King's Cross Fire in the London Underground November 18, 1987

A Report for Dr A. Buchanan Dept. of Civil Engineering Canterbury University

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Summary : The Night That Luck Ran Out.

The King's Cross tube station is one of the busiest and most complex in the London Underground network. In 1987, an average of 250,000 passengers were carried every weekday, with 100,000 in each of the peak periods 07:30 - 10:00 and 16:00 - 18:30.

Up until 18 November 1987, fire had only killed one person in London's Underground since the Second World War. However, a serious fire in the Oxford Circus station in November 1984 prompted an independent report to criticise lax fire precautions. The report concluded by saying "luck has a habit of running out." At 19:45 on Wednesday, November 18, 1987, the luck of the London Underground ran out. It was the worst fire in the history of the London Underground, with 31 people dying and many more seriously injured.

The fire began in a mixture of grease and debris which had accumulated on the running tracks of the Piccadilly line escalator number four during its entire operating life. It was later found that the escalator had never been completely cleaned since being installed in 1939. Ignition was attributed to a discarded match of a smoker, which fell between the tread and the skirting board of the escalator. Even though smoking is banned in the Underground, passengers are known to light up whilst riding the escalators to the surface. For twenty minutes after ignition the fire grew only slowly, eye-witnesses suggesting that no one expected a major incident to result. At 19:45, disaster struck in a fraction of a second. During the flashover, eye-witnesses said a huge ball of flame shot from the throat of the escalator shaft across the ceiling of the booking hall. Then all was total darkness and searing heat, the electricity went off, and the whole concourse was shrouded in impenetrable smoke. In the following hours chaos and confusion reigned, both in the station and on the streets above.

A full public inquiry was initiated by the then Prime Minister Margaret Thatcher. Beginning on February 2, 1988, the inquiry lasted about five months, the longest of its kind in British history. Our report contains research into several aspects of this event. Included are conclusions of the official investigation into the cause of the fire behaviour. The investigation uncovered a previously unknown effect termed the "trench effect". We also cover the serious disregard to fire safety displayed by London Underground Limited. It is obvious that if better safety procedures had been implemented prior to the fire, on the night that luck ran out, every life at King's Cross station may well have been saved.

(1) Introduction

(1.1) Setting The Scene [1,2]

The King's Cross area is the most intense centre of railway traffic in London. The underground station is built at five different levels, with a labyrinth of passages, shafts and tunnels, including a subway which connects the Piccadilly and Victoria platforms to the Midland City Station.

In 1987, the King's Cross Underground Station was the busiest station on the underground network. On average 250,000 passengers were carried every weekday, with 100,000 in each peak period 07:30 - 10:00 and 16:00 - 18:30.

The area of importance on the night of the disaster was the Tube Lines Ticket Hall (figure 1). There are two sets of escalators from the tube lines ticket hall, one serving the Northern and Piccadilly lines (where the fire started), and the other the Victoria line. In the ticket hall itself, a temporary hoarding had been erected across the right hand side of the ticket hall looking to the street from the Piccadilly escalator. This was to conceal from the public view workmen who were constructing a new station operations room. The hoarding had been painted with approved paint, but it also covered from view and access by people in the ticket hall the only fire hydrant and hose in the ticket hall area.

Figure 2 shows the basic layout of upper and lower escalator machine rooms. Because of a history of fires on these escalators, they had been fitted with "water fog" spray equipment. It had been originally intended that these sprays be operated daily to dampen down any smouldering or burning escalator components. The escalators were meant to be cleaned completely six monthly; in practice they were cleaned eleven monthly, and never completely enough to remove all the excess grease and detritus (fluff, dead matches, cigarette butts, & discarded tickets) from the escalator running tracks.

(1.2) History Of Fires In The Underground [1]

London first began installing wooden escalators in its underground system in 1911. A few years prior to this, in 1903, there was a severe escalator fire in a Paris Metro underground station in which 83 people died. In a report on this fire, the Board of Trade recommended that wood in underground stations be removed. Therefore the installations of wooden escalators in London was clearly a step backwards, although metal escalators were not available until the 1960's.

On 24th December 1944, a particularly severe fire occurred in which all the escalators leading from Bakerloo line at Paddington station on the London Underground were completely gutted.

Following this fire, a review of escalator fires was performed. This stated that there had been 77 escalator fires in the period 1939 to 1944 and that MH, MA, and M type escalators were particularly prone to fire. The report attributed ignition to smokers material igniting accumulated dirt under the escalators.

As a result of this report, the frequency of cleaning escalators was increased, and water fog equipment was fitted experimentally to 2 escalators. By 1948, water fog equipment had been fitted to a further 19 escalators, including those at Kings Cross station.

During the 1960's, some of the wooden escalators in the London Underground network had the plywood balustrade panels and skirting boards replaced by metal.

In 1966, the installation of smoke detectors at Kings Cross was estimated at costing 450 pounds, but these were never installed. Following this in 1976, smoke detection systems were fitted to a new escalator in Baker Street station as a trial. They were considered to be unreliable, and were therefore not generally adopted elsewhere.

In the period of 1956 to 1988, London Underground records showed 400 fires had occurred on escalators. Some of these were classified as only "smoulderings", but were in fact serious enough to cause evacuations of stations, serious delays, and considerable damage to the escalators involved. Statistics of these fires indicated that 45% occurred on MH type escalators. It was apparent that these MH type escalators were particularly prone to fires on their running tracks.

Of these fires, 46 were reviewed, with results showing that the established or attributed cause of fire was :

Smokers material	:	32
Electrical	:	8
Friction	:	1
Unknown	:	5

The investigation conducted into the Kings Cross fire found that the "keeping and analysis of statistics on fires by London Underground was quite unsatisfactory."

(1.3) Description Of MH Type Escalators [1]

During the period 1931 to 1961, a total of 108 'M' series escalators were installed on the London Underground network. The MH type machines were designed as special purpose machines for high rises and heavy traffic. They had a maximum rise of 27.5m and were designed for speeds between 30 and 35 metres per minute. All 'M' series machines (with the exception of MY type) were similar in appearance with wooden balustrading, decking, side panels, cleated steps, and risers. (figures 3 & 4) The escalator steps are metal backed plywood with maple wood cleats. At each side of the step is a metal "fire cleat", a tray which covers the

gap between the step and the skirting board. This gap may vary with running chain adjustment, but may be as much as 15mm. The purpose of these trays is to prevent cigarette ends and matches falling through this gap. On the Kings Cross escalators, about one third of these cleats were missing. Many of these MH type escalators were still in use in 1989.

The three MH type escalators in Kings Cross between the ticket hall and the Piccadilly line were installed in 1939. They were inclined at 30° and had a rise of 17.2m.

Figure 2 shows a longitudinal section of the escalator in its shaft, including the upper and lower machine rooms and layout of water fog spray nozzles. The upper machine room houses the :

- electric drive motors
- worm reduction gears
- chain drives to the driveshaft for each of the escalators
- electrical control gear
- circuit breakers connecting motors to mains supply
- water fog controls

The water fog equipment consists of pairs of sprinkler heads spaced at about 2m along the length of the escalators. The sprinkler heads are located each side of the centre line of the escalator with one of each pair pointing up towards the underneath of the steps, and the other downwards on the returning idle steps. The handrail driving gear is sprayed at the top of the escalator, and is controlled by a totally separate system.

The original intention of the water fog equipment was for it to be operated for a short time each night to dampen down any smouldering or burning escalator components. This procedure was practiced for some time until it became apparent that unacceptable corrosion of the machine was occurring. However, at the same time, some of the more flammable detritus was being removed by this procedure.

During the period 1948 to 1958 numerous proposals were presented on the installation of smoke detection systems that would automatically start the water fog equipment when alerted. The proposals were subsequently rejected on the grounds that the M series escalators did not have enough life left in them to justify expenditure. In fact, some of these escalators were expected to remain in use well into the next century.

The lower machine room houses the :

- lower carriages of the three escalators. These carriages carry the idle sprocket wheels over which the escalator steps pass by, and the chain drives to the handrail wheels.
- sump pump.

It can be seen by reference to figure 3 that there are two pairs of wheels beneath each step on the escalator, each running on the same track. One pair of these wheels, the chain wheels, run on

the outside of the track, whilst the other pair, the trailer wheels, run on the inside. A gap of 15cm exists between these two sets of wheels, allowing a large buildup of grease and debris to accumulate, which is difficult to remove. The difficulty in inspecting the machines is also apparent by reference to the cross section shown in figure 2. Here it is seen that there are three access stairways in the escalator shaft, one narrow access between each escalators 4 and 5, and 5 and 6, and a central, wider stairway under escalator 5. The central stairway is flanked on each side by supporting walls for escalator 5. These walls have periodic gaps through which the only, and very restricted view can be seen of the underneath of escalators 4 and 6.

After the November 1987 fire, the escalator maintenance manager at Kings Cross explained to the investigation team that the running track was only cleaned by hand, and was virtually impossible to reach without dismantling the escalator. He also stated that it had never been the practice of London Underground to remove escalator steps to facilitate cleaning, and that to the best of his knowledge the running tracks of escalators 4, 5, and 6 at Kings Cross had never been completely cleaned.

(2) The King's Cross Fire, 1987

(2.1) Timing Of The Fire [1,2,4,5,6]

The precise timing during the fire and the exact order of events cannot be established with absolute certainty. However, listed below is a sequence of events collected from various sources, which have been combined and checked against one another. These provide the most accurate account of events that took place during the fire that we could obtain.

19:25 - Suggested ignition time from in-situ fire test

19:29 - Passenger noticed a small fire underneath a step on the right hand side of the escalator about one third to half the way up.

19:30 - Another passenger noticed smoke two thirds of the way up, pressed the stop button, and shouted to people to get off the escalator.

19:32 - A British Transport Policeman (BTP) inspected the fire and saw flames just emerging from a gap between the sides and stairs of escalator, over the length of one step. He assessed the fire to be more serious underneath than it appeared to be on top.

- Escalators 5 and 6 were stopped.
- Further alarm was raised with booking clerk by another passenger.

19:33 - BTP control room was informed of the fire by a policeman from above ground. Contact could only be made by radio from above ground.

19:34 - London Fire Brigade (LFB) Headquarters at Wembley control room alerted of fire.

19:35 - Relief Station Inspector went to lower machine room. He saw and smelt nothing.

19:36 - BTP ordered evacuation of people up Victoria Line escalator.

- Escalator 4 blocked off with tape and builders skip at foot of escalator. People were seen to be stepping over tape and walking up escalator after this.
- 4 pump appliances and a turntable ladder were dispatched from Soho, Clerkenwell, and Manchester Square fire stations. The appliances at the nearest station were already out on another call.

19:37 - Light smoke was noticed at the station entrance.

- Piccadilly line controller informed of incident whilst discussing another matter with BTP information officer.

19:38 - LFB controller told London Underground Headquarters controller of a report of fire at Kings Cross station.

- BTP men observed fire as mainly on one side and stretching about half the way across the width of the escalator, over one or two steps. The fire was clean burning, with flames at about handrail height. The position was estimated as about half way down the escalator. In the period up to 19:43, other witnesses made similar observations to this report. This suggests that the fire was established but spreading slowly.

- Relief Station Inspector entered upper machine room, where he saw smoke and flames from under escalator 4. He couldn't get close enough to the fire to use a CO_2 extinguisher. He did not attempt to use the water fog equipment, he was preoccupied and forgot about it.

19:39 - BTP decided to evacuate the station.

- Piccadilly line controller phoned HQ controller to report of fire.

19:40 - Evacuation began via Victoria line escalators.

- BTP made decision to order trains not to stop at Kings Cross.

19:41 - Booking clerk told by BTP to stop selling tickets.

- One set of gates at stairs leading to perimeter subway from ticket hall was closed by Police.

19:42 - Station Inspector went to ticket hall via Khyber Pass (figure 1), opening security gates en route, and met Relief Station Inspector who had just come out of upper machine room.

- Eastbound Piccadilly line train stopped, and passengers got out.

- Northbound Northern line train stopped, and 50 passengers got out.

- Booking staff ordered to evacuate. (No one alerted staff in shop in ticket hall or anyone in underground public toilets to the emergency).

- Fire engines started to arrive at Kings Cross.

19:42:45 - Fire officers Townsley and Bell entered Kings Cross station.

19:43:00 - Relief Station Inspector entered upper machine room and operated circuit breakers.

- Ambulance requested.

- Westbound Piccadilly line train stopped and let passengers out.

19:43:30 - Townsley and Bell arrived at the top of escalator 4, and assessed fire as being about 4 feet high, about one third of the way down, with not much smoke. They determined that although the fire was significant, there was nothing to suggest that it would spread rapidly. Townsley stayed at the top, whilst sending Bell down to the bottom.

19:44:00 - HQ controller sent order to Piccadilly and Victoria line controllers that trains were not to stop. (Northern line trains continued to stop normally until 19:48).

- Townsley sent a message to the surface confirming seriousness of fire and need for ambulances.

19:44:30 - Bell arrived at the bottom of the escalator and turned away three passengers who were attempting to go up escalator. The fire was reported to have spread from the trench of the escalator, with flames now 5 to 6 feet high, 4 to 5 yards long, with flames shooting up both sides of the escalator.

19:45:00 - Mr Bates, a passenger, entered the ticket hall from Victoria line escalator and saw a relatively small flame at the top of escalator 4, between 0 to 3 feet above the floor.

19:45:15 - **Flashover** (Time confirmed by digital clock at top of Piccadilly line escalator which stopped with the heat of the flashover)

- Mr Bates saw flames sweep across the ticket hall accompanied shortly after by thick black smoke.

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- BTP officer reported to have seen a jet of flame emerge from the top of the escalator and strike the ticket hall ceiling. As the jet hit the ceiling, the ceiling turned into a layer of flame, rapidly spreading outward. Very shortly afterwards, he saw massive quantities of dark smoke begin to appear.

- 30 people including officer Townsley were killed almost instantly, many more were seriously injured. One burn victim died a week later in hospital.

19:45:58 - Major incident emergency message sent to BTP HQ by radio.

19:46 - Northbound Victoria line train travelling at walking pace was flagged down and stopped. 150 to 200 people were evacuated on this train. The procedure was repeated with two other trains.

19:47 - London Ambulance service received request for attendance at Kings Cross station.

19:49 - Ambulances dispatched.

19:52 - Metropolitan lines platforms cleared of people.

19:53 - LFB controller informed London Underground HQ - "Full fire at Kings Cross."

19:55 - Last passengers evacuated.

19:57 - HQ controller phoned London Underground duty officer at home and informed him of the fire.

19:59 - First ambulance arrives.

20:05 - 9 BTP and Underground staff evacuated by Metropolitan line train.

20:06 - BTP Inspector erroneously told BTP information room that fire had been extinguished.

20:08 - London Ambulance service puts hospitals on alert.

20:12 - 6 ambulances were on the scene.

20:17 - Two BT policemen evacuated a seriously injured person through Midland City subway after a cleaner unlocked the security gates.

20:25 - Most of the London Underground staff left the station via the Midland City subway.

20:45 - Northern line train driver who had not received orders not to stop, stopped and let passengers out. The passengers were ordered to reboard the train by BTP.

20:53 - Plans of Kings Cross were brought to Fire Brigade officer in command.

21:05 - London Underground Incident officer arrived on the Underground and shortly afterwards went to the surface via the Midland City subway. He there met with LFB officer in command, but didn't say he had been below.

21:15 - Fire Brigade dispatched men to enter via Midland City subway. For one and a half hours up to this time there had been 2 separate groups fighting the fire from either side.

21:32 - 14 ambulances were on the scene.

21:40 - 2 further Underground staff found in mess room and evacuated.

21:48 - LFB sent message, "Fire surrounded."

01:46 - LFB sent message "Stop", indicating fire contained.

(2.2) Scientific Investigations [1,2,3]

Eye-witnesses to the rapid development of the fire and subsequent flashover in general agreed that up to a couple of minutes before flashover occurred the fire was not causing excessive panic. These eye-witnesses included some of the first firemen to arrive on the scene, one of whom said it was "not a big fire" and the fire was "burning like a large cardboard box."
In about two minutes the fire had spread up the escalator shaft and had engulfed the ticket hall, creating large quantities of dense, black smoke.

At the commencement of the Investigation by Desmond Fennell, Q.C., it became apparent that there were two conflicting mechanisms of rapid fire development proposed by the scientific community. Scientists were not able to scientifically corroborate eye-witness evidence about the rapid rate of flame spread until after the first presentation of scientific evidence.

Scientists engaged by LUL said that the rapid spread of fire in the two or three minutes leading up to the flashover was due to burning of the paint used on the ceiling of the Piccadilly line escalator tunnel. This proprietary product, B2, by PRODORITE Ltd, had been previously tested and approved by LUL for use in railway stations because of its low rate of flame spread characteristics. The paint system was in use at Oxford Circus when a fire occurred on 23 November 1984, and had, according to the subsequent investigation, "performed entirely satisfactorily" in that fire.

Scientists from the Health and Safety Executive (H.S.E.), Buxton, and from the University of Edinburgh maintained that the mechanism of rapid fire spread was due, in the main to burning of escalator number four. They said burning of the tunnel ceiling paint was a secondary factor in the rapid development of the fire.

(2.2.1) Paint Testing

Samples of unburnt paint were removed from the escalator tunnel ceiling and tested by the Chatfield Applied Research Laboratories Limited. These test results indicated that PRODORITE B2 paint did not have the rapid flame spread characteristics that would have been required of it on the night of the fire. The flame spread rate of the paint when tested was on the order of tens of centimetres per minute and not the metres per minute that eye-witnesses said the flames travelled at.

(2.2.2) Ignition Testing

Tests were carried out on a variety of materials taken from the vicinity of the escalator. The most significant finding was that grease used to lubricate the escalator, although relatively difficult to ignite when on its own, could easily be ignited by

a small flame when mixed with detritus as found beneath the escalator.

An in-situ fire test was carried out on 8 January 1988 using an unburnt section of number four escalator. Three attempts to initiate a fire were made by dropping a smouldering cigarette through the gap at the side of the escalator onto the grease and detritus underneath. These attempts all failed, however the first lighted match dropped initiated a fire on the grease/fluff layer. Within three minutes the fire had travelled over one metre and the skirting board immediately above began to burn. After six to seven minutes the fire was developing rapidly beneath the escalator and flames were reaching up and preheating the sides of the escalator. However on the passenger side of the escalator, flames were only just becoming visible as they started to burn the bottom of the balustrades. The fire was extinguished for safety reasons at nine minutes.

(2.2.3) Numerical Modelling

In December 1987, the AERE Harwell Laboratory was commissioned by H.S.E. to carry out numerical modelling of the flows and temperature distributions in the Piccadilly Line escalator shaft and tube lines ticket hall in the time leading up to and after flashover. Harwell utilised their own HARWELL-FLOW 3D software package and their CRAY-2 supercomputer to assist them. Several cases of different heat input configurations and different magnitudes of heat input were modelled. The phenomenon that was uncovered by this modelling was not anticipated by any of the scientists involved in the investigation. The gas flow from the fire did not rise to the ceiling of the escalator shaft, but remained concentrated in the trench formed by the moving stairs and the balustrades of escalator number four. As the flow progressed up the escalator it appeared to divide, with part rising out of the trench and spiralling across the ceiling, and the other part continuing up the escalator trench into the tube lines ticket hall. Once in the ticket hall, the flow tended to pass between the ticket office and the temporary hoarding erected by workmen (figure 1), and then out through the entry from the perimeter subway, with some flow sweeping round the back of the ticket hall.

(2.2.4) Scale Testing

The results of the Harwell computer simulations prompted the H.S.E. at Buxton to carry out some fire tests on one-tenth scale models. The tests were done using cardboard lined, plywood backed trenches inclined at thirty degrees to the horizontal. These tests clearly demonstrated (figures 5a to 5d) what is now known as the "trench effect" whereby flames from the fire remained low-lying in the escalator shaft. Three factors combined to create this "trench effect" on the night of the fire. They were the slope of the escalator shaft (30°), the trench profile which affected the lateral movement of air and hot gases, and the

presence of flammable materials in the trench.

Following the indicative results of the one-tenth scale test a one third scale model was built and tested by H.S.E. at their Buxton test site. The model comprised approximately two thirds of the length of number four escalator including all essential wooden components. The escalator shaft and ticket hall ceilings were constructed from steel plate, as were the top end of escalators five and six. Four tests were carried out on the model. In the first three tests, the fire was started simultaneously across the full width of the escalator at the equivalent point to where the fire was presumed to have started in the actual incident. In the last test the fire was started across only half the staircase width. This was because inspection of the escalator after the fire indicated the fire started on the right side of escalator four's running tracks. In all the tests, once the fire became established, it travelled up the escalator at an exponentially increasing rate. In the last test it took forty seconds to reach the ticket hall. The flame front then jetted into the ticket hall with a velocity in excess of six to eight metres per minute, with virtually no prior warning of its impending arrival.

The increasing rate of advance of the fire was due to the flames lying down in the trench because of air entrainment both from above the fire and further down the escalator trench, and to a much lesser extent to air movements caused by trains arriving into the stations and forcing air up the escalator shaft. The flames lying down caused them to extend ahead of the burning wood, which resulted in both convective and radiative preheating of the wood. As the length of burning material increased, so did the flame length and the rate of advance of the fire up the shaft. Just before the flames shot into the ticket hall, flames also began to corkscrew across the tunnel roof. This set the paint alight and contributed to large amounts of dense, black smoke being generated. The time taken for the flame front to travel from the fire initiation point to the ticket hall (figure 6) was thirty to forty five seconds.

Using modelling criteria the H.S.E. were able to state that a full size fire could possibly take less time than the one third scale fire to transform from a relatively minor fire about halfway down the escalator shaft into a jet of flame entering the ticket hall and causing an uncontrollable major conflagration.

(2.3) Safety - What Was Missing? [1,2,3,6]

The need for high levels of safety in railway stations had long been recognised by authorities operating them. However, despite opportunities for LUL to improve their safety standards over the years, there had been very little work done by them to upgrade standards until the time of the King's Cross fire. LUL staff safety training was virtually non-existent.

On-site active fire fighting equipment consisted of one hydrant

and hose reel in the ticket hall, and the water fog spray equipment under the escalators. Some temporary hoarding had been erected in the ticket hall area to allow station renovations to be carried out without inconveniencing passengers. However, the hydrant and hose reel were hidden from public view behind this hoarding and the LFB were not informed the hoarding was erected. The hydrant was of a type not able to be connected into the LFB fire fighting equipment. The manually operated water fog system was accessible only through a locked door leading to the upper machine room. Most staff on duty were not even aware the system existed. There were no signs to indicate to passengers what to do in the case of an emergency, and no designated fire wardens amongst the on-duty staff. The LFB were not given clear instructions as to the exact location of the fire when they were first informed of the incident, and they did not have their own set of station layout plans. There was a set of layout plans in the ticket hall, but these were near the hydrant and hose reel and were also hidden from view.

The LFB, after a fire at the Oxford Circus Underground Station in 1984, during which they were not called as soon as the fire was discovered, sent a strongly worded memo to LUL authorities insisting that the LFB be called immediately a fire was suspected. Up to the time of the King's Cross fire, the LUL rule book told employees that, if they discovered a fire they should first try to extinguish it themselves and if that was not possible , only then should they call for Fire Brigade backup. Almost all of the staff on duty on the night of the fire had had no more than half an hour training in the use of safety equipment, and no training in the emergency evacuation of the station. The Station Inspector on duty on the night of the fire, who was the most senior member of LUL working in the station, had been given limited training in safety.

When the Station Inspector was notified of the fire, he went to investigate. However, instead of activating the water fog system, he tried to use a CO_2 fire extinguisher. He was unable to get close enough to the fire to effectively operate the extinguisher.

The water fog equipment was to be operated manually because of the possible electrical hazard to the escalator machinery should the water fog be accidentally triggered. No smoke detectors or heat sensors were in place under the escalators. These would have given the LFB an immediate indication as to the source of the fire upon their arrival at the station.

The BTP decided to evacuate the station, and sent a radio message to the Underground Line Controller ordering trains not to stop at King's Cross. The BTP evacuated passengers up the Victoria Line escalators. Some of the evacuees would be caught by the flashover minutes later. Previous LUL safety reports had indicated that in the event of a fire in an station, one of the best methods of evacuation would be via train. The BTP did not know this because they had not received training on emergency evacuation procedures of the station.

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After the LFB were called, a BTP officer was sent above ground to await the arrival of the LFB. However, there was no designated rendezvous point for either emergency services, staff, or passengers. The LFB initially went to the wrong entrance to the station.

Throughout the incident, no use was made of the Public Address system in the Underground to either alert passengers to the need to evacuate the station, or to co-ordinate staff involved in the evacuation.

(3) Conclusions

Prior to the November 1987 King's Cross fire, there had been a large number of fires in London Underground stations. The majority of these had been attributed to smokers dropping matches or cigarette butts. Many of the fires had involved wooden escalators. London Underground Limited had been advised many times following previous fire investigations that they should improve the quality of their staff emergency procedure training. They were also advised to replace wooden parts of escalators with metal, and to increase the frequency of cleaning of these escalators. Installation of detection equipment in the Underground network was another suggestion that was neglected.

On the night of the fire, the reaction of staff to the presence of the fire was slow and disorganised. The LFB was not notified about the fire until 5 minutes after it was reported to LUL staff. This was 10 minutes after the fire had started. When the Fire Brigade did arrive, they were not sure where to go to locate the fire. The Fire Brigade were present for only about 2 minutes before flashover occurred. From the time the fire started until flashover (about 20 minutes), not one drop of water had been put on the fire.

The scientific investigation into the fire uncovered a previously unknown phenomenon termed the "trench effect". This was discovered after numerical modelling of the fire was carried out using a computer program for fluid flow analysis. Scale testing was then done to confirm the results of the computer model. The trench effect occurred because the fire was burning on an inclined surface, surrounded by the floor and two sides of the escalator, which were all constructed of flammable material, forming a trench. Once the fire developed, the flames spread at an approximately exponentially increasing rate up the escalator shaft as the wood ahead of the pyrolysis front was preheated to ignition temperature.

Following the investigation, LUL was advised to dramatically change its approach to safety in their Underground network. These recommendations included :

- All escalator trusses be fitted with heat detectors
- Machine rooms be fitted with smoke detectors

- The detection equipment be connected to an alarm system, automatic sprinklers, or water fog equipment
- A replacement program for older escalators be established

The investigation into the cause of the fire, [1], made a total of 157 recommendations which covered LUL and the emergency services.

(4) Acknowledgements

We would like to thank Dr A. Buchanan for initially indicating how important the "trench effect" was.

We would like to thank the staff of the Christchurch City Public Library for their invaluable help with the use of, and copying from the microfilm catalogue.

(5) References

[1] *Investigation Into The King's Cross Fire. A Report for the Secretary of State for Transport by Desmond Fennell, OBE, QC November, 1988. Engineering School Library.*

[2] *The King's Cross Fire: Fire Dynamics And The Organization Of Safety. Papers presented to an Institution of Mechanical Engineers seminar. June 1989. Engineering School Library.*

[3] *New Scientist - 21 February 1985 (page 5)and 7 July 1988 (pages 29, 30 and 31). Engineering School Library.*

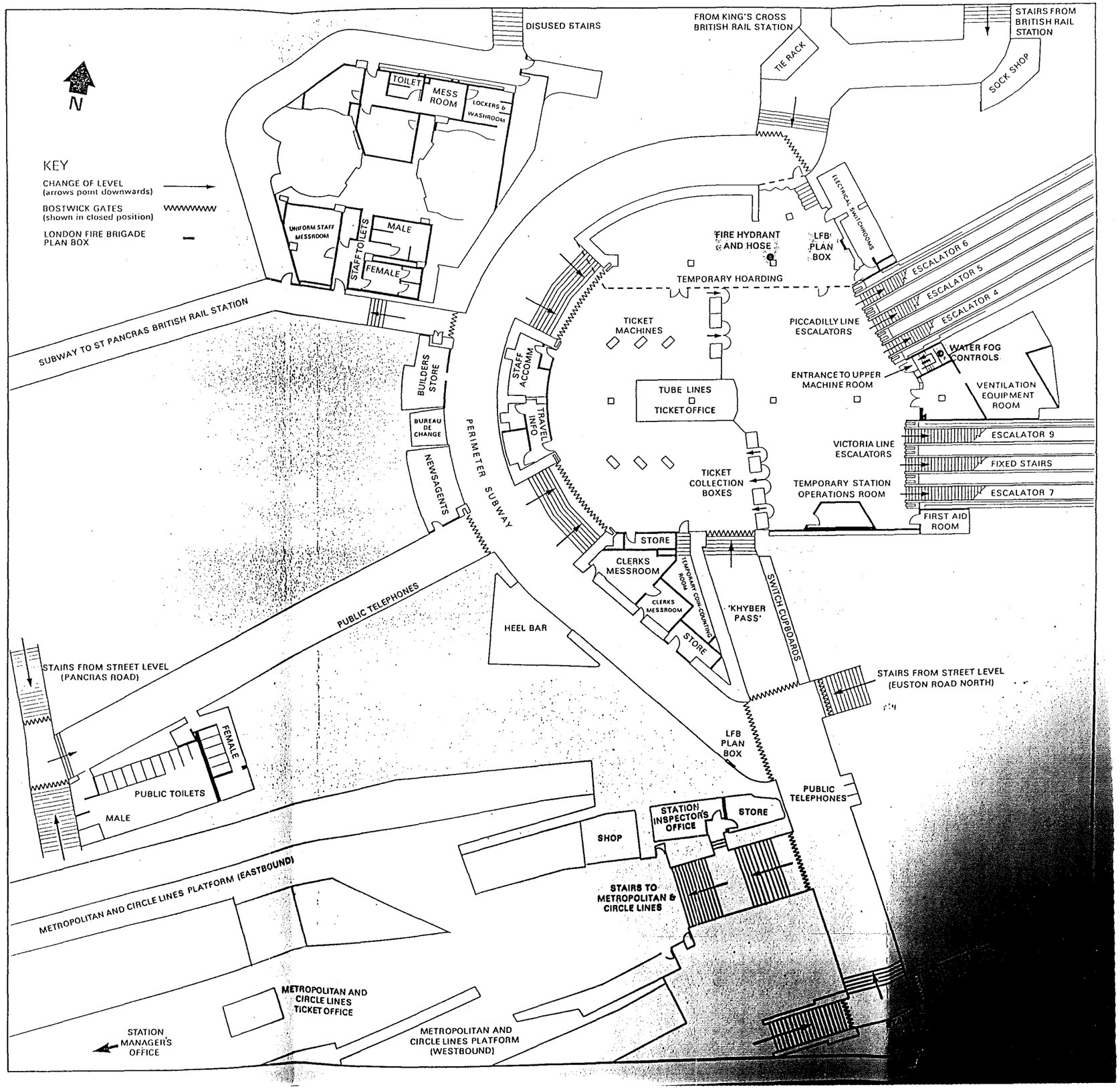
[4] *The Times newspaper, London, England, November 19, 20, 21, 23, and 24. Christchurch City Public Library.*

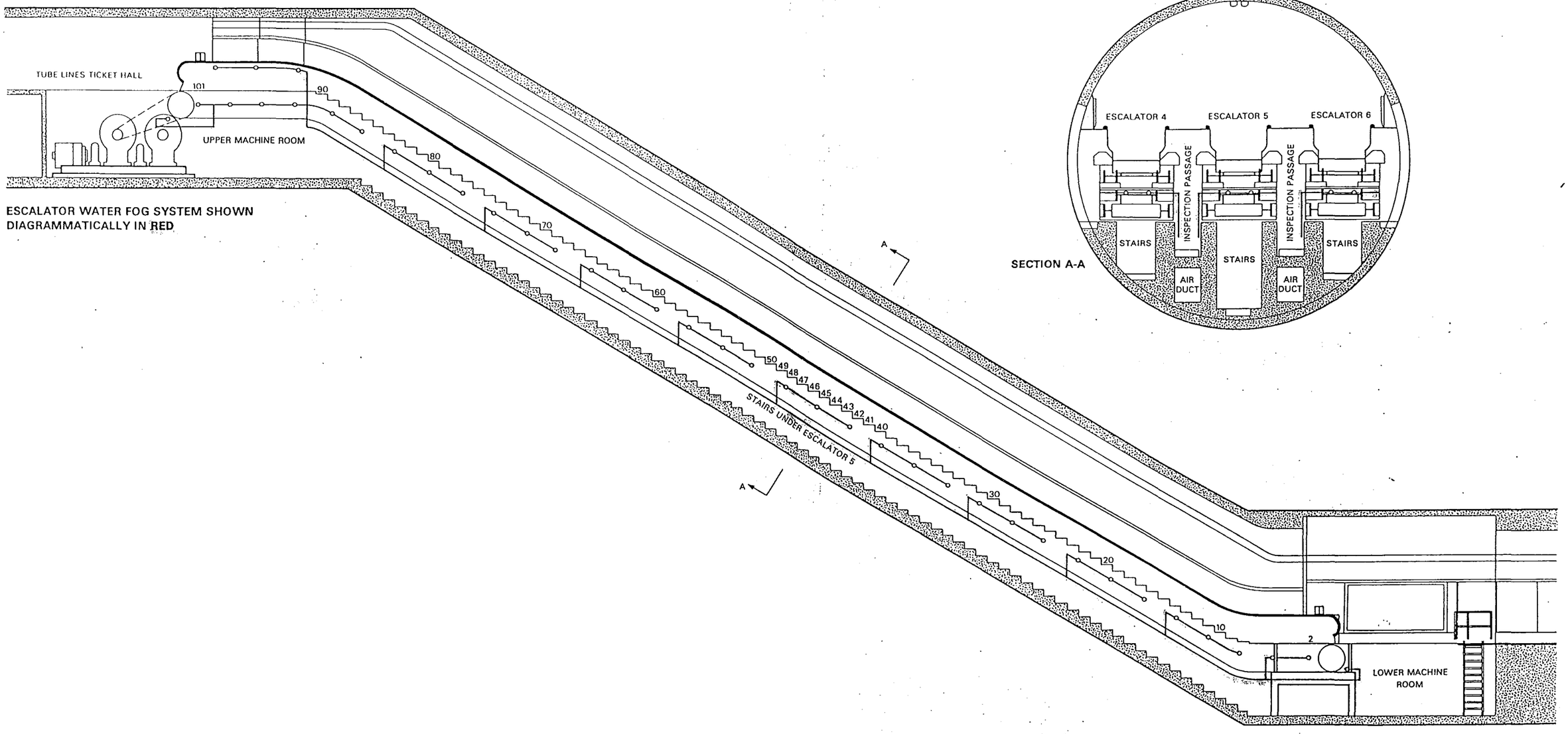
[5] *The Press newspaper, Christchurch, New Zealand, December 5, 1987. Christchurch City Public Library.*

[6] *Reader's Digest, Special Feature, Bob Woffinden, December, 1990.*

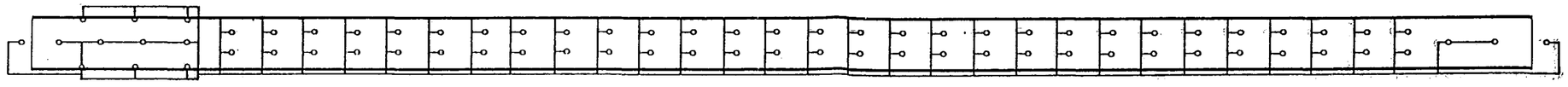
[7] *Figures 1, 2, 3, 4 and 6 were taken from [1] Figures 5a, 5b, 5c and 5d were taken from [2]*

FIGURE 1


N
KEY
CHANGE OF LEVEL (arrows point downwards)
BOSTWICK GATES (shown in closed position)
LONDON FIRE BRIGADE PLAN BOX
DISUSED STAIRS
FROM KING'S CROSS BRITISH RAIL STATION
STAIRS FROM BRITISH RAIL STATION
TIE RACK
SOCK SHOP
TOILET
MESS ROOM
LOCKERS & WASHROOM
UNIFORM STAFF MESSROOM
STAFF TOILETS
MALE
FEMALE
ELECTRICAL SWITCHROOMS
FIRE HYDRANT AND HOSE
LFB PLAN BOX
TEMPORARY HOARDING
ESCALATOR 6
ESCALATOR 5
ESCALATOR 4
SUBWAY TO ST PANCRAS BRITISH RAIL STATION
BUILDERS STORE
STAFF ACCOMM
TICKET MACHINES
PICCADILLY LINE ESCALATORS
WATER FOG CONTROLS
ENTRANCE TO UPPER MACHINE ROOM
VENTILATION EQUIPMENT ROOM
BUREAU DE CHANGE
TRAVEL INFO
TUBE LINES TICKET OFFICE
NEWSAGENTS
PERIMETER SUBWAY
VICTORIA LINE ESCALATORS
ESCALATOR 9
FIXED STAIRS
ESCALATOR 7
TICKET COLLECTION BOXES
TEMPORARY STATION OPERATIONS ROOM
FIRST AID ROOM
STORE
CLERKS MESSROOM
TEMPORARY COIN COUNTING ROOM
CLERKS MESSROOM
STORE
'KHYBER PASS'
SWITCH CUPBOARDS
PUBLIC TELEPHONES
HEEL BAR
STAIRS FROM STREET LEVEL (PANCRAS ROAD)
STAIRS FROM STREET LEVEL (EUSTON ROAD NORTH)
FEMALE
PUBLIC TOILETS
MALE
LFB PLAN BOX
PUBLIC TELEPHONES
STATION INSPECTOR'S OFFICE
STORE
SHOP
METROPOLITAN AND CIRCLE LINES PLATFORM (EASTBOUND)
STAIRS TO METROPOLITAN & CIRCLE LINES
METROPOLITAN AND CIRCLE LINES TICKET OFFICE
STATION MANAGER'S OFFICE
METROPOLITAN AND CIRCLE LINES PLATFORM (WESTBOUND)



DIAGRAMMATIC PLAN OF ESCALATOR WATER FOG SYSTEM



FIGURE

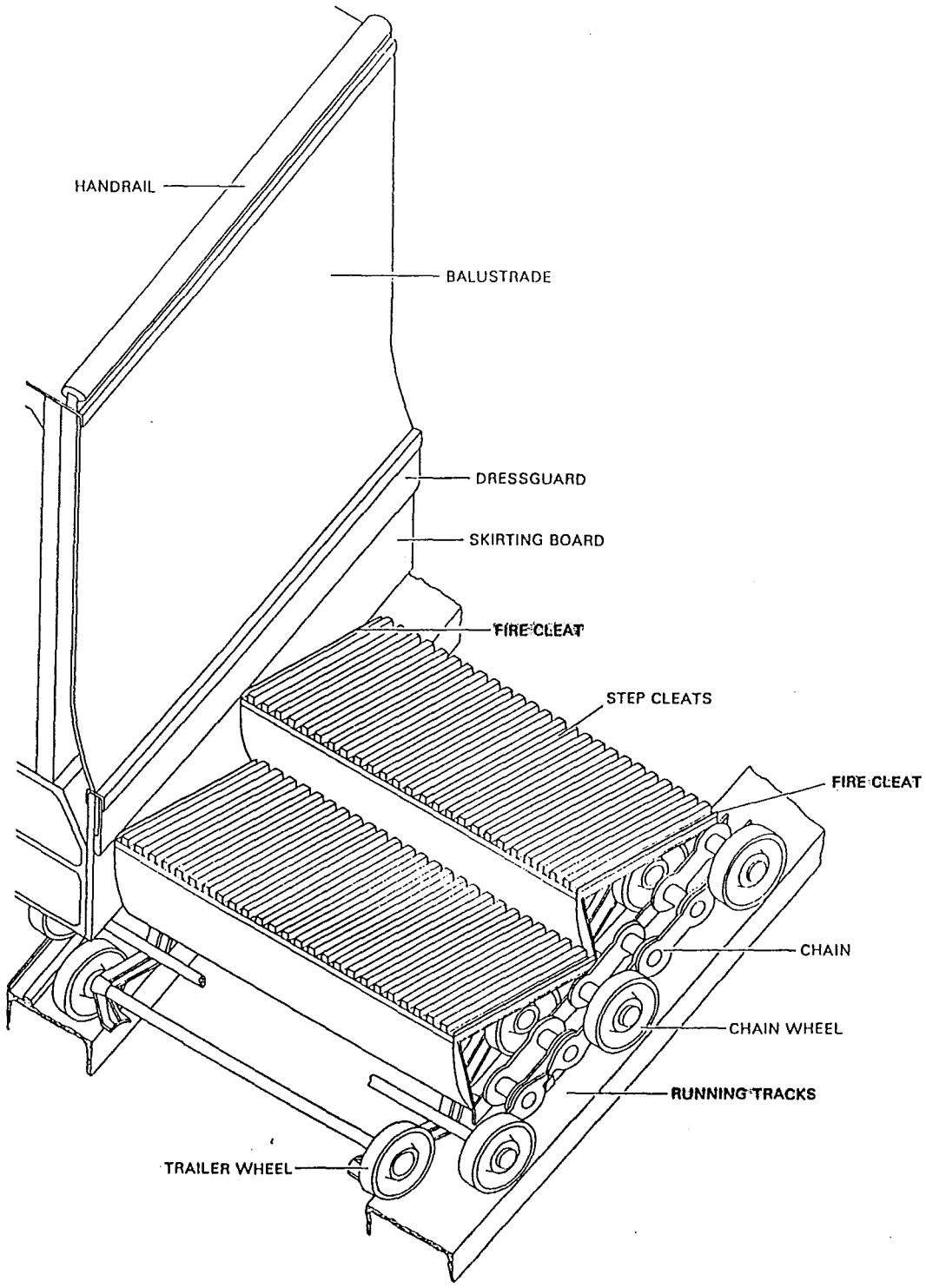
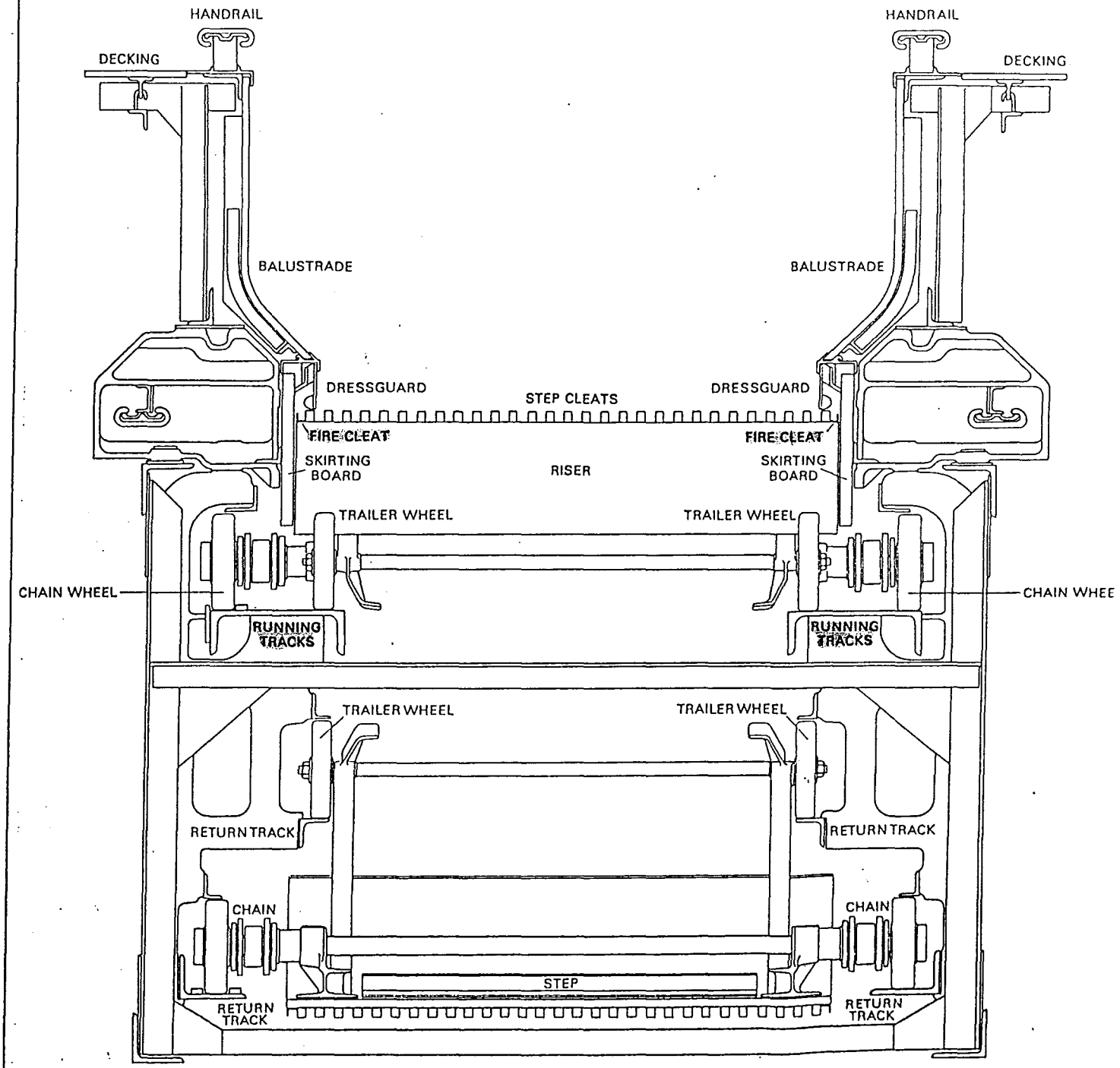

HANDRAIL
BALUSTRADE
DRESSGUARD
SKIRTING BOARD
FIRE CLEAT
STEP CLEATS
FIRE CLEAT
CHAIN
CHAIN WHEEL
RUNNING TRACKS
TRAILER WHEEL

FIGURE 4


HANDRAIL
DECKING
HANDRAIL
DECKING
BALUSTRADE
BALUSTRADE
DRESSGUARD
STEP CLEATS
DRESSGUARD
FIRE CLEAT
FIRE CLEAT
SKIRTING BOARD
RISER
SKIRTING BOARD
TRAILER WHEEL
TRAILER WHEEL
CHAIN WHEEL
CHAIN WHEE
RUNNING TRACKS
RUNNING TRACKS
TRAILER WHEEL
TRAILER WHEEL
RETURN TRACK
RETURN TRACK
CHAIN
CHAIN
STEP
RETURN TRACK
RETURN TRACK