Use of IG-541 (Inergen) Gaseous Fire Extinguishing Systems in Hydro Generators in New Zealand

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This paper presents the discussion of the performance criteria for IG-541 (Inergen), for use in hydroelectric generators as no current specific codes or testing results are applicable. A review of the codes for CO_2 in generators is undertaken for relevance for IG-541 and the extinguishing concentration levels discussed and formed into a design acceptance criterion for use of IG-541 for hydroelectric generators.

IG-541 is suitable for use in hydro generators on the basis of oxygen depletion capability for gaseous fire extinguishment.

A case study of a recent installation of IG-541 within hydroelectric generators is undertaken with test results provided indicating the IG-541, CO_2 and required Oxygen levels were achieved. Measurements of oxygen levels in lower floor levels of the case study power station during commissioning discharge tests of IG-541 have indicated that use of IG-541 is safe in surface hydroelectric generator applications.

Comparative advantages and disadvantages of IG-541 are discussed with respect to other gaseous fire extinguishing systems for a hydroelectric generator application. IG-541 and CO_2 are both suitable gases for gaseous fire extinguishing systems in hydroelectric generators.

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1. INTRODUCTION

IG 541 is a blend of Nitrogen, Argon and CO_2 (N_2 (50%) + Ar (40%) + CO_2 (8%) and is in the band of suppression gases of the inert gas blend type. [1]

The use of IG-541 (Inergen) in hydroelectric generators is not specifically documented in recognised International fire protection codes. Use of Carbon Dioxide CO_2 is documented widely for hydroelectric applications and is the industry standard for protection of hydro and thermal generators. The principal advantages of being the cost of the gas, efficacy of operation and the ability to cool the spaces concerned combined with the extinguishing capability through oxygen suppression.

In this case study the Principle's concern was with life safety of occupants of within both underground and surface located hydroelectric power stations, whereby leakage of toxic CO_2 was considered a life safety hazard because of the fundamental toxicity of CO_2. Overseas and in New Zealand CO_2 is widely used in hydro and thermal generators and for protecting ship engine rooms, with safety mechanisms in place to adequately protect occupants. Fatalities caused by CO_2 have been well documented [2]. The fatalities primarily relate to lock off valves not being effectively installed or not used during maintenance and accidental CO_2 discharges causing death. Deaths included the following; Accidental discharge while the spaces was occupied, leakage to adjacent areas by doors being left open or inadvertent pressure opening of doors or hatches, entering spaces where a discharge had occurred when the spaces were unsafe, controls malfunction, discharge of cylinders during cylinder change over. One hapless example included a sailor changing a light bulb inadvertently initiating the system. Modern gaseous suppression design codes have all but eliminated the potential for deaths by accidental discharge by incorporation and use of lock off valves during maintenance and testing, well documented maintenance and test procedures, and evacuation and safety procedures. Despite the improved safety record the basic toxicity of CO_2 still exists.

Another unmeasured factor for New Zealand compared with other countries is perhaps the lower critical mass of numbers of installed CO_2 systems and the extended age and perceived reliability. Hence Meridian has had little confidence in the reliability of installed CO_2 systems that has prompted investigating alternative gas suppression systems.

In New Zealand the market size is small and hence the critical mass of installed gaseous fire extinguishing suppression systems across a wide variety of industries including electricity generation has been limited and to a certain extent dominated by three products generally. Subjectively the three main products are CO_2, HFC-227ea (CF_3HFCF_3) – FM200 and IG-541 - Inergen. Other agents are gaining traction as confidence in these grows, suppliers and installers with the necessary back up enter the market and perhaps for reasons of specific highly specialised application or locational reasons to select a particular product.

By way of background the mechanism of fire extinguishment for the inert gases is to displace the oxygen by gross replacement of the air inside the risk area, to achieve an oxygen level that is unsustainable to fire. In the case of IG-541 Inergen the design levels are to a level to allow a safe to occupy, providing the system is not overdesigned. HFC-227ea (FM-200) extinguishment is a hydrofluorocabon and extinguishment is achieved by chemical interference with the fire. Other products do exist such as IG 55 (N_2A) Argonite and Inert Gas and FIC-5-12 $CF_3CF_2C(O)CF(CF_3)_2$ - Sapphire ® Novec a FK (flouroketone). All of these products have the ability to extinguish fires, which can make the choice of product difficult. Efficacy, environmental effects and side effects during a fire are points of difference made by suppliers, often with a “marketing slant”.

Some of these other products are gaining popularity as the market place looks for cost competition and gains confidence in the use of other products outside of the 3 main types of gaseous fire extinguishing systems described above.

Choice of extinguishing gas is often selected on efficiency, cost, effective maintenance support, installation competence, market penetration, available bottle storage, volume of the space to be protected and leakage of the space under consideration.

In the case of IG-541- Inergen the primary factors for selection by Meridian were efficiency, cost, life safety concerns, the ability to cater for generator enclosures that cannot be completely sealed and therefore ‘leak’, and service and installation support in remote geographical locations. These points are further discussed under the comparative analysis.

2. PERFORMANCE CRITERIA FOR USE OF IG-541 IN HYDROELECTRIC GENERATORS

In the absence of specific codes for use of IG-541 in hydroelectric generators a comparative check of codes looking at concentrations of CO_2 in hydroelectric generators was undertaken.

By way of background the original test for IG-541 is under UL, (Underwriters Laboratories), test procedures and is summarised [3]. Tests were undertaken using a wood crib for Class A Fires and heptane fuel for Class B Fires. A Class A Fire as per NFPA definition is a fire in ordinary combustible materials, such as wood, cloth, paper, rubber and many plastics. A Class B fire is in flammable liquids, combustible liquids, petroleum grease, tars, oils, oil based paints, solvents, lacquers, alcohols, and flammable gases. A Class C fire involves engergised electrical equipment.

In New Zealand and Australia the commonly used standards for gaseous fire extinguishing systems have been AS 4214, 2002 Gaseous Fire Extinguishing Systems (superseded), or NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems 2008 Edition. Largely these documents are similar apart from the application of local standards for components and appear based on the concentrations for IG-541 based around UL test [3] as the source.

It is noted also that AS 4124, 2002 Edition, Gaseous fire extinguishing systems has been recently superseded by AS/ISO 14520.1 Gaseous fire extinguishing systems – Physical properties and system design [6] and AS/ISO 14510.15 Gaseous fire extinguishing systems –Physical properties and system design IG-541 extinguishment [7]. Standards Australia have essentially merged the AS 4124 standard with ISO 14520 with some modifications for local standards and conditions. The AS/ISO 14510 standard series does not specify concentrations for IG-541 in hydroelectric generators.

To provide an effective specification of IG-541 concentrations for a hydroelectric generator application, it was determined that as long as IG-541 achieved the equivalent oxygen depletion as those achieved by CO_2 extinguishing standards for hydroelectric generators it was considered that this would achieve the acceptance criteria that could be the basis of the design, installation and commissioning acceptance of IG-541 for hydroelectric generators.

The effectiveness of CO_2 cooling was not defined in any standard, and was not quantifiable. There is an obvious traditional approach to use CO_2 for many applications because of the added cooling advantage and knowledge that CO_2 has worked in fires per se effectively and is widely used in Canada and the USA anecdotally. It was considered that as long as the oxygen depletion was achieved this was considered acceptable and the fire would be extinguished and meet the requirements of the UL test for IG-541. Whilst this could be considered subjective; IG-541 UL testing [3] has confirmed that Inergen is an effective extinguishing agent.

It therefore remained to undertake a literature search of relevant gaseous extinguishing standards for hydroelectric generators and to relate this back to a required IG-541 concentration.

Initially IG-541 concentration levels inside a hydroelectric generator were based on the following criteria from AS 4214;

- A minimum IG-541 concentration of 30% (14.7% Oxygen), within 2 minutes,
- A minimum IG-541 concentration of 50% (10.5% Oxygen), within 7 minutes,

- A minimum IG-541 concentration of 36.5% (13.5% Oxygen) for not less than 20 minutes after the design concentration is achieved (extended discharge period).

These concentrations are as specified in AS 4214 clauses F3.5.1, F3.5.3, Figure 3 and F3.6.5. Note that for the extended discharge period 36.5% IG-541 concentration is slightly higher than the 30% requirement specified by AS 4214 clause F3.6.5 and provides a slightly reduced oxygen level to provide a safety margin on the design. The 36.5% is taken from the design concentration for a surface fire involving a dry electrical hazard as per AS 4214 clause E3.3 Table E6 referring to IG-541 (Inergen).

The comparison with ISO 6183:2009E; Fire protection equipment – Carbon dioxide extinguishing systems for use on premises – Design and installation [8] is as follows;
Referring to Clause 7.7.1 and related clauses 7.6.2 the time to % concentrations to be achieved is similar. However, for ISO 6183 the ultimate design concentration is specified at 58% CO_2, compared with AS 4124 which required 50% CO_2 (10.5% maximum oxygen) concentration. Therefore, with reference to the attached Figure F3, ISO has appeared to decrease the design oxygen concentration accordingly (approx. 8.8%). In addition the hold time is until the unit has stopped where as AS 4124 specified for the deceleration period, (until the unit has stopped –the same) and not less than 20 minutes (clause F3.6.5).

By way of comparison NFPA 12: 2008 Edition Standard on Carbon Dioxide Extinguishing Systems clause 5.5.2.3 and table 5.4.2.1, has similar requirements to AS 4214. This is because it is assumed AS 4214 was derived from the UL Test [3] as was NFPA 12.

Given the above, it was concluded to increase the IG-541 concentration level from 50% to 58% CO_2 equivalent as recommended by ISO 6183 and the concentration of 58% to be achieved until the unit reached zero speed following a unit trip and automatic shutdown following a generator fire condition.

In summary the following concentration levels were adopted;

- A minimum IG-541 concentration of 30% (14.7% Oxygen), within 2 minutes,

- A minimum IG-541 concentration of 58% (8.8% Oxygen), within 7 minutes,

- A minimum IG-541 concentration of 36.5% (13.5% Oxygen) for not less than 20 minutes after the design concentration is achieved (extended discharge period).

It has been interesting to note that Standards Australia have at the time of writing this paper April 2011 issued AS 6163, 2011 Fire Protection equipment – Carbon dioxide extinguishing systems for use on premises-Design and installation (ISO 6183, MOD) [10]. This standard has adopted the same requirements as specified above, but was unavailable at the time of specifying the acceptance criteria and has proved that the correct acceptance criterion has been applied.

3. CASE STUDY OF IG-541 (INRERGEN) IN HYDROELECTRIC GENERATORS

As of April 2011, Meridian Energy has removed existing CO_2 gas suppression systems and installed IG-541 gaseous fire extinguishing systems to generators at Ohau A (264 MW) and Aviemore (220 MW) Power Stations. This project will include IG-541 installation at Benmore (540 MW), and Ohau B and C (212 MW each) power stations respectively. The systems installation contractor is Wormald NZ Ltd. Manapouri underground power station has already an IG-541 system installed since 2001. Ownership of Tekapo A & B power stations (25 MW, 160 MW respectively) is due to transfer to Genesis Energy in 2011, Meridian Energy do not intend to install IG-541 to these facilities.

System design specifications were jointly developed by Wormald, Meridian and Holmes Fire & Safety.

Whilst the intended operation of the systems is dictated by standards, some key components and features of the installation particular to the operation of the hydroelectric generators include;

1. The IG-541 discharge is initiated from 4 possible sources. These are smoke detection from an early warning aspirating smoke detection in each generator, automatic generator electrical protection trip function, generator air temperature, and local manual initiation.
2. The system comprises one bank of IG-541 cylinder per station, manifolded with directional valves to each generator. It was decided that for the systems to be cost effective gas bottle storage would be sufficient for only a single generator fire at one time at each facility.
3. Spare IG-541 cylinders are held by Meridian at a central location. Sufficient spare cylinders are held for full replacement of spent IG-541 cylinders at any facility. No redundancy of gas supply is available at a particular power station.
4. IG-541 cylinders are installed in modular frames with groups of 8 bottles, and can be lifted out and replaced quickly and efficiently.
5. A warning strobe system is installed throughout each facility distinguishing an Inergen release from a normal powerhouse fire alarm. The generator subject to the Inergen release is identified with warning strobes.
6. Initial gas pressure venting of the enclosures has proved unnecessary due to the leaky nature of the generator enclosures.
7. Commissioning tests included a full trial discharge for one generator at each site to confirm correct system operation and interfacing to other control, protection and monitoring systems. Oxygen and CO_2 levels within the generator enclosure in addition to around the powerhouse and its multiple levels were recorded before, during and after the trial discharge. The recorded results are particularly useful in determining risk areas demonstrating low oxygen levels. The recorded results indicate no questions as to occupant safety immediately outside of the generator enclosure, the enclosures being normally occupant vacant. Graphical results of the testing are provided in figures 1, 2 and 3 [11] below.
8. Key alarm outputs of the system are interfaced to each individual generator unit PLC control system and communicated via SCADA to Meridian's central Control and Dispatch Centre.
9. A Factory Acceptance Test (FAT) was conducted whereby a mock up of all new proposed control hardware and software was constructed in a test rig and tested prior to physical works at the first site to confirm correct operation of all equipment, hardware and software and correct interfacing between these systems and existing generator control, protection and indication systems. The FAT highlighted shortcomings that were remedied and re-tested prior to implementation on 'live' systems at site. This process was very valuable in avoiding issues on site to optimise the physical works and commissioning process.
10. Detailed maintenance and testing requirements have been developed to maintain system reliability and operability into the future.

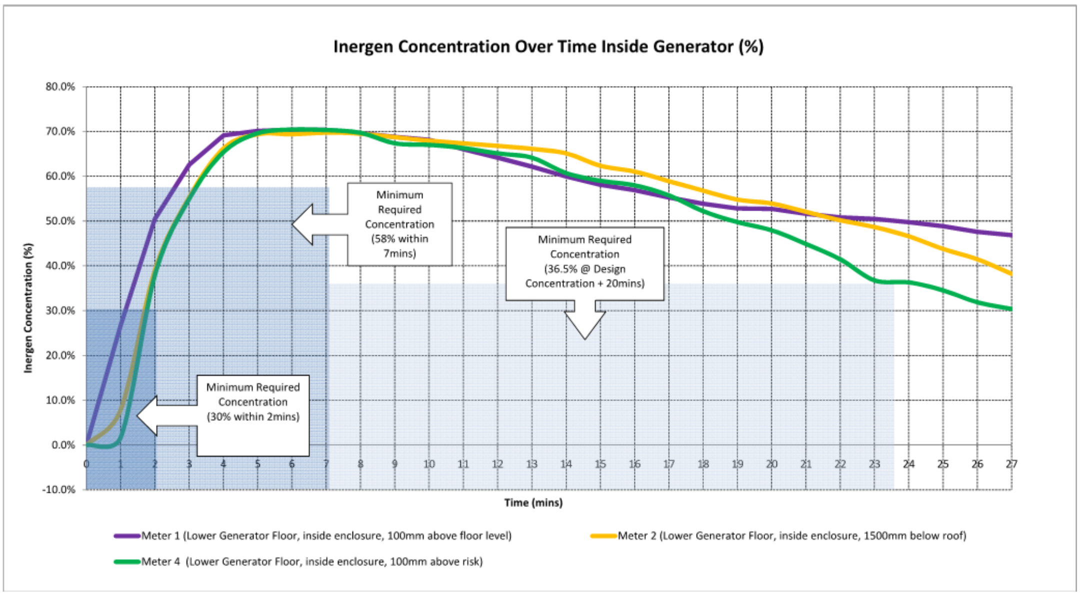

Figure 1 Inergen Concentration Over time Inside Generator (%) Ohau A Power Station

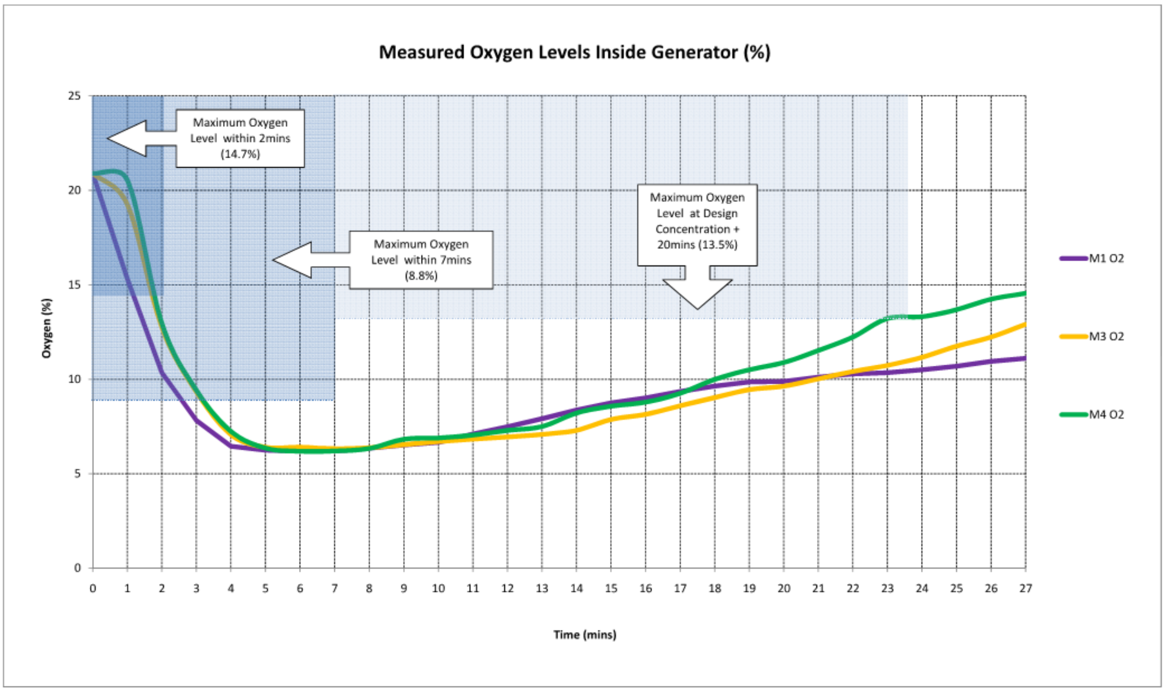

Figure 2 Measured Oxygen levels Inside Generator (%) Ohau A Power Station

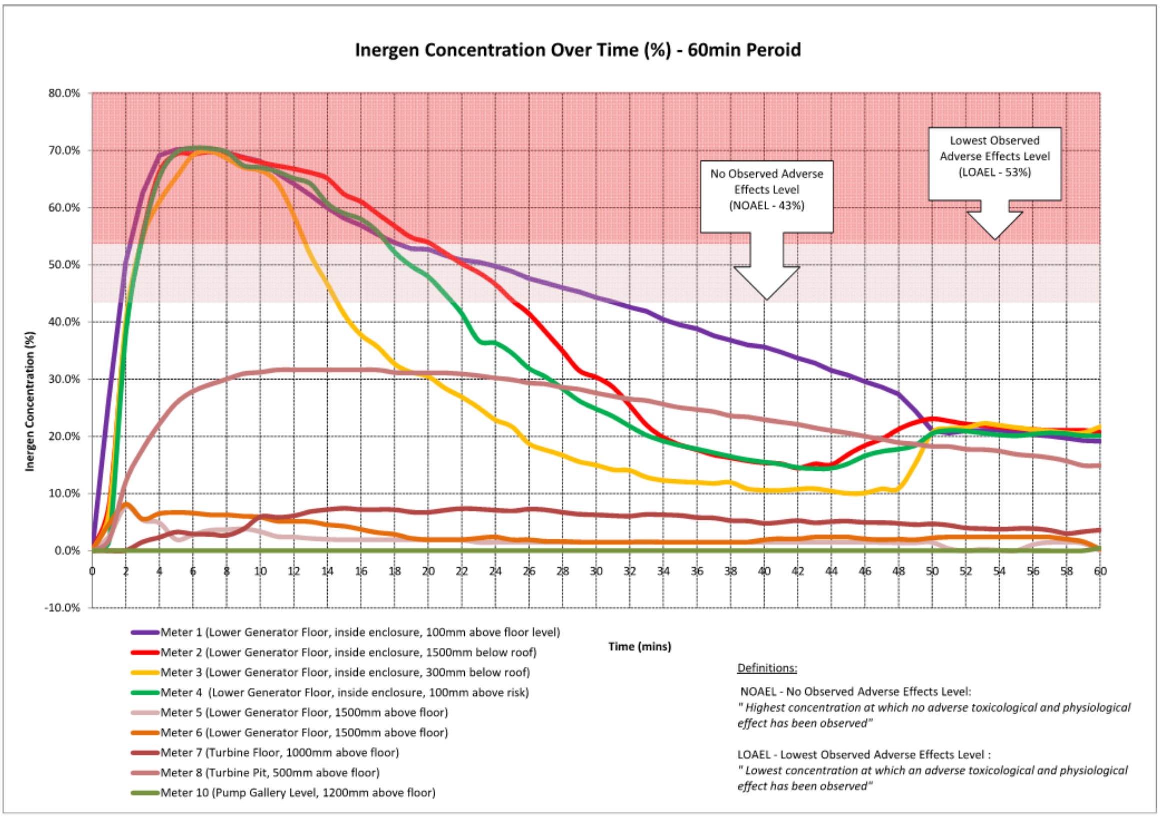

Figure 3 Inergen Concentration Over Time (&) – 60 min Period Various Locations of Power House Ohau A Power Station

The trial discharge results indicated that:

For all meters inside the enclosure, the minimum Inergen concentration of 30% (14.7% Oxygen), at 2mins, was achieved

For all meters inside the enclosure, the minimum Inergen concentration of 58% (8.8% Oxygen), within 7mins, was achieved.

For meters 1, 2 and 4 inside the enclosure, the minimum Inergen concentration of 36.5% (13.5% Oxygen), for not less than 20mins after the design concentration (58%) is reached, was achieved.

Figure 4 Inergen Concentrations Ohau A Power Station

Note that:
Meter 1= inside generator enclosure 100mm above floor level
Meter 2= inside generator enclosure 1500mm below roof of generator
Meter 3= inside generator enclosure 300mm below ceiling of generator enclosure
Meter 4 = inside generator enclosure 100mm above the fire risk, (i.e. the top of the generator stator windings)

The results of Figure 4 align with the developed acceptance criteria for the IG-541 concentrations.

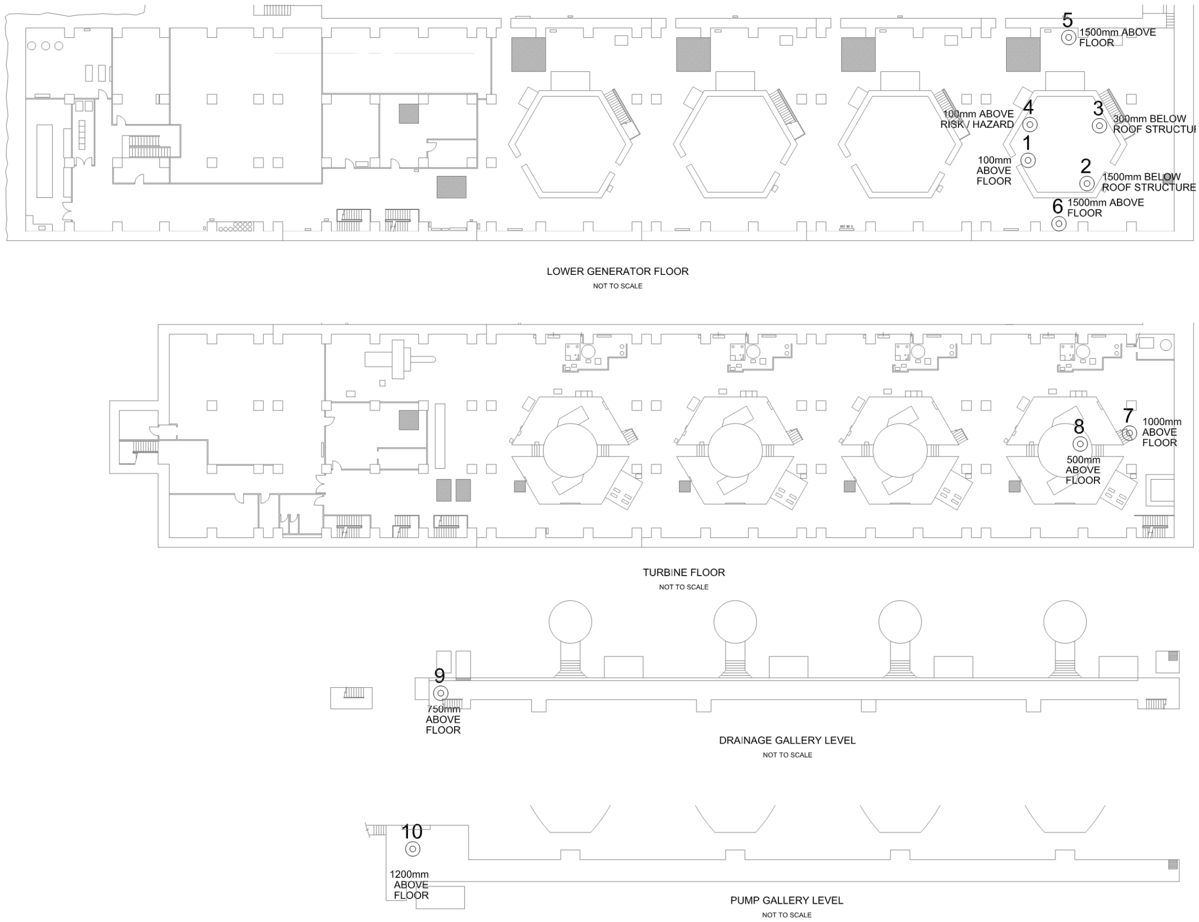

Figure 5 Ohau A power station layout and location of sampling on one generator during the commissioning Inergen discharge test

Figure 6 IG-541 Ohau A power station cylinder bank showing cylinder cage modules

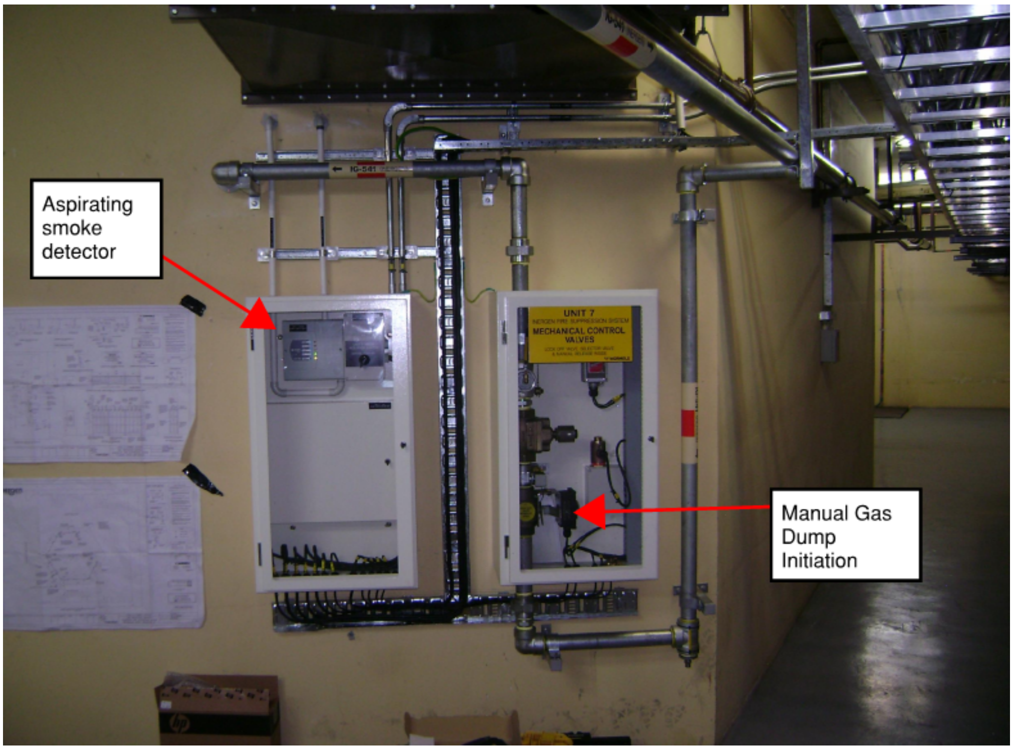

Figure 7 Ohau A Power Station Manual Gas Dump and Aspirating Smoke Detection Control Cabinets

Figure 8 [left] Ohau A power station inside Unit 7 generator showing Discharge Nozzle and Aspirating Smoke Detector, [right] gas release control panel located outside generator enclosure.

4. COMPARATIVE ANALYSIS OF IG-541

The following table summaries the key characteristics of key types of gases, that are utilised in gaseous fire extinguishing systems across many industries [12] [13] [14].

	FM-200, HFC – 227ea	**Carbon Dioxide (No trade name)**	**Inergen, IG–541 or Argonite IG – 55**	**Saphire, Novec 1230**
Chemical composition	Hydrogenated fluorocarbon CF_3HFCF_3 Heptafluoropropane	CO_2	N_2+A+CO_2 Inert Gas N_2 Inert Gas	$CF_3CF_2C(0)CF(CF_3)_2$, flouroketone
Fire Suppression Medium	Chemical inhibitor, operates by removing the heat of the chemical reaction at the molecular level. Industry claims are that it operates more efficiently than relying predominantly on oxygen depleting substances such as inert gases.	Oxygen Depletion	Oxygen depletion using an inert gas	Chemical Inhibitor similar mechanism to FM 200
NOAEL % v/v[2]	9%, use concentration typically 7.5% to 8.7% .	All practical functional equivalents of extinguishing concentrations exceed the NOAEL	43.0% [3]	10%, use concentration 4-6%.
Global warming potential [4]	GWP of 3,500 with a 100 year time horizon, 33 atmospheric lifetime (years). The effect is claimed as minimal due to the low usage rate compared to other fire extinguishing media and a low rate for fire instances requiring release into the environment. This product can also be reclaimed for reuse.	Global Warming Gas, but considered favourable as gas is CO_2 contained in the bottles and is removed from the atmosphere.	0	GWP of 1 with a 0.014 atmospheric lifetime (years)
ODP (Ozone Depletion)	0	0	0	0
Bottle Storage area	10 to 30% of the area required for Inergen depending on room size.	Approximately 25% of the floor area to that required for Inergen.	Requires up to 10 times the floor area of FM 200 & Sapphire depending on the room size.	10 to 30% of the area required for Inergen depending on room size
Room sealing / Pressure relief	Room must be sealed and dampers fitted to close off the room. Pressure relief not typically required. Gas probably not suitable for generators which are leaky and costs would be much higher than Inergen or $C0_2$.	Room must be sealed and dampers fitted to close off the room. Pressure relief not typically required	Specific venting must be provided due to larger volume of gas released and the pressures generated. Ceiling times must be tied down.	Room must be sealed and dampers fitted to close off the room. Pressure relief not typically required
Discharge time	10 seconds or less	1-2 minutes similar to Inergen	1 to 2 minutes	Probably similar to FM-200, data not found

	FM-200, HFC – 227ea	**Carbon Dioxide (No trade name)**	**Inergen, IG–541 or Argonite IG – 55**	**Saphire, Novec 1230**
Other Issues	Temperature drop occurs with all gaseous suppression systems and thermal shock on equipment has been questioned as an issue. In fact our understanding is that actual studies have indicated that this is not a significant issue.	Generally temperature drop caused by $C0_2$ is considered a major benefit in generator fires, but does not appear to be quantified. Evidence appears to be experientially based.	Extinguishment may not be achieved for smouldering fires where pyrolozates continue to be produced, even for a 10 minute soak density. Condensation may occur on the pipework.	Similar to FM-200
Maintenance	Inergen systems tend to have a slightly higher maintenance cost due to the manifolding and number of bottles. Manifolding is required where a number of rooms share the same bottle bank and are physically piped together. Control valves are required as part of this where the rooms are of different sizes to ensure the gas dump volume is appropriate for each room. $C0_2$ maintenance costs are similar to Inergen, as regular testing regimes are similar. As Inergen and $C0_2$ ages bottle testing (Up to 10 times the number of bottles for Inergen), can add cost and inconvenience as well as eventual bottle replacement at the end of their life. For 10 yearly hydrostatic bottle testing required, FM 200 gas can be reclaimed and reused though with about 5% losses. If a gas dump has not occurred then an external inspection may suffice. Inergen gas cannot be reclaimed and reused.			
Cleanup after fire discharge[1]	Hydrogen Fluoride HF, can be formed, though with a properly designed system if the fire is put out early then Hydrogen Fluoride generations should be minimal. The products of combustion, if a fire eventuates are considered much more significant.	Hydrogen Fluoride is not generated. The products of combustion, if a fire occurs are considered more significant.	Hydrogen Fluoride is not generated. The products of combustion, if a fire occurs are considered more significant.	Hydrogen Fluoride HF, can be formed, though with a properly designed system if the fire is put out early then this should be minimal. The products of combustion, if a fire occurs are considered more significant.
Cleanup after accidental discharge	Typically venting of the gas is all that is required for any of these systems. Material damage to equipment is not expected.			
Discharge Time	Discharge time is less than 10 seconds	Discharge time is at least 60 seconds	Discharge time is at least 60 seconds	Discharge time is less than 10 seconds
Agent Cost	FM200 gas is more expensive than Inergen, but a lot less of the gas is required	Gas cost is relatively cheap and no special refilling capability is required. The option for bulk filling tanks now exists (similar to hospital and brewery suppliers), but bulk filling not necessarily viable in remoter locations.	Gas cost is significantly lower than FM-200 and Sapphire. It uses gases that occur naturally in the atmosphere, But a lot more gas is required.	Generally considered to be 10% more expensive than FM 200
Equipment cost	FM-200 and Sapphire have much less valving than the Inergen systems. Therefore the hardware cost of Inergen systems is much higher This is related to the significantly larger number of bottles and manifolding required.			
Maintenance Costs	Annual maintenance costs for systems are similar for all systems due to regular testing regimes required by relevant standards and codes. Maintenance costs over 10 years relates to cost of gas bottle retesting, which with systems with fewer bottles can be significantly cheaper by a quantum of 50 to 10 times costs.			
Budget Capital Costings	Cost comparisons between systems are becoming less predominant as competition from suppliers and similar generic products become available. Costs also depend on how systems are manifolded and bottle redundancy requirements.			

Table 1 Summary of Gas Comparisons

[1] It should be noted that the products of a fire will release toxic gases which would be of significance when entering the room after a fire.

[2] NOAEL is the no observed effect level; This information is extracted from AS 4124 and manufacturers information. It is the highest concentration at which no adverse toxicological or physiological effect has been observed.

[3] Based on physiological effects on people in hypoxic atmospheres. These values are the functional equivalents of NOAEL and correspond to a 12% minimum oxygen at the NOAEL.

[4] For definitions of these items refer to http://www.climatechangesask.ca/html/learn_more/Emissions/Warming_potential/

5. CONCLUSIONS

1. As no specific design standards were sourced for IG-541 for hydroelectric applications, design criteria were adopted from existing gaseous fire extinguishing standards.
2. System design specifications were jointly developed by Wormald, Meridian and Holmes Fire & Safety. This ensured specification requirements were fit-for-purpose for the hydroelectric generator application.
3. Factory Acceptance Testing at Wormald's premises prior to physical works commencing on site was very valuable in ensuring correct system operation, integration and interfacing and optimised the physical works and on-site commissioning process.
4. Following system installation, confirmation of system design performance in terms of fire extinguishing and interfacing to existing hydroelectric generator control and protection systems was confirmed by actual trial discharge of IG-541 during commissioning on one generator unit, per power station.
5. Gas recording devices were employed for the discharge test during commissioning inside the generator enclosure and around the powerhouse and confirmed IG-541 and oxygen levels compliance with the developed specification requirements, and confirmed occupant safety immediately outside of the generator enclosure and around the powerhouse.
6. Detailed maintenance and testing requirements have been developed to maintain system reliability and operability into the future.

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