CREE

DEFINITIONS & CONCEPTS

Forward Current (I_F): The amount of current flowing through an LED lamp operating in forward bias, typically measured in milliamps (mA).

Forward Voltage (V_F): The voltage potential across an LED lamp operating in forward bias, typically measured in Volts (V).

Lumen Depreciation: The luminous flux output lost (expressed as a percentage of the initial output) at any selected elapsed operating time. Lumen depreciation is the converse of lumen maintenance.

Lumen Maintenance: The luminous flux output remaining (expressed as a percentage of the initial output) at any selected elapsed operating time. Lumen maintenance is the converse of lumen depreciation.

Lumen Maintenance Life: The elapsed operating time at which the specified percentage of lumen depreciation or lumen maintenance is reached, expressed in hours. Operating time does not include elapsed time when the light source is cycled off or periodically shut down.

Rated Lumen Maintenance Life (L_{xx}): The elapsed operating time over which the LED light source will maintain the percentage, xx, of its initial light output. For example,
L_{70} = Time to 70% lumen maintenance, in hours
L_{50} = Time to 50% lumen maintenance, in hours

For LED lamps, lumen maintenance is often shown as curves of relative lumen output over time for the LED under various operating conditions, such as drive current and junction temperature.

Temperature, Ambient Air (T_{AIR}): The temperature of the air immediately surrounding the LED. In general, this temperature should be measured outside the FWHM beam angle of the LED and within the same enclosure that contains the LED.

Temperature, Junction (T_J): The temperature of the junction of the LED die inside the LED lamp. Measuring the LED die temperature by direct mechanical means is difficult and may lead to erroneous results. Cree recommends measuring T_J indirectly through measurement of T

IES LM-80-2008 TEST METHODOLOGY

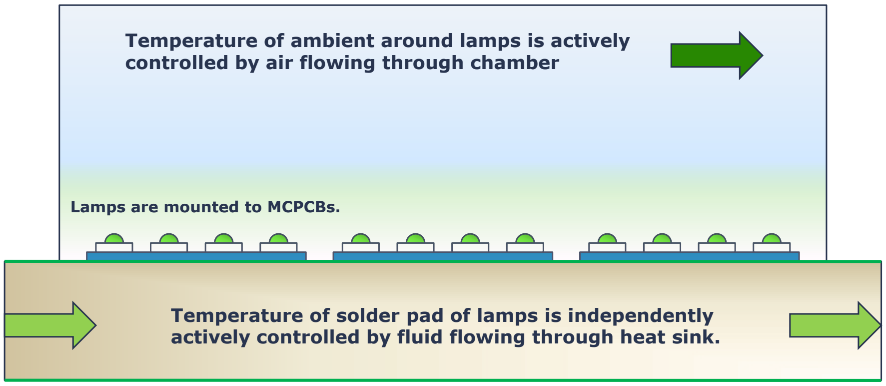
IES LM-80-2008, "Measuring Lumen Maintenance of LED Light Sources" ("LM-80") is the industry standard that defines the method for testing LED lamps, arrays and modules to determine their lumen depreciation characteristics and report the results. The goal of LM-80 is to allow a reliable comparison of test results among laboratories by establishing uniform test methods.

The US Department of Energy recognizes the validity of LM-80 and requires it to be used for testing LED lamps in luminaires that are submitted for Energy Star approval. As an Energy Star Partner, Cree uses the methods defined in LM-80 to test the long-term lumen maintenance of XLamp LED lamps.

CREE LM-80 COMPLIANT LUMEN MAINTENANCE TEST CONFIGURATION

Cree tests XLamp LED lamps for long-term lumen maintenance consistent with LM-80 methods. Specifically, sets of XLamp LED lamps are first mounted onto metal core printed circuit boards (MCPCB's). A set typically contains thirty individual XLamp LED lamps. The boards are then attached to heat sinks in environmental test chambers. The TSP of each LED lamp is actively monitored and controlled by continuously regulating the temperature of the heat sinks. Ambient air temperature (TAIR) in the chamber is also actively monitored and controlled by regulating the temperature of the air flowing through the chamber. Per LM-80 4.4.2, TAIR in the environmental chambers is controlled to be held within 5°C of TSP. Per LM-80 4.4.3, care is taken to minimize any drafts in the immediate vicinity of the devices under test.

The luminous flux and chromaticity of the XLamp LED lamps are initially measured in an integrating sphere before the testing begins (at t=0). The LED lamp sets are then placed into the environmental chambers – with various sets of lamps being operated at various drive currents (from nominal to maximum as specified in the XLamp data sheets). At regular intervals, the LED lamps are removed from the environmental test chambers and the luminous flux and chromaticity are re-measured in an integrating sphere.

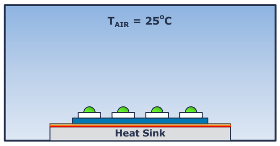


ADDITIONAL LUMEN MAINTENANCE TEST CONFIGURATIONS

Additional test conditions are also being used at Cree to study the long-term behavior of XLamp LED lamps. As with Cree's standard long-term testing configuration, LED lamps are tested in an integrating sphere for luminous flux and chromaticity at t=0 and at regular intervals during the testing period.

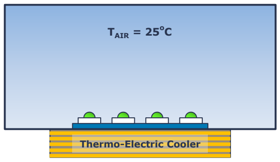
Room Temperature Testing

In the Room Temperature Testing configuration, TAIR is actively controlled at 25°C. Each test set uses identical heat sinks. The TSP is passively controlled by the drive current – the higher the drive current, the higher the resulting TSP.

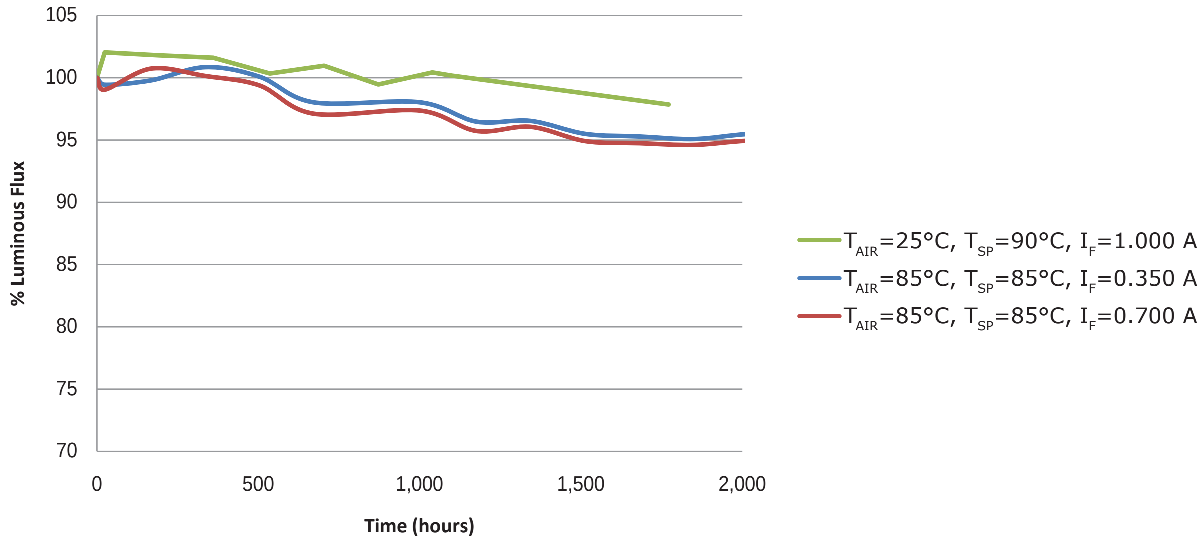


High Junction Temperature Testing

In the High Junction Temperature Testing configuration, TAIR is held at 25°C, while the LEDs are attached to thermo-electric coolers (TECs) so that the LED TSP (and thus the TJ) can be directly and precisely controlled up to 150°C.



LONG-TERM TESTING OBSERVATION



The LED industry currently examines junction temperature and drive current to predict an LED lamp's long-term lumen maintenance. However, Cree has observed that high ambient air temperatures also play an important role in the long-term lumen maintenance of silicone-encapsulated LED lamps.

As an example, the graph above shows the lumen maintenance results of XLamp XR-E white LED lamps under three different test conditions. Conventional wisdom dictates that the (TAIR=25°C, TSP=90°C, IF=1.000 A) case should have the worst lumen maintenance of the three cases because it has the highest junction temperature and drive current. Cree has observed repeatedly that in fact, higher ambient air temperatures will accelerate lumen depreciation to a degree that cannot be observed through TAIR = 25°C testing.

LONG-TERM TESTING OBSERVATIONS (CONTINUED)

Therefore, there is a third critical factor that affects the rate of lumen depreciation for LED lamps, the temperature of the air surrounding the LED lamp (T_A). Most high power LED lamps, including XLamp LED lamps, use silicone materials in the package. When exposed to high temperatures these silicone materials will degrade, reducing the light that is transmitted through them from the LED chip. Just as the industry has observed that higher T_J and T_{SP} accelerates the rate of lumen depreciation, higher T_{AIR} also accelerates the rate of lumen depreciation.

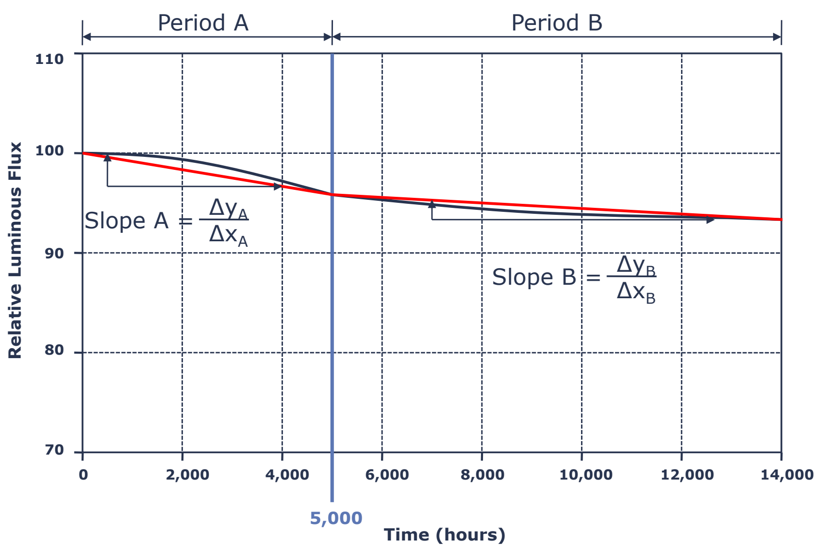
Cross-Section Diagram of a High-Power LED

FUNCTIONAL MODEL FOR XLAMP XR-E WHITE LUMEN MAINTENANCE

Cree has accumulated as much as 50,000 hours of XLamp LED lamp test data under both LM-80-compliant conditions and other conditions described in earlier sections. The effects of T_{AIR}, T_J, T_{SP} and I_F on long-term lumen maintenance have been closely studied and are well understood.

Cree has observed that the lumen maintenance characteristics of XLamp XR-E white LED lamps are different in the first 5,000 hours of test (called Period A below) than in the time period following 5,000 hours (called Period B below). A best-fit regression model for Period A was developed from 16 individual long-term data sets and includes variables such as TSP, IF, TJ and TAIR. Cree has observed that lumen maintenance in Period B is linear, so Period B uses a linear model that includes the same variables as Period A.

The lumen depreciation rates for both Period A and Period B for any combination of critical operating parameters (T_{SP}, I_F, T_J, T_{AIR}) can be calculated using these models. With both Period A and Period B lumen depreciation rates known, the final L_{70} lifetime can be determined. This is the method used to create the lifetime prediction graphs.



XLAMP XR-E WHITE L_{70} LIFETIME PREDICTIONS

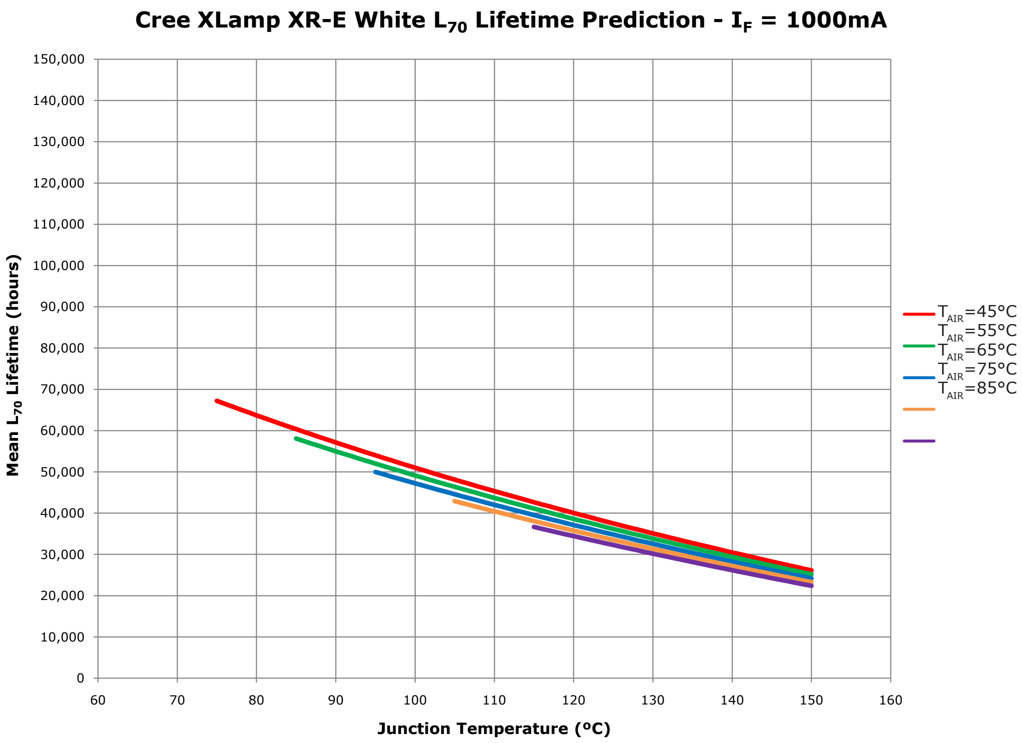
Cree has used the XLamp XR-E White LED lamp lumen maintenance model described above to create a complete set of mean L70 lifetime projections for a wide variety of operating conditions. These projections are shown in the following graphs. The lines in the graphs are truncated where TSP < TAIR.

The first set of graphs is grouped by IF. These graphs show the effect of ambient air temperature on L70 lifetime for the same drive current and junction temperature.

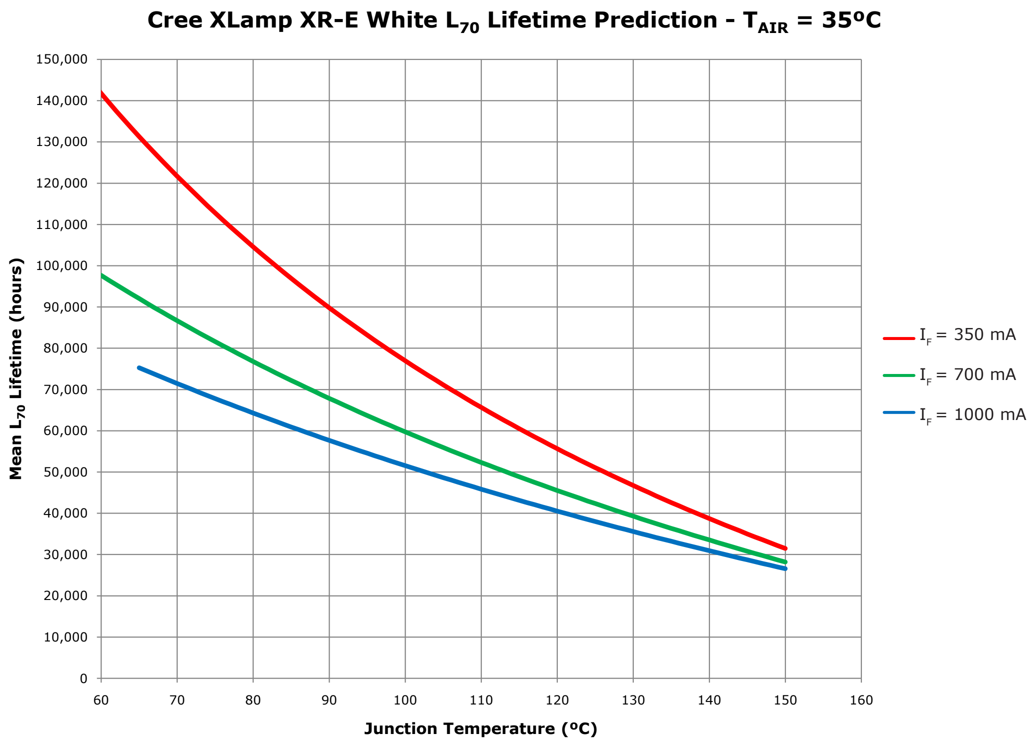
The second set of graphs is grouped by TAIR. These graphs show the effect of drive current on L70 lifetime for the same ambient air temperature and junction temperature.

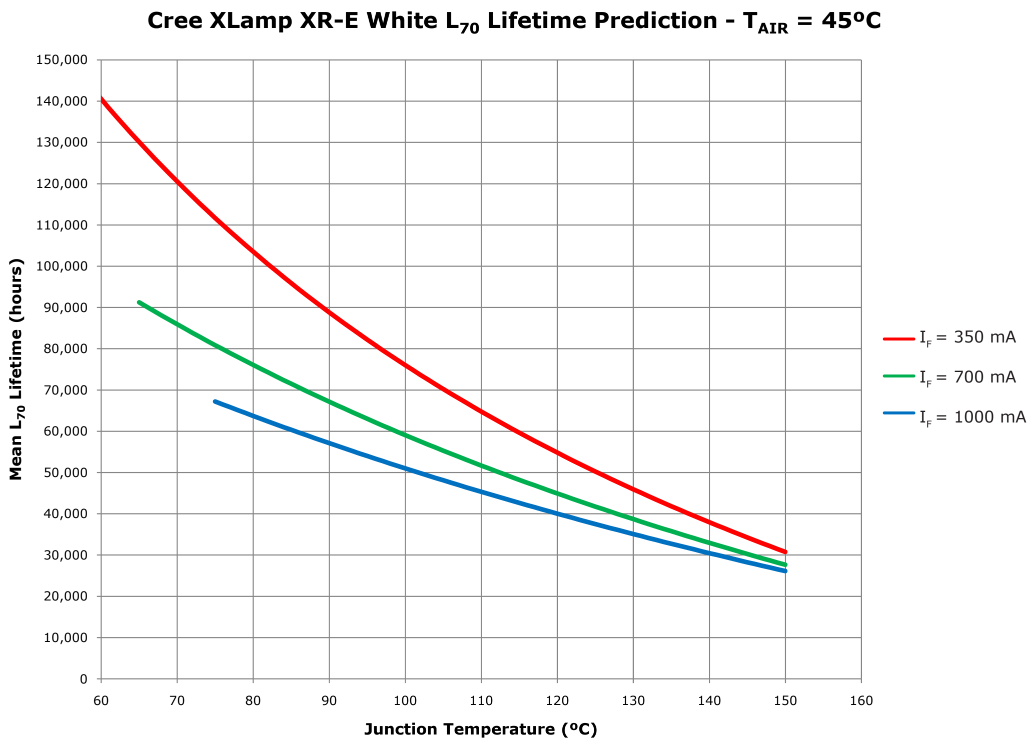
XLAMP XR-E WHITE L_{70} LIFETIME PREDICTION GRAPHS - GROUPED BY I_F

XLAMP XR-E WHITE L_{70} LIFETIME PREDICTION GRAPHS - GROUPED BY I_F (CONTINUED)

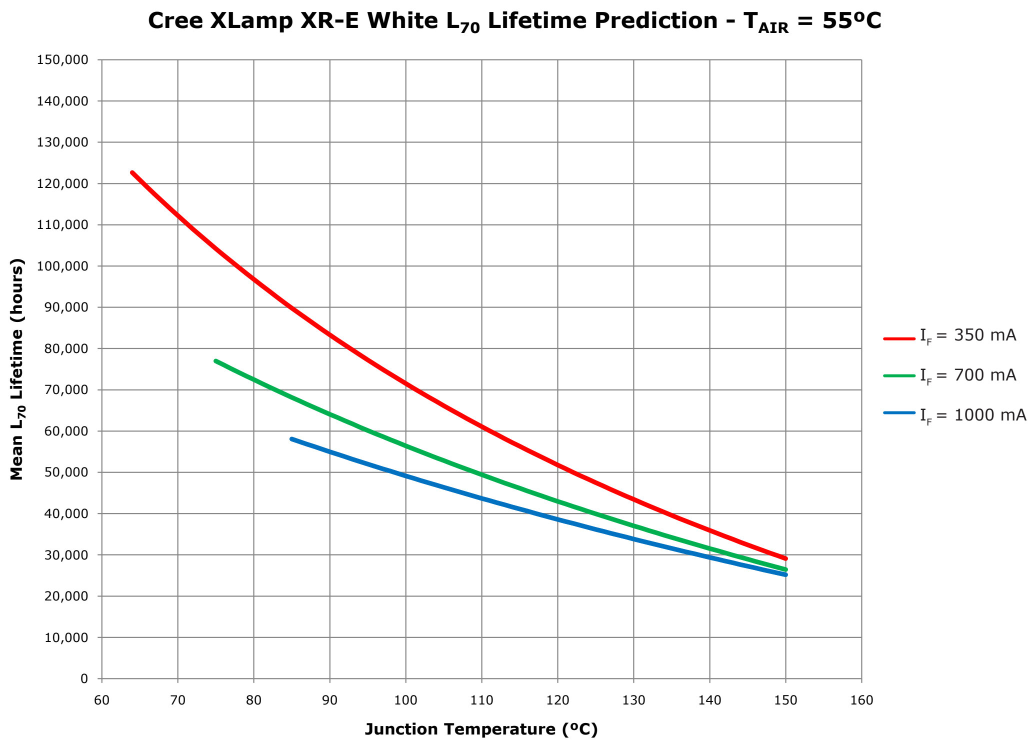


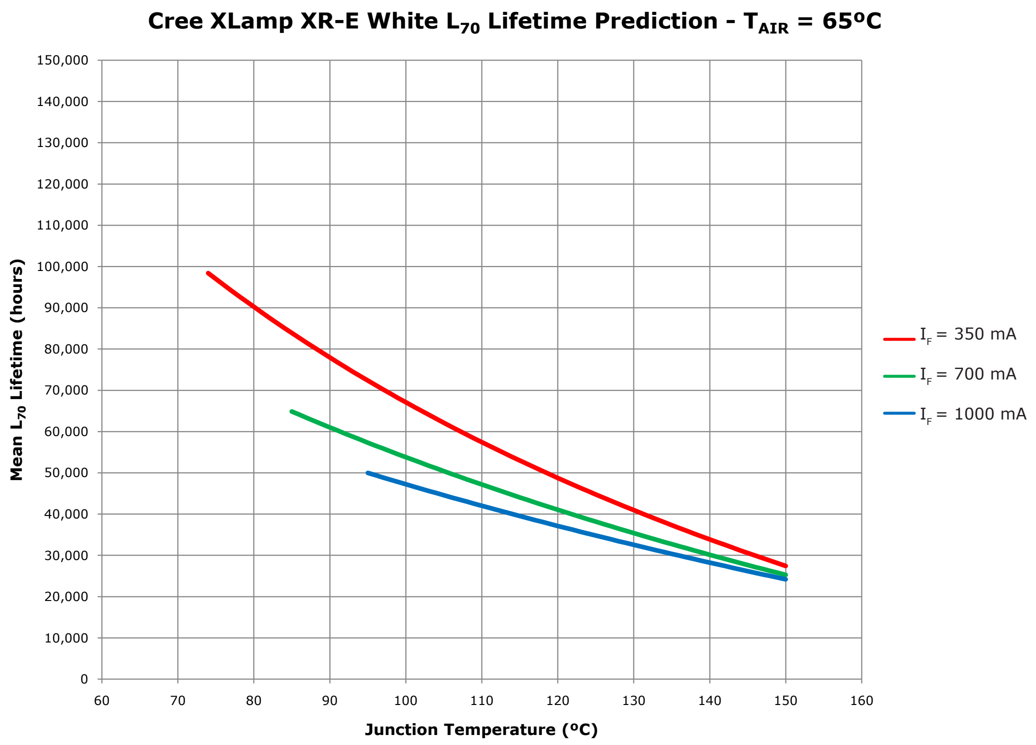
XLAMP XR-E WHITE L70 LIFETIME PREDICTION GRAPHS - GROUPED BY T_A





XLAMP XR-E WHITE L70 LIFETIME PREDICTION GRAPHS - GROUPED BY T_A (CONTINUED)





XLAMP XR-E WHITE L70 LIFETIME PREDICTION GRAPHS - GROUPED BY T_A (CONTINUED)