ABSTRACT

The introduction of the Envirotemp FR3 dielectric fluid and the findings that it drastically reduces the thermal aging of kraft paper in a transformer (TP03-DR-009) provides unique opportunities for transformer loading and/or transformer design. The use of FR3 fluid with thermally upgraded kraft paper, as addressed in this report, allows for increased loading capability and/or higher temperature operation while maintaining expected thermal life.

If a transformer designed and built for a mineral oil thermally upgraded kraft paper system is retro-filled with FR3 fluid:

- It will operate slightly hotter under identical loading.
- It will have greatly increased thermal life under identical loading.
- It will have greater over-loadability, depending upon component ratings, while maintaining the same thermal life.

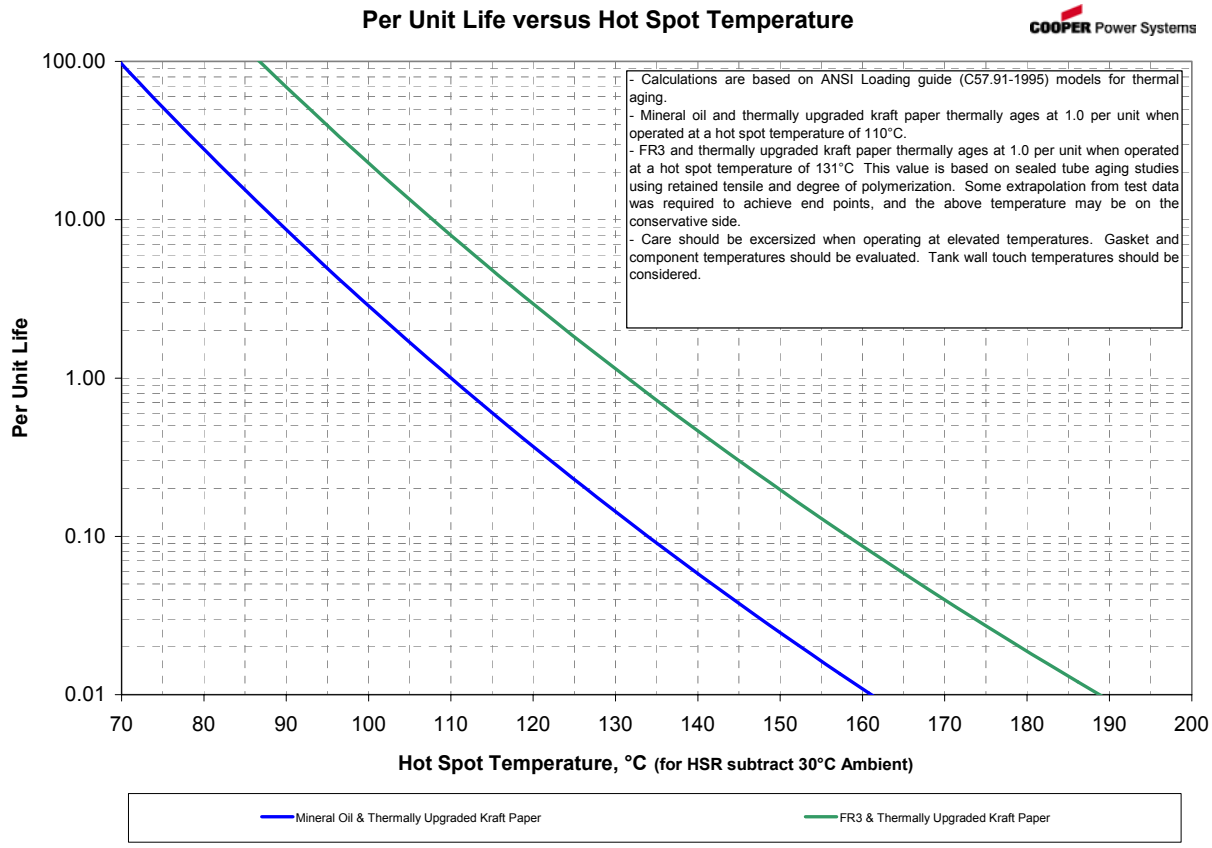
If a transformer designed and built for an FR3 fluid thermally upgraded kraft paper system is built to ANSI standard ONAN65 (80°C HSR) operation:

- It will operate at temperatures very similar to a comparable mineral oil unit.
- It will have greatly increased thermal life over a comparable mineral oil unit under identical loading.
- It will have greater over-loadability than a comparable mineral oil unit, depending upon component ratings, while maintaining the 1.0 per unit thermal life.

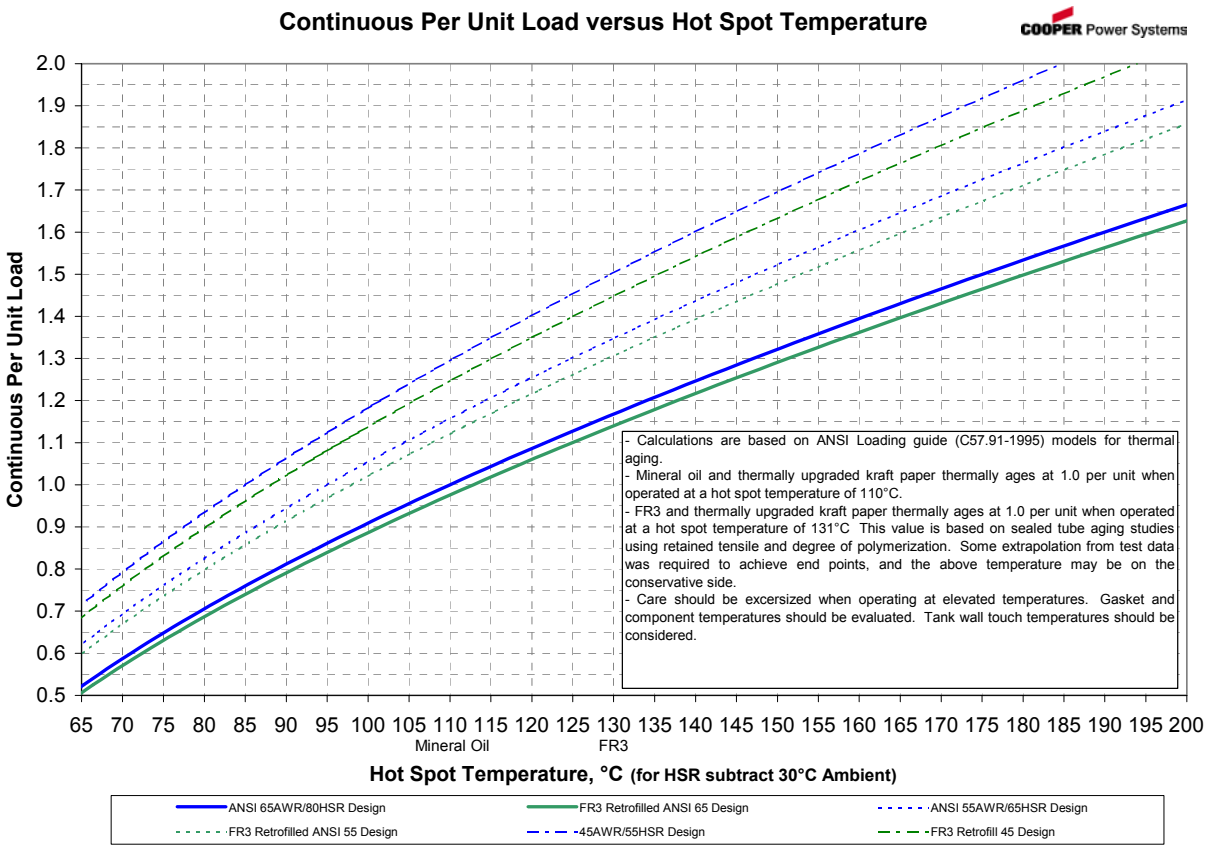
If a transformer designed and built for an FR3 fluid thermally upgraded kraft paper system is built to ONAN 100°C HSR operation:

- It will have thermal life comparable to a similar ONAN65 mineral oil unit under identical loading.
- It will have over-loadability comparable to a similar ONAN65 mineral oil unit.

The following graphs illustrate comparable mineral oil and FR3 fluid thermal, loading, and aging performance.

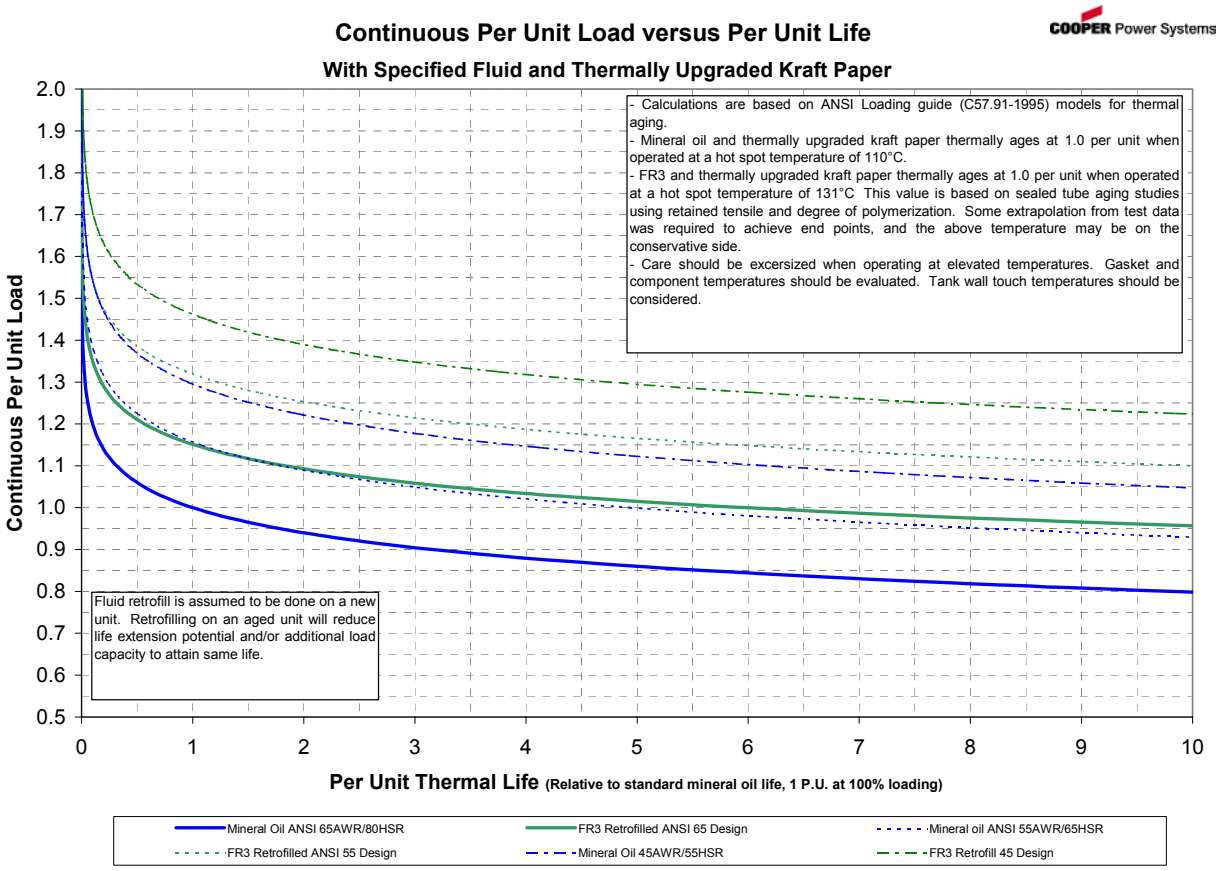


This graph illustrates the basic insulation system aging and a comparison between thermally upgraded kraft paper in mineral oil and in FR3 fluid. This graph clearly shows that at equivalent hot spot temperatures an FR3 fluid based system will have a thermal life between 7 and 8 times longer than a mineral oil based system. Alternatively, for equivalent thermal life, an FR3 fluid based system can operate 21°C hotter than a mineral oil system (Ref. TP03-DR-009).



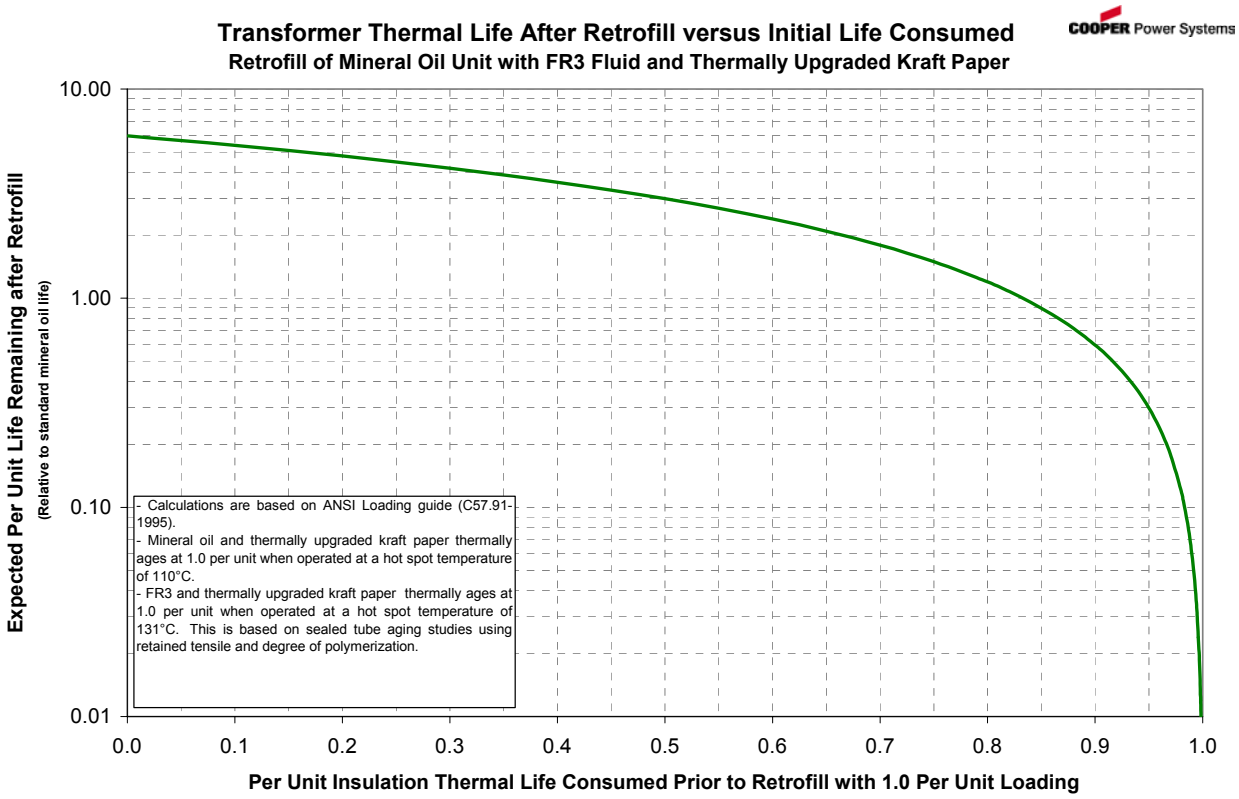
This graph is based on ANSI sample transformer characteristics and provides an estimated relation between loading and hot spot temperatures for several design configurations. The blue lines are mineral oil thermally upgraded kraft systems, and the green lines are FR3 fluid thermally upgraded kraft systems. Similar line styles represent similar unit designs. Going from a blue line of a given style to the same style green line represents the effects of retro-filling a mineral oil based system with FR3 fluid. For a given loading, retro-filling with FR3 fluid will increase the hot spot temperature by several degrees. But an FR3 fluid based system can operate 21°C higher with the same aging as a mineral oil system (Ref. TP03-DR-009).

Example: An ONAN65 mineral oil system operating at 1.0 per unit load and 110°C hot spot temperature can be retro-filled with FR3 fluid and operated at approximately 1.14 per unit load with the same expected thermal life.



This graph is based on ANSI sample transformer characteristics and provides an estimated relation between loading and expected thermal life for several design configurations. The blue lines are mineral oil thermally upgraded kraft systems, and the green lines are FR3 fluid thermally upgraded kraft systems. Similar line styles represent similar unit designs. Going from a blue line of a given style to the same style green line represents the effects of retro-filling a mineral oil based system with FR3 fluid. For a given loading, retro-filling with FR3 fluid will increase the expected thermal life considerably. Alternatively, loading can be increased by maintaining the same expected thermal life, and retro-filling with FR3 fluid. This graph also clearly demonstrates the non-linear effect of loading on thermal aging.

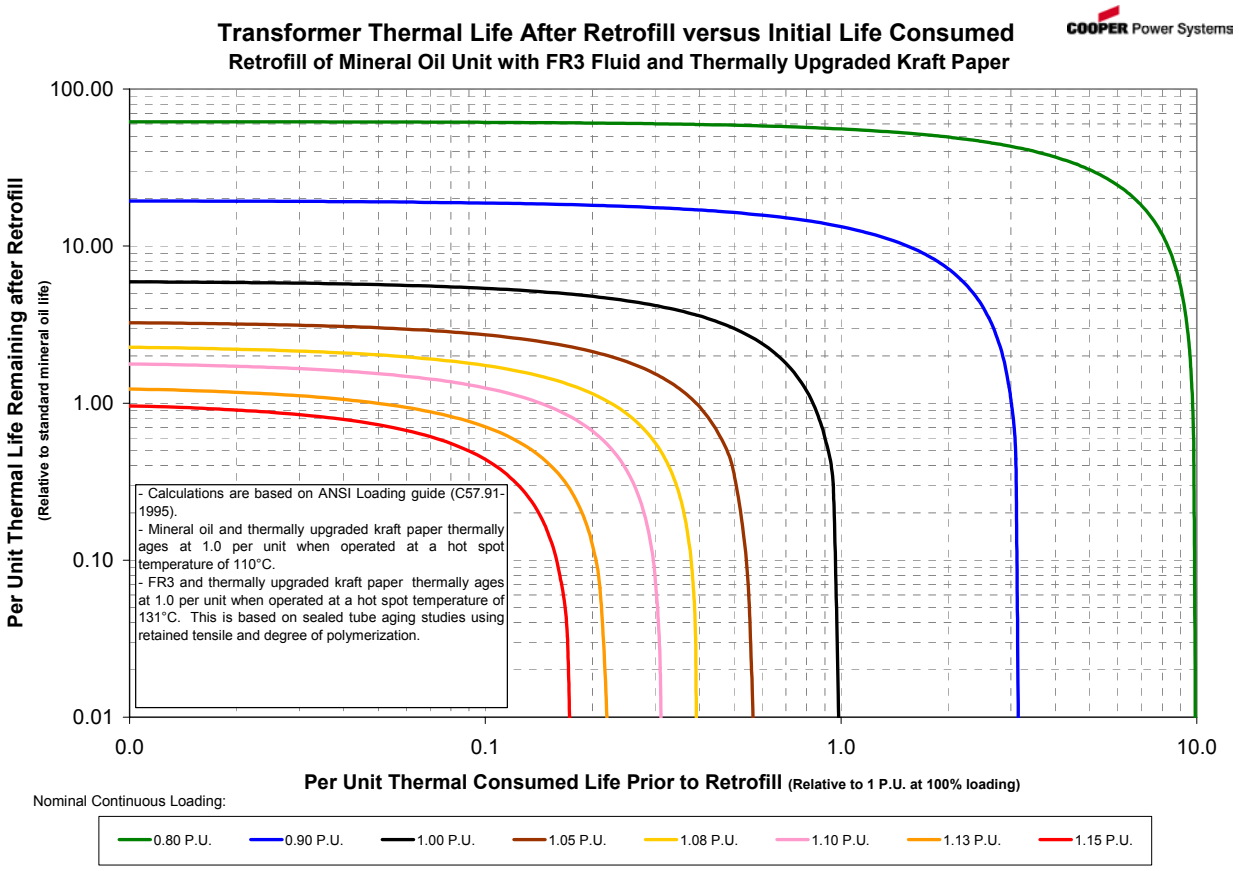
Example: An ONAN65 mineral oil system operating at 1.0 per unit load and 110°C hot spot temperature can be retro-filled with FR3 fluid and be expected to have an expected thermal life 7 times longer with the same loading.



This graph is based on ANSI sample transformer characteristics and provides an estimation of expected thermal life after retro-filling an aged mineral oil based unit with FR3 fluid.

Example: A mineral oil thermally upgraded kraft paper based unit that has been in service with 50% of its thermal life consumed can be retro-filled with FR3 fluid and be expected to then have 3.0 per unit thermal lives remaining; a 6 fold increase in life.

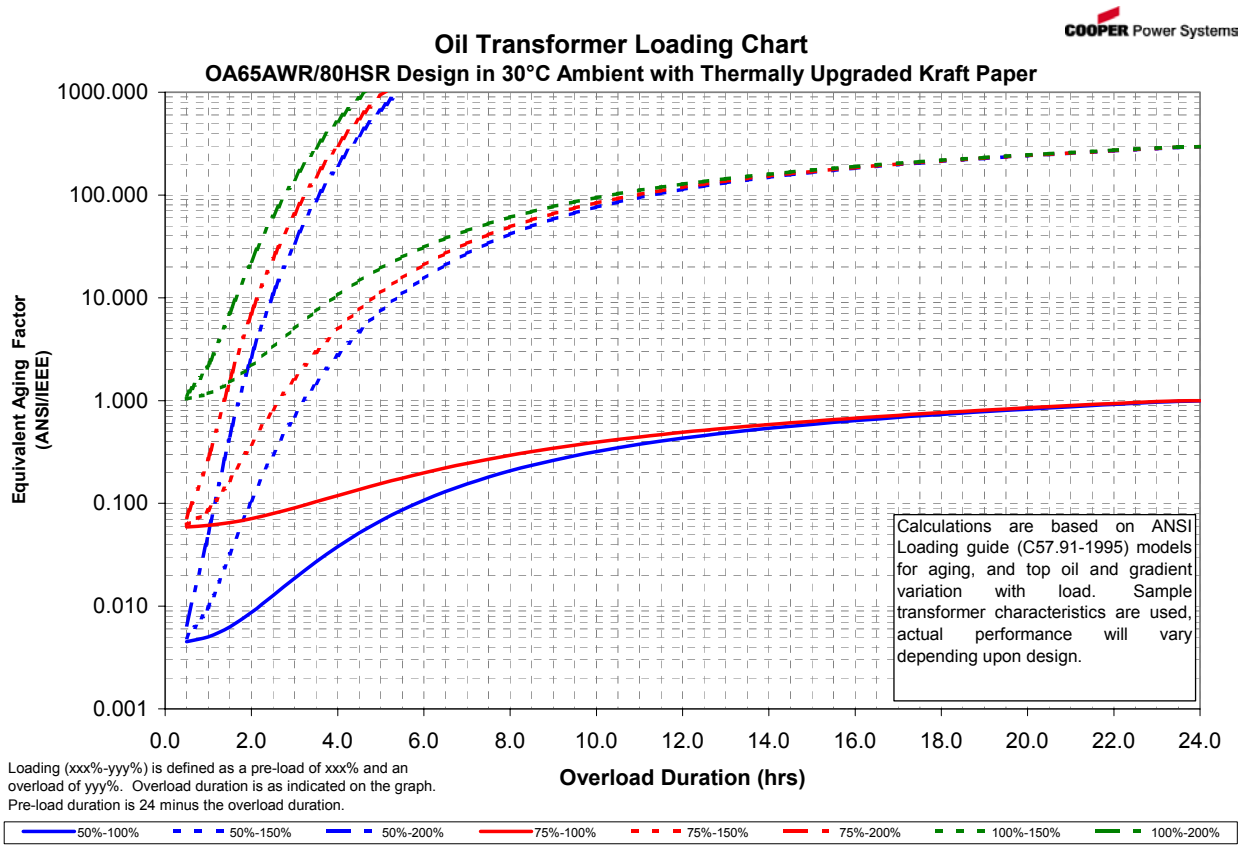
Example: A mineral oil thermally upgraded kraft paper based unit that has been in service with 83% of its thermal life consumed can be retro-filled with FR3 fluid and be expected to then have 1.0 per unit thermal life remaining; nearly a 6 fold increase in remaining life.



This graph is based on ANSI sample transformer characteristics and provides estimations of expected thermal life after retro-filling an aged mineral oil based unit with FR3 fluid under various loading conditions. Each line indicates a different nominal continuous condition on the transformer.

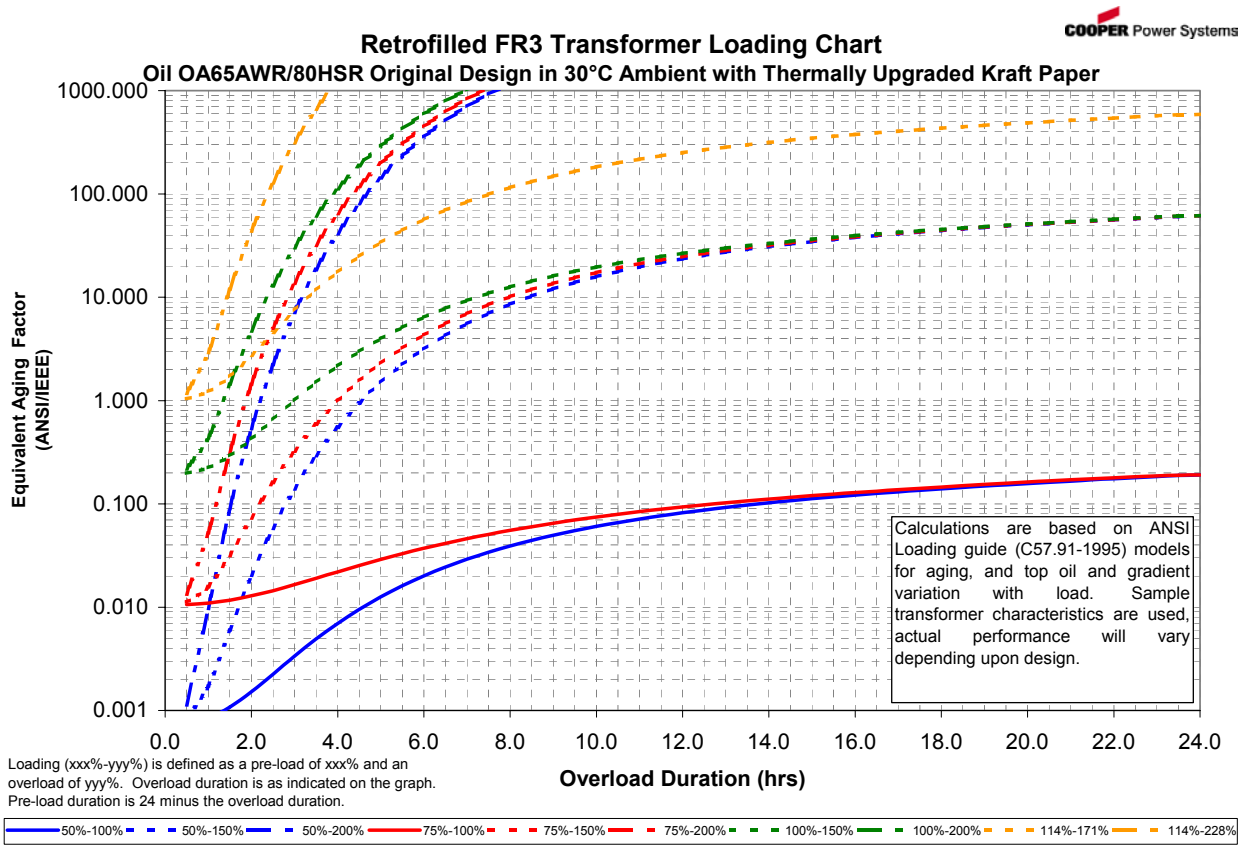
Example: A mineral oil thermally upgraded kraft paper based unit nominally loaded at 0.80 per unit (green line) has an expected thermal life of nearly 10.0 per unit. If the same unit were retro-filled with FR3 fluid after consumption of 1.0 thermal life, the unit would then have an expected remaining thermal life of between 50 and 60 per unit.

Example: A mineral oil thermally upgraded kraft paper based unit nominally loaded at 1.10 per unit (pink line, 6th from left) has an expected thermal life of slightly over 0.3 per unit. If the same unit were retro-filled with FR3 fluid after consumption of 0.15 thermal life (50% of total expected), the unit would then have an expected remaining thermal life of 1.0 per unit.



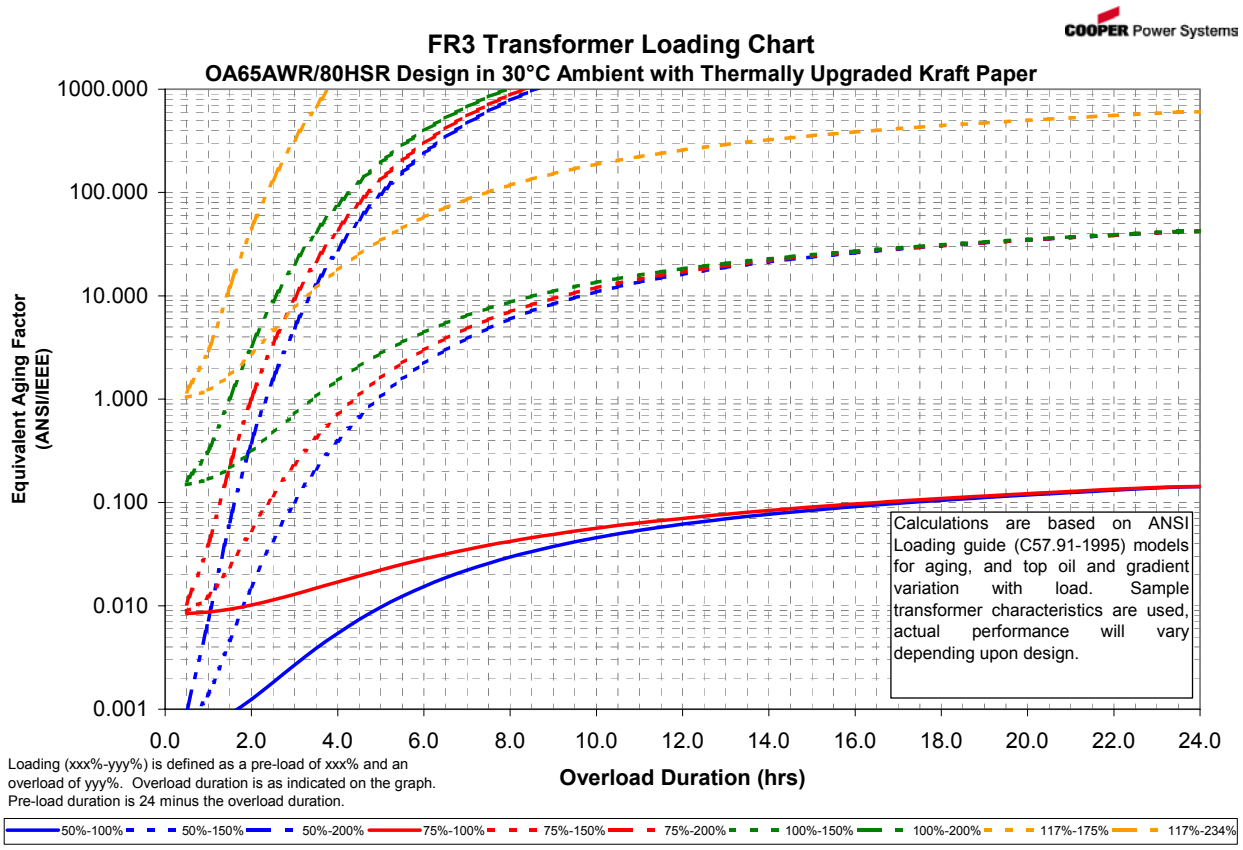
This graph is based on ANSI sample transformer characteristics and illustrates the equivalent aging factor (FAA in the Loading guide) under various bi-level load cycles. This specific graph is for a mineral oil thermally upgraded kraft paper system in a unit designed for nameplate operation at 65°C AWR/80°C HSR. The bi-level load cycles illustrated consist of a stable pre-load as indicated by the first (xxx%) number followed by a step change to higher load (yyy%) held for the time indicated on the X axis. Note that information similar to this had been presented in earlier Loading Guide revisions in tabular form. Different colors represent different pre-load levels, and different line types represent different overload levels.

Example: A transformer operated with a 75% pre-load (red line color) followed by a 150% overload (short dashed line) for a duration of 2.75 hours will have an equivalent aging of 1.0.



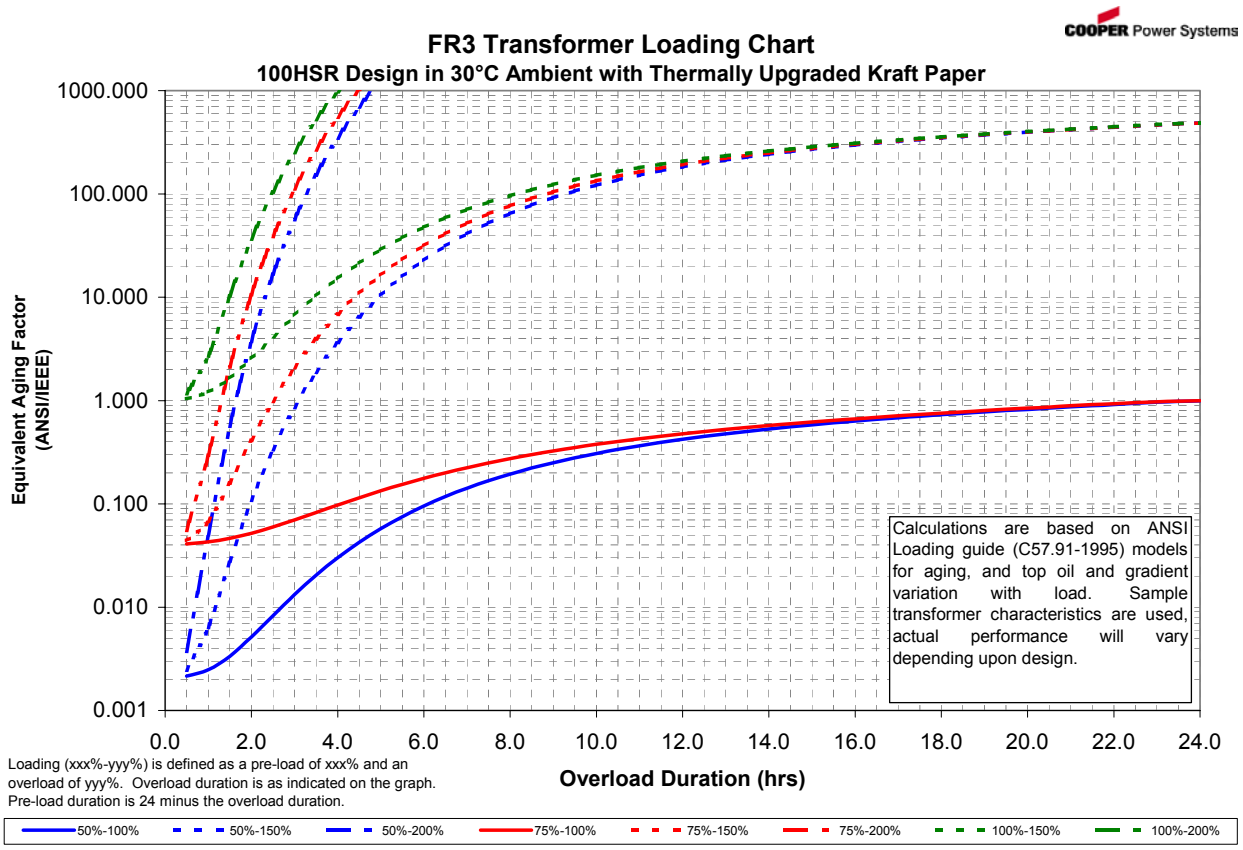
This graph is based on ANSI sample transformer characteristics and illustrates the equivalent aging factor (FAA in the Loading guide) under various bi-level load cycles. This specific graph is for a mineral oil thermally upgraded kraft paper system in a unit designed for nameplate operation at 65°C AWR/80°C HSR retro-filled with FR3 fluid. The bi-level load cycles illustrated consist of a stable pre-load as indicated by the first (xxx%) number followed by a step change to higher load (yyy%) held for the time indicated on the X axis. Note that information similar to this had been presented in earlier Loading Guide revisions in tabular form. Different colors represent different pre-load levels, and different line types represent different overload levels.

Example: A transformer operated with a 75% pre-load (red line color) followed by a 150% overload (short dashed line) for a duration of 4 hours will have an equivalent aging of 1.0.



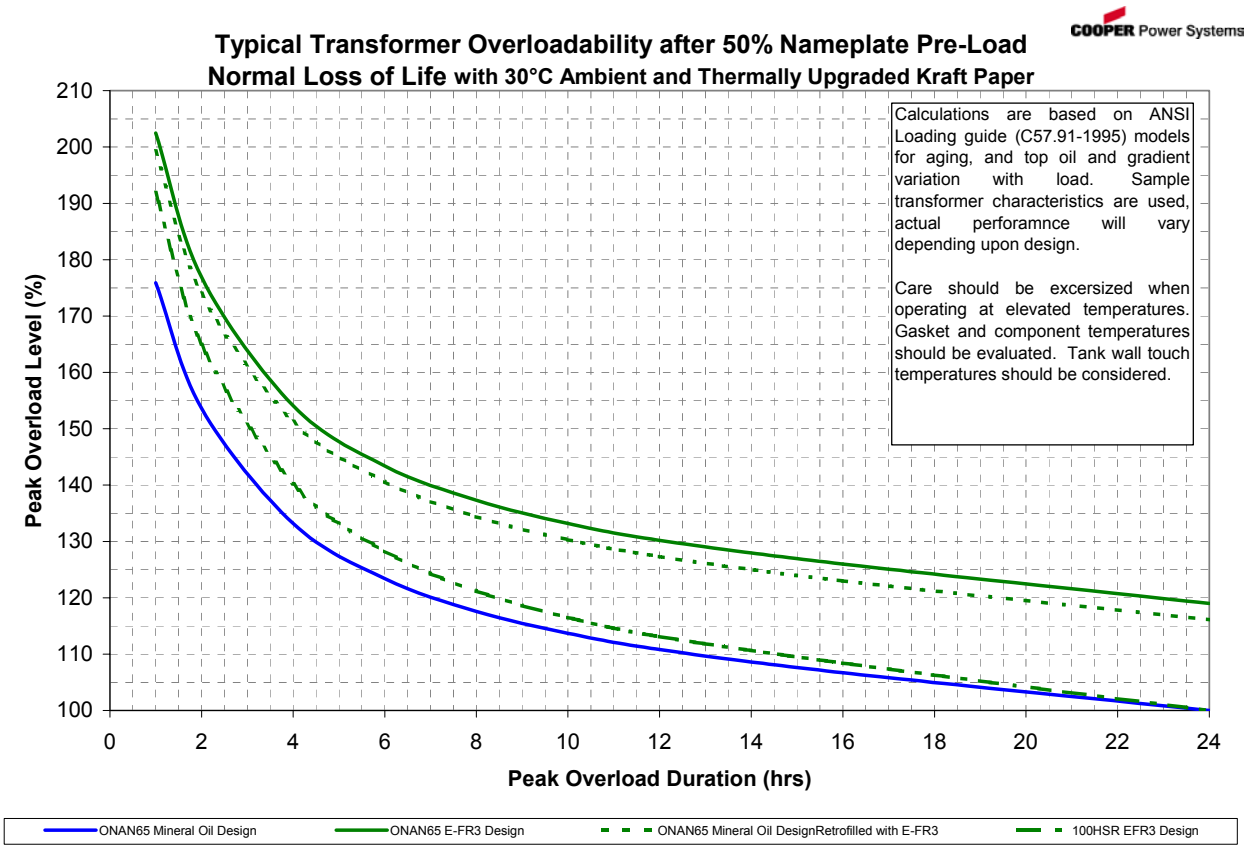
This graph is based on ANSI sample transformer characteristics and illustrates the equivalent aging factor (FAA in the Loading guide) under various bi-level load cycles. This specific graph is for an FR3 fluid thermally upgraded kraft paper system in a unit designed for nameplate operation at 65°C AWR/80°C HSR. The bi-level load cycles illustrated consist of a stable pre-load as indicated by the first (xxx%) number followed by a step change to higher load (yyy%) held for the time indicated on the X axis. Note that information similar to this had been presented in earlier Loading Guide revisions in tabular form. Different colors represent different pre-load levels, and different line types represent different overload levels.

Example: A transformer operated with a 75% pre-load (red line color) followed by a 150% overload (short dashed line) for a duration of 4.5 hours will have an equivalent aging of 1.0.



This graph is based on ANSI sample transformer characteristics and illustrates the equivalent aging factor (FAA in the Loading guide) under various bi-level load cycles. This specific graph is for an FR3 fluid thermally upgraded kraft paper system in a unit designed for nameplate operation at 100°C HSR. The bi-level load cycles illustrated consist of a stable pre-load as indicated by the first (xxx%) number followed by a step change to higher load (yyy%) held for the time indicated on the X axis. Note that information similar to this had been presented in earlier Loading Guide revisions in tabular form. Different colors represent different pre-load levels, and different line types represent different overload levels.

Example: A transformer operated with a 75% pre-load (red line color) followed by a 150% overload (short dashed line) for a duration of 2.5 hours will have an equivalent aging of 1.0.

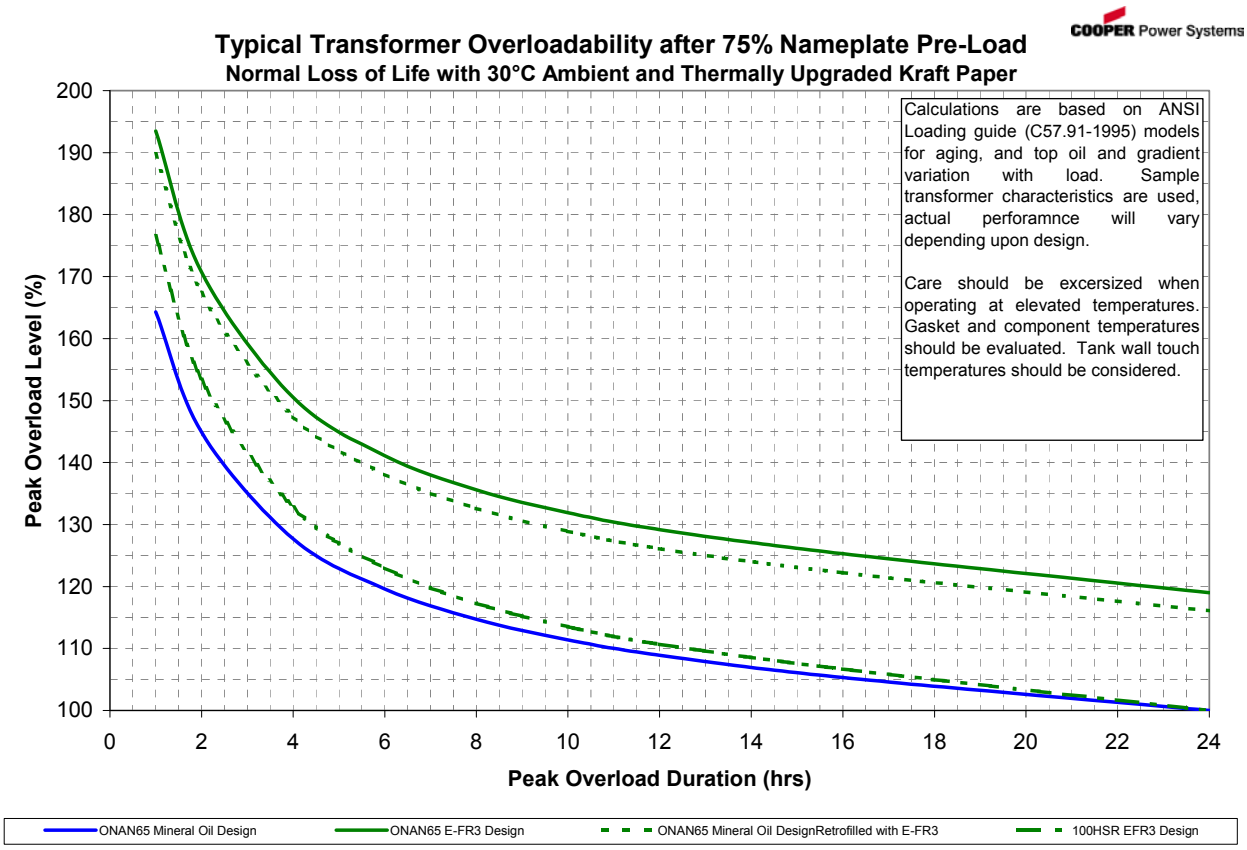


This graph is based on ANSI sample transformer characteristics and illustrates the peak load level versus duration for a bi-level load cycle starting with a steady state 50% nameplate pre-load for normal loss of life. This graph provides curves for 4 different transformer configurations utilizing thermally upgraded kraft paper:

- A mineral oil filled ONAN65 design.
- An FR3 fluid filled ONAN65 design.
- A mineral oil filled ONAN65 design that has been retro-filled with E-FR3.
- An FR3 fluid filled 100°C Hot Spot Rise ONAN design.

Note that information similar to this had been presented in earlier Loading Guide revisions in tabular form.

Example: An ONAN65 design transformer operated with a 50% pre-load can experience a 4 hour overload of 133.2% with mineral oil or 154.1% with FR3 fluid with normal loss of life.



This graph is based on ANSI sample transformer characteristics and illustrates the peak load level versus duration for a bi-level load cycle starting with a steady state 75% nameplate pre-load for normal loss of life. This graph provides curves for 4 different transformer configurations utilizing thermally upgraded kraft paper:

- A mineral oil filled ONAN65 design.
- An FR3 fluid filled ONAN65 design.
- A mineral oil filled ONAN65 design that has been retro-filled with E-FR3.
- An FR3 fluid filled 100°C Hot Spot Rise ONAN design.

Note that information similar to this had been presented in earlier Loading Guide revisions in tabular form.

Example: An ONAN65 design transformer operated with a 75% pre-load can experience a 4 hour overload of 127.7% with mineral oil or 1150.5% with FR3 fluid with normal loss of life.