Chapter 17
Breathing Apparatus for Mine Rescue in the UK, 1890s–1920s

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Abstract Breathing apparatus for use in irrespirable atmospheres in coal mines was developed in Britain and other countries in the late nineteenth and early twentieth centuries. Inspired in some respects by diving gear, the apparatus was used in mine rescue work and operations to recover mines after an explosion. The chapter focuses on the network of mining engineers, academics and businesses involved in the design and improvement of mine rescue apparatus. Although the profit motive was by no means absent, many of those working on breathing apparatus were inclined to share their ideas, particularly through the framework provided by the Institution of Mining Engineers, its regional affiliates and the journal *Transactions of the Institution of Mining Engineers*. Such collaboration was far from unique in the early stages of a technology, as economists and economic historians have shown in work on collective invention, open-source invention and user innovation.

Keywords Mining · Mine rescue · Breathing apparatus · Explosions · Collective invention

17.1 Introduction

Some of John Murray's later work, written in collaboration with Javier Silvestre, focuses on aspects of mine safety in the nineteenth and early twentieth centuries. Their 2015 article on small-scale technologies and declining fatality rates in

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P. Gray et al. (eds.), *Standard of Living*, Studies in Economic History,
https://doi.org/10.1007/978-3-031-06477-7_17

European coal mining between 1850 and 1900 will be of enduring value to researchers (Murray and Silvestre 2015). The objective of the current chapter is to examine the progress of a new safety and rescue technology – breathing apparatus for use in an irrespirable atmosphere underground – with the help of insights from the literature on collective invention and user innovation.

Breathing apparatus was used in mine rescue and related activities in the UK and other European countries from the late nineteenth century onwards. This chapter is a historical case study, grounded in a qualitative analysis of surviving records of mine rescue stations in the local government archives at Rotherham and contemporary articles and discussions in the *Transactions of the Institution of Mining Engineers* (hereafter *Transactions*). Collective invention and user innovation offer valuable lenses through which to observe the process of innovation and adaptation in the field of breathing apparatus.

Whilst not a direct component of the standard of living, mine safety impinged on living standards in several ways. The earning power of injured miners, and those suffering from industrial disease, was affected either temporarily or permanently. Despite the availability of compensation and other forms of relief, the dependants of miners killed at the pit were placed in difficult financial circumstances.[1]

The next section sets out the chapter's conceptual framework, reviewing relevant literature on collective invention and user innovation. Some historical context, especially on fires and explosions in coal mines, is given in the third section. The origins and design of breathing apparatus are discussed in Sect. 17.4. Section 17.5 examines the network working to improve breathing technology. Section 17.6 focuses more narrowly on debate within this community, as facilitated by the Institution of Mining Engineers (IME) and *Transactions*. Section 17.7, which examines the Rotherham and District Rescue Station, shows how breathing apparatus was chosen and adapted at the local level.

17.2 Collective Invention, Open-Source Invention and User Innovation

Collective invention, open-source invention and user innovation are the economic concepts employed in this chapter to make sense of the activities contributing to the improvement of breathing apparatus during the late nineteenth and early twentieth centuries.

According to Allen (1983), inventive activity may be performed by commercial enterprises, individual inventors, non-profit entities such as universities and governments, or networks of practitioners who swap ideas and technical information in a process of collective invention; in practice, several types of entity may be involved. Collective invention requires a mechanism to promote the exchange of technical

[1] For the social impact of the Hulton Colliery disaster in 1910 see Griffiths (2001).

information, perhaps not in full but in enough detail to spur other network members to take the technology further. Collective invention is more likely to occur when technical change is hard to patent or keep secret. Allen investigated the ironworks of Cleveland in England in the nineteenth century, where firms competed to improve performance by increasing the height and temperature of blast furnaces. Little was then known of the science pertaining to blast furnace design, and incremental improvements were the result of trial and error and could not be patented. Blast furnaces, moreover, were too big to hide. Ironmasters boasted of their achievements in the technical press, especially the *Journal of the Iron and Steel Institute*, a practice that encouraged efforts to surpass their achievements. Reverse engineering was relatively easy. Nuvolari (2004) offers support for the collective invention thesis in an article on steam pumping engines in Cornwall. Having been tormented by Watt's patent until 1800, Cornish engineers were disposed thereafter to share technical information. Collective invention was facilitated by a monthly publication, *Lean's Engine Reporter*, founded by mine managers in 1811. This journal recorded the technical specifications, method of operation and fuel efficiency of each new engine. Exchange of engineering information accelerated the development of pumping technology. Research on the Clyde shipbuilding industry in the nineteenth century demonstrates that family and friendship ties, and professional relationships strengthened by membership of the Institution of Engineers and Shipbuilders in Scotland, resulted in the exchange of technical information between apparent competitor firms (Schwerin 2004; Ingram and Lifschitz 2006).

Open-source technology is a term frequently given to technology that is not patented. Meyer (2007, 2013) argues that profits are elusive in the early days of a technology. Personal computing, for example, began as a hobby for tinkerers, and only later became immensely profitable. Meyer is interested in the motivation of inventors when technical success is uncertain and commercial viability a distant prospect. Research and experimentation will continue if inventors have some non-financial goals. Intrinsic motivations include a delight in tinkering and overcoming a challenge, or a desire for fame and honours; extrinsic motivations include a wish to help others by making the world a better or safer place. Where patents are used, this may be less to deter competitors than to advertise a promising technical development. Information brokers, including the authors and publishers of textbooks and bibliographies, perform an important role. Meyer illustrates open-source invention by examining collaboration between inventors working on powered flight before the emergence of a viable technology after 1900.

Unlike Allen's ironmasters, firms in the pottery industry during the Industrial Revolution showed no inclination to share technical information, yet they did not resort to patenting to safeguard their intellectual property. The key technical developments occurred in the mixing and processing of materials. Reverse engineering was virtually impossible, and recipes could be hidden from rivals, so patents were of little value (Lane 2019). Work on the English brewing industry finds that inventors deployed a range of appropriation strategies in relation to intellectual property, including secrecy, openness, patenting and a hybrid approach of selective openness. Information was more likely to be shared if it could neither be hidden nor patented, or if an inventor calculated that being open would enhance their career and reputation (Nuvolari and Sumner 2013). Clearly, much depended on the circumstances, including the industry and the characteristics of its main technologies.

Users are the experts in how equipment performs in practice. The users of a technology often modify and improve it, sometimes in cooperation with the manufacturers, and sometimes sharing their results freely with other users (von Hippel 2006). User innovation was common in the UK textile machinery industry in the mid-nineteenth century, and was also instrumental in the development of equipment for mountain climbing and related activities (Cookson 2018; Parsons and Rose 2009). The tea-shop company, J. Lyons, adapted the scientific computer to make the world's first business computer in 1949 – surely one of the most surprising examples of user innovation (Land 2000). Although user innovation need not involve information sharing and collaboration, it often does, and for the same reasons as those applying to collective invention (Harhoff and Lakhani 2016). Collaboration may involve other users, manufacturers or both. The contribution of users to the development of a technology varies, with some lead-users pushing the technology forward, whereas others confine themselves to adapting it to local conditions (Bogers et al. 2010).

Many of the practices discussed above can be seen in the following account of innovation in breathing apparatus. A network of engineering companies, mining companies, academic consultants and engineering societies worked to develop better breathing apparatus. This network extended beyond the UK to continental Europe, and to Germany in particular. Some inventions were patented, but others were shared freely, and there was a wide exchange of information and opinion through the auspices of the regional constituents of the IME and *Transactions*. Some network members were interested in profit, others in making the mines safer for workers and/or their businesses. Users adapted technologies to resolve defects, and sometimes came up with notable improvements. The development of mine safety breathing apparatus illustrates important aspects of collective invention and user innovation.

17.3 Underground Perils

Murray and Silvestre (2015) show that fatality rates in coal mining in the UK and other European countries were falling in the late nineteenth century. They argue that small-scale technical changes, including the adoption of reliable safety lamps and better ventilation techniques, played an important role in this trend. Tighter regulation may also have contributed to lower fatality rates, although enforcement was patchy, not least because of the underfunding of inspection (Mills 2010). Despite such improvements, however, around 1000 miners died each year in UK coal mines in the early twentieth century.[2] As the Welsh miners' leader and MP, William Brace, explained in the House of Commons in 1913: "Every year, broadly, the number of lives that are destroyed [in the coal mines] are equal to the number of lives which went down with the 'Titanic' when she was wrecked in the Atlantic".[3] Many more were injured, some seriously.

Most deaths at the pit were due to small-scale accidents involving individuals or a handful of men buried by collapsing roofs or roadways or crushed by waggons. The media barely noticed minor accidents, but explosions that took hundreds of lives in a matter of minutes or hours generated widespread public and political concern. Table 17.1 provides a list of the worst mining disasters in the UK in the early decades of the twentieth century.[4]

As well as destructive of life, explosions and fires were costly for the coalowners.[5] Little is known of the magnitude of such costs, but it could take months to restore a devastated colliery to full production and profitability.[6] Compensation had also to be paid to the injured and bereaved under legislation introduced in the 1890s. On the other hand, both coalowners and workmen, many of whom were pieceworkers, were tempted to trade off safety for higher production. Only a few mines exploded, and the probability that disaster would strike on any one shift was negligible. Several innovations designed to increase productivity, such as mechanical coal cutters and electrical power, actually made explosions more likely. Mechanical coal cutters generated more coal dust than hand tools, whilst primitive electrical apparatus often gave off sparks (Jones 2006; Rockley 1938, p. 23).

The best solution to the problem of explosions and fires was prevention. Improved ventilation, safer explosives and greater care during blasting could all lower the risk of disaster. Until after the outbreak of the First World War, however, there was no consensus as to the most effective means of preventing explosions involving coal

Table 17.1 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. Accessed 6 July 2021

[2] This chapter excludes consideration of deaths from industrial diseases contracted in mining.

[3] House of Commons Debates, 2 July 1913, vol. 54, col. 1972.

[4] On Senghenydd see Singleton (2016, pp. 108–123), and on Gresford see Williamson (1999).

[5] The term given to directors and large shareholders of mining companies.

[6] For a description of the recovery of a damaged colliery see Garforth (1909, pp. 52–72).

dust. The ignition of firedamp (methane gas) and/or coal dust could be devastating. Firedamp, which seeped naturally out of coal deposits, was liable to explode upon meeting a naked flame or spark when comprising between 5 and 15 per cent of the air. Thick and highly inflammable coal dust coated most underground surfaces. A firedamp explosion often ignited the coal dust as well, spreading destruction along the roadways for a considerable distance. Most fatalities in explosions were caused not by the initial blast, but rather by the inhalation of afterdamp (carbon monoxide) produced by burning coal dust and wood (Boyns 1986).

Coal dust was implicated in many disasters, and it could be ignited even in the absence of a prior firedamp explosion. Three solutions were proposed: extracting coal dust from the mine, spraying it with water on a regular basis, or spreading inert stone dust in the areas clogged with coal dust to prevent the temperature reaching ignition point. Experimental work on the coal dust problem was conducted in the UK, the USA and other countries. Only after the outbreak of the First World War, however, did a consensus in favour of stone dusting emerge. From 1920 it was compulsory to apply stone dust in most UK coal mines.[7]

Slow progress with prevention stimulated research into the second-best solution of improved rescue facilities and technology. A Royal Commission on Accidents in Mines (1886, p. 8) expressed support for the employment of breathing apparatus in rescue work. The first report of the later Royal Commission on Mines (1907, p. 10) reviewed each type of breathing apparatus then available. Collieries in Austria and Saxony were already required by law to keep breathing apparatus. Some Westphalian mines opted to invest in breathing apparatus despite the absence of compulsion. Although sympathetic in principle to the employment of breathing apparatus, the Royal Commission did not recommend compulsory adoption in the UK in 1907, on the reasonable grounds that the technology was as yet imperfect.

In the opening years of the twentieth century, employers' groups in several districts, with Yorkshire in the forefront, opened or planned to open joint rescue stations to hold breathing apparatus and train miners in its use (Habershon 1900–1901, 1904–1905; Singleton 2020). Pressure for change was accumulating, and in its second report the Royal Commission on Mines (1909, p. 170) warned that legislation to force coalowners to fund a national network of rescue stations equipped with breathing apparatus would be forthcoming unless the industry acted on its own initiative. An explosion that took 137 lives at Wellington Pit in 1910 proved to be the final straw. Located on the isolated Cumberland coast, the stricken pit lacked access to breathing apparatus, and had to send to distant Newcastle and Sheffield for help. Whether or not a faster response would have saved those trapped underground is debatable (Redmayne and Samuel Pope 1911). But the conclusion drawn by the unions, the public and the Mines Inspectorate was that breathing apparatus must now be provided, if not at every mine, then within each district. Embarrassed by the strength of feeling, the government responded with the Mines Accidents (Rescue

[7] Stone dust cooled the coal dust and held it in place (Rockley 1938, pp. 353–355). For an American perspective on explosions and stone dusting see Aldrich (1995).

and Aid) Act, 1910, which was soon reinforced by the Coal Mines Act 1911. Under this legislation the government issued statutory orders to compel coalowners to establish a network of rescue stations equipped with breathing apparatus.

The pace of change now accelerated, and by 1921 there were 49 rescue stations and 1758 sets of breathing apparatus in place on UK coalfields (Mines Department 1922, pp. 132–133). In the event, the cost of constructing, equipping and operating rescue stations was by no means onerous, not least because it was shared by groups of firms in each locality (Singleton 2020).

17.4 Varieties of Breathing Apparatus

Mine rescue breathing apparatus had a long gestation period. John Roberts, a miner from Wigan in Lancashire, 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.[8] In evidence to the Select Committee on Accidents in Mines in 1849, John Hutchinson, a London doctor, suggested that breathing apparatus employed in the Paris sewers, comprising a mask with valves connected to a bag of air kept in a basket on the wearer's back, could be adapted for use in mines (Rescue Regulations Committee 1926, pp. 6–7; House of Lords 1849, pp. 140, 160–162).

The first practical breathing apparatus for rescue and salvage work in mines was invented by Henry Fleuss. Coming from a maritime background, Fleuss devised a primitive self-contained underwater breathing apparatus (scuba) in 1879. This apparatus dispensed with the vulnerable air hose connecting the diver to the surface. Divers now carried a self-contained compressed oxygen supply, and a contrivance to regenerate oxygen from exhaled carbon dioxide. Fleuss obtained patents and began to collaborate with Siebe, Gorman & Co. of London, the premier makers of diving equipment in the UK. Surviving in a poisonous atmosphere underground presented a similar challenge to surviving underwater. A society of mining engineers invited Fleuss to exhibit an apparatus modified for use underground at an event in Chesterfield in 1881 to mark the centenary of George Stephenson's birth. Shortly afterwards, the apparatus was used in work to reopen Seaham Colliery after an explosion, and in rescue work at Killingworth Colliery where some miners were trapped by a falling roof. Siebe, Gorman manufactured and distributed the Fleuss apparatus, but it was expensive and not adopted widely. Nevertheless, the design, including the mechanism for regenerating oxygen with caustic soda, was highly influential. Fleuss and Siebe, Gorman continued to work together to perfect

[8] "Local Intelligence", Manchester Courier and Lancashire General Advertiser, 19 February 1825, p. 3.

improved models of mine rescue apparatus (Foregger 1974; H.M. Inspectors of Mines 1883, pp. 318–319; Jackson 2002).[9]

Two basic types of breathing apparatus were developed: the compressed oxygen system and the liquid air system.[10] Austria and Germany led the way in the 1890s and early 1900s. Walcher (Austrian) and Shamrock, Giersberg and Draeger (all German) breathing apparatus or "pneumatophores" used compressed oxygen cylinders, and a chemical process to "regenerate" exhaled air in a breathing bag strapped to the body. The rescuer wore an airtight helmet or mask. A mouthpiece was connected by tubes to the breathing bag and oxygen cylinder(s). The pneumatophore was similar in principle to the Fleuss machine.[11] The liquid air apparatus or Aerolith, designed in Austria by O. Suess, was a radical departure from the Fleuss design. Liquid air was poured into a pack on the wearer's back as he was about to start work. A tube connected the backpack to the wearer's mouth. Although simpler to operate than compressed oxygen apparatus, the liquid air apparatus had drawbacks. Unlike compressed oxygen, liquid air could not be stored for long. Rescue stations adopting this technology had to invest in an expensive liquid air producing plant and fragile vacuum storage flasks to convey liquid air to the colliery (Cremer et al. 1906–1907).[12]

New British models appeared in the early 1900s. The Proto compressed oxygen apparatus, introduced in 1906, and manufactured by Siebe, Gorman, was the fruit of cooperation with Fleuss. The Meco (1906), made by the Mining Engineering Company, Sheffield, was almost identical to the Shamrock. Both the Proto and the Meco introduced compressed oxygen into the circuit at a constant rate (Department of Scientific and Industrial Research Advisory Council 1918, pp. 7–10). William Garforth's Weg (1906) apparatus was more advanced, with the supply of compressed oxygen adjusting automatically to meet the wearer's requirements (Garforth 1905–1906). Henry Simonis & Co. of London, a firm best known for fire-fighting equipment, introduced the Aerolith system to Britain (Simonis 1906–1907). The original Aerolith suffered from the defect of not supplying the wearer with enough air. An improved and safer liquid air apparatus, known as the Aerophor (1910), was developed by mining engineers associated with the Elswick mine rescue station at Newcastle upon Tyne. The Aerophor, which also incorporated a purifier to

[9] 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 Meyer (1905–1906, pp. 574–581).

[10] For the best overview of these technologies see McAdam and Davidson (1955).

[11] Another device, the pneumatogen (also Austrian), dispensed with the heavy compressed oxygen cylinders, and relied totally on the regeneration of exhaled air through a chemical process involving peroxides. A small pneumatogen was designed as a "self-rescuer" for use by trapped miners. A larger pneumatogen intended for rescue work was not popular in Britain (Cremer 1897–1898, 1906–1907; Meyer 1905–1906, pp. 581–601).

[12] An alarming feature 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" (Elliston 1922, p. 329).

regenerate exhaled air, was manufactured by Simonis. Here, we have an important example of user innovation in mine rescue (Bulman and Mills 1921, pp. 54–59, 90–101).

If properly maintained, and worn by healthy and well-trained personnel, breathing apparatus could sustain life in irrespirable conditions for between 90 minutes and 2 hours. The dangers included defects or damage to the headgear, tubes and breathing bags, resulting in leakage of oxygen or inflow of poisonous gas, not to mention the wearer's exhaustion, perhaps hastened by overheating caused by chemical reactions, and sometimes panic.[13]

The Society of Arts invited designers and makers to enter their breathing apparatus for evaluation in a competition in 1911. Gold medals were awarded to Siebe, Gorman and Garforth and silver medals to Draeger and Meco.[14] By 1916, there were 913 Proto sets in use in the British coal industry, 455 Meco, 220 Draeger, 132 Weg and 96 Aerophor sets (Department of Scientific and Industrial Research Advisory Council 1918, p. 7). The Proto extended its leadership after 1918, with a reputation enhanced by its deployment by the army in rescue work in tunnels under the Western Front (Logan 1918–1919).[15] But updated versions of the Aerophor continued to have advocates, and remained in service at nationalisation in 1947 (McAdam and Davidson 1955, pp. 35–47).

17.5 The Inventive Community

Having surveyed the technology in the previous section, the time has come to introduce the main participants in the network that designed, produced, tested, adapted and used mine rescue breathing apparatus in the UK.

To begin with, there were the commercial suppliers. Siebe, Gorman was strong in both design and manufacturing. It enjoyed economies of scope arising from the similarities between scuba equipment for diving and mine rescue. Siebe, Gorman was a London firm selling a high-technology product to firms in the UK's industrial heartlands (Foregger 1974; Compton-Hall 2004). Marketing was another strong point of the company, and circa 1915 it distributed a glossy brochure of testimonials from satisfied Proto users from as far afield as Illinois and New Zealand (Rice 1927–1928, p. 426).[16] Henry Simonis & Co., a London-based maker of fire engines,

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[13] Good teeth were required to grip the mouthpieces used in most models, a factor that excluded many miners from rescue work.

[14] "Life-saving apparatus for use in noxious atmospheres", The Engineer, Vol. 111, 23 June 1911, pp. 651–52.

[15] As late as 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" (McAdam and Davidson 1955, p. 6).

[16] Mining Institute Archives, Newcastle, Siebe, Gorman, Rescue and recovery: bulletin of a few cases where the "Proto" (patent) breathing apparatus has been used, undated (possibly 1915).

and Meco, a producer of mining equipment in Sheffield, were dabblers in mine rescue breathing apparatus, and lacked the staying-power of Siebe, Gorman.[17] The Lubeck firm of Draeger specialised in technologies that used compressed oxygen and other gases, including advanced medical equipment. Draeger was a strong competitor in the UK market for breathing apparatus until the First World War.[18]

Regional associations or "institutions" (sometimes institutes) of mining engineers, and their national federation the IME, occupied a strategic position in relation to innovation. There were 1.2 mining engineers per British coal mine in 1914 (Church 1986, p. 429). By no means every director, agent (the owners' representative) or manager was a mining engineer, but the profession was forging ahead. Some mining engineers, particularly those who chose to engage in the activities of the institutions, had interests that stretched beyond short term commercial success. They were fascinated by technology, and they were committed by the founding documents of their profession to the quest for safer methods. 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" (Strong 1988, p. 108).

Members kept abreast of developments by attending meetings of their regional mining institution and by reading *Transactions.* This journal contained scientific papers read at institution meetings by practitioners and sometimes by academics. In addition, *Transactions* reported on the discussions that followed the papers. *Transactions* showed great interest in the causes of explosions, the prevention of accidents, the design and testing of breathing apparatus, the organisation of rescue stations, and the conduct of rescue operations. Readers would soon have become familiar with the advantages and disadvantages of the Proto, the Draeger, the Meco, the Aerophor and the Weg. Occasionally, mining engineers were accused of showing too much enthusiasm for the latest kit. At the annual general meeting of the South Midland Coal Owners' Rescue Station in 1913, one member "objected to so many engineers being on the Committee" and felt it was "necessary to take some commercial men on". He added that he was worried about the cost to member firms.[19]

A key individual member of the breathing apparatus network was William Edward Garforth, inventor of the Weg. The son of a Manchester ironworks and colliery owner, Garforth trained as a mining engineer, and was appointed agent of Pope

[17] 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, vol. 109, 13 May 1910, p. 502.

[18] Dräger, The History of Dräger. www.draeger.com/corporate/content/the_history_of_draeger_2.pdf. Accessed 8 July 2021. Richard Jacobson of London represented the German company in Britain, The Engineer, vol. 109, 13 May 1910, p. 502. The Draeger was the first type of breathing apparatus to be used in the USA in 1907 (Rice 1927–1928, p. 426). Both Draeger and Fleuss (Proto) sets were used at the North Butte copper mining disaster in 1917 (Punke 2016, p. 49).

[19] Leicestershire Record Office, DE1177/15, Minute Book of the Leicestershire and South Derbyshire Mine Rescue and Fire Station, 11 March 1913.

and Pearson's collieries in Yorkshire in 1879. He would become managing director and chairman of the company, president of the national employers' group, the Mining Association of Great Britain (MAGB) in 1907 and 1908, and president of the IME between 1911 and 1914 (Lloyd 1921–1922). Deeply affected by an explosion at Pope and Pearson's Altofts colliery, which extinguished 22 lives in 1886, Garforth began to investigate the scientific and organisational aspects of mine safety. He published a set of guidelines for use by managers after an explosion, established the UK's first rescue station at Altofts, and built experimental facilities for studying explosions. In collaboration with the MAGB and the government, Garforth and his team played an important role in confirming the stone dusting theory (Garforth 1909, 1912–1913). Garforth invented a coal cutting machine and owned the Diamond Coal Cutter works at Wakefield. He took out patents in relation to parts of the Weg apparatus and sold over 100 units. Whereas Garforth the inventor of coal-cutting machines sought profits, Garforth the inventor of breathing apparatus was guided seemingly by more altruistic motives. Although he declined to give away the key "lung-governing valve" at the heart of the Weg, he encouraged colleagues in the IME to make their own use of any other elements of the apparatus, for "everything associated with the saving of life should be as free to use as the air that we breathe" (Garforth 1905–1906, p. 653).

Garforth could have made more of the Weg, but seems to have been distracted by other commitments; nevertheless, his design inspired later generations of breathing apparatus, especially in the USA and Germany (McAdam and Davidson 1955, p. 21).[20] At the close of the First World War, Garforth called for a competition to develop a standard "British" model of breathing apparatus. He contended that progress would be rapid when "it becomes known that there is nothing to be patented, but that everything is to be done for the benefit of the miners" (Walker et al. 1918–1919, p. 246). But no standard "British" apparatus emerged to supersede the Proto.

Significant refinements to breathing apparatus were made by the users, the rescue stations and their staff and board members. The work of the Rotherham rescue station is considered in a later section, and the focus here is on the Durham and Northumberland Collieries Fire and Rescue Brigade (DNCFRB) and its leading lights William Cuthbert Blackett and Frederick P. Mills. The DNCFRB's first rescue station at Elswick worked closely with the fire brigade of the neighbouring Armstrong Whitworth shipbuilding and armaments complex (Blackett 1910–1911). Blackett, the chairman of the DNCFRB's management committee, was managing director of Charlaw and Sacriston collieries, and president of the IME in 1919 and 1920 (Tate 1934–1935). Patents for the Aerophor, the improved liquid air apparatus

[20] US mine safety experts and the embryonic Bureau of Mines were interested in the Weg, but disappointed when Garforth failed to develop his device commercially for the overseas market. This prompted the Americans to develop substitutes including the Gibbs apparatus (Rice 1927–1928, p. 427).

that Simonis would manufacture, were published in Blackett's name in 1911.[21] Frederick P. Mills, a mining engineer and manager, was appointed chief officer of the DNCFRB in 1913. Together with G.L. Brown of the North Midland Coal Owners' Rescue Stations (NMCORS), Mills worked on further refinements to the liquid air apparatus. Patents relating to the Brown Mills Aerophor were published in 1922, the applicants this time being Brown, Mills, the DNCFRB and the NMCORS (McAdam and Davidson 1955, p. 37).[22] In short, there was a community of mining engineers dedicated to improving existing rescue apparatus.

Foremost amongst the academics interested in explosions and rescue apparatus was John Scott Haldane. The UK's leading expert on physiology and respiration, and a Fellow of New College, Oxford, Haldane began investigating the effects of poisonous gases on coal miners in the late nineteenth century. He was active in the IME, holding the presidency between 1924 and 1927, a mark of acceptance by practical men. Although not an inventor of mine rescue apparatus, he commented extensively on the merits and demerits of each model on behalf of the government, the IME and coalowners. In 1912, whilst still on the staff at Oxford, he also became director of the Doncaster Coal Owners' Research Laboratory, where he oversaw research into a range of problems including spontaneous combustion, coal dust inhalation, and the defects of breathing apparatus.[23] Haldane exercised an important influence over the inventive community.

Henry Briggs, a lecturer at Heriot Watt College, and later professor at the University of Edinburgh, also made a mark. An academic entrepreneur, Briggs sought government support for research into rescue apparatus, and proposed a system of official inspection and authorisation. Heriot Watt trained colliery managers and cooperated with local collieries and the Carnegie Trustees to establish the Heriot Watt mine rescue station during the First World War.[24] The college principal contacted the Privy Council Commission on Scientific and Industrial Research in 1916 to propose working with the government on improvements to rescue apparatus.[25] Briggs hoped to develop 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".[26] The Commission viewed this

[21] Espacenet patent database: GB191017589 (A) 1911-02-09 and GB191122507 (A) 1911-12-14. Patents may be accessed through the website of the European Patent Office, www.epo.org

[22] Espacenet patent database: GB179094 (A) 1922-05-04; GB179126 (A) 1922-04-12; GB188612 (A) 1922-11-16; GB188677 (A) 1922-11-23.

[23] For a popular biography see Goodman (2007). For Haldane's contribution to the IME see Graham (1935–1936).

[24] Part of a training session at the Heriot Watt rescue station in 1938 may be viewed at http://movingimage.nls.uk/film/1862 starting at 19 minutes 45 seconds [accessed 6 July 2021]. The University of Birmingham also operated a mine rescue station.

[25] The National Archives, Kew [hereafter TNA], DSIR3/234, A. P. Laurie to the Secretary, Privy Council Commission for Scientific & Industrial Research, 12 July 1916.

[26] TNA, DSIR3/234, Henry Briggs to the Secretary, Privy Council Commission for Scientific & Industrial Research, 18 July 1916.

approach sceptically, but Garforth, hearing of Briggs's plans, made a small donation.[27] A tragedy in South Wales turned the tide in Briggs's favour. In 1917 three rescuers were asphyxiated in a training session at Duchy colliery, deaths that were attributed to faults in their Draeger apparatus (Department of Scientific and Industrial Research Advisory Council 1918, pp. 22–23). The Home Office now approved work along the lines suggested by Briggs.[28] Funded by the Department of Scientific and Industrial Research (DSIR), the research project was based at Heriot Watt and assisted by Haldane's Doncaster laboratory. An official Mine Rescue Apparatus Research Committee (MRARC), comprising William Walker (acting Chief Inspector of Mines), Haldane and Briggs, oversaw the research.[29] Briggs's team developed a new design of compressed oxygen breathing apparatus, incorporating several improvements including an improved purifier.[30] This apparatus would later be manufactured by Meco, but although serviceable the Briggs-Meco failed to break the stranglehold of the Proto.

Until 1917, the government had at first chivvied and then compelled coalowners to invest in mine rescue facilities, but it had not funded research into breathing apparatus. The formation of the MRARC foreshadowed greater intervention. Several reports were published by the committee. Existing models of breathing apparatus were evaluated in the first report and certain improvements were suggested. The second report concluded that enforced standardisation would constrain future research, but urged the government to test each type of apparatus before approving it for use (Department of Scientific and Industrial Research Advisory Council 1920, p. 5). A new regulation was issued in 1920 to the effect that: "No Breathing Apparatus shall be used except such as is approved by the Secretary of State [for Mines] (Bulman and Mills 1921, pp. 51-52)". Several types of apparatus were approved, albeit after modification, providing rescue stations with almost as much choice as before the war.

17.6 The Institution of Mining Engineers and *Transactions*

The IME and *Transactions* offered a platform for the exchange of information and opinion about types of breathing apparatus. They linked together the network described in the previous section.[31] Although this forum was largely British, some

[27] TNA, DSIR3/234, Notes on Heriot Watt proposal, 8 December 1916.

[28] 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.

[29] TNA, DSIR3/234, Communication to be made to the press, 11 July 1917.

[30] In one test of the Briggs apparatus the wearer was required to climb Arthur's Seat in Edinburgh (Department of Scientific and Industrial Research Advisory Council 1920, pp. 41–53).

[31] The contribution of the IME and *Transactions* to the circulation and testing of new methods and technologies is mentioned briefly in Scott (2006, pp. 25–26).

foreign equipment was examined, and several overseas experts were invited to speak at meetings and to contribute articles. Some examples of the contributions made through the IME are given below.

The years 1905–1907 saw the publication in *Transactions* of several detailed accounts and evaluations of breathing apparatus. G.A. Meyer of Shamrock colliery in Germany read a paper on the history of breathing apparatus, also describing the work of Westphalian rescue teams at the Courriéres colliery disaster in 1906 in which 1100 French miners died. Some of the German explorers at Courriéres had worn the Shamrock apparatus, designed by Meyer himself (Meyer 1905–1906).[32] Meyer was billed as Germany's premier expert on rescue apparatus, and his paper provoked a lively debate. Haldane noted that Meyer's latest model incorporated new safety features, but another mining engineer claimed that the Shamrock was too complicated for the average user. Doubts were expressed over the claims that the Shamrock could be worn safely for 2 hours. H.E. Gregory of Cortonwood colliery mentioned problems with an earlier version of the Shamrock. He criticised other models, including the Draeger, which incorporated a helmet rather than a mouthpiece on the grounds that the helmet caused discomfort and possibly danger (Gerrard et al. 1905–1906). 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. Anyone with access to *Transactions* could have studied the article and debate.

Shortly afterwards, the characteristics of the Weg and the Aerolith were explained in articles by Garforth (1905–1906) and Simonis (1906–1907) respectively. R. Cremer, a Leeds mining engineer, published a paper comparing five different types of breathing apparatus made on the European continent. He produced a table evaluating them according to 12 criteria, from the length of time they could be worn safely to the purchase and running costs (Cremer 1906–1907, pp. 68–69). Garforth's new apparatus also sparked controversy. Members of the IME were invited to attend a demonstration of the Weg at Altofts. Some were impressed, but W.C. Blackett questioned the value of "so-called rescue-appliances" and said he could not remember a single occasion when he would have felt safer wearing one. He wondered whether rescuers could be sufficiently well-trained to wear and operate complicated apparatus without putting their own lives at risk (Blackett et al. 1906–1907, p. 180).[33] Blackett, developer of the Aerophor, would soon change his tune, which suggests open-mindedness.

The most searching evaluation of existing types of breathing apparatus was supplied by Haldane in two articles in 1914. Haldane was tasked to recommend a type of breathing apparatus for the new Doncaster rescue station. The number of rescue stations was growing rapidly, Haldane's verdict was worth taking seriously, and the Doncaster coalowners were content for him to reprint his findings in *Transactions*.

[32] On Courriéres see Neville (1978).

[33] A later paper was even more brutal, describing breathing apparatus as "absurd walking 'fitters' shops'" that would never be of any value to rescuers (Harger 1911–1912, p. 139).

Haldane and his staff subjected each model of apparatus to extensive testing. Serious and potentially dangerous defects were found in each of them. For example, the Proto was prone to overheating which made breathing painful; the Weg leaked both inwards and outwards and needed an expert operator; the helmets of the Draeger and the Meco also leaked; carbon dioxide was liable to accumulate in the Draeger and the Aerophor; finally, the Aerophor was judged experimental and unsuitable for adoption (Haldane 1913–1914). Haldane could recommend no apparatus to the Doncaster coalowners. A second article recorded improvements hurriedly made to several types of apparatus including the Aerophor. Haldane now concluded that the Proto, despite some remaining deficiencies, was the best available, and it was adopted at Doncaster (Haldane 1914–1915).

Haldane's articles caused testy debate in the institutions. Dismissing Haldane as a mere academic, Jonathan Piggford accused him of unfair bias against the Aerophor. Piggford mounted a detailed defence of the liquid air apparatus, an early version of which was in service at his local rescue station, Mansfield (Piggford et al. 1914–1915, p. 585). Garforth deplored Piggford's outburst, and said that Haldane's first report "had done more good than anything else" in recent years, and that his criticism of existing models "had been taken advantage of by the makers" to improve their equipment. Although the Weg had cost over £1000 to develop, Garforth offered to share it with anyone in the interests of saving lives (Piggford et al. 1914–1915, p. 590).

An active community of experts keen to debate the merits of different types of breathing apparatus was sustained by the IME, not least in the pages of *Transactions*. Opposing viewpoints on technical matters were aired in detail, sometimes heatedly. The mining engineering profession was certainly highly argumentative. Informed debate fed back into the work of the designers of breathing apparatus, both professional and amateur. Collective invention and user innovation flourished, albeit within certain constraints for the commercial makers at least were interested in making a profit.

17.7 The Rotherham Apparatus

User innovation and tinkering were prominent in the affairs of the Rotherham mine rescue station which opened in 1914. Rotherham was an important mining, steel and engineering centre near Sheffield. Rotherham coalowners who sat on the management committee of the rescue station took their duties very seriously. Before choosing breathing apparatus for the new rescue station, they visited other stations to evaluate their equipment and methods, and found a variety of models in use at

Elswick (Aerophor), Howe Bridge (Proto), Mansfield (Meco), Altofts (Weg) and Wath (Draeger).[34]

Consideration was given to developing a hybrid breathing apparatus, taking the best features of several types, but this option was not pursued.[35] In 1913, the suppliers of the Draeger, Proto, Meco and Aerophor were invited to Rotherham, and their apparatus put through a series of tests and practices in a special gallery designed to replicate underground conditions. Although the Aerophor liquid air apparatus was worn by the most inexperienced rescue man attending the tests, he experienced the least discomfort and distress. It was resolved to adopt the Aerophor as the principal model of breathing apparatus for the Rotherham rescue station, supplemented by some Meco compressed oxygen sets, a decision which may have indicated some lingering doubts about the Aerophor. The liquid air system had a higher capital cost but lower running costs than the compressed oxygen system. The internal report on the trials said that cost not been a consideration in the choice of apparatus but expressed the hope that the best system would prove the cheapest in the long run.[36]

An order for Aerophor sets and liquid air plant was placed with the Simonis company. After the release of Haldane's damning report on the Aerophor, the Rotherham coalowners, desperate for reassurance, approached the famous scientist for advice. He recommended several modifications, which Simonis agreed to make.[37] When the Aerophors started to arrive at Rotherham in 1914, they were discovered to have faults which the rescue station decided to have fixed by local firms.[38] Relations with Simonis were becoming soured by disputes over cost, delays and poor quality work. Significant improvements to the design of the Aerophor were made locally in 1915. Simonis undertook to produce the remaining sets to the modified "Rotherham" design, but further defects were found upon delivery in 1916. At this point Simonis was dropped, and the Rotherham coalowners resolved to proceed with their own refinements to the liquid air sets.[39] Sergeant Major Elliston, the chief instructor at the rescue station, was instrumental in the development of what became known as the Rotherham apparatus. This was a classic case of tinkering. When appointed, Elliston had no prior experience of mine rescue work, having been a

[34] Rotherham Archives and Local Studies (hereafter 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.

[35] RLAS, 185/B/9/1/1, Minutes of Breathing Apparatus Committee, 14 August 1913.

[36] RLAS, 185/B/9/1/1, Record of demonstrations with various apparatus at the new rescue station, 3 September 1913.

[37] RLAS, RLAS, 185/B/9/1/2, Minutes of General Meeting, 31 March 1914.

[38] RLAS, RLAS, 185/B/9/1/2, Minutes of General Meeting, 14 October 1914.

[39] 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.

drill, musketry and engineering instructor in the Royal Engineers.[40] The improvements to the Aerophor were sufficiently extensive for the Rotherham device to be regarded as a distinct model, and it became the first type of liquid air apparatus endorsed by the Mines Department after 1920 (Elliston 1922).

In the early 1920s, the government Mines Department required further modifications to all types of breathing apparatus, including the Rotherham model which now acquired a better purifier and a protector for the breathing bag. Irritation was expressed that other rescue stations were copying these improvements without acknowledgement, and it was decided to seek patent protection.[41] 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.[42] The Rotherham apparatus was battle tested at the Maltby Main disaster in 1923. Although no lives could be saved on this occasion, the apparatus performed creditably in subsequent salvage and restoration operations.[43]

Rotherham coalowners worked closely with Simonis (and Haldane) on modifications to the liquid air breathing apparatus, but eventually went their own way when the performance of the London firm proved unsatisfactory. They sought help from other rescue stations when evaluating breathing apparatus, but later found some of them to be untrustworthy. Not surprisingly, the historical record offers a rather untidy illustration of collective invention and user innovation in this and other instances.

17.8 Conclusion

Strong elements of collective invention and user innovation were present in the network that developed rescue apparatus for use in coal mines in the UK in the late nineteenth and early twentieth centuries. Participants included commercial enterprises (Siebe, Gorman, Simonis and Meco), public spirited employers and engineers (Garforth and Blackett), academic scientists (Haldane and Briggs), the staff of mine rescue stations (Mills and Elliston) and government officials. The Institution of Mining Engineers and its journal *Transactions* provided a crucial platform for the exchange of information and ideas. Collective invention and user innovation were not to be found in their pure forms, but rather in somewhat untidy versions. Some, but not all, technical advances were shared freely. Cooperation was qualified by rivalry and tempers sometimes flared. Users and manufacturers worked together

[40] 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.

[41] RLAS, 185/B/9/1/2, Minutes of General Meeting, 23 March 1922.

[42] RLAS, 185/B/9/1/2, Minutes of General Meeting, 14 June 1922 and 24 August 1922.

[43] 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. See also Mottram (1924).

some of the time, but they could also fall out. Nevertheless, the story that emerges is one of a dynamic innovative network, which collaborated to develop a new technology for use in mine rescue and recovery. 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.[44] This study of mine rescue apparatus offers important insights into how advanced technologies were developed in Britain in the early twentieth century. The inventive network in question was able to span the worlds of practical mine engineering, commercial research and development, and the universities, and at its centre sat the Institution of Mining Engineers.

Acknowledgements I wish to thank Chris Corker, Sarah Holland, and Alan Malpass for research assistance; the staff at Rotherham Archives and Local Studies and Jennifer Hillyard of the North of England Institute of Mining and Mechanical Engineers, Newcastle upon Tyne for their help; and Javier Silvestre for illuminating email discussions of mine safety and rescue.

Appendix: Singleton on Murray

After moving from Wellington, New Zealand to Sheffield, Yorkshire at the end of 2010, I wanted to find a research topic with a local dimension and hit upon coal mine safety. Yorkshire was an important coal mining region until comparatively recently – the last Yorkshire (and UK) deep coal mine shut down in 2015. The publication in 2015 of an excellent article by John Murray and Javier Silvestre on the impact of better safety technology in European coal mines in the late nineteenth century gave a boost to what until then was a relatively neglected area of research. I was hoping to meet John at the Economic History Society Conference at the University of Keele in April 2018 where we were both scheduled to present papers on mine safety. John did not appear and a couple of days later I heard from Javier that he had died suddenly. The chapter presented here is based on my own paper from the conference at Keele.

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[44] 116 trapped men were saved by rescuers equipped with Proto apparatus at Knockshinnoch Castle Colliery in 1950 (Bryan 1951).

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