Manapouri Power Station Fire Life Safety and Asset Upgrade.

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EEA Conference & Exhibition 2017, 21-23 June, Wellington

Abstract:

Manapouri Power Station is New Zealand's largest hydro power station, the jewel in the crown of the Meridian's hydropower generation portfolio, generating nominally 800 megawatts with seven hydropower generators. Construction was completed in 1969 and became fully operational in 1972.

The generation facility consists of a power house, located 220m underground with a road tunnel and lift access, and an above ground surface control building and switchyard.

Meridian Energy over the last 14 years, has undertaken a number of upgrades to enhance the fire life safety and fire asset protection, modernising and improving many systems that have life safety and fire asset protection impact. The most recent upgrade being the replacement of the power house ventilation systems, incorporating the consented requirements of the fire engineering strategy, being the final piece of the works to complete all proposed life safety and fire upgrades at the facility.

This paper discusses the unique nature of the facility, summarises the life and fire strategy employed and the challenges that this has involved from a fire, life safety and asset protection perspective. This has included the analysis of the power house fire scenarios and occupant emergency egress times, provision of a power house underground refuge area, explosion venting to the surface for the underground power transformers, upgrading of gaseous fire extinguishing systems to the generators and consented fire safety upgrades of the personnel lift for use as fire emergency egress.

This paper describes the fire strategy employed, assessment of the Manapouri facility against the fire strategy, a summary of the scope of works implemented and a summary of the life safety, and fire safety and asset protection benefits as a result of the physical works implemented.

1. INTRODUCTION

Meridian Energy's iconic Manapouri Power Station is New Zealand's largest hydro-powered electricity generation site. The power station is located in the Fiordland National Park, part of the Southwest New Zealand UN World Heritage area. The station can produce 830 megawatts.

The facility consists of a 3 storey above ground support building and underground power house. The above ground facility includes a switchyard area with enclosed cable gallery and backup diesel generators. The 3 storey Control Building includes power house ventilation plantrooms that supply and extract ventilation air to & from the underground powerhouse, and connecting lift shaft to the underground power house.

The power house is located 220m underground and accessed via a 2km road access tunnel and lift system as the prime means of access and emergency egress. Meridian allow guided tours of the underground facility by members of the public, with access restricted to controlled areas only, and limited numbers of tourists at any one time that are supervised and guided by competent trained personnel. Stairs are provided adjacent to the lift in a shared vertical riser, and there are 2 other separate riser shafts with dedicated ladders, neither of which is considered for regular use by occupants. The access ladders are in riser shafts that are wet, damp and typically not practical for general use, due to the vertical nature of the ladders separated by platforms, and the approximately 220m overall height of the riser shafts. These riser shafts are considered "last resort" escape routes when the lift, lift shaft stairs and road access tunnel are unavailable for egress. Access riser adits link the road tunnel to the lift shaft and secondary riser shafts.

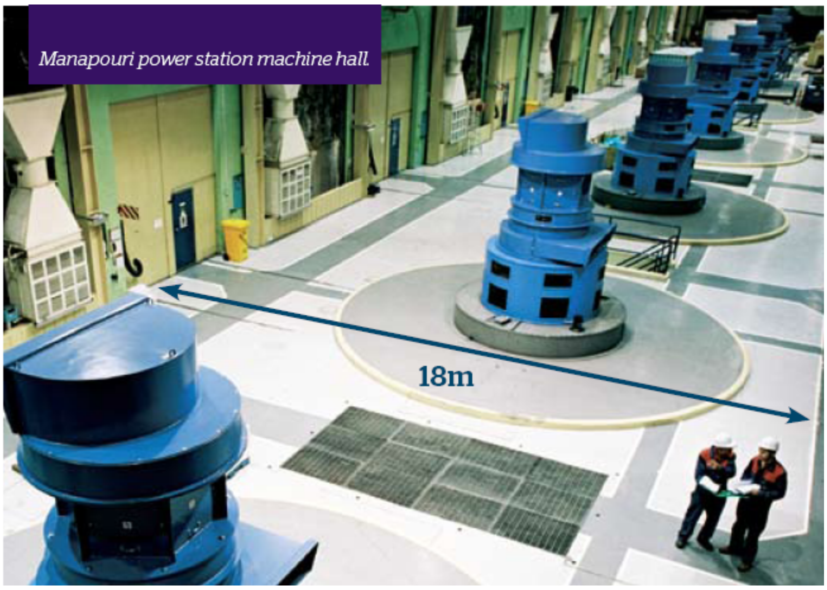

Figure 1 Manapouri Power Station Machine Hall Level

The above ground switchyard is linked to the Powerhouse via vertical shafts containing generator power cabling to the surface from the 7 generator transformers; two of which have ladders for "last resort" escape purposes. The transformers are located within fire separated transformer vaults within the underground power house.

The underground power house consists of a Machine Hall Floor, (with transformers and ceiling void), Stator/Generator Floor, Turbine Floor, Penstock Gallery, and Drainage Gallery with an overall elevational difference of 22 metres between the Drainage gallery and the Machine Hall floor.

The updated means of escape philosophy was developed very early on by Hamish MacLennan the Holmes Fire initial engineer on the project commissioned by Meridian Energy in May 2003. This has resulted in an ongoing relationship between Meridian Energy and Holmes Fire in the life and fire safety upgrade works as various refurbishment works have been undertaken since then and to date. The original concept as illustrated in Figure 1 with some refinement remains the overarching egress design for the Power Station.

The overall general layout of the facility is illustrated below in Figure 2, which is part of the consented fire strategy documentation. This is extracted from Holmes Fire, Fire Safety Strategy Report [1].

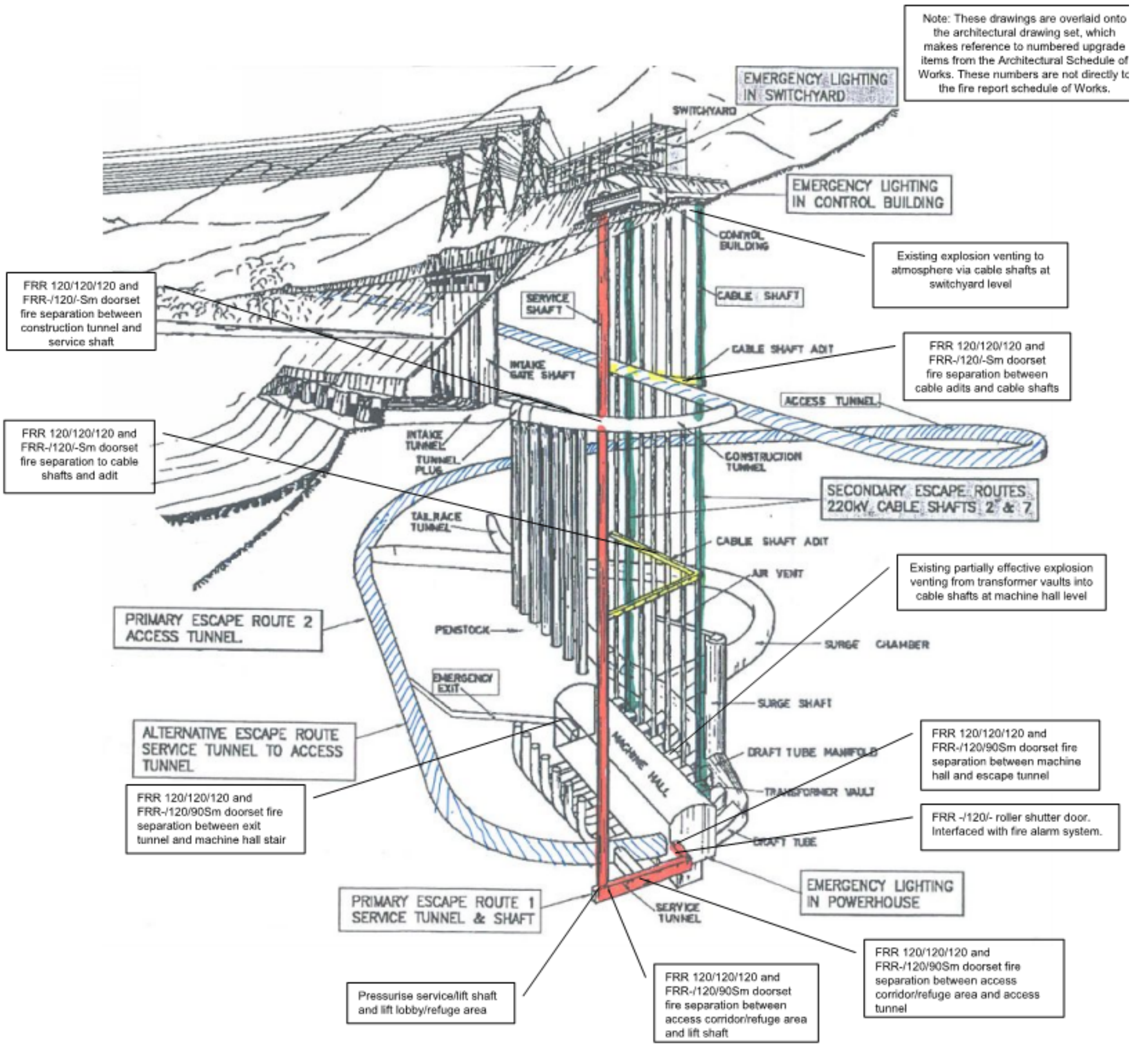

Figure 2 Manapouri Power Station Overall Egress Strategy

The challenges for Manapouri Power Station have included the following and this paper discusses some of these challenges and how they have been resolved and implemented.

1. Tourist buses visit the underground power house, though at the time of writing these visits have been suspended following the ventilation upgrade project, where the lift has been unavailable and more recently because of a re-evaluation of the tunnel traffic control system.
2. The location of the transformers underground in fire rated vaults with the original design having no explosion venting to the surface.
3. Operating 220m underground with access limited to 2 prime routes (lift shaft and road access tunnel), so that either one of these is viable in the event of a fire in the underground or above ground areas.
4. An underground power house that is open on multiple levels, which are interconnected by open stair voids and open hatchways.
5. A lift operation that involved waiting in the underground facility for a period of time, if the road access tunnel egress system is blocked.
6. Fire separation of the prime means of escape, (tunnel and lift), from an underground Power House fire, a fire in the road tunnel, and from each other.
7. Working more recently with the ventilation upgrade project to maintain continuity of life safety egress strategies whilst this work was in progress.
8. Works in wet areas requiring understanding of the high sulphur and moist environments relating to corrosion management and protection of systems and construction installed.
9. High pressure and high velocity ventilation systems using mining industry type fire damper technology and design strategies.
10. Maintaining a fire strategy for the Power House as various upgrade projects have been implemented, and ensuring that the works were consented with the cooperation of Southland District Council as legislative changes have occurred in how fire strategies in buildings are addressed.

2. SUMMARY OF FIRE LIFE SAFETY RELATED UPGRADE WORKS IMPLEMENTED IN CHRONOLOCICAL ORDER AT MANAPOURI POWER STATION SINCE 2002

Table 1 provides a summary of the works undertaken in chronological order and illustrates the extensive works and investment Meridian have made in addressing Manapouri Power Station's fire life safety and protection of the asset.

Approx. dates	Description of works	Comments
2002-2003	Upgraded emergency lighting exit signage works [1]	Initiated the building consent review of the entire complex.
2002-2003	Generator replacement suppression and detection systems. [1]	Installation including gaseous fire extinguishing systems to each generator and aspirating early warning smoke detection systems.
2005	2 hour roller shutter fire door installed between the Machine Hall and access tunnel.	Provides fire separation between the power house and road access tunnel, includes a modular construction to allow removal if need be, included surge venting dampers in the perimeter wall structure and fire door access. The door is sized to allow large items access including transformers.
2006	Partial explosion venting	These vent to the surface via the generator cable riser

Approx. dates	Description of works	Comments
	installed to transformer vaults.	shafts to the switchyard buildings.
2008-2009	Existing fire sprinkler systems coverage increased and upgraded. [1]	Generally throughout the facility where appropriate including covered cable gallery at above ground switchyard.
2008-2009	Smoke detection, warning systems and alarms upgrade works. [1]	Existing fire detection and alarm systems upgraded. Generally smoke detection installed throughout all areas of the Power House and Control Building.
2008-2009	Water supply tanks, external hydrants. [1]	New fire-fighting water tanks and upgraded in ground hydrant systems.
2010	Aspirating early warning smoke detection.	Installed to the Machine Hall floor at high and mid-levels.
2010-2011	Passive fire upgrade works throughout.	Works were extensive in terms of providing means of escape passive fire separation throughout the facility. Construction works included; - A new safe path internal stair transitioning 3 levels within the Power House from the Turbine Floor exiting directly to the road access tunnel, at the viewing platform end of the Power House from the lower levels. - A new fire and smoke separated underground safe refuge area for occupants to wait whilst the lift operates to transport occupants to the surface. - Fire separation between the Machine Hall (including roof void), and road access tunnel at the visitor's platform end of the power house. - Adit fire doors installed to fire separate these from the road access tunnel. - Adit fire doors installed to fire separate the lift riser shaft from the road access tunnel. - Upgrading of the Control Building means of escape 2 stairs. - Fire separation of the lift riser shaft from the Control Building. - Fire separation of the lift riser shaft from the underground Power House. - Fire separation within the switchyard cable gallery for sprinkler system compliance.
2010-2011	Further works to the emergency lighting and exit signage works. [1]	The original battery operated fittings came to the end of their economic life and the passive fire upgrading works required additional emergency signage.
2015-2016	Ventilation Upgrade works, including construction of a new Powerhouse ventilation plant building attached to the Control Building on the surface.	From a fire perspective the works included: - Manual controls possible of ventilation systems from the Control Building or underground power house. - New motorised fire damper at all fire boundaries in the Power House where fire boundaries had been previously constructed as above for the passive fire rating works. Many of these dampers are specialist high pressure fire dampers for which specific installation details were developed. - Interfacing of ventilation plant controls to fire alarms. - Construction of air pressurisation system for the underground safe refuge area to maintain tenability of this area whilst occupants wait for a lift ride to the surface. - While the original ventilation system was upgraded, provision of temporary ventilation fans installed at switchyard level and related fire interface controls using the existing cable riser shafts as ventilation supply routes. - Ventilation PLC control system installed includes position indication on all fire dampers and automated

Approx. dates	Description of works	Comments
		testing of the dampers incorporated into the controls design for enhanced reliability.
2016-2017 ongoing	Switchyard Local Service Transformer Upgrade.	Replacement local service transformers at above ground switchyard level. Options for SF_6 transformers over traditional oil filled being considered for environmental and fire safety reasons. Radiation study undertaken relating to SF_6 Transformer options.
2017	Final passive fire penetrations works wrap up throughout the Powerhouse and Control Building.	These works are the final works for achieving code compliance closeout including the ventilation upgrade consent works. Code compliance should have been achieved by the time this paper is presented.
2017	Switchyard generator building.	Generator building in switchyard asset fire risks being assessed for potential upgrade as part of building structural upgrade.

Table 1 Manapouri Power Station Summary of Fire Strategy Related Works

[1] **Holmes Fire were not design or specify these works in detail.**

Figure 3 below illustrates the overall fire strategy for the Machine Hall level, detailing the fire separations between the two principal egress works being the lift and the road access tunnel. This is extracted from Holmes Fire, Fire Safety Strategy Report [1].

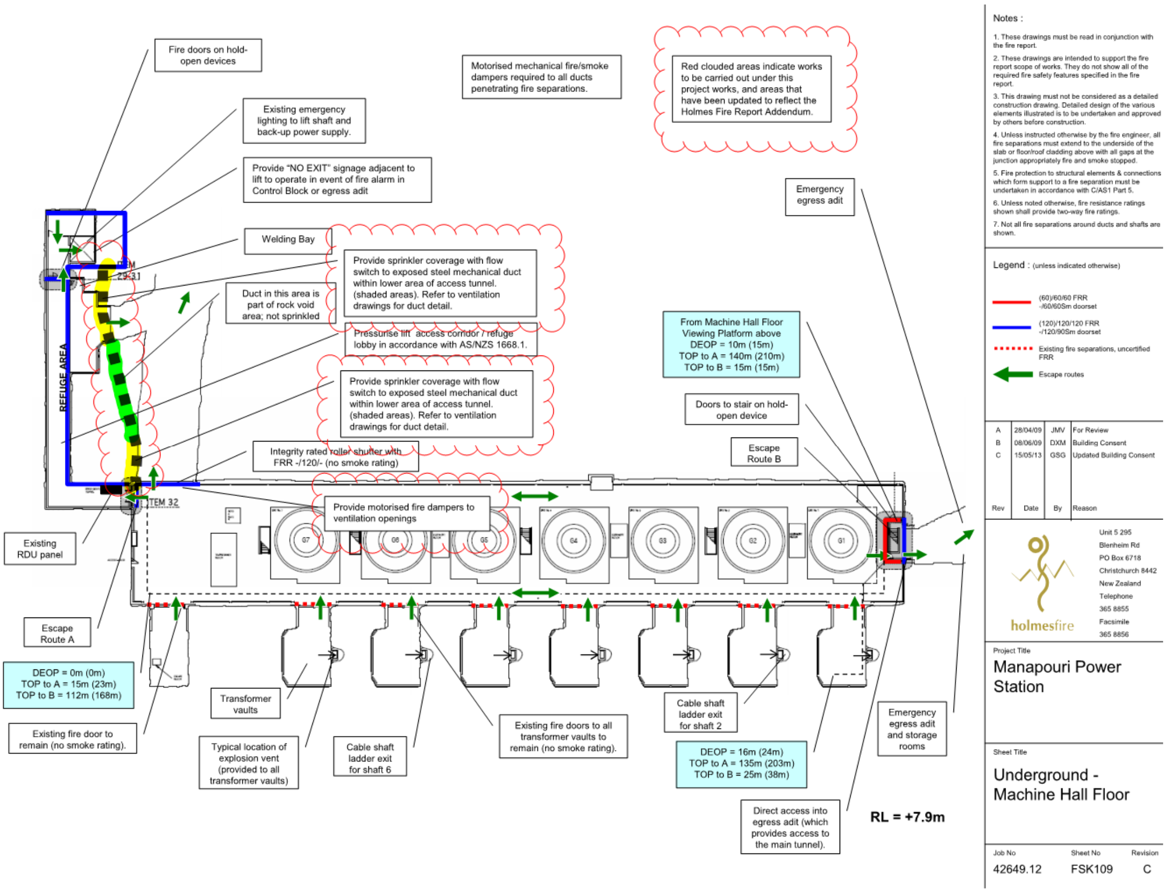

Figure 3 Manapouri Power Station Machine Hall Floor Fire Egress Strategy

Figure 4 below illustrates the works relating to construction of the new above ground ventilation building joined to the existing Control Building.

Figure 4 Manapouri Power New Ventilation Building Before and After Construction

3. SPECIFIC AREAS OF SPECIAL INTEREST

<u>Transformer vault explosion venting.</u>

Holmes Fire prepared a summary report [2] relating to this subject. Figure 5 below illustrates the proprietary FIKE^{TM} explosion vents installed before and after to the transformer vaults. These vent via each transformer cable riser shaft to the surface switch yard.

Vault Before – cable riser shaft behind concrete wall on left

Vault Vents installed

Surface vent

Riser shaft

Figure 5 Manapouri Power Station explosion Vents

The analysis of the venting areas was simplified with calculations based around NFPA 68 Guide for Venting of Deflagrations [3] with an understanding from Barbrauskas – Ignition Handbook [4] of which explosive gases and the resultant pressures generated in a transformer explosion which include mainly ethane, ethylene and methane. The mechanism for an explosion in the vault area being based on these gases filling the vault area and an ignition source such as an arcing fault being present.

Consideration was also given to the yield strength of the existing transformer vault bulkhead doors at approximately 270kPa for the panels and for the hinges approximately 60kPa.

The results of the calculations are represented in the following graph. The design point is 2.7 bar (270kPa). This would have required a vent area of 8.6m^2.

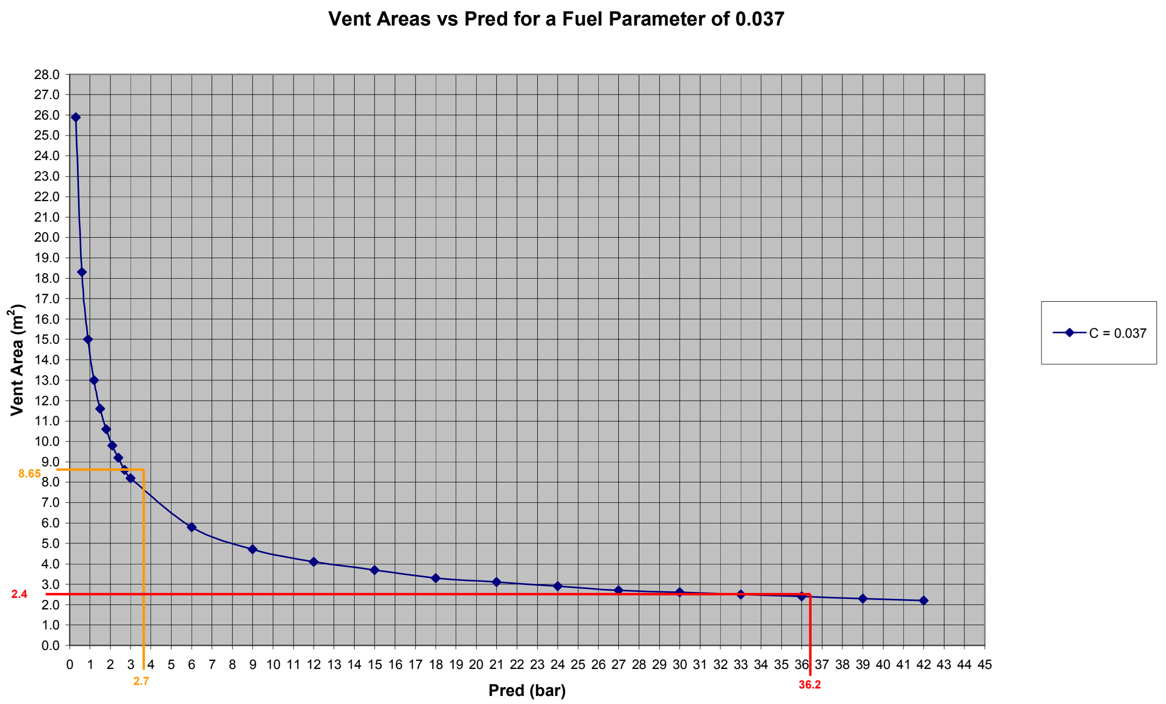

Figure 6 Explosion vent area vs pressure generated in the transformer vault

The available transformer riser shaft vent area is in fact approximately $2.4m^2$ and is the maximum available. The pressures calculated at a vent size of $2.4m^2$ are well above the capacity of the existing doors as indicated by the graph for this vent area, (possibly in the order of 30 bar). It was advised that at best the doors could be strengthened up to 5 bar, (with a significant cost and difficulty to do this), which would give a vent area requirement of $6.4m^2$. This is still well above the $2.4m^2$ available. Therefore failure of the doors is probable if a fully developed explosion occurred even if they are upgraded. The mitigating factor for this being the large void space of the Machine Hall adjacent to provide further vent relief, with natural relief venting for power house surge pressures through the access tunnel if it came to that.

Ultimately a pragmatic approach could only be adopted and the doors remained as constructed and the maximum vent areas achievable were added with the explosion vents as illustrated in the photos in Figure 5.

Other factors were also considered in the overall consideration of the final build strategy including the comprehensive modern transformer fast acting electrical protection systems and condition monitoring of the transformers. Transformer trip mechanisms are also interfaced to fire alarm warning evacuation as a further risk mitigation. An early warning aspirating smoke detection system is also provided to each transformer vault.

Automated suppression systems were not considered beneficial in fact for the transformer explosion mitigation as these systems would not be typically fast enough acting under explosion circumstances to provide suppression. However existing foam / water suppression systems installed in each transformer vault are retained and maintained in operable condition to provide fire protection. Oil containment and oil catchment provisions in each transformer vault exist, as well as oil separation provisions connected to the powerhouse drainage sump.

FM Global Property Loss Prevention Data Sheets; 1-44 Damage-Limiting Construction [5] and 5-4 Transformers [6] were used as further reference checks against the calculated pressures and risk mitigation strategies for the risk of transformer fire and/or explosion.

Power House Egress Analysis Assessment of Extended Travel Distances and Open Stair Voids

At the time of the Fire Safety Strategy Report [1] preparation and consenting process, the basis of the discussion related to hazard assessments presented, with the final analysis on the basis that the means of escape from fire for the underground Power Station multiple levels, with regard to the open stair voids and extended travel distances, was argued to comply with objectives of the New Zealand Building Code C/AS1 Deemed-to-Satisfy egress lengths as nearly as reasonably practicable.

In terms of this analysis, the C/AS1 Deemed-to-Satisfy egress lengths are exceeded in some areas of the underground powerhouse. Because of the open stair voids C/AS1 would require either a smoke control system (natural or mechanical) to be provided. Both of these issues relate to the safe egress of occupants from the underground Powerhouse levels in the event of fire. The practicalities of installation of natural or mechanical smoke control (venting solutions), would be highly problematic if not impossible, without excavation of rock and additional riser shafts provided.

Operationally the Machine Hall is open to the floors below, with open access stairs and service hatches providing access to lower levels. In addition the seven generator enclosures run full height through the floor slabs from the below Penstock Gallery up to the Machine Hall Floor (although these are sealed machinery, so any openings are minor in comparison to the stairs and access hatches).

Access and occupant numbers within the Machine Hall are limited by operational procedures. Tourists and members of the public are permitted in groups guided and controlled by dedicated, competent personnel, but access is restricted to the Machine Hall Mezzanine Floor only, which has a maximum travel distance of approximately 10m to the emergency egress adit.

During normal operation, access to all other areas of the underground powerhouse is restricted to trained and competent Meridian or Contractor personnel and, at peak times when major maintenance upgrades are being carried out, there may also be increased numbers of Meridian and Contractor personnel. Trained and competent Meridian and Contractor personnel are expected to be familiar with the building layout and evacuation procedures, and are expected to be fully ambulant.

The proposed solution was to establish at the Unit 1 end of the powerhouse from the Turbine Floor Level to the Machine Hall Floor Level and discharge directly into the emergency egress adit a fire-rated (FRR60/60/60) safe path. Once this new safe egress was completed fire and smoke separated egress directly into exitways would be provided as follows:

- Ceiling Void = egress adit end
- Machine Hall Floor = lift shaft end and egress adit end
- Stator/Generator Floor = lift shaft end and egress adit end
- Turbine Floor = egress adit end
- Penstock Gallery = N/A
- Drainage Gallery = N/A
- Supplementary to this, Cable Shaft 2 and Cable Shaft 6 are provided as supplementary “last resort” egress routes and are accessible at Stator/Generator Floor level.

The functionality of this new egress stair is to provide immediate access at each floor level of the mainly occupied Power House areas to enable a fire separated safe path stair that occupants that would then be directly connected to the road access tunnel, without having to re-enter the Power House if there was a fire condition. Refer to Figure 3 and 7.

Figure 7 Manapouri Power New Stair Enclosure Machine Hall level – before completion

In addition, active and passive fire safety systems that isolate, suppress or control potential fire risks have been provided throughout the underground facility, as per those summarised by the works in Table 1. These fire safety systems increase the level of life safety and level of property protection, by providing early warning of fire and acting to control or suppress potential fires.

Further the underground Power Station levels are generally provided with fire sprinkler, smoke detector and manual call point coverage. Emergency lighting systems and directional exit signage are provided to facilitate evacuation, and emergency station phones act as a communication system to allow tracking of egress. Mobile phone coverage is also possible within the underground powerhouse and lift shaft via dedicated mobile phone coverage provisions.

A detailed fire hazard assessment was undertaken and concluded that the fire risk associated with the underground Power Station levels and the open stair voids and extended travel distances has been addressed by consideration of the new and upgraded fire safety systems which act to mitigate the growth or spread of fire and smoke.

On the basis of the discussion above and hazard assessments presented, it is considered that the means of escape from fire for the underground Power Station levels, with regard to the open stair voids and extended travel distances, was argued successfully to comply with NZ Building Code's requirements for life safety and means of escape objectives as reasonably practicable and a building consent was issued accordingly by the Southland District Council.

4. CONCLUSIONS

Manapouri Power Station over the last 15 years has been progressively upgraded to achieve New Zealand Building Code compliance with a robust fire strategy implemented for the future use and operation of this facility.

5. REFERENCES

[1] Fire Safety Strategy Report Manapouri Power Station For Meridian Energy 11 November 2009 Version D, Holmes Fire & Safety.

[2] Transformer Explosion Venting Manapouri Power Station For Meridian Energy, 8th February 2005 Version A, Holmes Fire & Safety.

[3] NFPA 68 Guide for Venting Deflagrations 2002 Edition.

[4] Babrauskas Ignition Handbook Chapter 14 pages 766 to 769 Transformers.

[5] FM Global Property Loss Prevention Data Sheet; 1-44 Damage-Limiting Construction

[6] FM Global Property Loss Prevention Data Sheet; 5-4 Transformers.