



Traffic & Transportation

Jubilee Line Extension Tunnel

The Challenge

The £2.6 bn extension to the London Jubilee Line was during its time, one of the largest construction projects undertaken in Europe, and incorporated the largest active fire protection contracts.

When it was completed in 1999, the Jubilee Line extended by nearly 26 km into south and east London. This created a valuable link to the Docklands and brought many benefits to an area of London that is continuing to undergo regeneration.

The six year construction programme included 18 operating sites, of which 11 were stations. Six of these were designed and built for the JLE, while five existing London Underground Limited (LUL) stations were improved, re-designed, extended and modernised to the new Jubilee Line standards.

The extension brought Underground services to an entire area south of the River Thames for the first time, with stations provided in Southwark and Bermondsey. The North Greenwich peninsula has also been transformed with the creation of a new station which feeds the Millennium Dome, while south east London and Kent have been opened up to Underground commuters.

Mammoth Task

This massive project involved scores of contractors and specialist sub-contractors requiring co-ordinated project management on an immense scale. Tyco Fire & Integrated Solutions, working in partnership with Drake & Scull, was awarded the contract to install active fire protection, fire detection and alarms, and employed a dedicated team on the Jubilee Line project from its inception in 1994.

Tyco's task was to provide a fire protection infrastructure that would ensure the safety of the tunnel, its services and staff during construction, as well as protecting passengers once the line became operational.

To co-ordinate the project Tyco Fire & Integrated Solutions brought together a team of 12 engineers, who managed the highly complex logistics system from the project management headquarters based at Canary Wharf. Their job included design, specification, ordering, deliveries, storage, staff transport, work scheduling and installation.

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The decision to develop the system design on site, alongside other contractors and sub-contractors, brought many benefits in managing some 5,000 mechanical and electrical designs that were involved in each design at submission stage. The design programme was co-ordinated by JLE itself, which operated a 1,000 strong team of monitors and supervisors above and below ground.

Tyco's team included design managers and design project engineers, installation teams, surveyors, and a quality assurance and health and safety adviser. Due to the size of the project, the team was divided into four project groups covering specific geographical areas, working with site specific teams of foremen and operators who were spread the length of the Jubilee Line Extension, over 18 operational sites.



This project team was responsible for what was, in effect, a design and build contract to deliver a complex fire protection system involving stations, escalators and tunnels. The sheer size of the project (26 km) with access stations based in some of the country's most traffic-congested areas meant that it was highly complex.

Project Scope

Following the award of the contract to provide mechanical active fire protection, including water supply measures, Tyco Fire & Integrated Solutions was also given responsibility for installing the compressed air systems. These control the track points, track signalling, public and non-public ventilation systems, and sewage ejection systems, which force waste from underground station toilets up into the City's main drains above.

The scope of the contract therefore involved London Underground Stations, escape and ventilation shafts, as well as the underground tunnel itself. It included:

- Sprinkler systems (active)
- Hydrant systems (fire fighting)
- Hosereels systems (fire fighting)
- Portable extinguishers (fire fighting)
- Compressed air systems (non-fire)
- Detection, alarms and remote signalling (electrical)

Tyco's part in the Jubilee Line project was valued at more than £20m, over more than 5 years. In terms of equipment alone it involved 85 km. of pipework, 1,200 portable extinguishers, 150 hosereels, 500 hydrant outlets, 2,000 fire sprinklers and 450 control valves.

The electrical element of the contract involved 500 km. of mineral insulated cabling, 29 main fire alarm panels, 70 linear heat detection and sprinkler actuation panels, 200 ancillary/interface panels, 5,000 analogue addressable fire detectors, 2,000 manual callpoints and 55 km. of linear heat detection cabling.

For further information contact your local Tyco Fire & Integrated Solutions office on:

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Traffic & Transportation

High Speed 1 - St. Pancras CTRL Rail Link

The Challenge

The Channel Tunnel Rail Link is an extension to the existing Channel Tunnel railway, which runs from London to Paris. The part of the fast link that is now under construction runs from Ashford in Kent to St Pancras Station in London. This link is of both national and international importance.

Tyco Fire have been contracted to install the fire hydrant systems into the three railway tunnels known as Thames Tunnel and London Tunnels 1 and 2. Each section consists of two separate tunnel bores running parallel to each other. This gives a total length of the north and south bound tunnels of 46km. The tunnel length is interspersed with a number of ventilation and access shafts.

Each tunnel has its own stand-alone fire hydrant installation, which is a looped pipe work system running both north and south bound. The pipe work to be installed will be a mixture of both 150mm and 200mm diameters depending upon the hydraulic requirements of the systems.

The fire hydrants are spaced at a distance not exceeding 60 metres with system isolating valves installed at every third hydrant. Because of the client's particular requirements, each hydrant point has two independent pressure reducing hydrant valves. This gives a total number in the region of 1600 fire hydrants, with approximately 275 number 200mm or 150mm diameter isolating valves.

The installation works were due for completion by March 2006, with the railway opening for passenger revenue in January 2007.

One of the major challenges we faced was to install 43km of brackets, 200mm hydrant main and all components within tunnels to a tight co-ordinated installation programme and designed to withstand the specified surge pressures of 24 Barg and 56 KN of end cap loads (subject to the contractors design verification): -



Why is this fire protection project different to any other?

Size

- Largest Fire Protection contract carried out in the UK.
- 25 Miles of pipe work installed within tunnels.
- Circa 850 PRV Hydrant valves installed.
- Geographical, Ebbsfleet in Kent to St Pancras in London.

Safety

- Primary function was the safety of passengers and tunnel staff.
- Reliability of systems required a minimum 25 year design life.
- High speed trains.
- System integrity and capability – System must pass highest level of safety standards set for project (SIL 3) requires passing full fault tree analysis test.

Design

- Bespoke design of bracketry to withstand substantial surge pressures and Axial forces.
- Transient calculations, not normally carried out on fire systems.
- Supplying 4 Hydrants simultaneously at 35.3 L/s, BS 5306 Pt 1 requires 3 Hydrants at 25 L/s.
- Non-destructive and destructive test and load test at University specialist department.

Logistics

To install 25 miles of Hydrant main and all its component parts working off trains.

Managing material deliveries and labour over a site from Ebbsfleet, Kent to St Pancras, London. Pressure testing all pipe work to 24 Barg. The normal test pressure is 15 Barg Max.

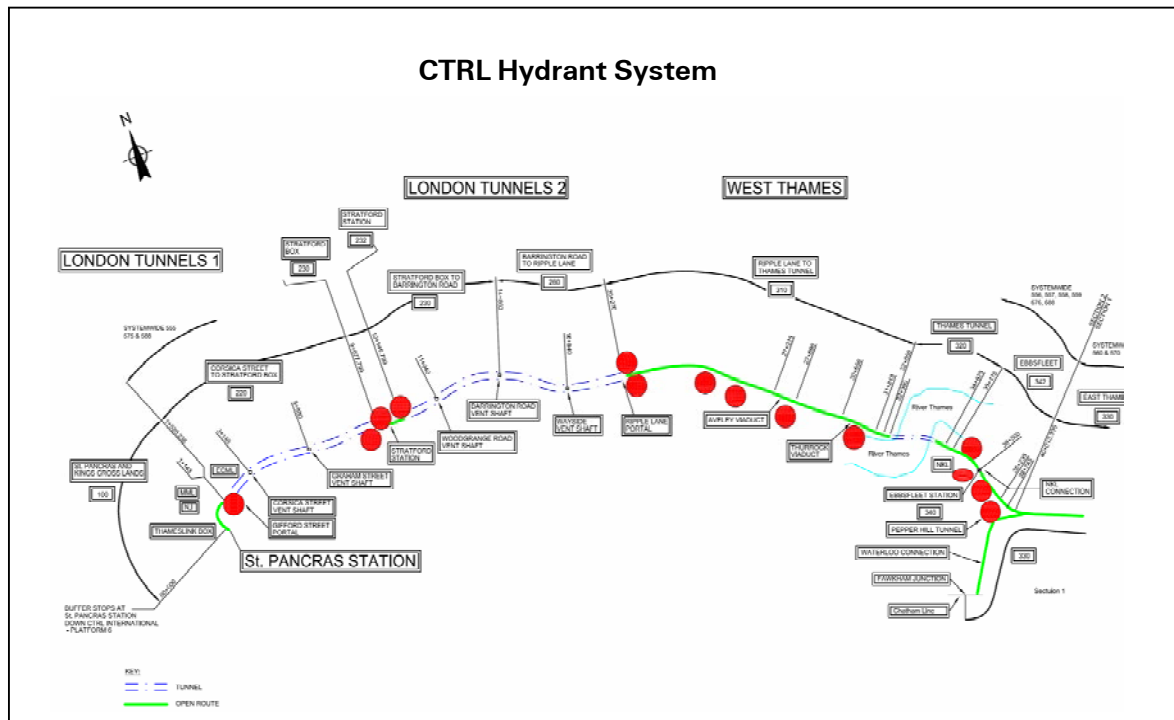
Full Dynamic flow and pressure test of hydrants from trains.

Scope / Overview

To supply design, install, test and commission Fire Hydrant Systems to three twin bore tunnels (known as Thames Tunnel, London Tunnel 2 and London Tunnel 1).

- Thames Tunnel is circa 3.5km each bore.
- London Tunnel 2 is circa 10.5km each bore.
- London Tunnel 1 is circa 7.5km each bore.

Total length of tunnels to be protected amounts to 43km (put into perspective this equates to 27 miles). There are eleven shafts/Portals serving the tunnels and thirty-four cross passages (the cross passages are passages interlinking two bores of a tunnel for the purpose of access between each bore).



There are circa 850 PRV (pressure regulating valves) hydrant valves located within the shafts and tunnels (tunnels at not more than 60 metres apart and shafts at each level).

The hydrant system to each twin bore tunnel is interlinked at each shaft and tunnel eye. The system is able to be used as a ring main and provides the emergency services with the facility to isolate sections of the hydrant system in order to maintain a fire fighting system in the event of damage to any section of the hydrant system.

The water supply is from a pair of four way Breaching outlets/inlets located at the top of each shaft (ground level). In order to activate the system the Fire Brigade connect their Fire Appliance to the breaching outlet (connected to Town's main water supply) and the breaching inlet (hydrant system water supply inlet). The Fire Brigade Appliance acts as the pump to provide the required flow and pressure to each hydrant valve.



West Box Portal Breaching Point

The schematic of the hydrant system for London Tunnel 2 shows the typical configuration of water supplies and pipework/valve arrangement to shaft and tunnels.

The hydrant main within the Tunnels (between shafts) can be fed from either shaft or both simultaneously providing the Fire Brigade with total flexibility.

SPECIFICATION REQUIREMENTS

Tyco Fire designed, supplied, installed, tested and commissioned the hydrant systems to BS 5306 PT1 and was able to supply four 20mm nozzles (Fire Brigade Branch) at any location of the tunnels or cross passages, at a total rate of 35.3 litres per second and at a pressure of 4.5 plus or minus 0.5 Barg at the hydrants.

The design flow and pressure was achieved from the supply point up to the adjacent possible supply point i.e. portal or shaft. To achieve the design flow rate the wet mains are charged by the Fire Brigade Appliance providing a minimum of 7 Barg outlet pressure at the pumps.

The system included pressure release valves on the downstream side of each inlet breaching connection, which should be set to open if the Fire Brigade Appliance pressure exceeds 10 Barg.

The systems are for fighting uncontrolled Class 'A' fires (defined as fire involving solid materials) on trains stopped in tunnels. They are wet systems kept under a low positive pressure and pressurised to the duty pressure by the Fire Brigade Appliances.





The systems were designed to form an effective means of rapidly bringing under control, fires in tunnels (running tunnels and cross passages). Their primary function is to ensure the safety of passengers and tunnel staff. The systems form part of the comprehensive safety provisions in Tunnels. The reliability of the systems is therefore paramount.

With these factors in mind, the system was designed to have a minimum life of at least 25 years. The system design also met the environmental corrosivity conditions of C4 (BS EN ISO 12944-2: 1998) and local IM2 regulations.

LOGISTICS

To install test and commission 43km of hydrant main and all its component parts within tunnels takes considerable planning and must be executed systematically to ensure revisits do not occur and delays are not caused to others.

To ensure this was achieved the brackets were installed prior to track laying, the brackets were off loaded along the tunnel for installation teams to install, all fixings being torqued to the correct NM (Newton Meters). This work was planned along with other contractors to ensure sequential completion of areas and use of shared welfare facilities within the tunnels.

The plan was to install 180 metres of pipe per day to meet the programme, although it soon became apparent that this did not leave sufficient programme float and being a partnering contract with incentives it was vital to consider ways of improving the output.

To this end a "brainstorming session" was held between Tyco Fire & Integrated Solutions and all parties involved, from the train loader, teams on the trains and engineers to review the installation methodology and investigate how to improve the productivity levels. This included the use of SIX SIGMA and the results enabled us to significantly increase our productivity to circa 230 metres a day including all components.

The hydrant main and all its components were installed after track laying from a diesel train equipped with welfare facilities, further trailers (flat beds) for the purpose of storage of materials (36 lengths of 6.5 metre pipework and all valves, fittings, jointing couplings etc. and finally two Hiabs for off loading pipework onto brackets and moving materials to the pre-fabrication workshop on one of the trailers.

This ensured the installation trains were fully self sufficient to off load and install circa 230 metres of pipework and all components per day.



Why Emcor Rail chose Tyco Fire

Emcor Rail was looking for partner contractors, but significantly, parties who had worked with them in the past. At Emcor's request, the Tyco Fire project team that worked very successfully for them on the Jubilee Line Extension was re-assembled. Tyco Fire, Slough completed the Jubilee Line Extension in 1999. It had a project value £23 million.

The success of this project was overwhelmingly down to unrivalled engineering expertise of this team. Emcor needed such a team, a team that could rise to unparalleled feats of engineering ingenuity, skill and expertise.

This requirement was particularly evident when calculating the system Design Pressure and Axial Forces.

The Tyco Fire design team ensured that the system could withstand significant surge pressure and axial forces at changes in direction and closed valve positions. They also had to account for specified expected maximum surge pressure of 23.6 Barg and expected maximum axial forces at bends being 55.7kn.

Material Selection and Bracket Design

Having carried out the hydraulic and transient pressure calculations materials had to be selected that would withstand the peak loads calculated along with designing bespoke brackets and associated fixings that would likewise withstand the expected loads and specified corrosion levels.

Fixings and brackets

The fixings and brackets had to withstand maximum transient pressure loads 24 Barg, end cap loads of 70kn (7 Tonne load plus safety margin) together with weight loadings, 20kn vertical reaction forces, curvature of tunnel wall, vibration and pressure variances caused by passing high speed trains,

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Tunnel Ring Roll (Final positioning of each concrete ring, making up tunnel wall, in relation to a fixed datum i.e. tunnel ring roll tolerance of plus or minus 40mm).

Detailed bracket and fixings design substantiation calculations and drawings were produced taking all the above into account. Various types of fixings were subjected to pull out tests (the tunnel curved wall was replicated for this purpose) to ensure the design calculations were physically achieved.

A sample batch of brackets were manufactured for testing purposes and the brackets were then subjected to non destructive (which also verified the galvanising thickness) and destructive tests at a specialist testing laboratory, a proportion of the brackets were taken to Reading University where they were subjected to rigorous loading tests (up to 8 Tonne) to prove their integrity.

Proving System Integrity and Performance

The hydrant systems successfully completed rigorous hydraulic pressure and performance testing to demonstrate their integrity and that they met the specified performance criteria.

All the systems had to be subjected to 24 Barg hydraulic pressure tests. Full dynamic flow and pressure tests had to be carried out to prove that any 4 PRV hydrant valves performed to the specified flow of 35.3 litre per second (2100 litres per minute) 4.5 plus or minus 0.5 Barg is achieved.

On time, on budget, every time

Once again, the great care and attention given by the Tyco fire Project Management team ensured that they were able to meet all the stringent requirements of Emcor Rail.



Traffic & Transportation

Palm Island Jumeirah, Vehicular Tunnel

The Challenge

The Jumeirah Palm Island, currently under construction off the coast of Dubai, is rapidly becoming one of the iconic structures in the region. Formed in the shape of a Desert Palm Tree, the "fronds" will be home to over 2,000 executive beach front villas, whilst the "trunk" and protective crescent shaped breakwater will be home to numerous 5-star developments and hotels.

Linking the Palm and the Crescent is a 1.4 Km long, underwater vehicular tunnel.

The tunnel has a three lane carriageway in each direction, separated by a service/emergency escape tunnel.

Tyco Fire & Security UAE LLC have been awarded the contract to Design, Supply & Install all of the Extra Low Voltage systems as an integrated solution, as well as the fire fighting systems for the tunnel and the two control buildings.

Tyco UAE's scope includes the provision of video smoke/fire detection, video analysis of traffic, voice evacuation systems, tunnel communications systems, traffic management and a Radio FM Re-Broadcasting/TETRA system.

All of the systems are monitored and controlled by a PLC based SCADA system, control of lighting levels, ventilation fans, sump and drainage pumps is also provided by the SCADA system.

Tyco's ability to undertake all of the works as well as provide additional solutions for the client has been a major influencing factor in securing the award of this project.

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Lötschberg Transalpine Tunnel

The Challenge

Switzerland, the tunnel building nation, is involved in the construction of a fast train link between northern and southern Europe.

The so called NEAT ("New Transalpine Tunnels"), is a very ambitious project: through the Lötschberg and Gotthard mountains.

The Lötschberg main tunnel runs through the Alps from Frutigen to Raron as part of the main line from Bern to Milano.

Most of the 34.6 km long tunnel is covered by two bores, each with a single directional track. The opening of this gigantic construction, the first high speed rail link through the Alps, is expected to be in December 2007.

The Government awarded BLS AlpTransit AG the contract to design and supply the new Lötschberg main link. For the tunnel safety solutions BLS AlpTransit AG has chosen the TSA Telecom/Tyco Fire & Integrated Solutions consortium as a partner.

The tender process took place during autumn 2001 and in the summer of 2002, Tyco received the order for the fire detection and suppression systems.

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Mammoth Task

Over 1500 fire sensors will be installed in the tunnel control and equipment rooms.

In addition, gas and water sensors as well as nearly 35 km of aspirating pipes for the Vesda air sampling smoke detectors, provide extra safety. Approx. 270 off EXPERT MX 1000 fire detection centers are controlling these sensors.

Supplementing the early fire detection system will be 93 INREGEN gas fire extinguishing systems housed in the equipment rooms. A fire can be extinguished at its initial phase as these systems are triggered by the early fire detection systems.

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London Main Line Stations CCTV Systems

The Challenge

Tyco Traffic & Transportation has supplied, designed and installed the largest CCTV system in the rail industry within the UK. The networked CCTV Control system covers 16 main line London stations and over 2,300 high performance colour cameras.

It also boasts Remote and Local Monitoring and Archiving, which is complimented by a comprehensive Tyco Maintenance Package.

All of the cameras are networked back to one "nerve centre" Control Room operated by Tyco Traffic & Transportation and British Transport Police. The images are recorded 24 hours a day, 365 days a year.

Tyco Traffic & Transportation CCTV and Maintenance have contributed to the Secure Stations Programme by aiding many of the London stations with their quest for the Secure Stations Award. Recently, awards were presented to the Kings Cross, City Thames Link and Fenchurch Street Stations.

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Tyco Traffic & Transportation protected the following 16 London Main Line Stations:

- Blackfriars
- Cannon Street
- Charing Cross
- City Thames Link
- Euston
- Fenchurch Street
- Kings Cross
- Liverpool Street
- London Bridge
- Maryleborne
- Paddington
- St. Pancras
- Victoria
- Waterloo Main
- Waterloo East

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EARTH TECH'S EXPERIENCE IN TUNNEL VENTILATION

I. COMPANY BACKGROUND

1. Earth Tech's Company Profile

Earth Tech is part of Tyco Fire & Security, providing fully integrated capabilities to clients. As one of America's largest transportation engineering and construction companies, Earth Tech has worked for every major transit agency in the United States, numerous state departments of transportation, the federal government, and agencies in over 90 foreign countries on six continents.

We have been or are currently involved in major transit projects in Baltimore, Boston, Chicago, Connecticut, Cleveland, Dallas, Honolulu, Jacksonville, New Jersey, New York, Long Beach, Los Angeles, Miami, Philadelphia, Phoenix, Pittsburgh, San Diego, Seattle, San Francisco, Tampa, and Washington DC, and internationally in Canada, England, Hong Kong, India, Korea, Philippines, Romania, Singapore, Taiwan, and Turkey, etc.

We participated in a system wide ventilation study to assess the existing ventilation system capabilities for the New York City Transit Authority and recommend upgrades to comply with NFPA 130 requirements. We also completed a system wide study to upgrade the existing subway ventilation system in Chicago, which is almost 50 years old, and to bring it to the current industry standards. We completed the detailed design for the upgrade of 56 fan plants, for a global capacity (estimated by SES computer simulation) of 18.5 million m³ per hour, with a capital cost of US\$38.7 million.

We normally undertake a thorough examination of the proposed Design Criteria for the Ventilation system and offer our opinion regarding the suitability and practicality, as well as a comparison with criteria applied by other transit agencies. The list of applicable codes and standards identified by the Client are reviewed for completeness, and suggestions for additional codes or standards are made accordingly.

Amendments or improvements to the Conceptual Design will be proposed as appropriate, when benefits could be identified and justified either to improve the safety, or to reduce the cost.

2. Computer Simulation and Analysis

In case of a vehicle fire in the tunnel, the tunnel ventilation system should be capable of controlling the propagation of smoke by creating an air stream with a velocity past the fire greater than the velocity required to prevent smoke back layering. This minimum velocity is commonly known as Critical Velocity and is calculated based on the vehicle's Heat Release Rate (HRR) and the expected fire temperature, tunnel geometry and gradient, ambient temperature, etc. Earth Tech, Inc. developed a simple program to easily calculate the critical velocity wherever necessary.

For a station fire the trackway/tunnel ventilation plants, complemented by the station ECS plant, should be designed with adequate capacity for smoke extraction and protection of passengers' evacuation route. We understand that the conceptual design normally provides for individual trackway extract and supply ventilation system for both ventilation and heat removal during normal and congested operation, as well as for smoke extraction during fire conditions.

There are two main computer programs applicable to accomplish the scope of services required by Transit Operators:

- ***Subway Environment Simulation (SES)***, a single-dimensional, multi-task software developed by the joint venture of Associated Engineers for the U.S. Department of Transportation, and available in the public domain. We have the latest version 4 of the program, supplemented by our own enhancements.
- ***Computational Fluid Dynamics (CFD)***, three-dimensional software, available mainly from various vendors, usually for an annual license fee.

Earth Tech, Inc. is one of few international consultants with extensive experience in using both these programs for numerous transit projects similar to this project.

In the past several years, we have used three different CFD programs: FLUENT, CFD-FLOW3D (currently CFX) and CFX TASCflow. Our experience demonstrated that CFX TASCflow is more appropriate and versatile for application in station and tunnel fire analysis.

2.1 Subway Environment Simulation (SES)

As an active participant in the development of the SES in the mid 1970s (part of the Associated Engineers Joint Venture), Tyco is very familiar with the software and has been using it continuously since then. In the early 1990s Earth Tech was the first consultant to develop a PC version of the SES. Later on, a Windows-based version was created by us. It was normal for the DOT to commission Earth Tech again in 1996, together with another consultant, to update the original SES version and produce the new Windows-based Version 4.0. The software was reviewed and upgraded as Version 4.1 and is currently in the process of being prepared for distribution by the U.S. Volpe National Transportation Systems Centre (NTSC) in Cambridge, Massachusetts.

Earth Tech has been using the SES computer program to model and simulate fire conditions in subways since 1974 at Baltimore, BART, Boston, Bucharest, Chicago, Copenhagen, Dallas, London Underground, Montreal, New York City, San Francisco Muni, Seoul, San Louis, Toronto, Washington, etc.

We will use the SES computer program to verify the effectiveness of the natural ventilation system for normal conditions and mechanical ventilation in case of a major fire at selected locations.

Based on computer simulation we determine the size of the fan plants and recommend fan operation procedures in emergency situations. These may consist of “push-pull” or “all-exhaust” operation, as applicable; running multiple fans for a fire incident, coupled with closing certain dampers; or use of temporary air-barriers.

The proposed alternatives will be in line with the current international practice (mid-tunnel, end-of-stations, under-platform, etc.), but also cost-effective and specific for the subway conditions under consideration.

Tunnel fire conditions are suitable for one-dimensional analysis using programs such as SES to predict the airflows in the entire tunnel network including the airflow past the fire. The advantage of the one-dimensional analysis is the ability to model and analyze an entire tunnel network assuring well defined boundary conditions. In cut-and-cover stations, without Platform Screen Doors (PSD), which are quite open at both platform and concourse/ticket hall levels, with multiple and often large connections from one level to the next, the one-dimensional analysis is still important to provide the overall airflow pattern in the complex station/tunnel network.

With operation of the tunnel ventilation fans, airflow can either be brought down the entrances (all-exhaust mode) or moved along the platforms (push-pull mode), providing clear paths for the largest possible portion of the evacuation route.

When PSDs are installed, however, the platform, mezzanine and concourse areas of the station are unaffected by the tunnel fan operation. The station Environmental Control System (ECS) is operated separately, either by fans alone, or by conditioned Air Handling Units (AHU) and cooling plants. Should a train fire occur in these stations, the airflows and migration of smoke will be controlled by tunnel ventilation. While the station is generally kept under a positive pressure to prevent the smoke penetration, some leakage either through the gaps or through open PDS may occur and the station may become contaminated. In these circumstances, a one-dimensional model cannot provide much insight as to how smoke may accumulate, and what recirculation may occur.

2.2 CFD Modelling and Analysis

Valuable insights can be gained about a fire in a subway station by simulating the thermodynamic conditions in three dimensions using software capable of handling phenomena such as combustion, buoyancy, heat transfer (conduction, convection, radiation), and the concentration of various products, such as smoke. Such software involves repetitive calculations of three dimensional fluid dynamics and thermodynamic equations. This software, which uses computational fluid dynamics algorithms, is a relatively new modelling tool which has only recently been used and accepted by some transit authorities.

Earth Tech has been using CFD for simulating the movement, temperature, and composition of fluids (liquid and gas) for several years. This program is used to analyze the 3-dimensional behaviour of heat and airflow in a subway station during fire conditions. By using the CFD program, the effects of fire location, size, growth and products of combustion on emergency evacuation plans and supporting ventilation procedures can be predicted. We have used CFD for similar projects, including DART in Dallas, BART in San Francisco, TTC in Toronto, CTA in Chicago, LINK in Seattle, MTRC in Hong Kong, Bursa Ray in Turkey, and others.

In summary, our proposal brings the Client a wealth of prior experience and technical capabilities in the area of tunnel ventilation and safety, coupled with the solid reputation of our firm, which makes our design team unmatched by any other. However, our key to success is the relationship we establish with our clients in working together.

Our approach is to build a close working relationship with our client, with a continuous exchange of information, in order to maximize valuable ideas and solutions during the entire study development.

II. TUNNEL VENTILATION PROJECTS (*)

1. Subway Environment Simulation (SES) Computer Program Upgrade

Tyco participated in the SES software upgrade for the U. S. Department of Transportation, Volpe National Transportation Systems Centre to produce Version 4 of the program that is now available.

Tyco's tasks were to develop and test a Windows-based Graphical User Interface (GUI) for the preparation and execution of input data files. A GUI User's Manual was prepared and submitted for distribution with the program. Test datasets were developed and tested using the new interface. A general SES program documentation review was conducted also.

Tyco Engineers were part of the initial team that developed the SES program and we have been using it to evaluate ventilation systems since 1974. We have continued to expand and upgrade the program, and Tyco has become the recognised leader in using the SES to assess emergency ventilation requirements and capabilities.

2. New York City Transit - 100TH Street Bus Depot

The 100th Street Bus Depot is a mezzanine and four-story building with approximately 80,000 square feet on each floor, located in the East Harlem section of Manhattan, and used as a bus storage and maintenance facility. Ramps for bus access connect the floors.

The ventilation system was designed by STV Inc. based on guidelines for the number of air changes per hour required by code in this type of facility. Earth Tech was sub-contracted to perform a Computational Fluid Dynamics (CFD) analysis of the exhaust distribution for this purpose of confirming the effectiveness of the ventilation system. We used the latest version of A.E.A.'s CFX TASCflow software running on a fast workstation.

Based on our simulation results the ventilation design for the bus depot was adjusted and improved.

3. Kallang and Paya Lebar Expressways, Singapore – Tunnel Ventilation Design Review

Earth Tech and Meinhardt (Singapore) were retained by the Land Transport Authority (LTA) to review the Conceptual, Preliminary and Final Design prepared by another consultant for this new facility, consisting of a network of 9.6 km dual-three lane tunnels, 17 slip roads (ramps) and six ventilation buildings. A large portion of the expressways will be constructed in heavily urbanized areas, requiring special considerations for ventilation and emissions control. The design involved the application of the SES and CFD computer programs, to provide for Fire-Life safety and evacuation in case of a major fire.

Based on our recommendations the design was improved and has now moved to the final stage.

4. Bursa Ray Light Rail Transit System Tunnel Ventilation Study, Bursa, Turkey

Tyco conducted this study to determine the required ventilation system capability for the subway in downtown area of Bursa, as part of the new Bursa Ray Light Rail Transit System. The tunnel is a single cut and cover box

with tracks for eastbound and westbound trains. The tunnels are shallow and the ground cover varies from approximately 0.2 m to 8.5 m above top of tunnels and stations. The alignment from the west portal to the east portal rises to a maximum of 72 m and some sections of the alignment at steep grade (4.8 percent grade for approximately 776 m). The total length of the alignment is approximately 3.6 km. There are four underground stations: two with side platforms and with a mezzanine the length of the station, the other two with a centre platform, stairs at the end of the platform and two short mezzanines.

Computer modelling and simulations were performed to size the eight fan plants, using the SES computer program, Version 4 with our own enhancements. Computational Fluid Dynamics (CFD) modelling of three stations for fire and smoke control was performed also.

5. Sound Transit LINK Preliminary Design, Seattle, Washington State

Earth Tech is in charge of the tunnel and station ventilation system design for this extension of the existing Downtown Seattle Transit Tunnels (DSTT). The extension towards north is 4.64-mile (7.5km) long, with four underground stations, and a separate, south tunnel half-mile long with an underground station. SES and CFD computer programs are used to model the airflow and predict the environment for normal, congested and emergency (fire) conditions in all tunnel sections and at station platforms.

6. Toronto Transit Commission (TTC), Fire Ventilation Upgrade Program, Peer Review.

This current contract consists of reviewing the proposed upgrade of the TTC ventilation system to comply with the current safety standards. The design work was performed by TTC in-house, using both SES and CFD computer programs. Our recommendations are being implemented by TTC.

7. Reno Railroad Corridor, Cover-and-Cut Tunnel Alternative Ventilation Study.

This project consists of a 1-km long depressed, cover-and-cut tunnel for the railway administration in the city of Reno, Nevada. An existing Amtrak station will have access to a 300 m long platform inside the tunnel. Both passenger and freight trains powered by diesel locomotives will use the tunnel.

SES computer simulations were performed to size the required ventilation system for purging the tunnel during normal train operation and to ventilate in case of a train fire in the tunnel or at the platform. Ventilation systems with large axial fans in a shaft, 14 jet fans along the tunnel and a duct system were analyzed.

8. San Francisco International Airport – Smoke Control in the New BART Station

Tyco, Inc. was retained as an independent consultant to review the design and to express their professional opinion on the operational feasibility of the emergency ventilation system designed by other consultants for this station. CFD analysis was necessary and appropriate to verify the compliance of the initial design with code requirements. Both steady-state and transient analyses were conducted for a small fire and for a large train fire, with a natural ventilation system and with a mechanical extract system.

Based on our study the design was changed to incorporate smoke exhaust fans and the construction is now complete.

9. Tren Urbano, Minillas Extension Ventilation Study, San Juan, Puerto Rico

This study consisted of a 1.5-km subway with two underground stations equipped with platform screen doors (PSD) and provided with air-conditioning systems.

SES and CFD computer programs were used to model the airflow in tunnel and stations, for various operational conditions (normal, congested, emergency) and for the "worst-case" scenarios.

10. ACDA Pittsburgh International Airport, Ventilation System Design

This project was undertaken to assist the Construction Management phase to comply with the NFPA 130 Standard in the people mover enclosure between the Airside and Landside terminals.

We conducted SES computer simulations of the airflow for normal and emergency train operation. The existing tunnel ventilation fans were left in place to be used for normal ventilation of the Adtranz tunnels and to supply emergency air to the centre tunnel of the system. Modifications to add a vertical concrete relief shaft in each station roof to relieve air pressure caused by the piston effect of the vehicles were recommended. The shafts will be equipped with two fully reversible Vane Axial fans rated for high temperature. The Honeywell control system will be upgraded to control the new emergency tunnel ventilation fans and to work with both the emergency and new operating system installed.

11. J. F. Kennedy International Airport, New York City, L.R.T. Station Smoke Ventilation Study - Design Review.

Tyco was retained perform the review as an independent consultant not being associated with the project or any participating organizations of the conceptual, preliminary and final design reports by Arup Fire for the above named project.

The review focused on the following design elements and how they were applied in the design:

- Design Criteria and Fire-Life Safety Requirements
- Design Alternatives Considered
- Design Calculations and Assumptions
- Trade-Offs
- Computer Simulation (model and scenarios)
- Input Data Used in Simulation
- Design Features for Normal Operation and for Smoke Extraction
- Compliance with applicable Codes and Standards:
 - ❖ NFPA 130
 - ❖ Unified Building Code (UBC)
 - ❖ American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook
- Design Parameters

The review focused on the completeness of the documentation and identifying any apparent shortcomings or lack of sufficient details/explanations of the design process. During their review, Tyco identified other specific information and supplemental design documents required to substantiate and clarify the design process and alternatives.

12. Tseung Kwan O Extension, Hong Kong, Environmental Control System Design

Tyco in association with Hyder Consulting Ltd., Inc. were retained by Mass Transit Rail Corporation (MTRC) to provide consultant engineering services for the tunnel Environmental Control System (ECS) design for the new Tseung Kwan O (TKO) Extension (TKE), also known as the E653 Project.

Conceptual and Preliminary design of the tunnel ECS performed by another consultant was thoroughly reviewed by the Tyco specialists and a detailed review report was submitted to MTRC before the actual design work began. In addition to checking the calculations, assumptions and computer simulation results, significant changes were proposed to improve the ECS. The owner accepted the recommended changes and they were later implemented in the final design.

Tyco/Hyder team advanced the design from the preliminary stage into detailed design. Tender Documents were prepared for the installation of tunnel ECS equipment. Because the basic design concept was to isolate the running tunnels from the station platform areas using platform screen doors (PSDs), the tunnel ECS consisted of those provisions required to maintain an acceptable environment in the running tunnels.

The Kaiser/Hyder design team prepared and submitted to MTRC, as part of their deliverables, three main reports, for which Tyco was responsible:

1. Review of the Conceptual and Preliminary Design reports, as part of Milestone 1.
2. Computer Simulation and Analysis Report (Final), as part of Milestone 2.
3. Computational Fluid Dynamics (CFD) Simulation Report (Milestone 2).
4. Quarry Bay Relief Computer Simulation and Analysis Report (Milestone 3).

Several Working Papers and Technical Reports were prepared and submitted also.

13. San Francisco CalTrain Tunnel and Station Ventilation Study

This project examined various alternatives of extending the existing CalTrain railway line to downtown San Francisco, through tunnels and ending with an underground station that would require a complex ventilation system. Our study examined the requirements for normal ventilation to dilute diesel and LNG locomotive emissions, to maintain air velocities and temperatures under allowable limits. Ventilation requirements for fire emergency in the tunnels and in the station were also investigated, using the SES software.

14. Copenhagen Metro Ventilation System Design Audit and Verification

Tyco was retained by KRM Associates Ltd. of London, UK to perform an audit of the Conceptual Design of the Copenhagen Mini-Metro Tunnel Ventilation System prepared by G Maunsell and Partners Consulting Engineers for the COMET GROUP.

The audit was based on the limited information available to us about the proposed ventilation system, as referenced above, and on our experience with similar transit systems. Specific analyses or refinement techniques were recommended as appropriate

Following the audit, Tyco was retained to provide Maunsell Associates with the preliminary design verification by using computer modelling and simulation.

The Copenhagen Metro is a new light rail system currently under construction in downtown Copenhagen, Denmark. It consists of an underground section in the city centre connected to surface lines beyond Lergravsparken and west Amager/Ørestaden. There are plans for additional phases of the system to connect to suburbs.

The central underground section of the metro system consists of the following structures:

- Approximately 8.3 km route length of twin running tunnels
- Six deep underground stations: Forum, Norreport, Kongens Nytorv, Christianshavn, Amargerbro and Lergravsparken
- One shallow underground station (Islands Brigge)
- Emergency and ventilation shafts
- Additional underground structures for crossovers and bifurcations.

Tyco conducted modelling the underground portion of the metro system and performed computer simulations of airflow to verify the preliminary design of the ventilation system. The study was conducted using the SES computer program, in a PC version 3.1 re-compiled by Tyco.

15. Chicago Transit Authority - Subway Ventilation System Upgrade Project

Chicago Transit Authority (CTA) as part of its overall capital improvement program has directed a study be performed to assess the capabilities and operations of the ventilation systems installed in all the subways. CTA recognized that much of the ventilation equipment was installed over fifty (50) years ago. The condition and dependability of fan plants and the electrical feeders were a concern. The capability and performance levels of even more recent subways were considered not in conformance with present industry standards. CTA wanted to institute comprehensive, system-wide emergency ventilation procedures, prepared as matrices, to ensure control of heat and smoke within the subway sections in the event of a fire.

The project required the conduct of a survey of the existing subway plants, including construction and equipment, and physical locations, in order to help determine necessary ventilation capabilities and how this could be accomplished in the most expeditious manner, consistent with the operational concerns of the agency.

CTA retained Tyco 1994 to conduct the following activities:

- survey the tunnels and stations, as well as the existing equipment and their locations to determine how the tunnel ventilation control can be best accomplished with minimum disruption to revenue service, and in the most expeditious manner
- establish criteria and guidelines for the installation of new equipment
- define the ventilation capabilities necessary to bring the CTA emergency ventilation system in line with the intent of current industry standards
- prepare conceptual designs and costs for the new equipment and installations.

There are five subways in the CTA transit system, consisting of 23.1 track miles and serves 17 underground stations. The air movements are controlled by 56 fan plants, 69 vent louvers and 71 blast shafts. Most of the dampers and louvers were found to be rusted, and the fans and motors were found to be corroded and in poor condition.

The results of computer simulation and analysis for emergency conditions were presented for each subway and for various tunnel and station fire locations.

CFD analysis was performed for several stations to demonstrate the complexity of the smoke flow patterns in the stations and to confirm the SES solutions for smoke control and evacuation procedures. For CFD analysis the geometry of each station was defined and two trains were assumed to be present in each model, one on each track since this offers the greatest resistance to air flow. Boundary conditions were defined at the tunnel openings and station entrances based upon SES results for the case being studied.

The results provide smoke concentration, temperature and velocity distributions throughout the station and are presented graphically.

For each of the station fire scenarios studied, the fire was modelled as 10MW (34 MBtu/hr) of energy and 0.67 kg/s (1.48 lb/s) of mass (for fuel) added over a volume surrounding the sides and top of one car. The total amount of smoke generated was based on the size of the fire, a heat of combustion of 14 J/kg and an air to fuel ratio of 14:1.

The cost estimates were prepared assuming work would be done in the time period from mid-night to 5:00 AM, and that workers would be paid 1.5 times the standard rate, but for an 8-hour shift. All estimates were based on the conceptual designs and every effort was made to reduce the costs.

Tyco conducted the detailed design for implementation of the proposed capital improvement program for the ventilation system, estimated at US\$34.4 million and scheduled for two years.

16. Korea High Speed Rail Project - Aerodynamic Study.

Tyco performed an Aerodynamic Study of the Taejon and Taegu underground stations of the new Korea High Speed Rail Project, as sub consultant to Bechtel International. The study involved computer modelling and simulation of aerodynamic conditions created by high speed trains passing through the two long tunnels (15 and 18 km) in the cities of Taejon and Taegu, and the impacts of pressure transients on the passengers and station structures.

17. Bucharest Metro Ventilation Rehabilitation Study.

Tyco performed this study funded by the U.S. Trade and Development Agency for the Bucharest Metro. The existing ventilation system does not satisfy current industry standards for fire emergency and smoke control.

Two different models were prepared and fire simulations conducted for both station and tunnel fires, using the SES computer program. Required fan capacities, operation modes and changes to the existing ventilation structures were evaluated and cost estimated. Our recommendations were implemented during the construction of a new extension.

18. London Underground Limited (LUL) - Jubilee Line Extension

Tyco was part of the design team retained by the LUL for this project. The new Jubilee Line Extension consists of eleven new stations, eight underground and three at grade. Of those eleven stations, six provide interchanges to other LUL lines, six provide interchanges to British Rail services, and three provide interchanges to the Docklands LRT. A new yard and shop facility was provided adjacent to the new terminal station, as well as a new control centre constructed adjacent to the existing portion of the line.

To estimate the expected environmental conditions that would result from normal, congested, and emergency conditions, computer models of the baseline ventilation system were developed for analysis by the SES computer program. Computer simulations were made of normal train operation to identify areas with air temperatures or air velocities exceeding the design criteria. System modifications such as tunnel enlargements or the addition of draught relief shafts were examined in order to determine what steps should be taken to provide all areas with an acceptable environment.

The impact of certain design changes was also evaluated. These changes included the elimination of transition tunnels at the ends of stations, elimination/relocation of certain ventilation shafts, and elimination of fan by-pass areas. Train fire emergency conditions were examined for trains in tunnels between stations and for trains in stations. Also, special conditions were examined to develop a more complete understanding of the ventilation system capabilities.

Congested conditions were simulated to determine what fan operation would be required if trains were delayed for extended periods in the tunnels. The SES computer program was used to perform the computations necessary to predict the environmental conditions of the underground that would result during normal, congested, and emergency conditions.

In order to evaluate the effectiveness of tunnel ventilation under emergency conditions, a "worst-case" train fire condition was considered. If the ventilation system can adequately ventilate the fire under these worst-case conditions, then it can adequately ventilate the fire under any other emergency conditions.

For a station fire, adequacy of ventilation was judged by the ability of the fans to provide fresh air, remove smoke, and maintain a clean evacuation route for the duration of the evacuation.

Several locations for tunnel fires and fires at each and every station were simulated under different local conditions and fan operations.

Several special issues related to the tunnel ventilation on the Jubilee Line Extension were also addressed. These issues include:

- The impact of adding full height platform screen doors at stations
- An evaluation of the fan requirements between a station and a portal
- Evaluation of pressure transients and site-specific deviations.

In 1995, Tyco was retained by the JLE Project Team as an outside (independent) consultant to review the detailed design and equipment specifications. On this consultancy agreement basis we provided technical support and documentation review during the detail design and construction phase to ensure conformance to the preliminary design and design criteria established earlier.

Jubilee Line Extension Project is now complete and in operation. The ventilation system was implemented based on the conceptual and preliminary design by Tyco, and their review of the final, detailed design.

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19. Dallas Area Rapid Transit (DART) Ventilation Study

This study was performed by Tyco to evaluate the requirements for ventilation and air-conditioning system designed by Sverdrup Engineers for the new City place Station, as well as the emergency evacuation in case of a fire in tunnels or at the station platforms.

Both SES and CFD computer programs were used for the evaluation of the ventilation requirements of the 3.4-mile (5.5km) section of the DART subway. Based on the application of the CFD technique in the analysis of smoke and heat migration in case of a major fire at the station platform we recommended the Fan-Damper Operation Mode (table) that was later implemented.

20. New York City Transit - System wide Ventilation Study

Tyco teamed up with Parsons Brinckerhoff, Quade and Douglas to conduct this two-year study for the entire network of tunnels and underground stations in the Greater New York City area. Our engineers participated in the development of design criteria and project standards.

Tyco was responsible for the application of modelling technique for the assigned parts of the subway network of tunnels, stations, fan plants and other structures. Conducted numerous computer simulations using the SES program. Numerous fire scenarios have been analyzed for low-intensity, intermediate-intensity and high-intensity fires, using the "*worst-case*" concept for each section of the assigned tunnels and stations.

Strategy concepts of meeting the industry standards and NFPA 130 requirements were developed, as well as recommendations for the system wide upgrade of the ventilation system summarized in an eight-volume report.

21. New York City Transit Authority, Emergency Ventilation Study

Tyco prepared the Emergency Ventilation Study for the new Archer Avenue and 63rd Street lines, using the DOT-sponsored SES computer program. Prepared the ventilation models and all input data required ran the program in various "*worst-case*" scenarios, prepared reports and made presentations to NYCTA.

22. Baltimore Metro Tunnel Ventilation Design

This transit system was the first one designed from the beginning using the SES computer program. Tyco prepared and simulated models and conditions for various sections of the system by running the SES computer program to simulate various environmental situations and fire scenarios, to determine required air conditioning loads at stations, emergency fan capabilities and operating modes.

23. San Francisco Bay Area Rapid Transit (BART), Oakland Wye Ventilation Study.

This study was conducted to evaluate the ventilation requirements and available fan capacity of the Oakland Wye system, consisting of three underground stations and several miles of connecting tunnels, eight portals, and twenty fan plants. Various fan operation modes were simulated, as well as the use of air barriers to restrict the air flow where it was not desired, and to force the air along the simulated train fire in order to satisfy the "*Critical Velocity*" criteria.

Since the simulations demonstrated that the existing ventilation system capabilities for some locations in the Oakland Wye were inadequate for a major fire, BART retained us to conduct a Risk Assessment Study. The study analysed both normal and abnormal train operations to determine the likelihood of an incident occurring in an area where the existing ventilation system may not maintain control of the heat and smoke. The study used BART statistics on incidents and accidents, as well as data from other sources, such as Federal Transportation Administration (FTA) and Volpe National Transportation Systems Centre (VNTSC) to determine various levels of risk.

24. Toronto Transit Commission (TTC), Spadina Line Extension

Tyco performed a detailed design and examined the structural design of the West Sheppard Station and adjacent tunnels in view of providing adequate ventilation capacity and flexibility in case of emergency situations.

We performed SES computer simulations for the new station and tunnels, for both normal and emergency conditions, and were responsible for the three-dimensional station model, using the CFD technique, to examine the spread of smoke and heat in case of a fire. The station was built based on our design and is now in operation.

25. Airport Busway HOV Facility Ventilation Study

The objective of the ventilation system design for Berry Street and Wabash Tunnels was to provide for a high quality, economical system that is easy to maintain and operate. For normal conditions the ventilation system should be able to remove vehicle heat, smoke and exhausts and to flush contaminated air and dangerous heavy gases that could be trapped in the invert. During fire emergencies, the system should be able to control the direction of the smoke movement and the air temperature to allow for a safe evacuation of passengers/commuters and to facilitate fire fighting.

Both emergency and normal ventilation requirements were investigated in depth. The ventilation systems designed for Berry Street and Wabash Tunnels were simulated with various worst-case combinations for operating, traffic, ambient conditions and fire scenarios. Simulation results were summarized and compared with the ventilation requirements based on industry standards and federal regulations.

Design optimization was conducted to minimize the number of fans to be installed in these two tunnels. The emergency power supply issue was also addressed in the study. Finally, an investigation was performed to estimate the requirements of air quality monitoring and controls in these two tunnels.

Subway Environment Simulation (SES) software was used to simulate the fire in tunnel and to predict airflow for the scenarios examined. During normal operation, the ventilation system should be able to dilute and flush away the discharges from vehicles and maintain hazard gases concentration under certain levels. TUNVEN computer program was used to study this requirement for tunnel ventilation.

Wabash Tunnel has a length of 3645.8 ft, an area of 435.5 ft² and a grade of 0.953%. The traffic is uni-directional, with two lanes, high occupancy vehicles (HOV) representing 95% of traffic, the remaining 5% being regular buses.

Berry Street Tunnel has a length of 2980 ft, an area of 567 ft² a height of 21.5 ft and a grade of 0.48%, with two lanes of bi-directional traffic and buses used 100% (basic design condition).

The ambient conditions used in simulations were for winter with $T_{db} = 5^{\circ}\text{F}$ (97.5% occurrence).

The following fire sizes were simulated: HOV – 17 MBtu/hr (5 MW), Bus – 68 MBtu/hr (20 MW) and gas puddle – 341 MBtu/hr (100 MW).

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