooled the coal dust and held it in place. Rockley, *Royal Commission on Safety*, pp. 353-355. For an American perspective on the origins of stone dusting see Mark Aldrich (1995), "'The needless peril of the coal mine': The Bureau of Mines and the campaign against coal mine explosions, 1910-1940", *Technology and Culture*, 36 (3), pp. 483-518.

<sup>16</sup> Steven Thompson (2003), 'To relieve the sufferings of humanity, irrespective of party, politics or creed? Conflict, consensus and voluntary hospital provision in Edwardian South Wales', *Social History of Medicine*, 16 (2), pp. 247-262.

was intersected by the mining engineering profession, which had the promotion of safer working conditions as a core objective. Almost by definition, mining engineers were interested in technological progress, and breathing apparatus was a shiny new technology. The coal industry also realised that neglect of mine rescue would render it more vulnerable to government interference. Breathing apparatus, moreover, was a dual purpose technology that could be used to hasten the restoration of production in damaged mines - it proved effective in this role at the Norton colliery in Staffordshire in 1912.<sup>17</sup>

Political interest in rescue technology gathered pace. In 1886 the Royal Commission on Accidents in Mines urged employers to set up rescue centres equipped with apparatus for exploring mines. The first report of the Royal Commission on Mines in 1907 commented upon the types of breathing apparatus available, and once more recommended that rescue stations be established in the mining districts. Collieries in Austria, Belgium and France were required to purchase breathing apparatus, but the Royal Commission did not think the time was ripe for compulsion in Britain, not least because the technology was imperfect.<sup>18</sup> Employers' groups in several districts had already opened, or were planning to open, rescue stations to hold breathing apparatus and train miners in their use. The first British stations were Altofts and Tankersley in Yorkshire.<sup>19</sup> Agitation for compulsion was growing, even though no lives had yet been saved in British collieries by rescuers wearing breathing apparatus. The Royal Commission's second report in 1909 hinted that legislation on rescue apparatus was likely if voluntarism failed.<sup>20</sup>

The explosion at Wellington Pit, which took 137 lives in 1910, was the final straw. Located near Whitehaven on the isolated Cumberland coast, the stricken pit lacked ready access to breathing apparatus. Rescuers had to send to Newcastle and

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<sup>17</sup> Proto breathing apparatus was used without mishap in this operation which lasted 120 days. As well as benefitting the company, the Norton operation demonstrated the resilience of the Proto and the skill of the 'rescue' teams trained at Stoke on Trent. J.R.L. Allott (1912-1913), 'The reopening of Norton Colliery with self-contained breathing-apparatus after an explosion', *Transactions of the Institution of Mining Engineers*, Vol. 45, pp. 595-617.

<sup>18</sup> Royal Commission on Mines (1907), *First Report of the Royal Commission on Mines*, Cd. 3548, London: HMSO, p. 10.

<sup>19</sup> M.H. Habershon (1900-1901), 'A joint colliery rescue station', *Transactions of the Institution of Mining Engineers*, Vol. 21, pp. 100-110; M.H. Habershon (1904-1905), 'The work of a joint colliery rescue-station', *Transactions of the Institution of Mining Engineers*, Vol. 28, pp. 254-263.

<sup>20</sup> Royal Commission on Mines (1909), *Second Report of the Royal Commission on Mines*, Cd. 4820, London: HMSO, p. 170.

Sheffield for apparatus; when it arrived elements were missing, evidently forgotten in the panic. Whether those trapped underground could have been saved by a faster response is debatable. The conclusion drawn by the union, the public, and the Mines Inspectorate was that breathing apparatus must be made available, if not at every mine, then within each district.<sup>21</sup> Embarrassed by the strength of feeling, the government responded with the Mines Accidents (Rescue and Aid) Act, 1910.<sup>22</sup> The Coal Mines Act 1911 reinforced this legislation. Under these acts and subsequent official orders, a network of rescue stations equipped with breathing apparatus, and funded by the employers, was established across the coalfields. Until the introduction of stone-dusting, rescue technology offered a second-best solution to the threat posed by explosions. That it was second-best is confirmed by the fact that it was not until 1913 that a British miner was saved by rescuers wearing breathing apparatus.<sup>23</sup>

### 3. The technology

It is not our purpose to identify the first viable mine rescue apparatus, but there is merit in recording some of the pre-history of this technology. In 1926, the Rescue Regulations Committee of the Mines Department began its survey of the development of breathing apparatus with a nod to John Roberts and his safety-hood.<sup>24</sup> The intrepid Roberts, a miner from Wigan, demonstrated his protective hood in 1825, spending 20 minutes in a 'cast-iron drying stove' filled with noxious fumes at a Manchester foundry, before emerging unharmed.<sup>25</sup> In evidence given to the House of Lords Select Committee on Accidents in Mines in 1849, John Hutchinson, a London doctor, explained how the breathing apparatus used in the Paris sewers,

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<sup>21</sup> Richard A.S. Redmayne and Samuel Pope (1911), *Explosion and Underground Fire at the Wellington Pit, Whitehaven Colliery. Report on the Causes of and Circumstances Attending an Explosion and Underground Fire which Occurred at the Wellington Pit, Whitehaven Colliery on the 11<sup>th</sup> May, 1910*, Cd. 5524, London: HMSO; Reveley and Singleton, 'Carbon copy'.

<sup>22</sup> Earl Beauchamp, House of Lords Debates, 25 July, vol. 6, cols 414-415.

<sup>23</sup> The lucky chap was Albert Schofield. W.D. Lloyd (1913-1914), 'An account of the use of rescue-apparatus at Lodge Mill Colliery, Huddersfield', *Transactions of the Institution of Mining Engineers*, vol. 46, pp. 250-254.

<sup>24</sup> Mines Department (1926), *Report of the Departmental Committee Appointed by the Secretary of State of Mines to Investigate the Existing Arrangements for the Provision and Maintenance of Rescue Appliances and for the Formation and Training of Rescue Corps and Brigades*, London: HMSO, p. 6.

<sup>25</sup> 'Local Intelligence', *Manchester Courier and Lancashire General Advertiser*, 19 February 1825, p. 3.

comprising a mask with valves connected to a bag of air carried in a basket on the wearer's back, could be adapted for use in mines.<sup>26</sup>

Perhaps the first practical breathing apparatus for rescue and salvage work in coal mines was invented by Henry Fleuss, the son of a teacher at Marlborough College. Fleuss became interested in diving equipment whilst working for the P&O steamship company. His apparatus of 1879 was a primitive self-contained underwater breathing apparatus or scuba. It dispensed with the vulnerable air hose connecting the diver to the surface. Divers would instead carry a self-contained compressed oxygen supply, plus a contrivance to recover (regenerate) oxygen from exhaled carbon dioxide. Fleuss obtained patents and started his own company. He also collaborated with Siebe, Gorman & Co. of London, the premier makers of diving equipment. The Fleuss apparatus was soon adapted for use in mines: surviving in a poisonous atmosphere underground presented the same challenge as surviving underwater. An association of mining engineers invited Fleuss to exhibit his modified apparatus at a celebration of the centenary of George Stephenson's birth at Chesterfield in June 1881. Shortly afterwards, the Fleuss was deployed in work to reopen Seaham Colliery, County Durham following an explosion. It also saw action at Killingworth Colliery, where miners were trapped by a roof fall in 1882. According to the Mines Inspectorate, however, the apparatus, though welcome, was not the decisive factor in the rescue's success. Siebe, Gorman manufactured and distributed the apparatus on behalf of Fleuss. Although not adopted widely, possibly because of the cost, the design of the Fleuss, including the system for regenerating oxygen with caustic soda, proved very influential. After 1900, Fleuss cooperated with his friend Robert H. Davis, the manager of Siebe, Gorman, on a new generation of mine rescue apparatus.<sup>27</sup>

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<sup>26</sup> Mines Department (1926), *Report of the Departmental Committee*, pp. 6-7; House of Lords (1849), *Report from the Select Committee of the House of Lords Appointed to Inquire into the Best Means of Preventing the Occurrence of Dangerous Accidents in Coal Mines*, London: HMSO, C. 613, pp. 140, 160-162.

<sup>27</sup> Richard Foregger (1974), 'Development of mine rescue and underwater breathing apparatus: appliances of Henry Fleuss', *Journal of the History of Medicine*, 29 (3), pp. 317-30; H.M. Inspectors of Mines (1883), *Reports of the Inspectors of Mines to Her Majesty's Secretary of State for 1882*, London: Eyre and Spottiswoode, C. 3621, pp. 318-319; Peter Jackson (2002), 'O<sub>2</sub> under H<sub>2</sub>O: the Fleuss apparatus: a short history of the re-breather', *Historical Diver*, 10 (2), pp. 26-31. Fleuss was influenced by earlier inventors, including the Belgian physiologist, Théodore Schwann, who had constructed a prototype breathing apparatus in 1854. On Schwann's contribution see G.A. Meyer

Austria and Germany were at the forefront of efforts to develop breathing apparatus for use in irrespirable atmospheres underground in the 1890s and early 1900s. The Walcher (Austrian), and the Shamrock, the Giersberg, and the Draeger (German) were types of breathing apparatus or 'pneumatophore' that incorporated compressed oxygen cylinders, and employed a chemical process to regenerate exhaled air in a large breathing bag strapped to the chest. The wearer was fitted with an airtight helmet or mask and mouthpiece connected by tubes to the breathing bag and oxygen cylinder(s). The pneumatophore was similar in principle to the Fleuss apparatus. Technical progress in Austria and Germany was stimulated by the introduction of legal requirements for the mines in some districts to have access to rescue apparatus. A somewhat different solution, developed in Austria, was offered by the pneumatogen; this dispensed with the heavy compressed oxygen cylinders required by the pneumatophore, and instead relied totally on the regeneration of exhaled air through a chemical process involving peroxides. The smaller version of the pneumatogen was designed as a 'self-rescuer' for use by trapped miners, whilst the larger was more suitable for rescue workers.<sup>28</sup> An even more radical departure from the Fleuss design was the liquid air apparatus or Aerolith, designed in Austria by O. Suess. The liquid air apparatus was simpler to operate and had fewer parts. Unlike compressed oxygen, however, liquid air could not be stored and soon evaporated. A bulky liquid air producing plant and fragile Dewar vacuum storage flasks had to be purchased in conjunction with the Aerolith.<sup>29</sup>

New British models began to appear in the early 1900s. The Proto, introduced in 1906, and manufactured by Siebe, Gorman, was the fruit of the Davis-Fleuss partnership. It was similar in principle to the Fleuss apparatus and the foreign

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(1905-06), 'Rescue-apparatus and the experiences gained therewith at the Courrières collieries by the German rescue-party', *Transactions of the Institution of Mining Engineers*, vol. 31, pp. 574-581.

<sup>28</sup> Richard Cremer (1897-98), 'The Walcher pneumatophore, and the employment of oxygen for life-saving purposes', *Transactions of the Federated Institution of Mining Engineers*, Vol. 14, pp. 595-585; Meyer, 'Rescue-apparatus and the experiences gained therewith at the Courrières collieries [for the Shamrock]', pp. 581-601; Richard Cremer (1906-07), 'The pneumatogen: the self-generating rescue-apparatus, compared with other types', *Transactions of the Institution of Mining Engineers*, Vol. 32, pp. 51-71.

<sup>29</sup> Hermann Grahn (1906-07), 'Discussion - Liquid air and its use in rescue apparatus' *Transactions of the Institution of Mining Engineers*, Vol. 32, p. 542-543. An alarming feature to our ears of the liquid air system was its use of asbestos. The liquid air container carried on the wearer's back was 'filled with asbestos fibre which absorbs the liquid air as it is poured in and prevents it from running into the [breathing] tubes in liquid form.' E.C. Elliston, 'The "Rotherham" rescue apparatus', *Colliery Guardian*, 11 August 1922, p. 329.

pneumatophores, which had gained a toehold in British mines. The Meco (1906), produced by the Mining Engineering Company, Sheffield, was almost identical to the Shamrock. All of these models introduced compressed oxygen into the circuit at a constant rate.<sup>30</sup> In the Weg (1906) apparatus designed by William Edward Garforth, however, the supply of compressed oxygen varied automatically to meet the wearer's requirements.<sup>31</sup> Henry Simonis & Co. of London, a firm widely known for fire-fighting equipment, introduced the Aerolith liquid air system to Britain.<sup>32</sup> The original Aerolith was dangerous because it did not supply enough air to keep the wearer safe. An improved and safer liquid air breathing apparatus, known as the Aerophor (1910), was developed by mining engineers associated with the Elswick mine rescue station at Newcastle-upon-Tyne. The Aerophor incorporated a purifier to regenerate exhaled air, and was manufactured by Henry Simonis.<sup>33</sup> The Society of Arts invited makers to submit their breathing apparatus to a competition. Gold medals were awarded in 1911 to Siebe, Gorman and Garforth and silver to Draeger and Meco.<sup>34</sup>

By 1916, there were 913 Proto sets in use in Britain, together with 455 Meco, 220 Draeger, 132 Weg, and 96 Aerophor.<sup>35</sup> After the First World War, the Proto extended its market leadership, helped no doubt by its exclusive adoption by the British Army for rescue work in tunnels under the Western Front.<sup>36</sup> Updated versions of the Aerophor, however, continued to have advocates at some stations and remained in service after nationalization.<sup>37</sup> If in good working order, and worn by

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<sup>30</sup> Department of Scientific and Industrial Research Advisory Council (1918), *First Report of the Mine Rescue Apparatus Research Committee*, London: DSIR, pp. 7-10.

<sup>31</sup> W. E. Garforth (1905-06), 'A new apparatus for rescue-work in mines', *Transactions of the Institution of Mining Engineers*, Vol. 31, pp. 625-654.

<sup>32</sup> Otto Simonis (1906-07), 'Liquid air and its use in rescue apparatus', *Transactions of the Institution of Mining Engineers*, Vol. 32, pp. 534-538.

<sup>33</sup> H. F. Bulman and Frederick P. Mills (1921), *Mine Rescue Work and Organization*, London: Crosby, Lockwood & Son, pp. 54-59, 90-101.

<sup>34</sup> 'Life-saving apparatus for use in noxious atmospheres', *The Engineer*, Vol. 111, 23 June 1911, pp. 651-652.

<sup>35</sup> DSIR Advisory Council, *First Report of the Mine Rescue Apparatus Research Committee*, p. 7.

<sup>36</sup> Lt. Col. D. Dale Logan (1918-1919), 'The difficulties and dangers of mine-rescue work on the Western Front; and mining operations carried out by men wearing rescue-apparatus', *Transactions of the Institution of Mining Engineers*, Vol. 57, pp. 197-222. By the 1950s, the Proto was 'undoubtedly the most popular breathing apparatus used in British mines, and ... in common use in Africa, Australia, New Zealand, Canada, and India.' R. McAdam and D Davidson (1955), *Mine Rescue Work*, Edinburgh: Oliver & Boyd, p. 6.

<sup>37</sup> McAdam and Davidson, *Mine Rescue Work*, pp. 35-47.

healthy and well-trained personnel, breathing apparatus could sustain life in irrespirable conditions for between 90 minutes to two hours. The dangers included defects or damage to the headgear, tubes, and breathing bags, resulting in the leakage of oxygen or the inflow of poisonous gas, not to mention the wearer's exhaustion, perhaps hastened by overheating caused by chemical reactions, or blind panic.<sup>38</sup>

#### 4. The ingredients

The milieu in which mine rescue breathing apparatus evolved was complex. It was not simply a matter of commercial firms bringing models to the market to be accepted or rejected by customers. Mining engineers, rescue station personnel, academics, and latterly government officials were involved in the evaluation of existing models; they also contributed, sometime decisively, to the development of improved ones. They cooperated as well as competed.

The main commercial suppliers have already been introduced. Siebe, Gorman was Britain's leading designer and manufacturer of diving suits and equipment and supplied the Royal Navy. Siebe, Gorman worked with Fleuss to develop improved mine rescue apparatus. Marked similarities in the technological characteristics of breathing apparatus used by divers, mine rescuers, and fire-fighters offered the company economies of scope. Siebe, Gorman was a London firm selling a market leading high-technology product to firms in Britain's industrial heartlands.<sup>39</sup> Marketing was another strong point of Siebe, Gorman, which distributed a glossy brochure (c. 1915) of testimonials from satisfied users of the Proto as far afield as Illinois and New Zealand.<sup>40</sup> Henry Simonis & Co., the London-based maker of fire engines, and Meco, the Sheffield-based manufacturer of mining equipment, were to some extent dabbling in mine rescue apparatus, and lacked the expertise and staying-power of

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<sup>38</sup> Good teeth were required to grip the mouthpieces used in most models, a factor that excluded many miners from rescue work.

<sup>39</sup> Foregger, 'Development of mine rescue and underwater breathing apparatus'; Richard Compton-Hall, 'Davis, Sir Robert Henry (1870–1965)', *Oxford Dictionary of National Biography*, Oxford: Oxford University Press, 2004 [<http://www.oxforddnb.com/view/article/56874> accessed 10 Oct 2017]

<sup>40</sup> Mining Institute Archives, Siebe, Gorman (undated 1915?), *Rescue and Recovery: Bulletin of a Few Cases where the "Proto" (Patent) Breathing Apparatus has been Used*, London: Siebe, Gorman.

Siebe, Gorman.<sup>41</sup> The Lubeck firm of Draeger was a specialist in technology that used compressed oxygen and other gases,<sup>42</sup> including equipment for hospitals. Draeger was a strong competitor in the market for mine rescue apparatus until the First World War, when supplies became hard to obtain. Richard Jacobson of London represented the German company in Britain.<sup>43</sup>

Associations of mining engineers based in the regions, but federated nationally, occupied an important position in the coal industry. By 1914 there were 1.2 mining engineers per British coal mine.<sup>44</sup> Although by no means every coal mine director, agent (the owners' representative), manager or undermanager was a mining engineer, the profession was becoming ubiquitous. The best mining engineers were interested in technological progress as well as in commercial success. Moreover, the founding documents of their profession committed them to the quest for safer working methods. For example, the North of England Institute of Mining Engineers, established in 1852, undertook to meet regularly to 'discuss the means for ventilation of coal mines for the prevention of accidents and for general purposes connected with the winning and working of collieries.'<sup>45</sup> Mining engineers could keep abreast of developments by attending meetings of their regional Mining Institution, or by reading the *Transactions of the Institution of Mining Engineers*. The *Transactions* contained scientific papers - some of them lengthy - delivered at meetings of the profession by leading practitioners and academics from university mining departments and colleges. In addition, the *Transactions* reproduced the discussions that followed. During the fifteen or so years leading up to the First World War, the *Transactions* showed great interest in the causes of explosions, accident prevention, the design and testing of breathing apparatus, the organisation of rescue stations, and the conduct of rescue operations. Readers would have become familiar with the advantages and disadvantages of the Proto, the Draeger, the Meco, the Aerophor,

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<sup>41</sup> A summary of Meco's catalogue in 1910 mentioned rescue apparatus last, after an 'automatic rope greaser, a guide greaser, an electric rotary drill, a percussive coal cutting machine, automatic feed apparatus for drills, [and] a hand drilling machine'. *The Engineer*, 13 May 1910, p. 502.

<sup>42</sup> Dräger (undated 2010?), *The History of Dräger*, Lubeck: Dräger [http://legacy.draeger.com/ebooks/index\_ebook\_history\_en.html#/0 accessed 10 Oct 2017].

<sup>43</sup> *The Engineer*, 13 May 1910, p. 502.

<sup>44</sup> Roy Church with the assistance of Alan Hall and John Kanefsky (1986), *The History of the British Coal Industry*, Vol. 3, Oxford: Clarendon Press, p. 429.

<sup>45</sup> George R. Strong (1988), *A History of the Institution of Mining Engineers 1889-1989*, Doncaster: Institution of Mining Engineers, p. 108.

and the Weg. These were absorbing and perhaps exciting topics for engineers. Occasionally, they were accused of showing too much enthusiasm for the latest kit. At the first AGM of the South Midland Coal Owners' rescue station at Ashby de la Zouch in 1913, John Roberts 'objected to so many engineers being on the Committee, in his opinion it is necessary to take some commercial men on.' Roberts added that his firm would be keeping a close eye on how costs were allocated between member collieries.<sup>46</sup>

William Edward Garforth, a significant figure in the coal industry, was an enthusiastic supporter of breathing apparatus. As well as developing the Weg, he investigated the causes of explosions and experimented with stone dusting as a preventative. The son of an ironworks and colliery owner from Manchester, Garforth trained as a mining engineer, and was appointed agent of Pope & Pearson's collieries near Normanton in Yorkshire in 1879. He became managing director and chairman of the company, and served as president of the employers' group, the Mining Association of Great Britain (MAGB) in 1907 and 1908, and as president of the IME between 1911 and 1914. He was knighted in 1914.<sup>47</sup> Deeply affected by the explosion at Pope & Pearson's Altofts colliery in 1886, which claimed 22 lives, Garforth became interested in the scientific and organizational aspects of mine safety. He published an influential set of guidelines for use by managers after an explosion, established a private rescue station at Altofts, and built experimental facilities for studying explosions. In collaboration with the MAGB and the government, Garforth and his assistants demonstrated that the best safeguard against the ignition of coal dust was to coat it with finely ground stone dust.<sup>48</sup> Garforth invented and commercialised coal cutting machinery, owning the Diamond Coal Cutter works at Wakefield. Patents were also taken out for the Weg breathing apparatus, and over 100 units sold. However, whereas Garforth the inventor of coal cutting machinery sought a profit, Garforth the inventor of breathing apparatus was guided by more altruistic motives. Although he declined to give away the key 'lung-governing valve'

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<sup>46</sup> Leicestershire Record Office, DE1177/15, Minute Book of the Leicestershire and South Derbyshire Mine Rescue and Fire Station, 11 March 1913.

<sup>47</sup> W.D. Lloyd (1921-1922), 'Memoir of the Late Sir William Garforth', *Transactions of the Institution of Mining Engineers*, Vol. 62, pp. 202-2015.

<sup>48</sup> W.E. Garforth (1897-1898), 'Suggested rules for the recovery of coal-mines after explosions', *Transactions of the Institution of Mining Engineers*, Vol. 14, pp. 495-533; W.E. Garforth (1912-1913), 'A record of the origin of the principle of stone-dusting for the prevention of explosions', *Transactions of the Institution of Mining Engineers*, Vol. 45, pp. 562-575.

at the heart of the Weg, he invited colleagues in the IME to adopt any other elements of the apparatus that appealed to them. Garforth added that 'everything associated with the saving of life should be as free to use as the air that we breathe', and encouraged IME members to exercise 'their best skill and ingenuity to perfect' the new type of apparatus.<sup>49</sup> The Weg inspired later generations of breathing apparatus, especially in the USA and Germany, but its potential was not exploited within Britain until the 1950s, either by Garforth or by others.<sup>50</sup> At the close of the First World War, Garforth called for a competition to find the best type of rescue apparatus. He felt that all parties should cooperate to develop a standard 'British' apparatus. Rapid progress would be made when 'it becomes known that there is nothing to be patented, but that everything is to be done for the benefit of the miners'.<sup>51</sup> But no collective 'British' apparatus was forthcoming.

Rescue stations were prominent in the refinement of breathing apparatus. In a later section we examine the work of the Rotherham rescue station. Here, however, we focus on the Durham and Northumberland Collieries Fire and Rescue Brigade (DNCFRB) and two of its leading lights, William Cuthbert Blackett and Frederick P. Mills. The DNCFRB opened four rescue stations. The principal one at Elswick, near Newcastle, worked closely with the fire brigade of the neighbouring Armstrong Whitworth shipbuilding and armaments complex.<sup>52</sup> Despite at one time expressing doubts about the practicality of breathing apparatus, Blackett was appointed chairman of the management committee of the DNCFRB. A mining engineer, Blackett had studied at Durham College of Physical Science (now Newcastle University). He was managing director of Charlaw and Sacriston Collieries near Durham, and would be president of the IME in 1919 and 1920. The Blackett conveyor, introduced in the early 1900s, was still in service in the 1930s.<sup>53</sup> Blackett also collaborated with Garforth and G.W. Bousfield on an improved conveyor.<sup>54</sup>

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<sup>49</sup> Garforth, 'A new apparatus', pp. 653-654.

<sup>50</sup> McAdam and Davidson, *Mine Rescue Work*, p. 21.

<sup>51</sup> W.E. Garforth (1918-1919), in 'Discussion - Accidents due to defects of apparatus', *Transactions of the Institution of Mining Engineers*, Vol. 57, p. 246.

<sup>52</sup> W.C. Blackett (1910-1911), 'The Fire- and Rescue-Station of the Durham and Northumberland Collieries Fire- and Rescue-Brigade', *Transactions of the Institution of Mining Engineers*, Vol. 41, pp. 253-271.

<sup>53</sup> R.S. Tate (1934-1935), 'Memoir of the late Colonel William Cuthbert Blackett', *Transactions of the Institution of Mining Engineers*, Vol. 89, pp. 339-341.

<sup>54</sup> Espacenet patent database: GB190723582 (A) 1908-08-27.

Patents were published in Blckett's own name (not that of the DNCFRB) for the Aerophor, or improved liquid air apparatus, in 1911.<sup>55</sup> In 1913 Frederick P. Mills, an alumnus of Wigan Mining College, and former general manager of Pearson & Knowles Coal & Iron of Wigan, was appointed chief officer of the DNCFRB. Together with G. L. Brown of the North Midland Coal Owners' Rescue Stations (NMCORS) at Mansfield, he worked on further refinements to the liquid air apparatus. Patents relating to the Brown Mills Aerophor were published in 1922, the applicants being Brown, Mills, the DNCFRB and the NMCORS. The apparatus was manufactured by Guest and Chrimes of Rotherham.<sup>56</sup> In the early twentieth century there existed a community of practitioners in the mining engineering community dedicated to improving rescue apparatus, sometimes but not always in collaboration with external firms such as Simonis.

Foremost amongst the academics interested in explosions and rescue apparatus was John Scott Haldane, Britain's leading expert on physiology and respiration and a Fellow of New College at the University of Oxford. Haldane had been investigating the effects of poisonous gases on coal miners since the late nineteenth century. He was active in the IME, holding the presidency between 1924 and 1927, a mark of the respect in which he was held by practical men. Although Haldane did not invent breathing apparatus for mine rescue (he did, however, devise a primitive military gas mask in 1915), he commented extensively as a physiologist on the merits and demerits of the apparatus available, on behalf of the government, the IME, and mine owners. In 1912, whilst still on the staff at Oxford, he was appointed director of the Doncaster Coal Owners' Research Laboratory, where he oversaw the investigation of a range of problems including spontaneous combustion, coal dust inhalation, and the defects of breathing apparatus.<sup>57</sup> There can be no

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<sup>55</sup> Espacenet patent database: GB191017589 (A) 1911-02-09 and GB191122507 (A) 1911-12-14.

<sup>56</sup> Espacenet patent database: GB179094 (A) 1922-05-04; GB179126 (A) 1922-04-12; GB188612 (A) 1922-11-16; GB188677 (A) 1922-11-23; McAdam and Davidson, *Mine Rescue Work*, p. 37.

<sup>57</sup> For a popular biography see Martin Goodman (2007), *Suffer and survive: gas attacks, miners' canaries, spacesuits and the bends: the extreme life of J.S. Haldane*, London: Pocket. For his contribution to the work of the Institution see J. Ivon Graham (1935-1936), 'Memoir of the late John Scott Haldane', *Transactions of the Institution of Mining Engineers*, Vol. 91, pp. 417-420. Haldane may have been one of Britain's top scientists, but he did make one catastrophic error, insisting until the 1930s that inhaling coal dust did no harm to miners' lungs and may even have made them healthier. On this see M.W. Bufton and J.M. Melling (2005), "Coming up for air": experts, employees and workers in campaigns to compensate silicosis sufferers in Britain 1918-1939', *Social History of Medicine*, Vol. 18, No. 1, pp. 63-86.

doubt that Haldane influenced the development of breathing apparatus along safer lines.

Henry Briggs, a lecturer at Heriot Watt College, and subsequently professor at the University of Edinburgh, also contributed to the refinement of rescue apparatus. Briggs was an academic entrepreneur who sought to involve the government in the quest for better rescue apparatus. He also proposed a system of official inspection and authorization. Heriot Watt's Department of Mining trained colliery managers; the college also cooperated with local collieries and the Carnegie Trustees to establish the Heriot Watt mine rescue station in 1915-16.<sup>58</sup> The principal, A.P. Laurie, contacted the Privy Council Commission on Scientific and Industrial Research (PCCSIR) in July 1916 to express an interest in working with the government on the improvement of rescue apparatus.<sup>59</sup> Briggs had in mind the development of an 'apparatus which would combine ...the more useful features of [the five or six] existing types, with the final object of evolving a design which could be officially recommended'.<sup>60</sup> The Commission appears to have regarded this approach sceptically. Garforth, hearing of Briggs's plans, made a small donation.<sup>61</sup> A tragedy in South Wales turned the tide in Briggs's favour. In March 1917 three rescuers were asphyxiated during a training session at Duchy Colliery, deaths attributed to faults in their Draeger sets.<sup>62</sup> With some urgency, the Home Office now demanded work along the lines suggested by Briggs. The committee supervising this research would also consider the question of enforced standardization.<sup>63</sup> Funded by the Department of Scientific and Industrial Research (DSIR), the project was based at Heriot Watt, assisted by the Doncaster Coal Owners' Research Laboratory. An official Mine Rescue Apparatus Research Committee (MRARC) was established to oversee the

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<sup>58</sup> Part of a training session at the Heriot Watt rescue station in 1938 may be viewed at <http://movingimage.nls.uk/film/1862> [accessed 13 November 2017]. The University of Birmingham also operated a mine rescue station.

<sup>59</sup> TNA, DSIR3/234, A. P. Laurie to the Secretary, Privy Council Commission for Scientific & Industrial Research, 12 July 1916.

<sup>60</sup> TNA, DSIR3/234, Henry Briggs to the Secretary, Privy Council Commission for Scientific & Industrial Research, 18 July 1916.

<sup>61</sup> TNA, DSIR3/234, Notes on Heriot Watt proposal, 8 December 1916.

<sup>62</sup> DSIR Advisory Council, *First Report of the Mine Rescue Apparatus Research Committee*, pp. 22-23.

<sup>63</sup> TNA, DSIR3/234, Memorandum on a Proposal from the Home Office to Establish a Research Committee to Investigate the Best Form of Mine Rescue Apparatus, 23 May 1917; Minutes of Advisory Committee of the Department of Scientific and Industrial Research, 23 May 1917.

research and report on progress. The members were William Walker, acting Chief Inspector of Mines, Haldane and Briggs.<sup>64</sup>

Until the First World War, the government had chivvied and then required the coal industry to invest in mine rescue stations and breathing apparatus, but it had not funded research or attempted to impose a particular type of apparatus. The MRARC foreshadowed a more interventionist approach to mine rescue. Three reports were published by the committee. Existing breathing apparatus was evaluated and improvements recommended and explained in detail. The MRARC's second report concluded that enforced uniformity in matter of breathing apparatus would unduly constrain future research. However, the committee believed that the government should test each type of apparatus before approving it for use underground.<sup>65</sup> Briggs's team also developed a new design of compressed oxygen breathing apparatus, incorporating several improvements including an improved purifier.<sup>66</sup> The Briggs apparatus would later be manufactured by Meco. Although the Briggs-Meco (subsequently the Briggs-Siebe) was a serviceable device, it failed to break the stranglehold of the Proto.

The MRARC's proposal for the official testing of breathing apparatus was accepted by the government, and a new regulation was announced in 1920: 'No Breathing Apparatus shall be used except such as is approved by the Secretary of State [for Mines].'<sup>67</sup> Several types of apparatus were approved, providing rescue stations with as much choice as before the war.

## **5. Collective innovation: mixing ideas in the *Transactions***

The IME and *Transactions* provided a forum for the exchange of ideas about the types of breathing apparatus on offer and their merits and demerits. Although this forum was largely British, foreign equipment was also assessed, while overseas experts were invited to contribute articles and spoke at meetings.

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<sup>64</sup> TNA, DSIR3/234, Communication to be Made to the Press, 11 July 1917.

<sup>65</sup> DSIR Advisory Council (1920), *Second Report of the Mine Rescue Apparatus Research Committee*, London: HMSO, p. 5.

<sup>66</sup> In one of the tests of the Briggs apparatus the intrepid wearer clambered up Arthur's Seat in Edinburgh. DSIR Advisory Council, *Second Report of the Mine Rescue Apparatus Research Committee*, pp. 41-53.

<sup>67</sup> Bulman and Mills, *Mine Rescue Work and Organization*, pp. 51-52.

The years 1905-07 saw the publication of several detailed examinations of breathing apparatus in *Transactions*. G.A. Meyer of Shamrock colliery in Germany supplied a paper on the history of breathing apparatus, and the work of Westphalian rescue teams at the Courrières colliery disaster, where 1100 French miners died in 1906. Some German teams had worn the Shamrock apparatus, designed by Meyer himself.<sup>68</sup> In the ensuing discussion, Meyer was warmly welcomed as Germany's premier expert on rescue apparatus. The debate was lively. Haldane stressed that Meyer's latest model incorporated several new safety features. But A.M. Henshaw, a mining engineer from Stoke on Trent, argued that the Shamrock was too complicated for many users. Scepticism was expressed over the claim that the Shamrock could be worn safely for two hours. H.E. Gregory of Cortonwood colliery mentioned problems with an earlier version of the Shamrock, and criticized other models (including the Draeger) that had a helmet rather than a mouthpiece - the helmet caused discomfort and possibly danger.<sup>69</sup> The discussion brought together practitioners (mining engineers and managers), a leading British scientist (Haldane), a representative of the Mines Inspectorate, and a respected foreign designer (Meyer). Anyone with access to *Transactions* would have gained from studying the article and debate.

Shortly afterwards, the characteristics of the Weg and the Aerolith were explained in articles by Garforth and Simonis respectively.<sup>70</sup> R. Cremer, a Leeds-based mining engineer, published a paper comparing five types of breathing apparatus made on the continent. He included a table comparing them in relation to twelve criteria, from the length of time they could be worn safely to purchase and running costs.<sup>71</sup> Garforth's new apparatus provoked energetic debate. Members of the IME attended a demonstration of the Weg at Altofts rescue station. Although some were impressed, W.C. Blackett called into question the value of 'so-called rescue-appliances', and said he could not remember a single occasion when he

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<sup>68</sup> Meyer, 'Rescue-apparatus and the experiences gained therewith at the Courrières collieries', pp. 575-613. On Courrières see Robert G. Neville (1978), 'The Courrières colliery disaster, 1906', *Journal of Contemporary History*, Vol. 13, pp. 33-52.

<sup>69</sup> John Gerrard et al (1905-1906) 'Discussion - Rescue-apparatus and the experiences gained therewith at the Courrières collieries', *Transactions of the Institution of Mining Engineers*, Vol. 31, pp. 614-624.

<sup>70</sup> Garforth, 'A new apparatus for rescue-work in mines'; Simonis, 'Liquid air and its use in rescue apparatus'.

<sup>71</sup> Cremer, 'The pneumatogen: compared with other types', pp. 68-69.

would have felt safer wearing one. Blackett wondered whether rescuers could be kept at a sufficiently high pitch of training to be able to wear and operate complicated apparatus without putting their own lives at risk.<sup>72</sup> Interestingly, Blackett later changed his mind, developing the Aerophor, and becoming the lynchpin of the DNCFRB. Ideas circulated within the mining engineering community and beyond, even converting some sceptics.

The most searching evaluation in *Transactions* of existing types of breathing apparatus was provided by Haldane in two articles in 1914. In his capacity as director of the Doncaster Coal Owners' Research Laboratory, Haldane was tasked to recommend a type of apparatus for use at the Doncaster rescue station. By 1914 the number of rescue stations was expanding rapidly in order to comply with legislation, and Haldane's verdict was important. He and his staff subjected each model to extensive testing. The articles regurgitated Haldane's reports to the Doncaster employers, who were content for his findings to be circulated. Haldane discovered serious and potentially dangerous defects in each model. For example, the Proto was prone to overheat and the oxygen supply was painful to inhale. The Weg leaked both inwards and outwards and required an expert operator. Leaks occurred through the helmets of the Draeger and the Meco. Carbon dioxide was liable to build up in the Draeger and the Aerophor because of poor design. In Haldane's opinion, the Aerophor was experimental and unsuitable for adoption.<sup>73</sup> The second article noted recent improvements in several types, including the Aerophor, but concluded that the Proto, notwithstanding some deficiencies, was the best available.<sup>74</sup>

Haldane's articles generated a sometimes ill-tempered debate amongst mining engineers. After dismissing Haldane as an academic, Jonathan Piggford of Teversall colliery accused him of unwarranted bias against the Aerophor. Piggford launched into a point by point defence of the liquid air apparatus, an early version of

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<sup>72</sup> W.C. Blackett (1906-1907), 'Discussion - A new apparatus for rescue-work in mines', *Transactions of the Institution of Mining Engineers*, Vol. 31, p. 180. A later paper by a scientist with a doctorate from Heidelberg was even more brutal, describing breathing apparatus as 'absurd walking "fitters' shops"'. John Harger (1911-1912), 'The prevention of explosions in mines', *Transactions of the Institution of Mining Engineers*, Vol. 43, p. 139.

<sup>73</sup> John S. Haldane (1913-1914), 'Self-contained rescue-apparatus for use in irrespirable atmospheres: report to the Doncaster Coal-Owners' (Gob-Fire Research) Committee', *Transactions of the Institution of Mining Engineers*, Vol. 47, pp. 725-776.

<sup>74</sup> John S. Haldane (1914-1915), 'Self-contained rescue-apparatus and smoke-helmets: second report to the Doncaster Coal-Owners' (Gob-Fire Research) Committee', *Transactions of the Institution of Mining Engineers*, Vol. 48, pp. 550-585.

which was in service at his local rescue station at Mansfield.<sup>75</sup> Garforth censured Piggford's outburst, stating that Haldane's first report 'had done more good than anything else' in recent years, and the 'criticism that he had offered on the various types of apparatus in a most scientific way had been taken advantage of by the makers' to improve their equipment. Garforth added that although the Weg had cost over £1000 to develop, he would share it with anyone in the interests of saving lives.<sup>76</sup>

An active community of experts keen to debate the advantages and disadvantages of different types of breathing apparatus was fostered and sustained by the IME, not least in the pages of the *Transactions*. Conflicting viewpoints on technical matters were aired in detail; the mining engineering profession was highly argumentative. Informed debate fed back into the work of the designers of apparatus, whether professional or amateur. Collective invention and open source invention flourished in this environment, albeit within the constraints imposed by self-interest.

## **6. User innovation: the Rotherham model**

User innovation and tinkering were in evidence at the Rotherham rescue station, opened in 1914. Before selecting a type of apparatus, representatives of the Rotherham and district employers visited other rescue stations to evaluate their equipment and methods. They were thorough, visiting Elswick (Aerophor), Howe Bridge (Proto), Mansfield (Meco), Altofts (Weg) and Wath (Draeger).<sup>77</sup> Consideration was also given to the possible development of a hybrid apparatus, taking the best features of several types.<sup>78</sup> In September 1913, the suppliers of the Draeger, Proto, Meco, and Aerophor were invited to Rotherham, and their apparatus put through a rigorous series of tests and practice exercises in a special gallery designed to replicate underground conditions. Although the Aerophor was given to the least experienced rescue man, he experienced the least discomfort and distress. It was

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<sup>75</sup> Jonathan Piggford et al (1914-1915), 'Discussion - Self-contained rescue-apparatus and smoke-helmets', *Transactions of the Institution of Mining Engineers*, Vol. 48, p. 585.

<sup>76</sup> *Ibid*, p. 590.

<sup>77</sup> Rotherham Archives and Local Studies (RALS), 185/B/9/1/1, Rotherham and District Rescue Station, Minutes of Meeting, 4 November 1912; Notes on a visit to the Northumberland and Durham Rescue Station at Elswick, Newcastle upon Tyne, 29 May 1912; Visit to Howe Bridge Station, Lancashire, 12 June 1912; Visit to Mansfield Station, 19 June 1912; Notes of a Visit to Wath Rescue Station, 2 October 2 1912; Visit to the Altofts Station to Inspect the "W.E.G." Apparatus, 26 June 1912.

<sup>78</sup> RALS, 185/B/9/1/1, Minutes of Breathing Apparatus Committee, 14 August 1913.

resolved to adopt the Aerophor (liquid air system) as the main type of breathing apparatus for the Rotherham station, with some Mecos sets for back up. The liquid air system had a higher initial cost than the compressed oxygen system, because expensive plant for generating the liquid air had to be installed at the station; on the other hand, running costs were lower with liquid air. The report on the trials stated that cost was not a consideration, and that the best system would likely prove the cheapest in the long run.<sup>79</sup>

An order for Aerophor sets and liquid air plant was placed with the Simonis organization. After the release of Haldane's damning report on the liquid air system for the Doncaster employers, the Rotherham employers, now desperate for reassurance, approached the scientist for advice. He recommended several modifications to the Aerophor, and Simonis agreed to make them.<sup>80</sup> When the first Aerophor sets arrived at Rotherham in 1914, they were found to have faults, and the station had them fixed by local firms.<sup>81</sup> Relations with Simonis became increasingly edgy over costs, delays, and poor quality. During 1915, significant improvements were made in Rotherham to the design of the Aerophor. Simonis undertook to make the remaining sets to the 'Rotherham' design, but new defects were discovered when they were delivered in 1916. Rotherham now decided to drop Simonis, and make any further refinements to the liquid air sets locally.<sup>82</sup> Sergeant Major Elliston, the chief instructor at the rescue station, played a key part in the development of the Rotherham type of apparatus. This was a classic case of tinkering. Elliston had no prior experience of mine rescue work, having been a drill, musketry and engineering instructor in the Royal Engineers.<sup>83</sup> The improvements to the Aerophor were sufficiently extensive for the Rotherham device to be regarded as a distinct model, and it was the first type of liquid air apparatus to be approved for use by the Mines Department after 1920.<sup>84</sup>

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<sup>79</sup> RLAS, 185/B/9/1/1, Record of Demonstrations with Various Apparatus at the New Rescue Station, 3 September 1913.

<sup>80</sup> RLAS, RLAS, 185/B/9/1/2, Minutes of General Meeting, 31 March 1914.

<sup>81</sup> RLAS, RLAS, 185/B/9/1/2, Minutes of General Meeting, 14 October 1914.

<sup>82</sup> RLAS, RLAS, 185/B/9/1/2, Minutes of General Meeting, 11 June 1915; Aerophor, 1 October 1915; Minutes of Breathing Apparatus Committee, 29 September 1915; Minutes of General Meeting, 14 October 1915; Secretary's Report for year ending 30 June 1916.

<sup>83</sup> RLAS, 185/B/9/1/1, Minutes of General Meeting of the Board, 2 December 1913; 185/B/9/1/2, Note on Miscellaneous Matters, 17 September 1918.

<sup>84</sup> Elliston, 'The "Rotherham" rescue apparatus', pp. 329-330.



FIGS. 1 AND 2.—FRONT AND BACK VIEWS OF APPARATUS.

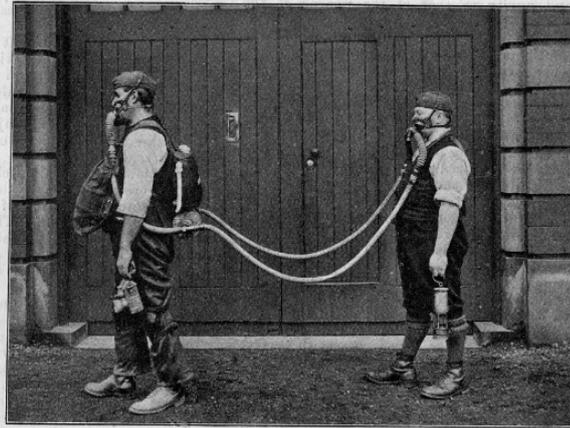


FIG. 4.—APPARATUS EQUIPPED WITH EMERGENCY FITTING.

**Fig 2.** The Rotherham liquid air apparatus. Source: E.C. Elliston, 'The "Rotherham" rescue apparatus', *Colliery Guardian*, 11 August 1922, p. 329.

In the early 1920s, the Mines Department required further modifications to all types of breathing apparatus. The changes made to the Rotherham model included a better purifier and a protector for the breathing bag. Irritation was expressed that other stations were copying these improvements without acknowledgement, and it was decided to seek patent protection.<sup>85</sup> In order to defray the cost of modifications and patents, other liquid air stations (including Mansfield, Elswick and Brierley) were invited to re-equip with the Rotherham apparatus, but they declined to do so.<sup>86</sup> Nevertheless, the Rotherham employers were satisfied that they had the best apparatus, and believed that the station's rescue workers were in agreement.<sup>87</sup> The Rotherham model was battle tested at the Maltby disaster in 1923, although no lives could be saved because of heavy falls and fears of more explosions; the apparatus was also used in the salvage and restoration operations, performing creditably.<sup>88</sup>

## Conclusion

Breathing apparatus for mine rescue was developed in several countries in the late nineteenth and early twentieth centuries. In the British case, the players included

<sup>85</sup> RLAS, 185/B/9/1/2, Minutes of General Meeting, 23 March 1922.

<sup>86</sup> RLAS, 185/B/9/1/2, Minutes of General Meeting, 14 June 1922 and 24 August 1922.

<sup>87</sup> RLAS, 185/B/9/1/2, Minutes of General Meeting, 2 March 1923.

<sup>88</sup> Two miners trained as rescuers at the Rotherham station died at Maltby, but they were not involved in the rescue operation. RLAS, 185/B/9/1/2, Minutes of AGM, 11 October 1923; Minutes of General Meeting, 6 March 1924 and 28 May 1924; Mines Department (1924), *Explosion at the Maltby Main Colliery, Yorkshire: Report*, Cmd 2047, London: HMSO.

commercial companies (Siebe, Gorman, Simonis and Meco), public spirited employers and engineers (Garforth and Blakett), academic scientists (Haldane and Briggs), and the staff of mine rescue stations (Mills and Elliston). The Institution of Mining Engineers and its journal, *Transactions*, provided a critical forum for the exchange of information and ideas. Strong elements of collective invention were at play, but it would be an exaggeration to claim that network members enjoyed unfettered access to one another's technology because some improvements were protected by patents. Apparatus users, including the rescue stations at Elswick and Rotherham, made significant improvements to the equipment available on the market. Both Elswick and Rotherham sought to cooperate with Simonis, perhaps more successfully in the former than in the latter case. Breathing apparatus may not have saved many lives in British coal mines in the period examined - its finest hour was not until 1950 - but it did provide a measure of insurance.<sup>89</sup> This case study of mine rescue apparatus offers insights into how advanced technologies were developed in the early twentieth century. The inventive network in operation spanned the worlds of practical mine engineering, commercial research and development, and the academic sphere.



**Fig. 3.** On the catwalk: Durham miner wearing the 'Westphalia' or Shamrock apparatus. Source: Lawrence Austin (1907-1908), 'Demonstration of Rescue-Apparatus, Felling, August 31<sup>st</sup>, 1907', *Transactions of the Institution of Mining Engineers*, vol. 35, plate X.

<sup>89</sup> 116 trapped men were saved by rescuers equipped with Proto apparatus at Knockshinnoch Castle Colliery in 1950. Sir Andrew Bryan (1951), *Accident at Knockshinnoch Castle Colliery, Ayrshire: Report*, Cmd. 8180, London: HMSO.