Pacific Northwest
NATIONAL LABORATORY

Long-Term Performance of LED Downlights

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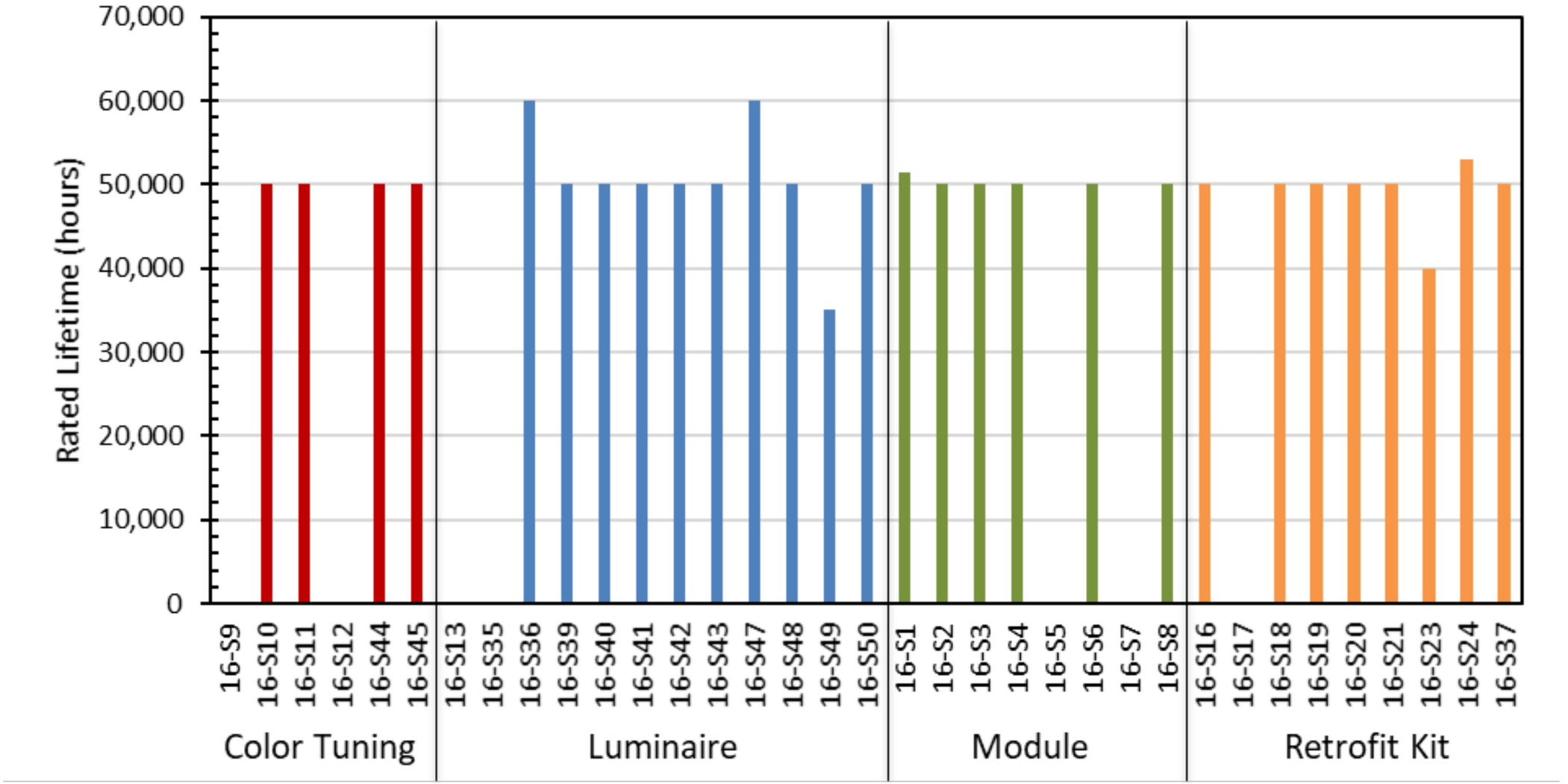
U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

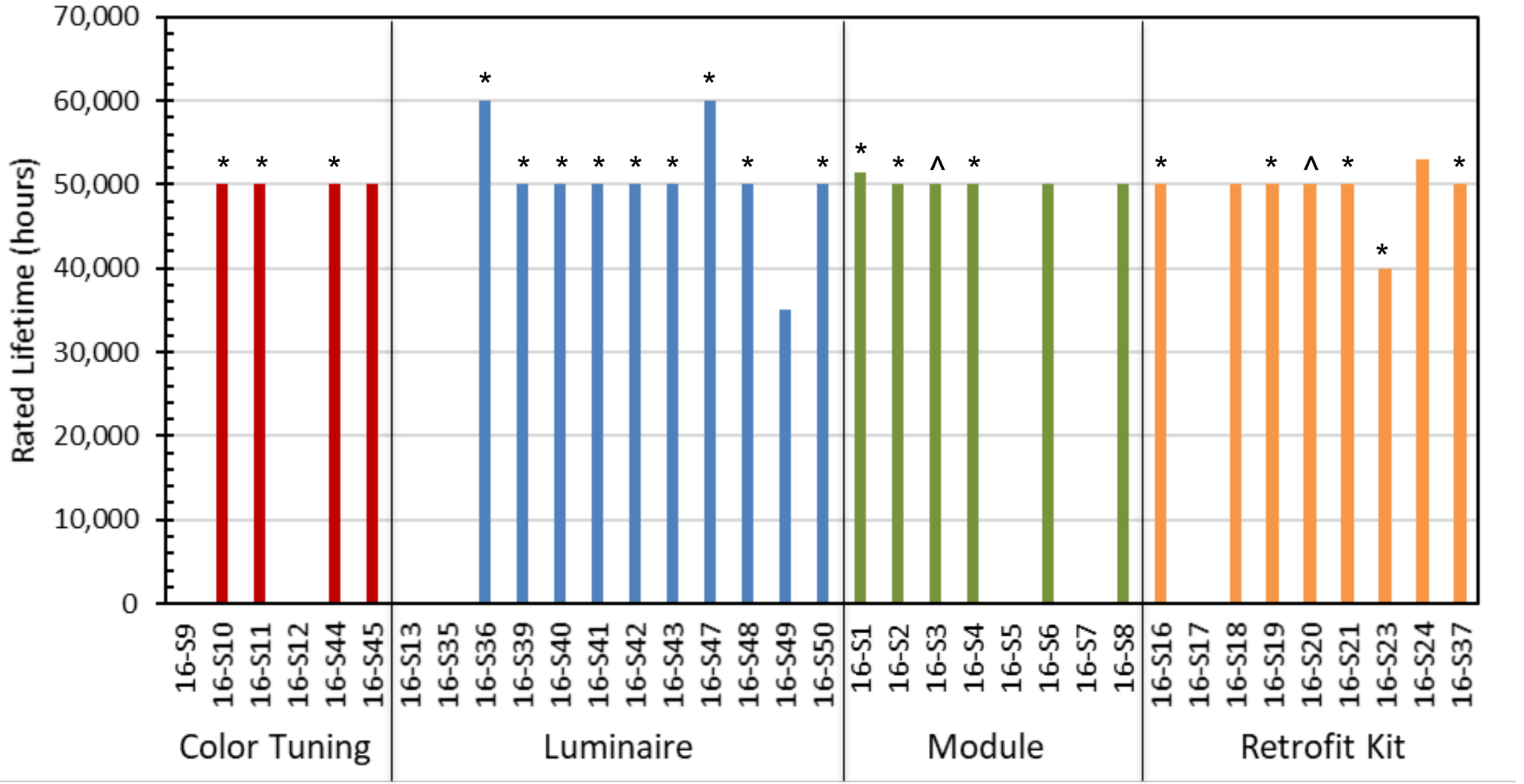
Experiment

- 70 total samples
- 35 different models
  - 12 Luminaires
  - 9 Retrofit Kits
  - 8 Module-based
  - 6 Color-tuning
- Two operating cycles
  - Continuous
  - 8 on 4 off
- Ambient Temperature (25 °C)
- Operating since summer 2016 (~3.5 years)
  - ~28,000 hours continuous
  - ~19,000 hours cycled

Lifetime Rating

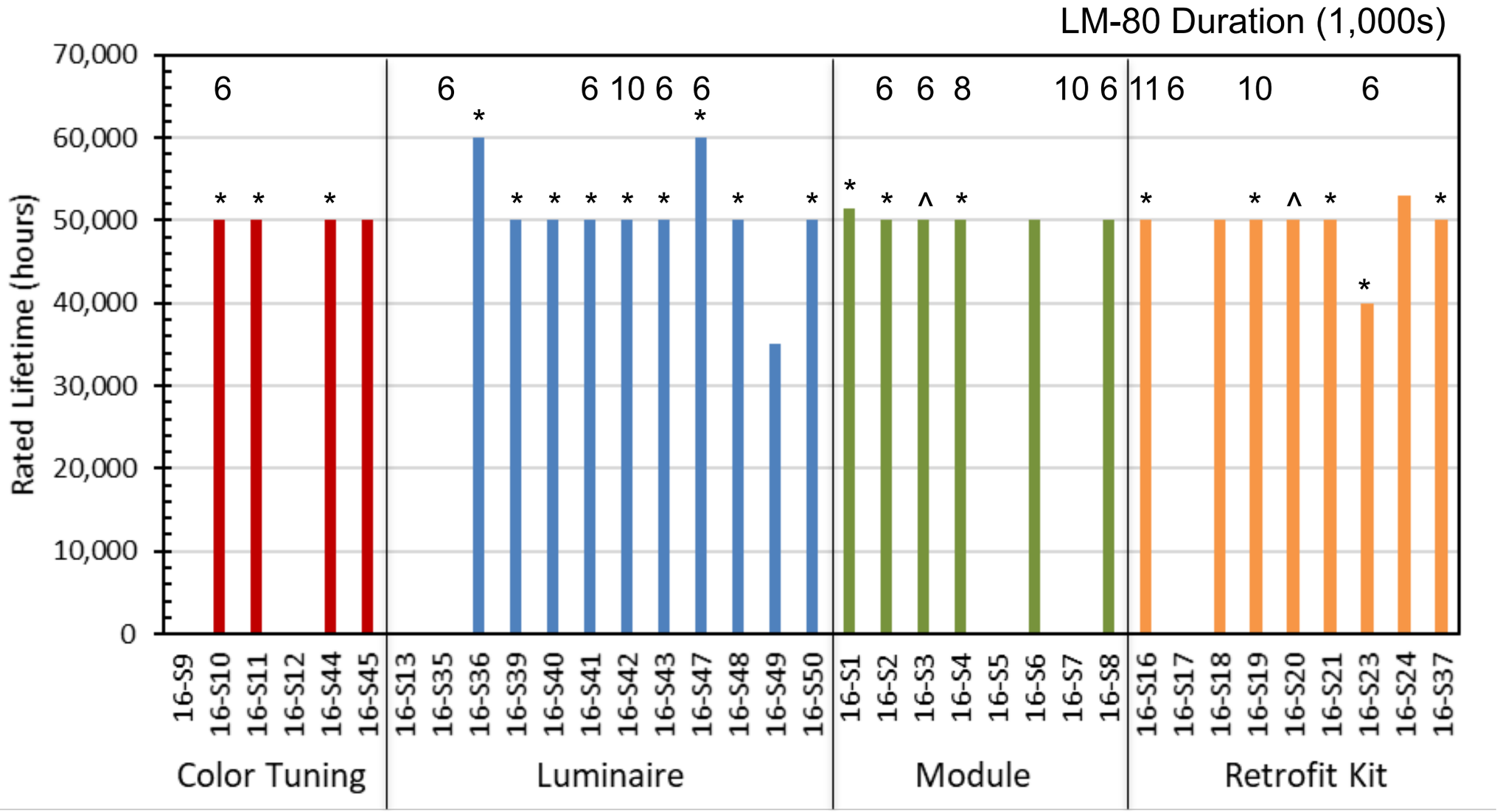


Lifetime Rating



* Based on L70
^ Based on L80 or L85

Lifetime Rating



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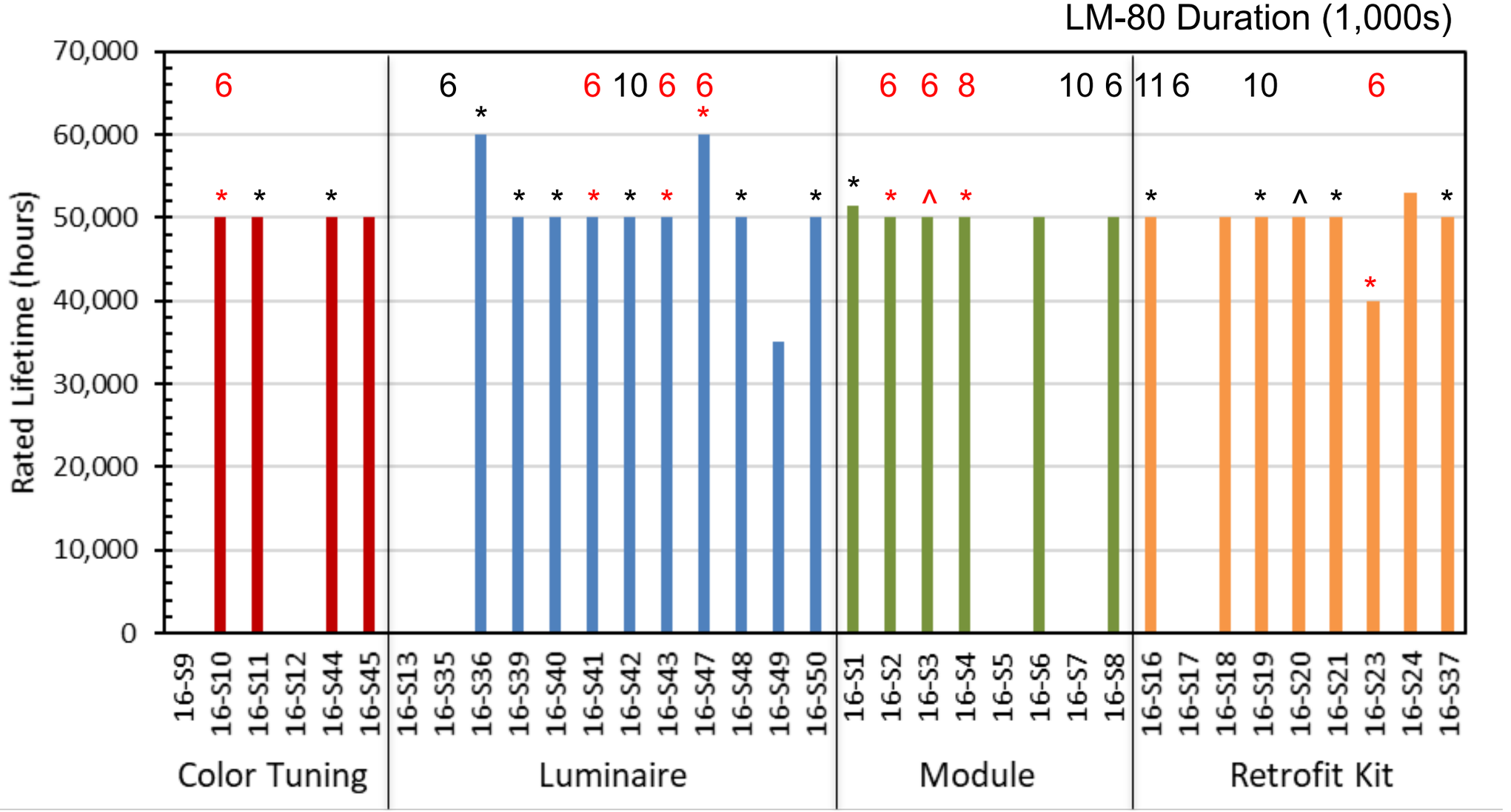
Lifetime Rating

Improper Reporting (TM-21)



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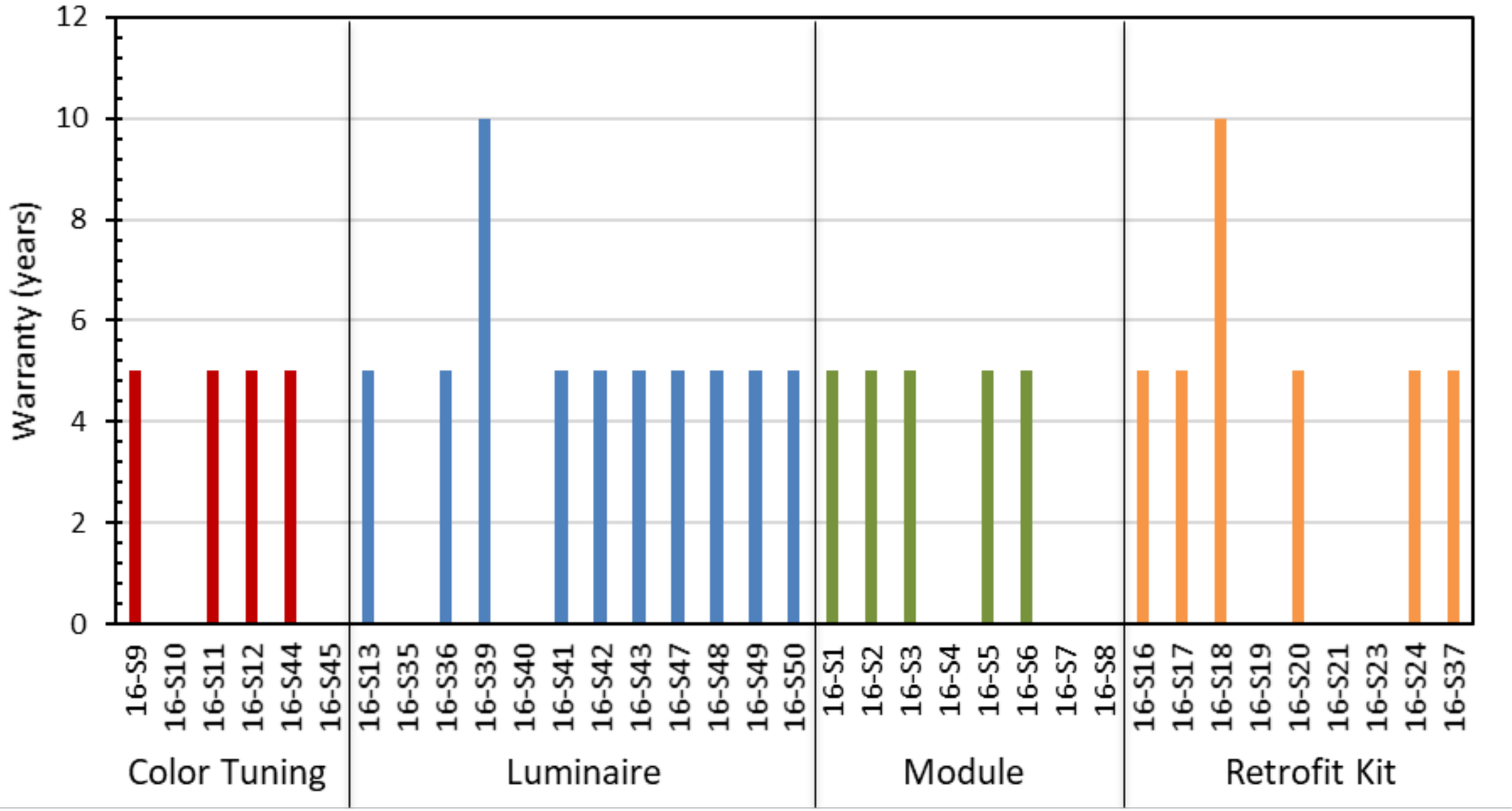
Warranty


Warranty (years)
0
2
4
6
8
10
12
16-S9
16-S10
16-S11
16-S12
16-S44
16-S45
16-S13
16-S35
16-S36
16-S39
16-S40
16-S41
16-S42
16-S43
16-S47
16-S48
16-S49
16-S50
16-S1
16-S2
16-S3
16-S4
16-S5
16-S6
16-S7
16-S8
16-S16
16-S17
16-S18
16-S19
16-S20
16-S21
16-S23
16-S24
16-S37
Color Tuning
Luminaire
Module
Retrofit Kit

Failure Criteria:

Catastrophic

Off or Strobing

Luminous Flux Maintenance

$\Phi < 70\%$

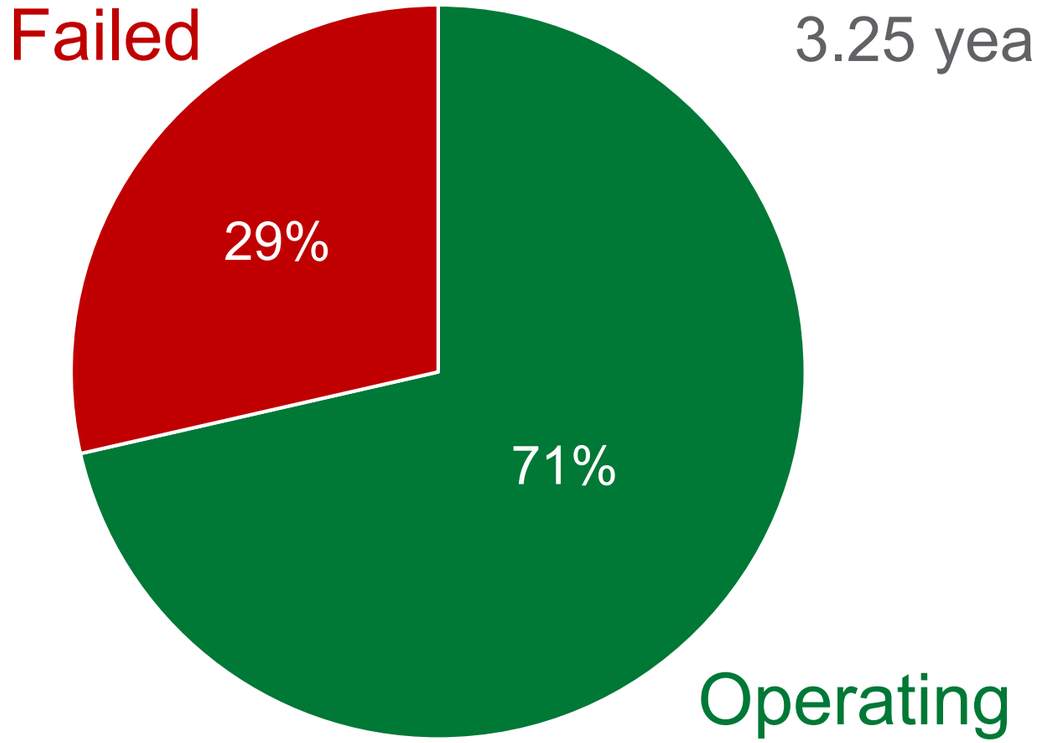
Chromaticity Shift

$\Delta u'v' > 0.007$

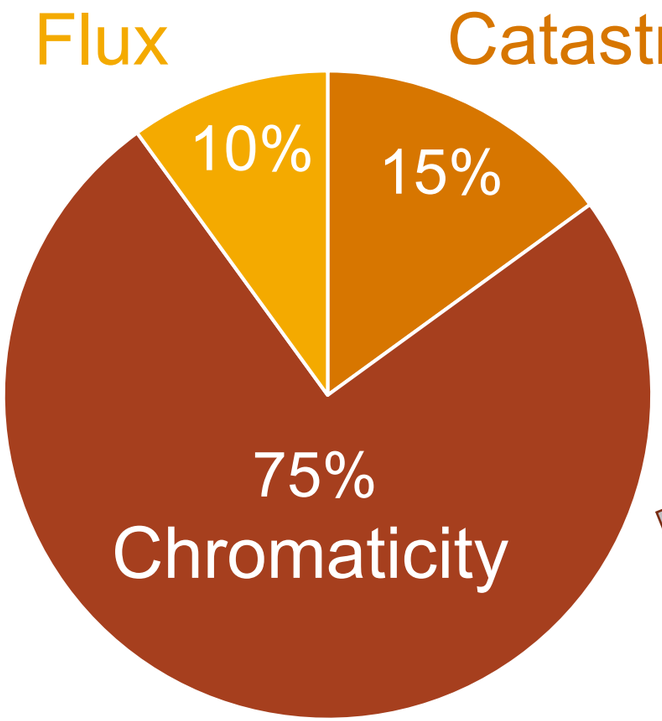
[Current Status]

~19k or 28k hours

3.25 years



[Initial Failure Type]



[Current Status]

~19k or 28k hours

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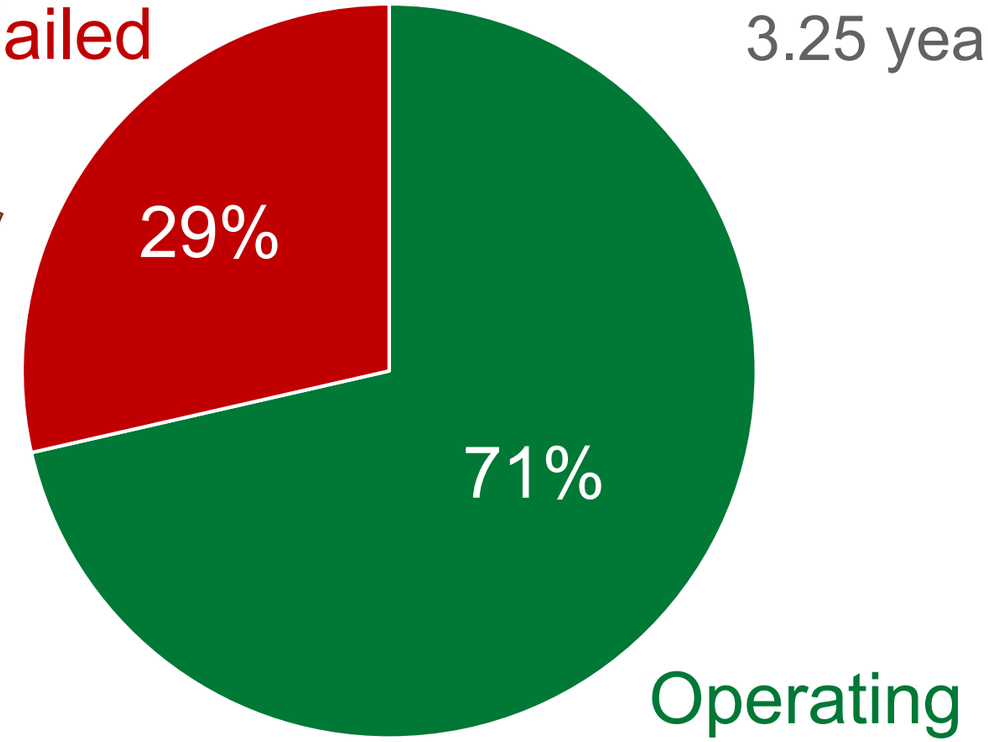


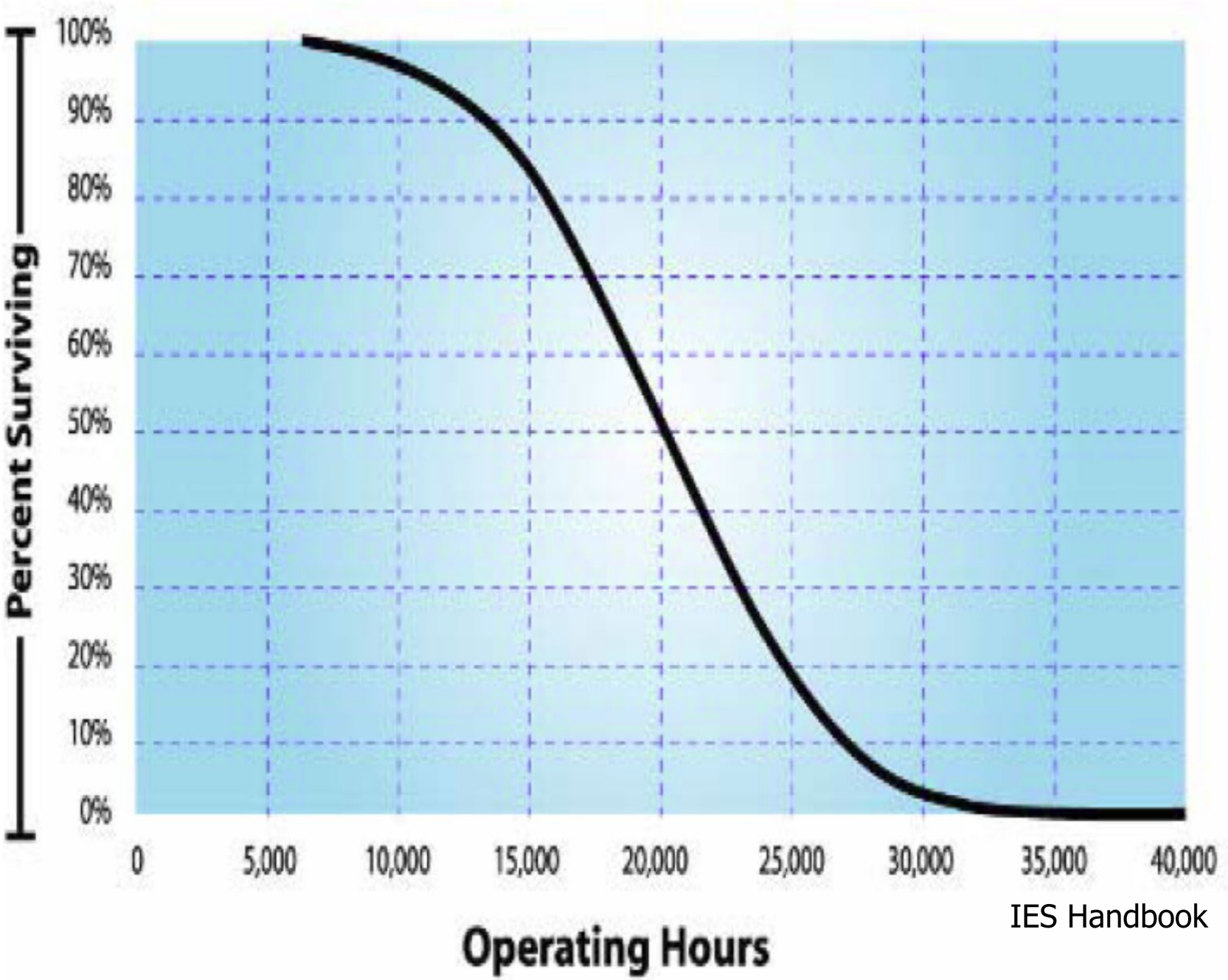
8 Samples (11%) Flux Fail

16 Samples (23%) Chromaticity Fail

7 Samples (10%) Catastrophic Fail

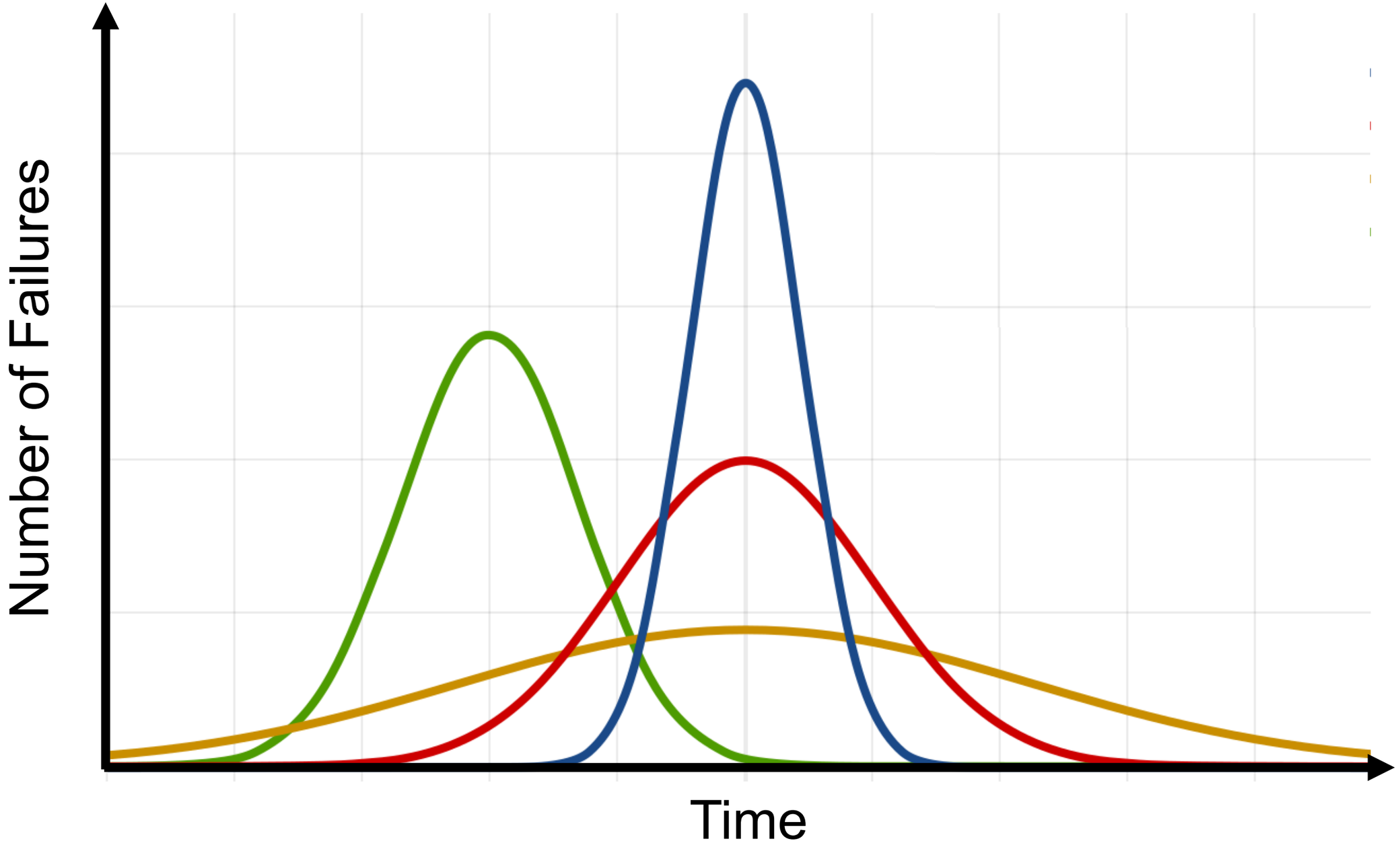
20 Samples (29%) Total Failed

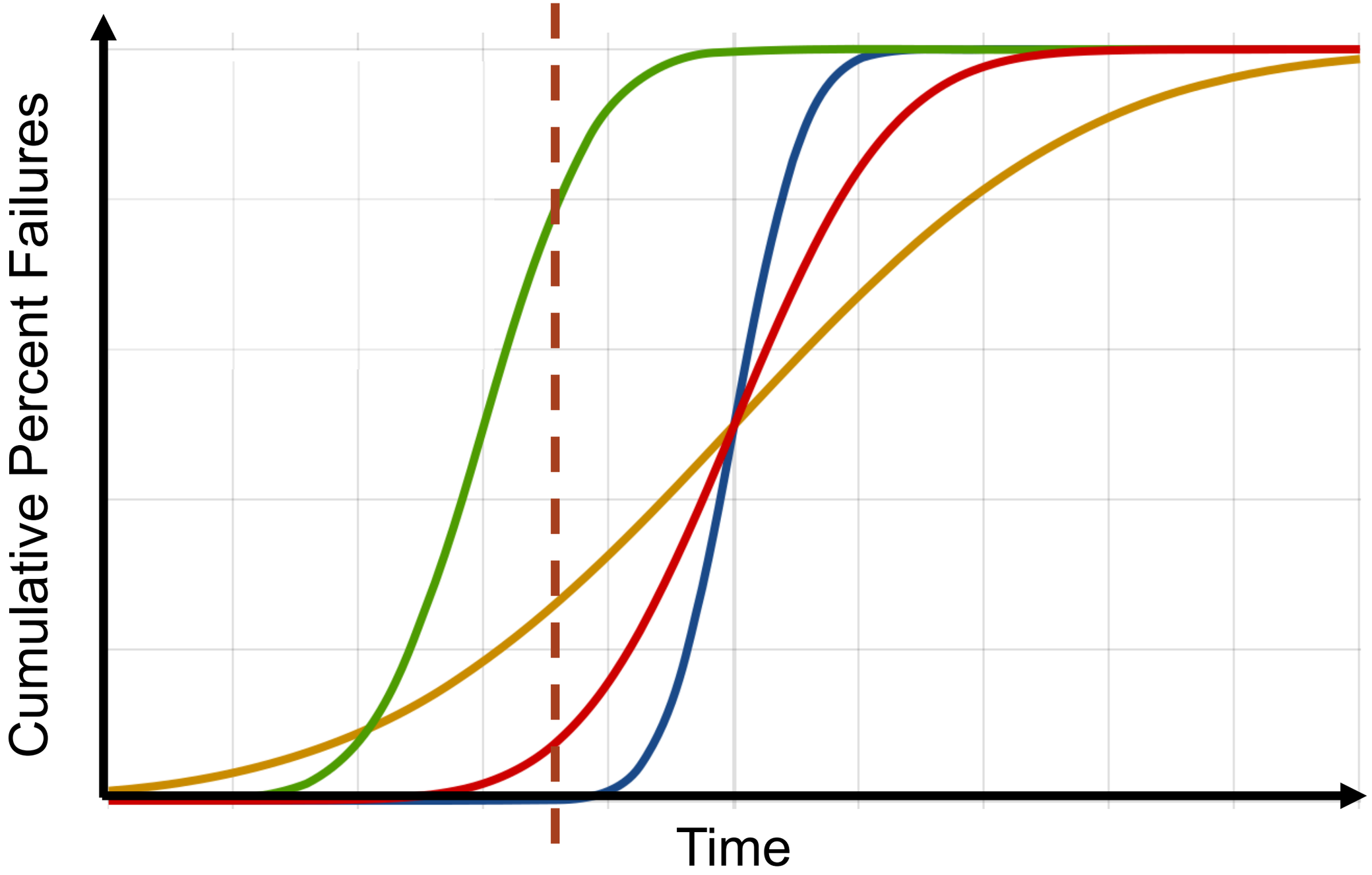
12 Samples (17%) Failed Excl. Chromaticity

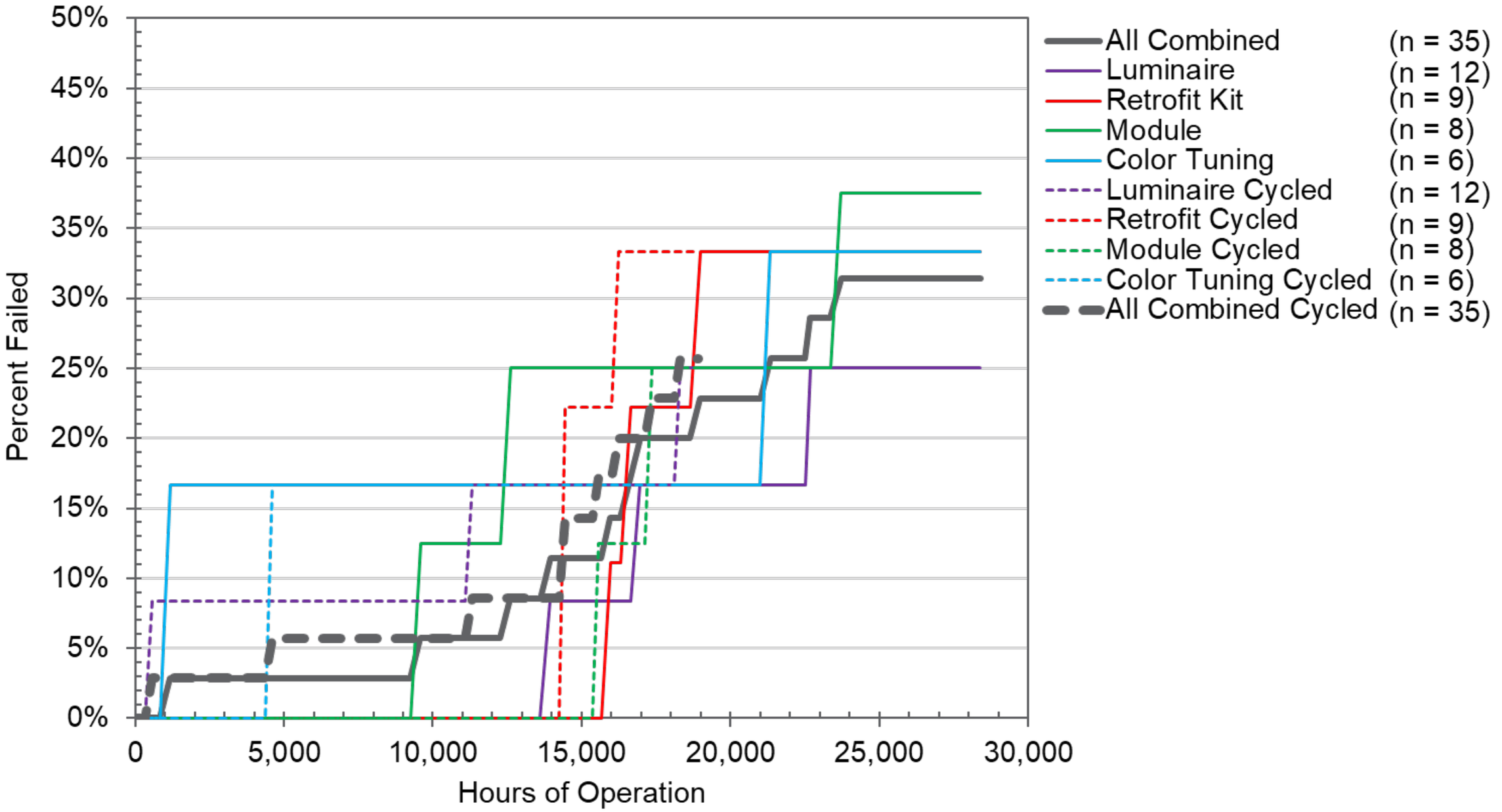


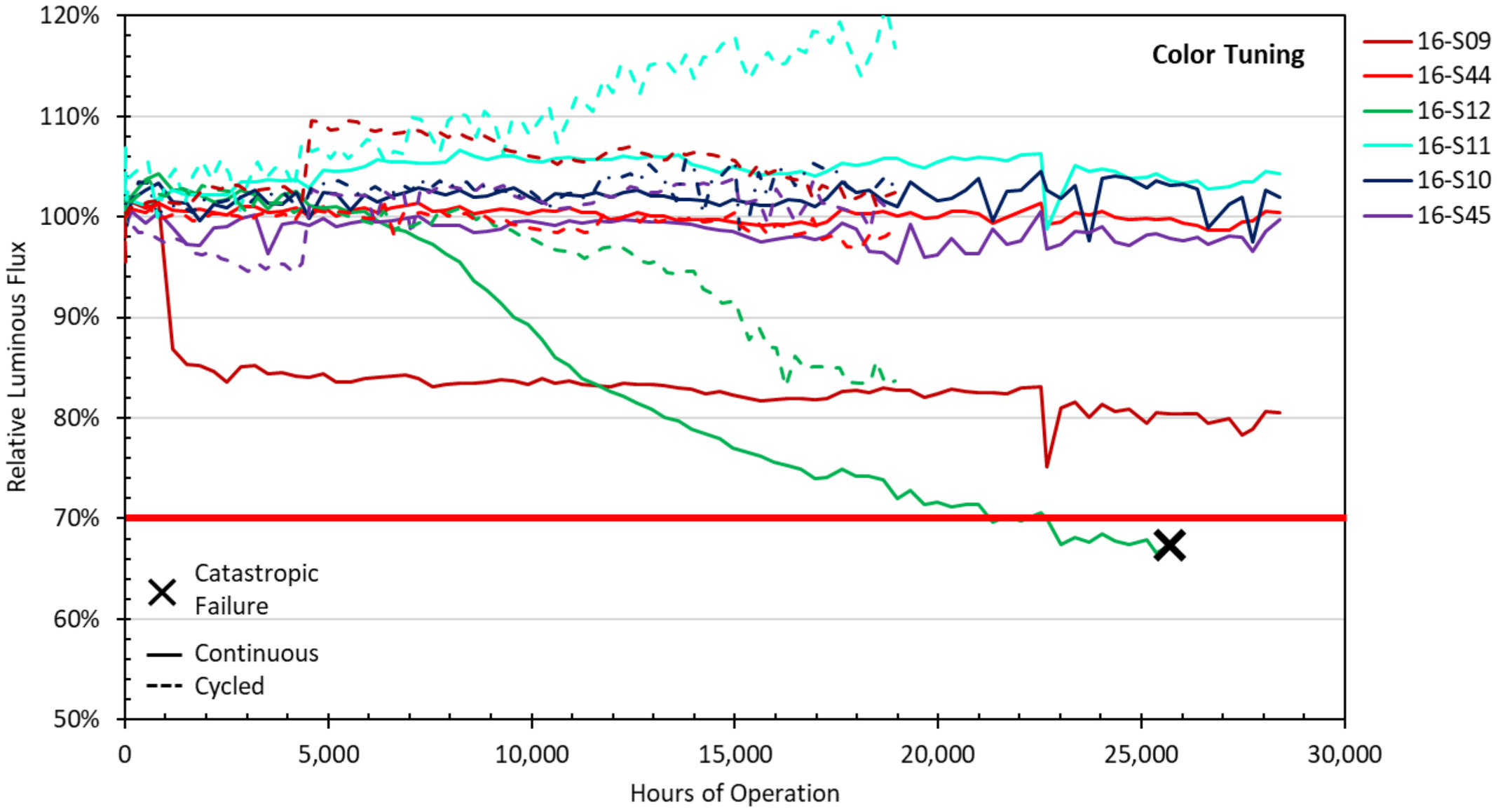
IES Handbook

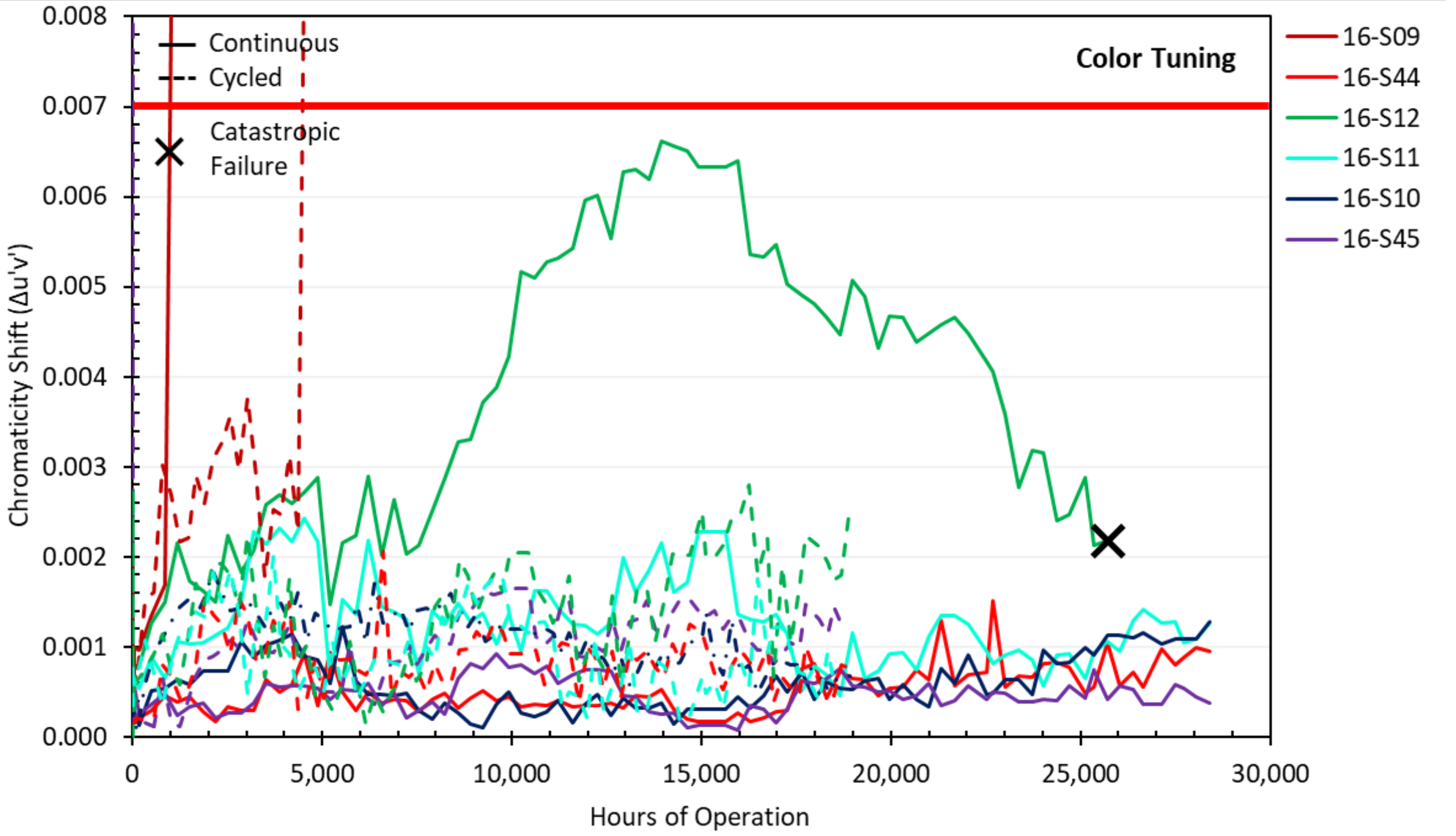
Rated lamp life is point where 50% of lamps have failed, or 20,000 hours on this curve.


Number of Failures
Time


Cumulative Percent Failures
Time


50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Percent Failed
0
5,000
10,000
15,000
20,000
25,000
30,000
Hours of Operation
All Combined (n = 35)
Luminaire (n = 12)
Retrofit Kit (n = 9)
Module (n = 8)
Color Tuning (n = 6)
Luminaire Cycled (n = 12)
Retrofit Cycled (n = 9)
Module Cycled (n = 8)
Color Tuning Cycled (n = 6)
All Combined Cycled (n = 35)


Color Tuning
16-S09
16-S44
16-S12
16-S11
16-S10
16-S45
120%
110%
100%
90%
80%
70%
60%
50%
Relative Luminous Flux
0
5,000
10,000
15,000
20,000
25,000
30,000
Hours of Operation
Catastropic Failure
Continuous
Cycled


Color Tuning
Continuous
Cycled
Catastrophic Failure
16-S09
16-S44
16-S12
16-S11
16-S10
16-S45
Chromaticity Shift (Δu'v')
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
5,000
10,000
15,000
20,000
25,000
30,000
Hours of Operation

Interim Conclusions

- Testing to continue until at least 50% failure
- No substantial differences based on form factor or cycling
- Many products failed before rated lifetime / warranty period
  - May be in line with distribution of failures, but probably not expected by user
  - Failure definitions/warranty coverage may vary
  - (Behavior for two samples of same model tended to be consistent)
- Chromaticity shift was dominant initial failure mechanism
  - Frequently accompanied by lumen depreciation (or increase)
  - Often preceded catastrophic failure
  - Does it matter? Is 0.007 too strict compared to L70?
- Future Work:
  - Specific comparisons to ratings/warranties
  - Teardowns and failure analysis

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