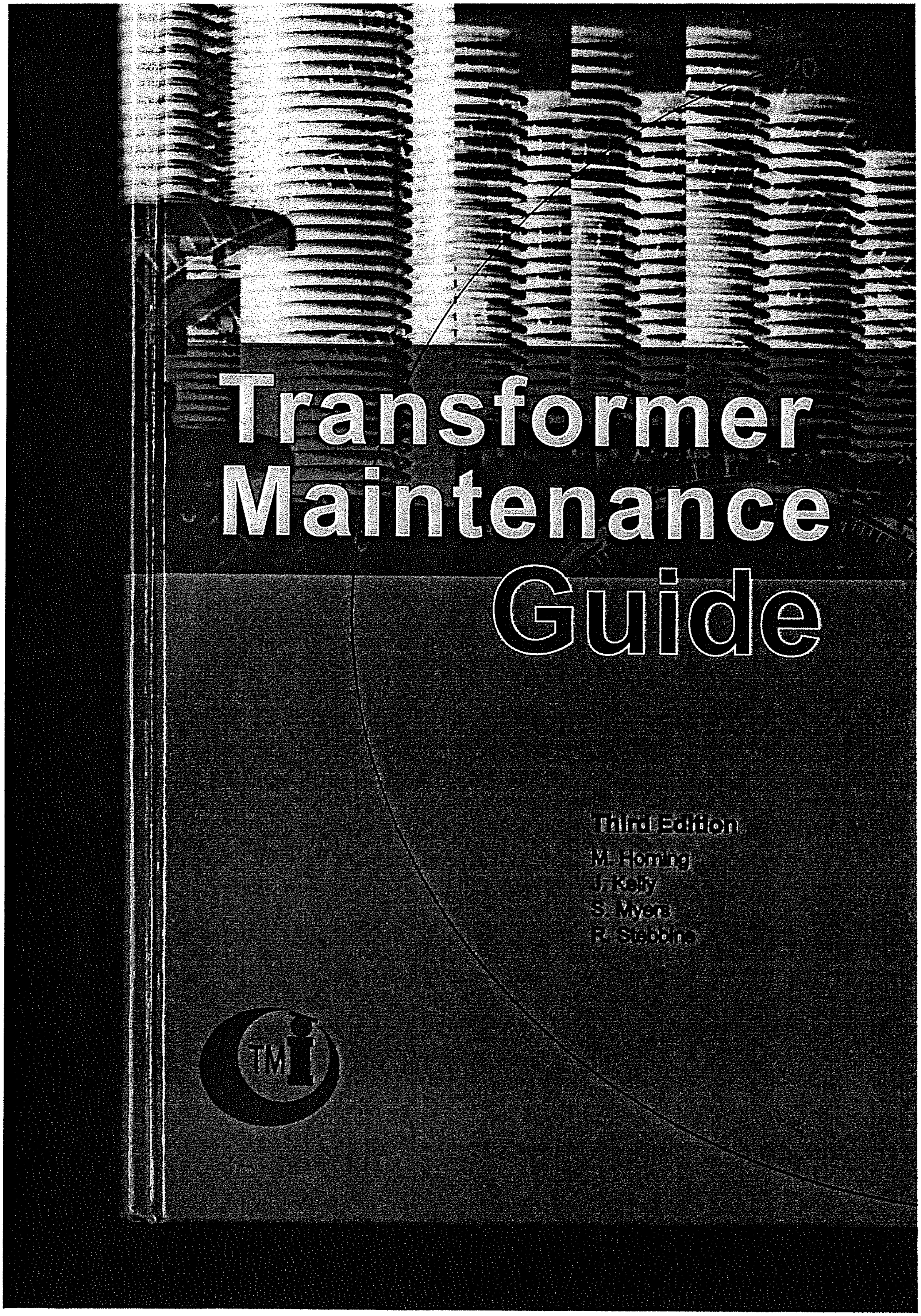
Q. Re: Upgrade Power Transformers Volume II (Tab 17)
Are there any specific industry standards to support Hydro's planned replacement strategy?

A. Hydro's Transformer strategy is based upon the Degree of Polymerization (DP) of cellulose insulation paper being less than 400 of significant combustible gas being generated in the transformer. The standard Hydro has adapted for DP is essentially outlined in the Transformer Maintenance Guide, second edition by M. Horning, J. Kelly and S. Myers. Please see attachment.

The second criteria regarding significant combustible gas being generated has been added based upon Hydro's own experience in performing Dissolved Gas Analysis of Power Transformers over many years. As hot spots or faults develop in transformers, combustible gases such as hydrogen, carbon monoxide, methane, ethane, ethylene, and acetylene are produced. If corrective action is unable to repair a gassing problem, there is no option but to take the unit out of service due to the safety concerns resulting from continually generating combustible gases inside the transformer.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Similarly, the end of the QU range is intended to be equivalent to a point where substantial and measurable damage to the solid insulation occurs. 250 ppb of total furans corresponds roughly to a 25% loss of life.

Degree of Polymerization

ASTM Standard Method D 4243

If a small sample of the insulation paper is obtained from the transformer, the degree of polymerization may be obtained by directly testing the paper sample. The sample is dissolved in a special solution, and the viscosity is measured by passing the dissolved paper through a small orifice. The viscosity measured in this way has a direct relationship to the degree of polymerization of the paper.

This is a more practical method of measuring the remaining life of the paper compared to tensile strength testing due to the much larger sample required for tensile strength determinations. There still are difficulties, however. The process requires that an outage for the equipment be taken and that the unit be opened and perhaps drained to obtain a sample. Where can one obtain a representative sample? There is no written standard practice available defining how and where such a sample can be taken. For a transformer that is intended to continue in service, DP testing is also impractical. The major uses of DP testing are to evaluate transformers being taken out of service or to define rewinding and remanufacturing needs.

Calculating Degree of Polymerization and Remaining Life from Furan Results

Degree of polymerization can be calculated from furan results. Since an oil sample is more practical to obtain and since the furan content gives a more average value for the calculated DP, the results are generally more useful and representative.

There are two distinct populations of transformers. Transformers that do not have thermally upgraded paper form a much higher concentration of furans compared to transformers that do have thermally upgraded paper. The furanic compounds are also somewhat more subject to decomposition in the presence of the additives used to thermally upgrade the paper.

Transformers without thermally upgraded paper typically included 55 °C rise transformers manufactured in North America before the early 1960's and almost all transformers manufactured outside of North America - only recently have manufacturers in Europe and Japan offered thermally upgraded paper, and it remains an option that the purchaser has to specifically request. 55/65 °C rise and 65 °C transformers manufactured in North America since the early 1960's typically used thermally upgraded paper (this includes almost all North American manufactured units in that time period).

Furan content is a reasonably good predictor of DP if one segregates these two populations and applies a different calculation for estimating DP to each population. Since DP has been established as a measure of end of reliable life, the furanic compounds analysis can be applied to that use, as well. For transformers without thermally upgraded paper, the best estimation of DP is calculated using the 2-furaldehyde content. For transformers with thermally upgraded paper, the calculation is based on the total furan content. The equations used for these calculations are updated periodically. The ones that are being used at press time can be summarized by the following table:

Not Thermally Upgraded Paper 2FAL (ppb)	Thermally Upgraded Paper Total Furans	Calculated DP	Estimated % Life Used
58	51	800	0
130	100	700	10
292	195	600	21
654	381	500	34
1464	745	400	50
1720	852	380	54
2021	974	360	58
2374	1113	340	62
2789	1273	320	66
3277	1455	300	71
3851	1664	280	76
4524	1902	260	81
5315	2175	240	87
6245	2487	220	93
7337	2843	200	100

Analysis of Polychlorinated Biphenyls (PCBs) in Insulating Oil

ASTM Standard Method D 4059

The ASTM standard method for PCBs in insulating oil uses gas chromatography with either a packed column or mega-bore capillary column and an electron capture detector. PCB content is quantified by comparison to standards prepared from Aroclors, commercial mixtures of PCBs that were used as insulating liquids, and reported as parts per million by weight (milligrams per kilogram) of the appropriate Aroclor(s). For classifying equipment for environmental management according to the Federal PCBs rules contained in 40CFR761, this method of analysis and reporting is preferred.

There are other PCB analysis methods, mainly those EPA methods from SW-846, that are used as appropriate for waste oils and solids, to characterize spill sites, and to confirm clean-up efforts. Some of these are Aroclor matching patterns while others quantify individual congeners of PCB.