BC Hydro
Power smart

Distribution Line Strategy and Standards

July 2016 | Underground Vault Inventory

Revision: R3

A Strategy to Manage Safety Risks Associated with Underground Equipment in Street Vaults

Issued: **July 2016**

[redacted]

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Acronyms and Abbreviations

CLF	Current Limiting Fuse
GRA	A G&W type oil switch. Similar to RAL but with grounded switch position
MV	Medium Voltage (12 kV or 25 kV)
PILC	Paper Insulated Lead Cover (feeder cable)
RAL type	Switch category including RAL, GRA, and GRAM
RAL	A G&W type oil switch. The RAL switch is a 3 way, loop through and tap switch
XLPE	Cross-link Polyethylene (feeder cable)

This report could not have been completed without the contributions of the following:

[redacted]

Cover photo: Corroded Oil fused cut outs in Vault 49

1. EXECUTIVE SUMMARY

This project was undertaken to collect information and evaluate public and worker safety risk caused by street vaults containing aging oil filled switches and other associated aging assets in the vaults. The information is used to develop a holistic strategy to deal with these aging assets. A database was created that includes a spectrum of information for both risk analysis and maintenance on vaults and manholes throughout the province which were believed to contain oil switches. This database includes several other risk type equipment including oil fused cut outs, cable transition splices, and transformers.

The undertaking found that there are five primary vault configurations. The majority of oil filled equipment is found in two of these configurations; single radial feed to transformer through a switch, and dual radial feed to transformer through one or two switches. 14 vaults in Vancouver are considered very high risk with equipment likely to be in very poor condition as per Appendix A. Consequences of this high risk equipment could include public or worker severe injury or death. Public deaths and injuries as a result of underground oil filled equipment have previously occurred in North America. In BC Hydro a worker was seriously injured while maintaining aging underground oil filled switching equipment in December 2009.

Recommendations have been made to address risks:

Immediate term (F17 and F18) it is recommended that:

- Verify the database information in the field, repeat the risk prioritization method for new information, and update SAM/DAD.
- Install overhead current limiting fuses (CFLs) to protect three phase underground oil filled equipment in single radial and OH fed street vaults. While, the best safety informed solution requires a CLF installed for all oil filled equipment, given the space constraint in dual radial vaults fed by UG supply, continued close monitoring of UG fed dual radial vaults with immediate action on those which become poor condition can be a practical safety informed solution.
- Replace and upgrade the five dual radial street vaults (V58, V67, V69, V70, and V73). To align with System Planning's recommendation to upgrade to an open loop configuration with dual ratio submersible transformers with built-in CLFs.
- Repair, maintain and implement the recommendations for the remaining 9 units as outlined in appendix A.
- Investigate suitable replacements for RAL, VacPac, and non-vista SF6 switches, as well as oil fused cutouts.
- Sample all oil filled switches to determine if PCB contaminated and assess condition and action.
- Develop oil sampling procedure for transformers.

Mid-term (F19 to F20), it is recommended that:

- Sample transformer oil using the procedure developed in F17 and F18 to determine if PCB contamination is greater than 50 ppm.
- The remaining oil filled switches and transformers that are identified to be in fair condition are maintained, repaired, or replaced with suitable alternative (if feasible) to align with the strategy for downtown redevelopment project.
- Continued close monitoring of dual radial vaults without CLF and immediate action on poor and fair condition
- Investigate to improve tracking and record keeping for oil test.
- Fix sumps to prevent standing water causing corrosion issues.

Long Term (F21 and beyond):

- Replace all remaining non-oil filled three phase switch (e.g SF6, VacPac) with vista or suitable alternative aligning with downtown redevelopment strategy.
- Replace all remaining oil filled switches by December 31, 2025.
- Replace transformers with PCB contamination greater than 50 ppm by December 31, 2025.

Strategic opportunities include:

- Since the oil fused cutouts were installed around 50 years ago, it is likely that they contain PCBs and thus should be removed from service as opportunities arise. BC Hydro must meet a deadline of no PCBs greater than 50 ppm by December 31, 2025.
- There is an opportunity to proactively address WSBC regulation 9.4 by investigating non-oil type transformers for confined spaces.
- When installing new equipment into existing vault, the civil structures must be assessed to ensure its suitability for the life of the new equipment and to ensure that the condition and the size of the structures can accommodate the new equipment.

2. INTRODUCTION

A request was made by Asset Investment Management to review the safety risk associated with RAL switches and other underground infrastructure and to develop a strategy to address these aging assets. This request was triggered by BC Hydro (BCH) Incident #24760, a failure of an aging underground transformer which resulted in contaminated oil being released into the vault. Street vaults generally house a step down transformer downstream of an isolation point to provide energy to customers. The isolation point is typically one or both of oil fused cutouts and a three phase switch (often RAL or similar). Street vaults are akin to large through type manholes, with two larger top openings to allow the placement of equipment.

This report details the safety review, which includes the creation of an inventory of assets, a qualitative risk analysis, and a set of recommendations, such as installation of current limiting fuses (CLFs), repair and replacement of equipment, etc., to reduce risks associated with these underground assets.

3. SCOPE

In scope:

- Vault inventory containing aging oil filled switches
    - V#### series vaults in the City of Vancouver
    - Manholes and Vaults anywhere in BC which field crews or engineers believed may contain a switch
    - Locations where Distribution Analysis and Design (DAD) software indicates internal switch = 'RAL'
- Analysis of Risks associated with the above which directly have immediate effect on human life
- High level risk mitigation recommendations

Not in scope:

- Business and Cost analysis of alternatives
- Properties risks (for instance, risk of over voltage to customers due to lack of three phase switch feeding transformer)
- Environmental risk associated with existing or replacement equipment
- Detailed review of work procedures associated with working in and around these underground vaults/equipment

4. METHODOLGY

The first step to the safety review was to gather relevant information on the oil filled switches and other equipment in the underground infrastructure to understand what devices are in the field, in what configurations, and for what purpose.

The database was built as a desktop exercise only. Through the construction of the database, additional at risk equipment was identified. This database was then used to prioritize vault risk based on hazards associated with oil filled equipment using a qualitative risk analysis. Finally recommendations were made as to a risk mitigation approach.

This section describes the methods used for the risk analysis including assumptions, and vault information compilation.

4.1. Risk Evaluation

Risk analysis was done by a qualitative approach using the best available desktop information. In order to perform this analysis, it was necessary to understand:

- The hazards associated with the equipment and configuration
- The scenarios, associated with those hazards, which present safety risk
- The validity of those hazard scenarios
- Potential mitigation controls for these hazards, including examining the factors which escalate the risk

This lead to risk evaluation and recommended actions based on:

- Type of equipment
- Condition of equipment
- Protection scheme of equipment (i.e. presence of CLF)
- Maintenance of equipment
- Location of equipment

Several assumptions were made in this risk evaluation:

1. Likelihood of a risk event
    a. Poorly maintained equipment has a higher chance of failure
    b. Poor condition equipment has a higher chance of failure
    c. Well maintained equipment with no signs of reduced condition (rust, leaks) is unlikely to fail regardless of age
    d. Without a CLF, oil filled equipment failure is more likely to create a severe consequence event which could be fatal
2. Public exposure to a vault can be estimated by its general area
3. Even with a CLF, failed oil filled equipment may still create a hazardous event, however it is expected to be less severe
4. New submersible equipment is in good condition therefore standing water is not an escalating factor

4.2. Vault Information Compilation

The investigation was carried out as a desktop review only. Except where explicitly noted no field checks were performed.

Data was collected on each vault through desktop exercise to capture both information pertaining to risk as well as that which will be beneficial for maintenance, operation, and design. This included gathering information on

- The location of the vault
- The feed to the vault including circuit, protection, cable type, duct material and size
- The equipment in the vault, the condition of the equipment, how it has been maintained, and how it is configured
- The condition of the vault, including sump pumps and asbestos inventory
- The crew's comments about the vault and equipment

This information was gathered from multiple records, including drawings, inspection reports, photos, and subject matter experts. Detailed information on sources and how conflicts between sources were resolved is shown in Appendix B.

5. VAULT INFORMATION RESULTS

This section explains what was found to be in the field, how the technology progressed, and where vaults are located.

5.1. Street Vault and Equipment Configuration Information

Configuration of these vaults varied and could be divided into five typical configurations. This section describes the typical equipment and the five categories. Information is then presented on the progression of technology and locations of street vaults in Vancouver.

- Cutouts (aka Oil Fuse Cutout)
  - G&W oil filled device designed to provide isolation and overcurrent protection which is often not recognized by crews. These are likely to contain PCBs. These have never been maintained. In some cases these may be gang operated but this is not clear. This equipment is from the 1960's and has no spare parts or replacements available.
- Three phase switch
  - Provides isolation, as well as three phase switching capability which prevents single phasing transformers protecting customers from over voltage due to ferroresonance
  - Several types include:
    - RAL type oil filled switches
      - RAL – A switch (shown Figure 3 and Figure 4) is an oil filled switch which allows two sources to be either off, or tied together temporarily for switching purposes, or fed to the output. Generally used in single radial vaults, this switch has PILC connections, and cannot be maintained without a prolonged outage.
      - GRA – are from the same family (GRAM) of oil filled switches from G&W as the RAL, where the tie position is replaced by a grounded position. Generally used in dual radial vaults, PILC in, XLPE out. GRA switches (shown Figure 7 and Figure 8)
    - Vacuum type, typically VacPac, with no operating procedures, remote operational capability, or spare parts
    - SF6 (non-vista) type, either single or dual radial, with no operating procedures, remote operational capability, or spare parts
    - Vista (housed outside of vault), open loop
- Transformer , oil filled device provides voltage step down
- Cable Transition Splices (Cable Transition Modules) transition to/from XLPE/PILC cable

- Junction Bars are an XLPE insulated equipment that allows the connection of multiple cables. These allow connections to be switched around for open loop, and are used to connect the transformer to switches in dual radial vaults.
- Network protector, a device common in Victoria, used in two spot network vaults in Vancouver
- Sump Pumps keep vaults dry

RAL type switches are currently slated for replacement. These switches are approaching end of life, and present operational challenges.

The following table describes typical configurations of the equipment mentioned above and shows the approximate number of each configuration found within the BC Hydro system

Table 1 - Vault Configuration

Configuration	Description	Approximate Count
1	Direct feed to transformer without 3 phase switch in vault, includes recently installed vista fed transformer vaults	42
2	Single radial, including switching capability and a transformer. Typically this uses RAL switches	19 (16 with oil filled switch)
3	Dual radial, including switching capability and a transformer. Often uses oil filled GRA switches, some SF6 and Vacuum	21 (14 with oil filled switch)
4	Open Loop with J-Bar. Only transformer contains oil.	4
5	Network, Vaults 13 and 38. Only transformer contains oil.	2

Configuration 1 – Single Radial direct feed to the submersible transformer
Isolation device oil fused cut outs

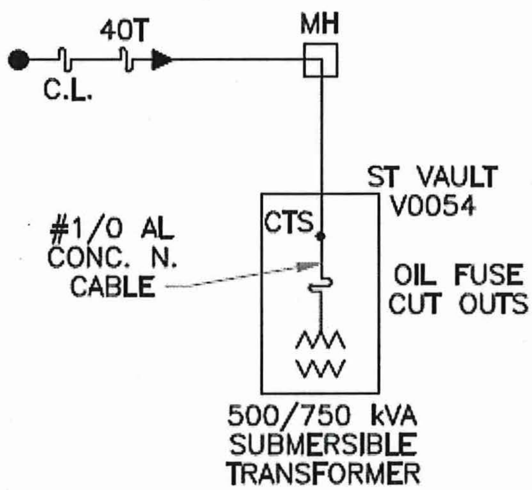

Figure 1 - Single radial one line without switch

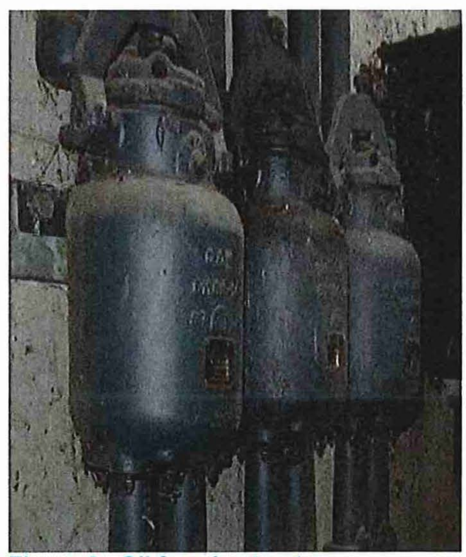

Figure 2 - Oil fused cut outs

Configuration 2 – Single Radial with 3 phase isolation switch

Typical isolation switches ; RAL switch, VacPac switch, JB

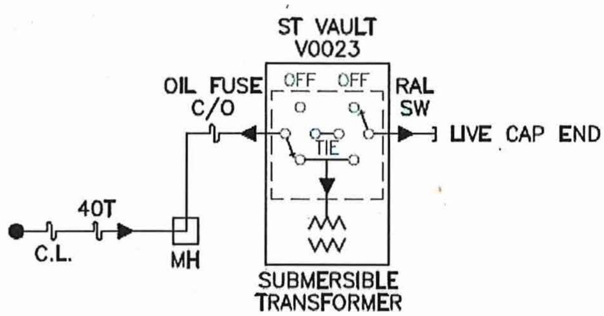

Figure 3 - Single Radial one line with RAL

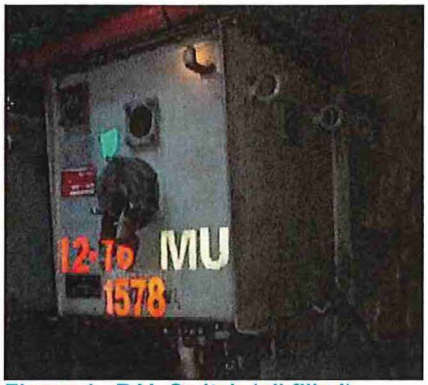

Figure 4 - RAL Switch (oil filled)

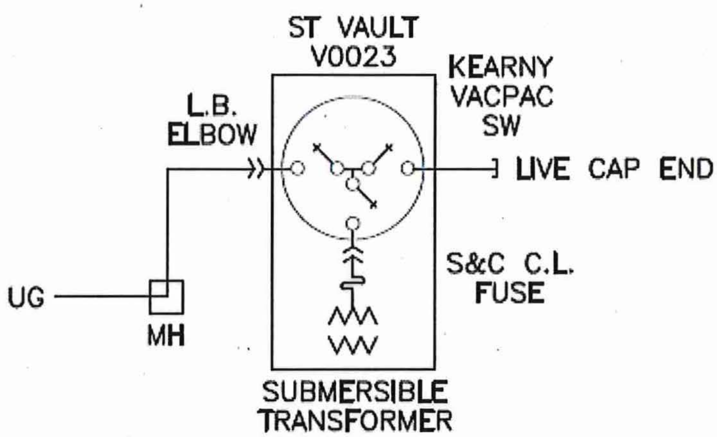

Figure 5 - Single Radial one line with VacPac Switch

Figure 6 - VacPac Switch

Configuration 3 – Dual Radial with 3 phase isolation switch

Typical isolation switches: SF6 switch, Vacuum switch, GRA switch, SVRAM33 switch

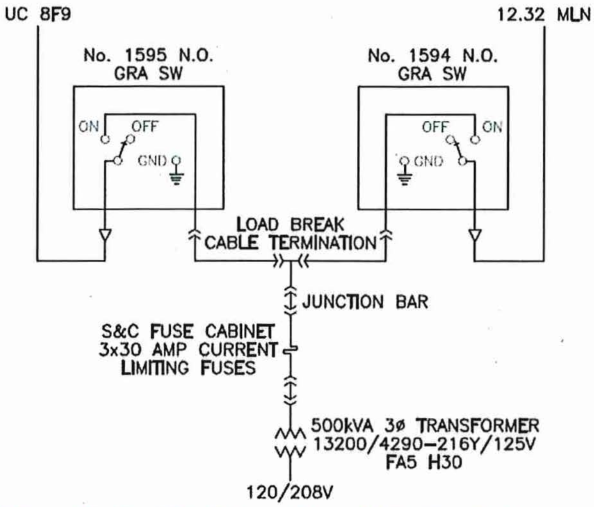

Figure 7 - Dual Radial one line with GRA switch

Figure 8 - GRA switch (oil filled)

Configuration 4 – Open Loop (Street vaults 1,2 ,10,24)

Isolation device is junction bars

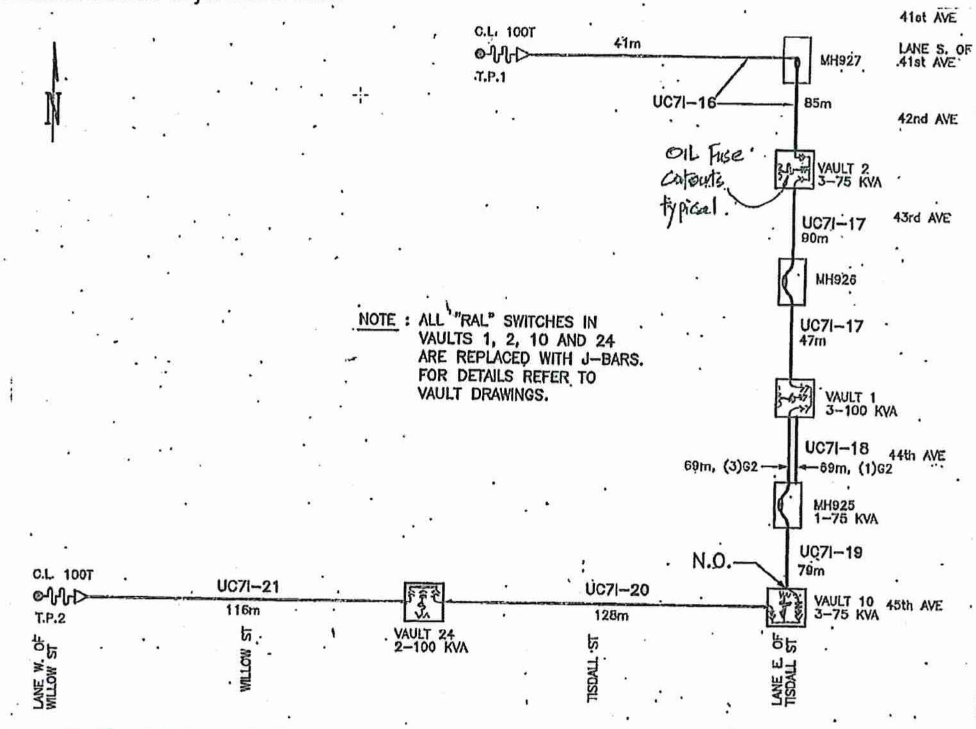

Figure 9 - Open loop one line

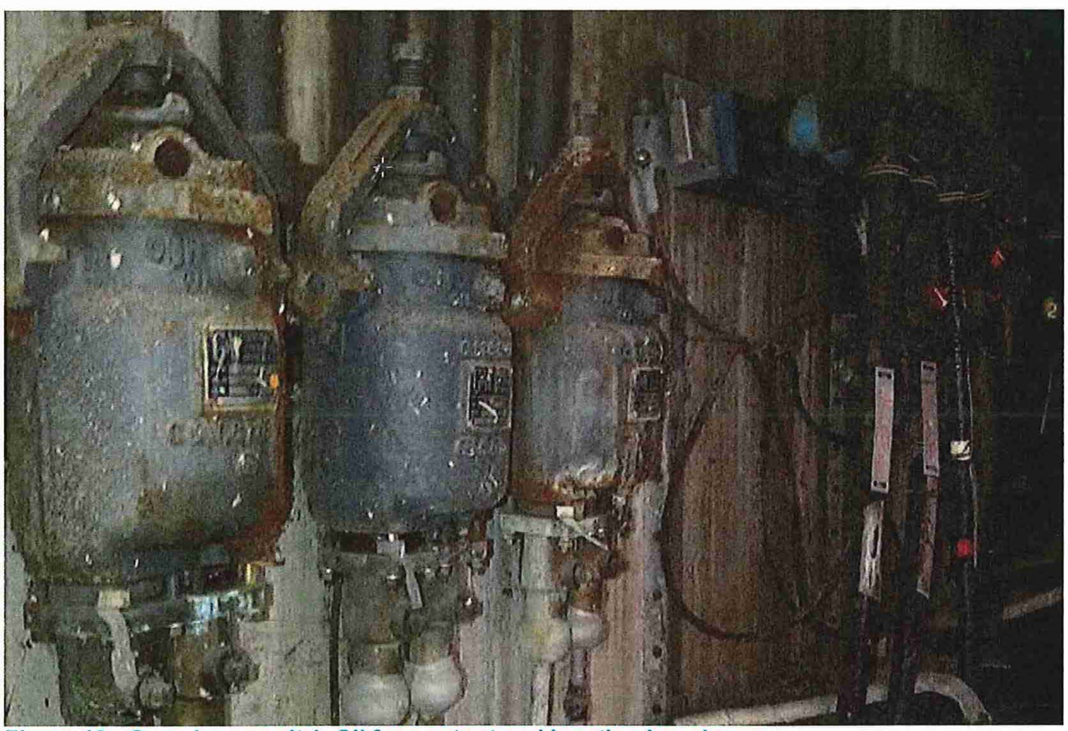

Figure 10 - Open loop vault 1, Oil fuse cutout and junction bar shown

Configuration 5 – Spot Network (Street vaults 13,38)

Isolation device is network protector

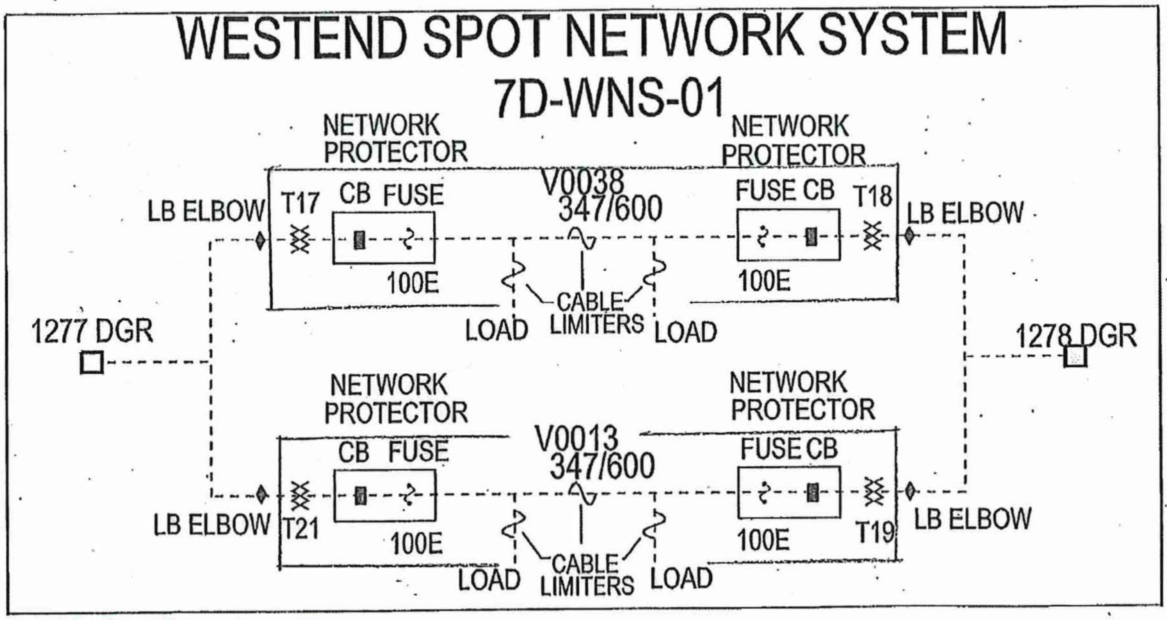

Figure 11 - Spot Network one line

Figure 12 - Spot Network 1500kVA transformer

5.2. *Technology progression*

Figure 13 - Technology Chronology

Early vaults are generally single radial feeds, later including RAL switches. Typically these vaults are fed from an overhead dip designed with a current limiting fuse and feed into the vault through underground oil fused cutouts.

The next era was of GRA switches and began the age of dual radial vaults fed with both primary and standby circuits. These are most commonly underground fed, and have current limiting fuses within the vault between the GRA switches and the transformer.
Vac Pac switches were installed in the mid 1990's, mostly in Kamloops. SF6 switches were then installed through to the end of the 1990's, many of which as part of the Gastown redevelopment project.

Starting in 2012-2013 Vista switches began to be used to feed transformer vaults as part of the H-Frame elimination program.

Historically vaults were built with Transite or Black Fiber ducts. Transite and Black Fiber ducts typically contain asbestos. BC Hydro stopped using Transite ducts in 1975.

5.3. *Installation Locations*

The majority of vaults can be found in Vancouver (shown in Figure 14). Kamloops has 6 manholes which were believed to contain switches. Of these, 2 are empty (MH 18 and 20) and 4 contain VacPac switches (MH69, MH71, MH72, MH73) and are currently slated for replacement by system planning. VacPac switches do not present immediate public safety risk, but are identified as priority 7.
Duncan has 1 vault with three oil filled transformers fed from a junction bar. Drawings for these vaults are included in Appendix E.

Victoria has 9 vaults identified as not in scope. Identified vaults V-201, 202, 203, 204, 205, and 511 are planned to be upgraded by VI-SVI-254. Identified vaults V1, 2, and 12 are identified to be upgraded by a combination of maintenance and VI-SVI-259. Drawings for these vaults are included in Appendix F.

White Rock reported they have several underground transformer installations which at the time of this report had been slated for replacement by SI project LM-FVW-409 therefore are not examined in detail. Prince George reported three vaults which contain non-standard junction bar installations. Drawings showing the non-standard installations in White Rock, and Prince George are shown in Appendix F.

Four customer structures appear to possibly contain RAL switches per our DAD database. Three of these customers are IPPs. These four are located at Lougheed, Cascades, Field, and Kitimat.

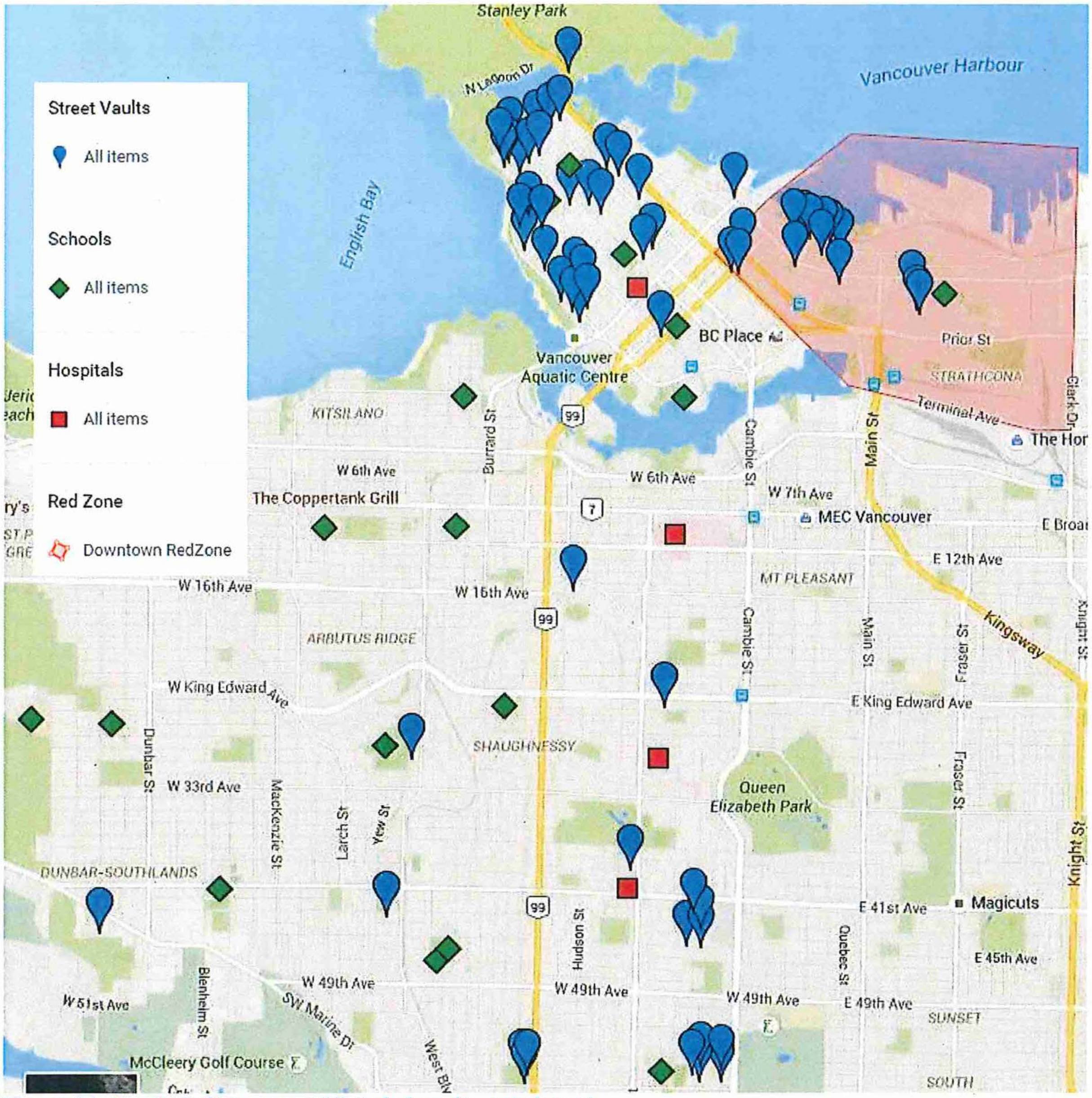

Figure 14 - Vaults in Vancouver (Vista fed vaults not shown)

6. RISK ANALYSIS

This section uses the findings of equipment to identify the associated hazards, the possible event sequence, consequence of those hazards, and past events relevant to determining the validity of the consequences. This was used to identify escalation factors to a vault event, highlight applicable barriers, and evaluate the effectiveness of various barriers. The priority vaults are then identified.

6.1. *Hazards associated with Vaults*

This section discusses the key hazards typical of street vaults. Hazards which do not pose immediate risk to public and worker life are shown in Appendix G.

1. Energy
   a. Electrical Energy from grid (12kV)
   b. Chemical Energy from
      i. oil in oil filled equipment
      ii. built up methane gasses from decomposition
2. Equipment
   a. Poor maintenance

6.2. *Vault Event Sequences*

The following vault event sequences were considered. Additional event sequences were discussed, and are shown in Appendix G.

In this report, any reference to a "Vault Event" refers to the following two scenarios.

1. High current (low impedance) fault in switch or transformer causes immediate failure
   a. Fault causes pressure to build rapidly
   b. If present, a CLF is expected to trip fast enough to prevent tank rupture in most instances
   c. If pressure causes tank to rupture, overheated oil, air, and spark mix may create an event which rapidly releases energy in a sudden heat and pressure wave
2. Low current (high impedance) fault in switch or transformer causes oil release
   a. Pressure builds until tank ruptures, problem is noticed, or protection operates
   b. Sprays or leaks hot oil possibly causing fire

The events and scenarios above could lead to several consequences including

- Severe burns or death to public in vicinity of vault
- Severe burns or death to workers in vault
- Exposure to PCBs

This report does not study in detail the procedures or work methods used in the vaults. Worker risk evaluation is based on exposure to the events above.

6.3. *Past BC Hydro and Industry Incidents*

Past events were researched to verify the validity of the vault event sequences presented in section 6.2.

BC Hydro Incidents:

- BC Hydro incident #82695 Level 1 employee injury. A RAL switch faulted during work on live switch. This lead to investigation 3363. The incident was caused by human error, but could have been prevented by either reduced frequency of maintenance or equipment which did not require maintenance which involved touching components of switch that would normally be live.

Utility Incidents (Public):

- Winnipeg 1976 a man received burns from a vault explosion (Ottawa Citizen, July 14, 1984 Page 13).

- Winnipeg July 11 1984 transformer explosion severely burned mother and two children, son died of burns on October 2 1984 after being in critical and intensive cares and on life support (Ottawa Citizen, October 4, 1984 Page A15). Several people believed to be exposed to PCB oil (Ottawa Citizen, July 12, 1984 Page 3).
- UC Berkeley September 30 2013 an underground oil switch manufactured by Trayer Engineering Corporation exploded causing 2nd degree burns to a student (~130 gallons oil capacity)
- San Francisco PG&E UG Transformer explosion August 19, 2005 burned head and neck of nearby woman and broke windows of nearby building.

6.4. Identification of Barriers and Escalation Factors

Given the findings for vault event sequences, the critical event was chosen to be the release of a wave of heat and pressure due to the sudden release of energy from both the electrical grid and available combustible sources. The hazard which initiates this event is the potential for a fault to occur.

Control barriers prevent the potential for an electrical fault from causing a Vault Event are shown in Figure 16 to be insulation and protection. Insulation is protected from oil deterioration and leaks by maintenance and equipment condition (Equipment Condition prevents oil contamination). Protection is protecting a fault from occurring due to transient over voltage, and preventing a fault creating a vault event by reducing the energy delivered to the fault.

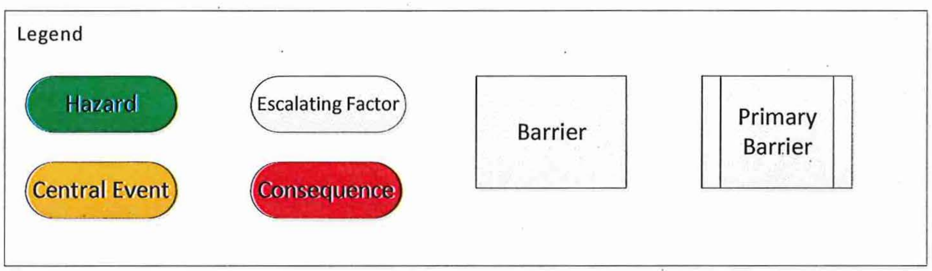

Figure 15 - Legend for following figures

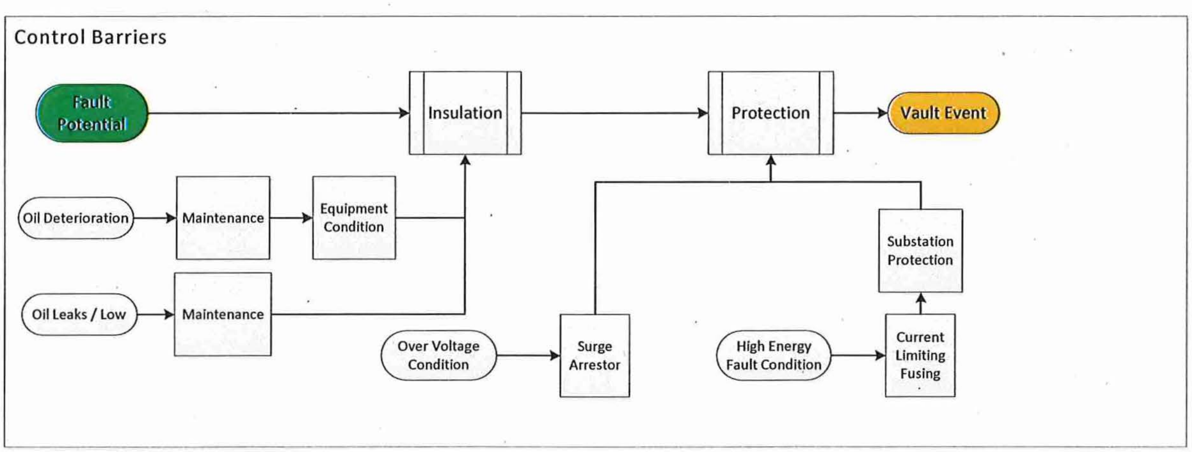

Figure 16 - Control Barriers

Mitigation barriers reduce the occurrence of injury to public or worker given the occurrence of a Vault Event. These mitigation barriers include isolation to reduce fault energy delivered, equipment which does not contribute to the available energy for the Vault Event, distance between the Vault Event and a person, and the Emergency Response available to aid the people affected. The escalation factors and barriers associated with post vault event incident mitigation are shown in Figure 17.

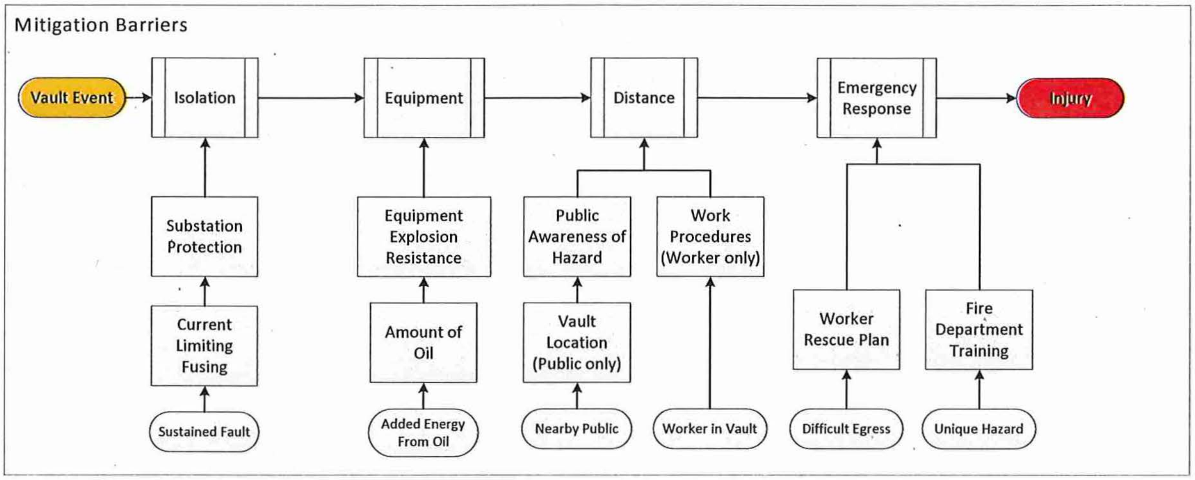

Figure 17 - Mitigation Barriers

6.5. Extract of Barriers to Use for Risk Reduction

Several of the barriers from Figure 16 and Figure 17 were identified as plausible options which would be a possible risk reduction option for some vaults, these are listed below

1. Add CLF
2. Replace poor condition equipment like for like
3. Maintain equipment with dirty or low oil
4. Repair equipment with oil leaks
5. Replace oil switches with a modern alternative (done correctly this could also; reduce worker exposure to being in the vault by reducing maintenance requirements, reduce the complexity of switching, improve the barrier which keeps workers at a distance from switching from work procedure to equipment design, and address the PCB in the oil fused cutouts by using a switch which provides overload protection)
6. Re-configure vaults to be fed by vista switchgear and contain only a transformer. *(Note: Refer to Engineering Standards Technical Report (ETR 050 R0 D2) on the options and other technical considerations for the replacement of oil filled switches, transformers and fuses)*
7. Place alternative switchgear outside of the vault
8. Increase vault inspection frequency
9. Move the vault to lower public exposure area (such as lane instead of sidewalk)

Other barriers, such as substation protection may be effective if improved but the consideration was not possible for this analysis as the effects of any changes have widespread impacts and thus should be carefully considered.

6.6. *Barrier Effectiveness Evaluation*

Using section 6.5 various risk reduction options were evaluated to determine how well they addressed the escalating factors which deteriorate the effect of either control or mitigation barriers. Table 2 presents which risk factors each mitigation strategy addresses.

Explosion chance and severity are considered the most important to control, as these affect both workers and public. Public and Worker exposure are on similar grounds.

Table 2 - Evaluation of remedial action alternatives

		Barrier Improvement Activity					
		Add CLF	Repair switch	Upgrade switch	Repair Tx	Upgrade Tx	Relocate Vault
Control	Tx Fault	Improvement	No Change	Some Improvement	Improvement	Improvement	No Change
	Switch Fault	Improvement	Improvement	Improvement	No Change	No Change	No Change
Mitigate	Public	Improvement	Some Improvement	Improvement	Some Improvement	Improvement	Improvement
	Worker	Some Improvement	Some Improvement	Some Improvement	Some Improvement	Improvement	No Change

Control: Evaluated on ability to control or prevent an vault event **Mitigate**: Evaluated on ability to reduce consequences given a vault event has occurred.	Legend:	Improvement Some Improvement No Change

Add CLF
The addition of a CLF above all oil filled equipment is both a control and mitigation barrier. By reducing available fault energy a CLF reduces the likelihood of oil filled equipment bursting. If the equipment does rupture, it is likely to be less severe, resulting in a more controlled oil air mixture rather than a severe Vault Event.

Repair Switch
Repairing the switch prevents oil loss and deterioration. Repair may also improve the condition of the switch, reducing the chance of the tank rupturing if a fault occurs within it.

Upgrade Switch
Upgrading the switch to a modern day non-oil switch has several improvements. Modern switches do not have oil which eliminates a source of energy which could contribute to a vault event. Additionally, they offer protection which can assist in mitigating the effects of a vault event caused by a fault in the transformer. The final benefit of upgrading the switch is to allow the removal of the oil fused cutouts which are likely to contain PCB oil and thus must be removed by December 31, 2025.

Repair Transformer
Repairing the transformer prevents the occurrence of a transformer fault similar to repairing a switch.

Upgrade Transformer
Upgrading the transformer allows for the specification of a blast resistant transformer with built in CLF, which mitigates the effect of a vault event on crew within the vault.

Relocate Vault
Relocating the vault provides the opportunity to increase the distance between vault and public. Relocation could be to a nearby alley, or to the street instead of sidewalk if in an area where loitering in alleys is a concern.

6.7. Ranking Qualitative Escalation Factors

As it was found that equipment condition and maintenance were important factors in the likelihood of a vault event, vaults were given a ranking for equipment condition as described in Table 3 in order to ensure consistency or risk ranking across vaults. A separate ranking was given for each vault for public exposure level, as this is an important mitigation control.

Quantifying vault condition was done based on maintenance information and condition notes from recent inspections. Maintenance records for transformers were not considered as part of condition rating due to consistently inconsistent records. Transformer condition notes were considered.

As over 50 vaults have no verified CLF, this was not considered in equipment condition rating under the intention that all vaults are to be retrofitted to be CLF protected.

Table 3 - Equipment Condition Ratings

Equipment Condition Rating (database value)	Description of equipment
Poor (1)	Heavily damaged or severe condition per either SAM or 2012 asbestos reports. Noted as overdue for inspection in SAM or unknown condition/maintenance
Fair (2)	Fair condition, may have slight oil leaks and corrosion or hot connection
Good (3)	Good condition equipment. No known defects Requires field validation.
Excellent (4)	No high risk equipment (except asbestos)

Quantifying public exposure was done by area, and particular risk factors.

Table 4 - Public Exposure Ratings

Public Exposure Rating	Description
1	High pedestrian traffic, parks, schools, commercial, entertainment districts, and the red zone. This includes the first block off of major beaches.
2	Other metropolitan areas
3	Suburban areas (single family dwellings) and rural. Additionally alleyways not in the red zone.

6.8. Vault Risk Results

Vaults were categorized into risk levels, which were consolidated into priorities. Table 5 shows the number of vaults ranked at each priority, assuming that a CLF has been added to all vaults. Condition 1 vaults are listed in Appendix A. Priority 1 vaults are the most urgent to address.

Table 5 - Number of vaults by priority

Rating		Priority	Number of Vaults
Equipment Condition	Public Exposure		
Poor	1	1	9
Poor	2	2	3
Poor	3	3	2
Fair	1	4	8
Fair	2	5	13
Fair	3	6	7
Good	1	7	21
Good	2		
Good	3		
Excellent	X	NA	27

7. RECOMMENDED ACTION ITEMS

This section presents immediate term, mid-term, and long-term recommended actions. Strategic opportunities have been identified which help BC Hydro meet regulatory requirements moving forwards.

7.1. *Immediate Term (F17 and F18)*

- Verify the database information in the field, repeat the risk prioritization method for new information, and update SAM/DAD.
- Install overhead current limiting fuses (CFLs) to protect three phase underground oil filled equipment in single radial and OH fed street vaults. While, the best safety informed solution requires a CLF installed for all oil filled equipment, given the space constraint in dual radial vaults fed by UG supply, continued close monitoring of UG fed dual radial vaults with immediate action on those which become poor condition can be a practical safety informed solution.
- Replace and upgrade the five dual radial street vaults (V58, V67, V69, V70, and V73). To align with System Planning's recommendation to upgrade to an open loop configuration with dual ratio submersible transformers with built-in CLFs.
- Repair, maintain and implement the recommendations for the remaining 9 units as outlined in appendix A.
- Investigate suitable replacements for RAL, VacPac, and non-vista SF6 switches, as well as oil fused cutouts.
- Sample all oil filled switches to determine if PCB contaminated and assess condition and action.
- Develop oil sampling procedure for transformers.

7.2. *Mid Term (F19 and F20)*

- Sample transformer oil using the procedure developed in F17 and F18 to determine if PCB contamination is greater than 50 ppm.
- The remaining oil filled switches and transformers that are identified to be in fair condition are maintained, repaired, or replaced with suitable alternative (if feasible) to align with the strategy for downtown redevelopment project.
- Continued close monitoring of dual radial vaults without CLF and immediate action on poor and fair condition
- Investigate to improve tracking and record keeping for oil tests.
- Fix sumps to prevent standing water causing corrosion issues.

7.3. *Long Term (F21 and beyond)*

- Replace all remaining oil filled switches by December 31, 2025
- Replace transformers with PCB contamination greater than 50 ppm by December 31, 2025.
- Replace all remaining <u>non-oil filled</u> three phase switch (e.g. SF6, VacPac) with vista or suitable alternative aligning with downtown redevelopment strategy.

7.4. *Strategic Opportunities*

- Since the oil fused cutouts were installed around 50 years ago, it is likely that they contain PCBs and thus should be removed from service as opportunities arise. BC Hydro must meet a deadline of no PCBs greater than 50 ppm by December 31, 2025.
- There is an opportunity to proactively address WSBC regulation 9.4 by investigating non-oil type transformers for confined spaces.

- When installing new equipment into existing vault, the civil structures must be assessed to ensure its suitability for the life of the new equipment and to ensure that the condition and the size of the structures can accommodate the new equipment.

8. ADDITIONAL FINDINGS AND RECOMMENDATIONS

There were findings through this investigation not related immediately to vault risk for explosion. These are presented in the table below.

Table 6 - Additional Findings

Finding	Recommendation
Poor reference between civil and electrical drawings	Implement drafting process to include electrical reference on civil drawings and vice versa
Confusion due to repeated use of terms for different meanings over time	Implement process to ensure drawing type names are not recycled for different purposes over time (for instance UDD)
Inaccurate or out of date information in DAD	Add component of DAD training which tells users who to contact about inaccurate information (for instance drawing references)
Records are spread out and difficult to find	Consider a record keeping system that kept reference to all drawings and maintenance records in one place for a given vault, and searchable by equipment type to be able to find all of a given type of equipment more accurately than currently available through DAD

9. CONCLUSION

Risk analysis was performed for underground oil switches and other aging underground equipment. A database was created to collect information about these switches which will be a resource for both continued vault risk monitoring and maintenance. Following the recommended action items will reduce the risks to public and contribute to reduced risk to workers represented by aging oil filled equipment in BC Hydro underground structures.

10. REFERENCES

BC Hydro. (n.d.). *Business Case F15, F16 Underground Equipment Replacement Program.*

BC Hydro. (n.d.). *ES 64-C-03.03.*

Boy dies of burns from transformer blast. (1984, October 4). *Ottawa Citizen*, p. A15.

Engineering, P. (2008, 11 01). *Oil-Filled Transformer Explosions.* Retrieved 04 2016, from Power Engineering: http://www.power-eng.com/articles/print/volume-112/issue-11/features/oil-filled-transformer-explosions.html

Experts still baffled by fiery explosion of hydro transformer. (1984, July 14). *Ottawa Citizen*, p. 13.

Mom kids scorched as Winnipeg blast hurls fireball. (1984, July 12). *Ottawa Citizen*, p. 3.

Park, S. (2013, 12 16). Dirks states Sept 30 explosion likely caused from short in electrical switch. *The Daily Californian.*

Subject Matter Experts. (2016, February - March). (See Aknowledgements).

Suit filed in Winnipeg blast. (1984, September 07). *Ottawa Citizen*, p. 12.

Vrecko, B. (2016, March 10). Email RE: V63 drawing - 603-D522682. (H. C. Luk, Interviewer)

Wahlgren, C., Leix, K., & Webb, J. (1992). Current Limiting Fuses Address Safety and Power Quality Concerns. *Rural Electric Power Conference* (pp. C4-1 - C4-5). New Orleans, Louisiana: IEEE.

Work Safe BC. (n.d.). *Part 9 Confined Spaces.* Retrieved 04 2016, from Work Safe BC: https://www2.worksafebc.com/Publications/OHSRegulation/part9.asp#SectionNumber:9.4

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APPENDIX A: LIST OF "POOR CONDITION VAULTS"

This Appendix shows the 14 vaults considered in poor condition (to be verified), ordered first by location, then severity.

Public Exposure	Vault	Configuration	Location Description	Main Issue	Recommended Action
	V8	3	E Georgia st, 49ft E of Dunlevy	Tx and switch bad shape. Single RAL used for dual radial service.	Assess condition. Replace with suitable alternative if condition is poor
	V70	3	on Abbott St 20' N of Water	Tx needs replacement for damage and corrosion. 7*C elbow heating	Rebuild vault with new equipment (i.e. 3-way vista and submersible transformer). Replace elbow.
	V69	3	On Water 170' E of cambie	Tx corroded and needs replacement	Rebuild vault with new equipment (i.e. 3-way vista and submersible transformer)
	V49	2	Broughton st, lane N of beach	Severe corrosion on all equipment, oil dark and low	Change Oil, assess condition. Replace with suitable alternative if condition is poor.
	V15	2	Lane W of Arbutus, S of Valley	Lid welded on (no maintenance)	Change Oil, assess condition. Replace with suitable alternative if condition is poor.
	V28	2	Lane S of Alberni St E of Jervis	Dark RAL oil and unclear viewing window, no oil sample, swollen splice	Change oil, assess condition. Replace with suitable alternative if condition is poor. Replace splice.
	V67	3	On Water, 220' W of cambie	Oil failed insulation test	Rebuild vault with new equipment (i.e. 3-way Vista and submersible transformer)
	V58	3	Carrall St and Lane N of Cordova	Switch 1685 has rusting on top, little information	Rebuild vault with new equipment

				in butterfly	(i.e. 3-way Vista and submersible transformer)
	V12	1	Lane N of Burnaby on Bidwell	Inspection overdue, corrosion, cutouts may be bypassed.	Repair equipment
2	V73	3	on Burrard St 72' N of Hastings	Oil failed insulation test, not shown on UDD	Rebuild vault with new equipment (i.e. 3-way Vista and submersible transformer)
	V21	2	Lane N of Pendrell at Gilford St	RAL leaking, oil level "not in sight" (too full or empty?)	Replace RAL with spare unit
	V22	2	Lane N of Barclay on Chilco St	Switch oil dark and low	Change oil
3	V29	1	St Clair Place rear 46 at olympic	Tx connection loose (fixed yet?)	Repair equipment
	V40	2	Lane S of Robson E of Chilco	5 year inspection last done 2005	Change oil

APPENDIX B: VAULT INFORMATION SOURCES

Below describes typical information sources, along with the method used to ensure the best possible information was kept. The table correlates sources to information gathered. Exceptions to these typical information sources are listed in Appendix C by vault.

- Asbestos photos, entry logs (butterfly reports), and consultant reports
- Vault Diagrams (historical) provided by field crews responsible for maintenance
- Underground Distribution Diagrams (historical UC series)
- Underground Distribution Diagrams (current series)
- U06 drawings
- U07 drawings
- GIS (DAD and SAM)
- PowerTech oil sampling records
- Dual radial vault inspection whiteboard from HPN
- Vault inspection logs from CLF check
- Google Maps and Streetview
- Subject Matter Experts (see acknowledgements)
- Other drawings and historical drawings as required to fill in information gaps

Appendix B shows details to assist the reader in understanding where each specific type of information was gathered from. Appendix C shows vault specific information sourcing exceptions. As some information had multiple sources, conflicts were found. Where conflicts arose either the most recent reliable information or most conservative information was kept, as described below.

Example of where most recent reliable information is kept. Much information comes from street vault diagrams or distribution operating diagrams (depending on era), which show the original build, typically including revisions and modifications up to the late 80's or early 90's. If a more recent source, such as DAD contradicts this, the more current source is taken as correct, unless 2012 asbestos photo's support the original design in which case a risk note is entered to raise awareness of the conflict.

Example of where information retention overrules currency. If the 2012 butterfly report indicated that the transformer was leaking, but DAD zone awareness did not, the information is kept that the transformer is leaking, as the butterfly is considered reliable, entry may have been missed into DAD, and we seek to be conservative. However for inspections it is assumed that DAD/SAM is correct.

Type	Typical Source
Configuration	Amalgamated from all vault information
Dimensions	Vault List from David Calder
Location	Vault List from David Calder
Area	Vault List from David Calder
Civil Drawing Number	Vault List from David Calder
UDD	UDD lookup by intersection
CCT #	Various, including DAD which was considered most reliable.
Configuration	Various, including vault list from David Calder, U06 drawings, DAD. Considered OH if the upstream CLF to protect whole vault would be placed on a TP
Cable Type	Based on Cable size code, U06 drawing, photos, DAD zone awareness
Cable Size	U06 Drawing, or UDD(UC series)
Primary Duct	U07 drawing, may include some secondary ducts, Vista vaults appear to follow trend of 2x4" and 2x5", some note that the 4" are primary, it is assumed this is typical. Some may even include communications ducts if indistinguishable
Transite Duct	U07 drawing or DAD, or Asbestos report if duct or collar specified as Transite. Any asbestos material not either conduit or collar is not considered in this column. (Ex. V25 has ACM putty near collars, this means the vault has asbestos but not "Transite duct" with the assumption this could be removed before pulling cable.
Feed CLF	Street Vault diagram notes, UDD(UC series),
Feed CLF Verified	Verification by field reports from David Calder
Tx CLF	Street vault diagram, in many instances fuse known to be S&C by observing the revision date which added CLF (~1988) on the vault diagram, along with CLF model number pattern to be similar to that of Vault 72 known to be S&C by picture
Tx CLF Verified	This is either noted by DC inspections, or shown in a picture (a picture may not confirm the CLF is connected)
Switch	Street Vault Diagram, Photo's, DAD
Switch Termination	Switch type, photo's
Switch oil test	Powertech oil sample dates

Type	Typical Source
CTS	Estimate based on cable types at various locations and photos
Cutout	Photos, Butterfly, Street Vault Diagram
Transformer	Street Vault Diagram, Butterfly, DAD,
Transformer age	Butterfly report. Note: Unknown means not noted, where "No Date" means nameplate does not indicate date
Transformer oil test	Powertech oil analysis records,
Next 1 year	This documents the next 1 year inspection date as taken from HPN office tracking system for dual radial oil filled switch vaults around Vancouver. Failed indicates the last oil test was a fail, unknown indicates it is a dual radial vault with oil filled switches that is not tracked.
Standing Water	Butterfly, asbestos report
Asbestos	asbestos report
Public Exposure	Google maps overlaid with vault co-ordinates based on DAD, streetview, and UCC drawings combined. Rankings per table in report. 1 high (many people walking), 3 low (single family dwelling area)
Equipment Condition	Uses condition notes on equipment and equipment type to quantify the likelihood of a failure occurring in a given vault. Ranking per table in report. 1 high (sever condition equipment), 4 low (no standing water or at risk equipment)

APPENDIX C: EXCEPTIONS TO VAULT INFORMATION SOURCES

Vault	Variance
MH 914	Powertech oil lab results, MH 914 inspection folder, dwg 12.67 DGR
V0008	all information usually from David C sourced instead from DAD and inspection.
V0013	additional information source underground feeder diagram 12F77DGR
V0038	additional information source underground feeder diagram 12F77DGR
V0067	cable size from butterfly not electrical drawings
V0069	duct size from DAD not civil
V0069	cable size from butterfly not electrical drawings
V79	No photo verification of termination types or equipment other than GRA switches, assumption of PILC to XLPE transition at GRA switch based on preceding vaults
V82	Source pictures and asbestos inspections and DAD only. No design drawings found
V70	Cable size from butterfly only
V16	size from TD19765 as size in DC list appeared erroneous
V68	Cable size assumption 4/0 for size due to dual radial and lack of drawing
V92	3x500kVA transformers cannot fit in the vault size noted in 455-U07-D1516, it is suspected that the vault size is the standard vista vault 6.3x2.4x3.25m
V42	Location based on DAD as file location appears inaccurate

APPENDIX D: EXCERPT OF DATABASE

The following pages contains the following printed excerpts of the database:

- Safety Consideration Printable Extract
- Reference Material Printable Extract
- Vault Summary Printable Extract
- List of vaults outside scope of project that should be field checked
- List of disqualified vaults, which were at one time believed to contain a switch but determined to be either out of scope or found to not contain a switch

Database column descriptions are shown in appendix H.

APPENDIX E: VAULT DRAWINGS

Appendix E contains vault drawings for vaults contained in the database with known vault drawings

APPENDIX F: NON STANDARD VAULT DRAWINGS

Appendix F contains drawings and email records regarding non-standard vaults found in Whiterock, and Prince George.

Appendixes D, E, and F are large and are contained in separate PDF files, included at the back of printed report.

APPENDIX G: ADDITIONAL HAZARDS AND SEQUENCES

This appendix shows all discussed hazards and safety sequences, including those which did not fit within the scope of the report.

Hazards:

1. This section discusses the hazards typical of street vaults. This appendix includes hazards not considered key hazards therefore not discussed in the report body. Energy
    a. Electrical Energy from grid (12kV)
    b. Chemical Energy from
        i. oil in oil filled equipment
        ii. built up methane gasses from decomposition
        iii. nearby gas lines
2. Equipment
    a. May not meet today's standards (including for visual open verification)
    b. May not be installed to today's standards
    c. May not be installed to industry best practice (No CLF)
    d. End of Life
    e. Poor maintenance
3. Chemical
    a. PCBs
    b. Asbestos
4. Confined Space

Safety Sequences:

1. High current fault in switch or transformer causes immediate failure
    a. Fault causes pressure to build rapidly
    b. Pressure causes tank to rupture at which point overheated oil, air, and spark mix may create an event which releases sudden heat and pressure wave
2. Low current fault in switch or transformer causes oil spray or explosion
    a. Pressure builds until tank ruptures, problem is noticed, or protection operates
    b. Sprays or leaks hot oil possibly causing fire
3. Leaking oil (with PCB)
4. Cable fault creates arc flash, possible cable fire
5. Inability to sample oil for single radial RAL switches due to inability to refill oil on live switch
6. Inability to operate switch due to dirty oil preventing visibility of open

The events and scenarios above could lead to several consequences including

- Severe burns or death to public walking above vault (caused by 1 and 2)
- Severe burns or death to workers in vault (caused by 1 and 2)
- Exposure to PCBs (caused by 1, 2, and 3)
- Lack of knowledge of switch condition (caused by 4)
- Prolonged customer outages (caused by 5)

To match the report scope, risk event sequences 1, 2, and 3 are considered, with emphasis on 1 and 2.

Risk event sequence 4, while presenting an event consequence similar to those of sequences 1 and 2 has been addressed by arc flash requirements and distribution standards modified manhole covers. Therefore consequences are not discussed.

APPENDIX H: DESCRIPTION OF DATABASE COLUMNS

	Information	Description
Vault Info	Region	Describes region, for example Vancouver or Kamloops
	Number	The vault identification number (or manhole number)
	Config 1	The configuration of the vault (single or dual radial, etc)
	Dimensions (LWH)	The dimensions of the vault structure itself
	Location Description	Describes vault in relation to street intersections
	Area No	The area number used in drawing numbers describing the vault
	Civil Drawing Number	Typically the digits following "Area no-U07-0..."
	Vault Dwg Number	The drawing number of a drawing which shows electrical configuration of vault
Feed	UC / Elec Dwg Number	The drawing number that shows the feed to the vault
	UDD #	The map section which includes the vault
	CCT #	The circuit numbers which feed the vault
	Config 2	Identifies if feed is overhead or underground, using criteria "where would CLF be placed upstream of vault"
	Cable type	Identifies if PILC cable is used
	Cable size	Identifies cable code believed to feed vault
	Primary Duct	Identifies number and size of primary ducts feeding vault. May include secondary ducts if unclear
	Transite Duct?	Identifies if the duct has been identified as transite or black fiber
	before vault	Identifies if a CLF is shown in design drawings to be before the vault
	b4 vault verified	Identifies if a field check has confirmed presense of the CLF before vault
	before Tx	Identifies if a CLF is shown in design drawings to be before the transformer
	b4 Tx verified	Identifies if a field check has confirmed presense of the CLF before transformer
Switch	type/ make/model	Identifies switch type (Eg. RAL, VacPac, etc)
	Switch Source termination	Identifies if switch termination is PILC or XLPE
	Switch Load termination	Identifies if switch termination is PILC or XLPE
	Powertech Oil Test	Notes date of most recent oil sample received from powertech, for the switch in the vault which was least recently tested
	Next 1 yr Insp	Identifies when the HPN switching vault maintenance whiteboard identifies the next 1 year inspection to be required

	HPN Inspection	Identifies the date of the inspection performed in 2015, "?" suggests a record was received in the 2015 inspection records but not dated
Splice	CTS	Identifies if it appears there is a cable transition splice in the vault
Cutout	type/make	Notes cutout type which could be an oil fused cutout, or a CLF inside vault
	Cutout termination	Identifies if cutout termination is PILC or XLPE
Transformer	Size	Size (kVA) and number of transformers
	Secondary Voltage	Secondary voltage of transformer
	Transformer termination	Primary termination of transformer (PILC or XLPE)
	Age	Age of transformer (if known)
	Powertech Oil Test	Date of most recent powertech record for transformer oil test
Hazards	Standing Water	Identifies if vault is noted to have standing water
	Asbestos testing	Result of 2012 asbestos testing (Positive or Negative)
	Exposure	Rating of 1-3 for how much public exposure the vault has
	Condition	Rating of 1-4 for the condition of the equipmetn in the vault
	Overall Rank	Rating of 1-7 of how immediately further action should be performed on the vault
	Risk Notes	Records condition notes, and other notes on the vault collected through all sources including SAM, Inspection reports, pictures, google maps street view, etc.