Phosphor Thermometry Short Course

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What is a Phosphor

- In appearance, a phosphor is usually a fine white or pastel-colored powder. There are two general types of phosphors: organic and inorganic. This presentation deals exclusively with inorganic as the majority of thermometry applications in our experience have involved such. Nonetheless, organic fluorescing materials may have advantages in certain situations and should be considered.

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What is a Phosphor

Inorganic phosphors consist of:

- Host material: e.g.. oxide, garnet, sulfide, oxysulfide, vanadate, germanate, etc.
- Activator material (a.k.a. dopant or impurity): usually rare-earth or transition metal elements.
- An advantage of these dopants is that, typically, the emission consists of narrow bands.

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There are a wide variety of ceramic phosphors which fit these characteristics

- Able to survive hazardous chemical environments
- Not water soluble
- Durable
- Easy to apply

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Background

- Phosphors became technologically and industrially important with the introduction of fluorescent lamps in 1938.
- Thermometry use suggested in German patent in 1938. First peer-reviewed article, to our knowledge, appeared in 1949.
- Between approximately 1950 to 1980, it was not widely used. Its most common use was for aerodynamic applications.
- Advances in lasers, microelectronics, and other supporting technologies enabled additional commercial as well as scientific uses.

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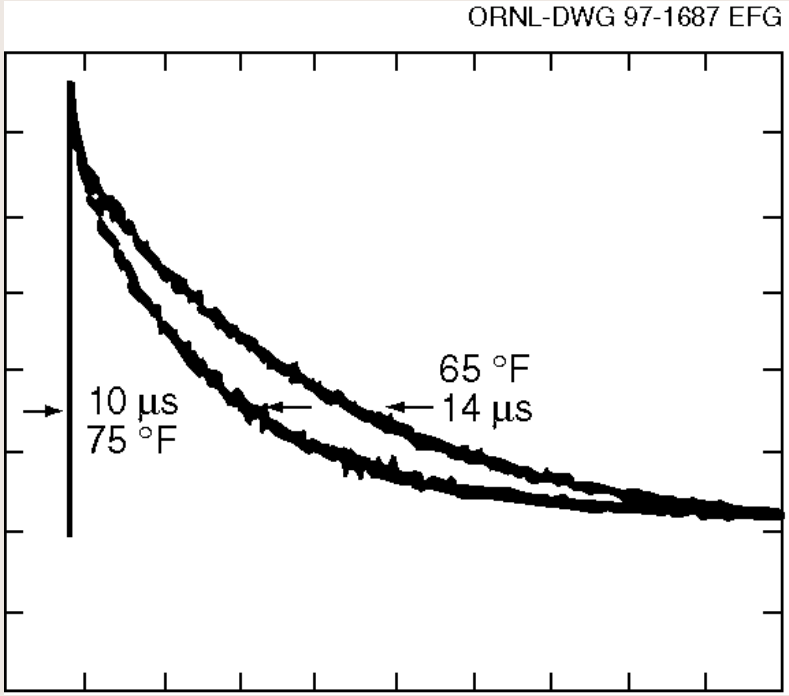
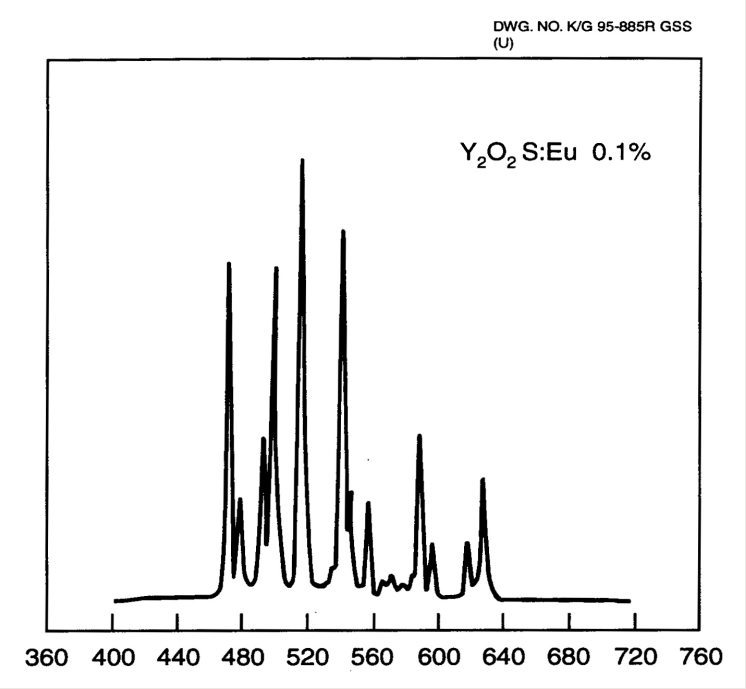
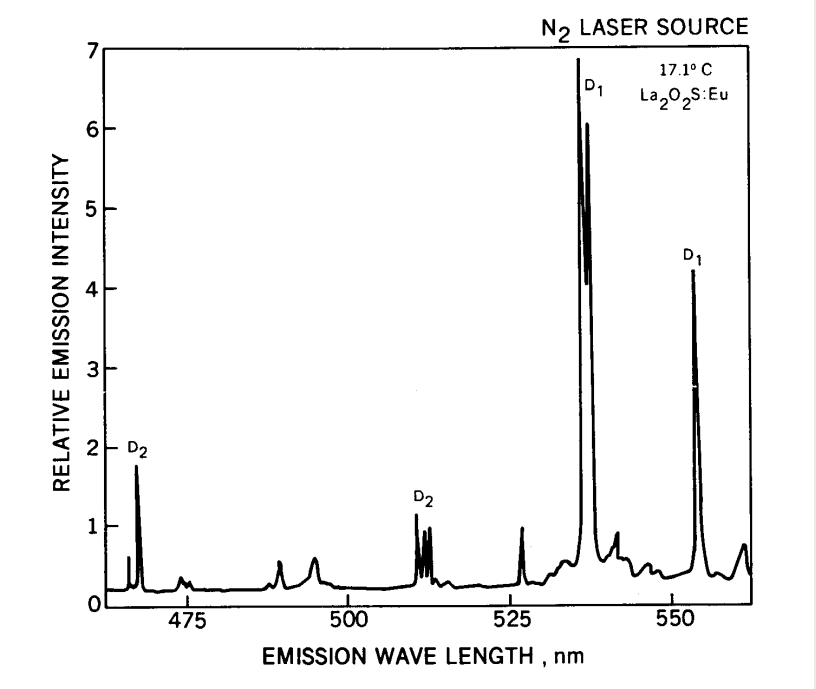
Parameters affected by Temperature

1. Decay time
2. Line shift and broadening
3. Ratio of emission lines
4. Emission distribution
5. Absorption band width and position
6. Excitation band width and position



Typical Fluorescence Spectra for Rare-Earth Doped Phosphor





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Factors that Affect Fluorescence

- **Dopant Concentration**
  - The spectrum may change with increasing dopant concentration. Optimum concentration which maximizes fluorescence varies with dopant and host. At high concentrations, the decay deviates from being a simple single exponential. Risetimes are affected by dopant concentration. Eg. For Y2O3:Eu, decay time increases form 440 to 600 microseconds with particle size increase from 0.42 to 11 microns.
- **Impurities**
  - Deliberately added RE-impurities may either sensitize (i.e.. enhance) or degrade fluorescence efficiency. This is determined by how energy levels match. The literature contains info on which pairings favor enhancement.
- **Magnetic Field**
  - Approximately one tesla is required to observe a change in fluorescence spectra and the material must be very cold, say 20 K.

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Decay Time vs. Temperature for Selected Phosphors

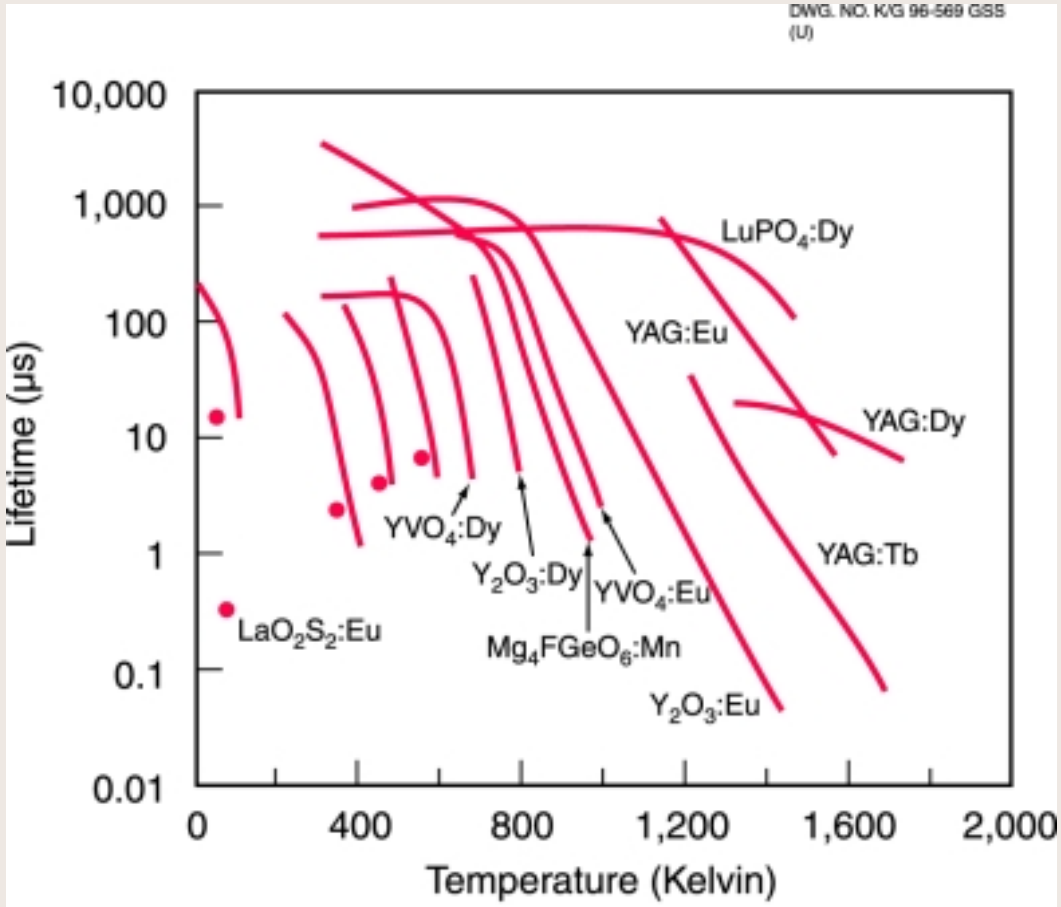

Figure 12. Lifetime versus temperature of selected phosphors.

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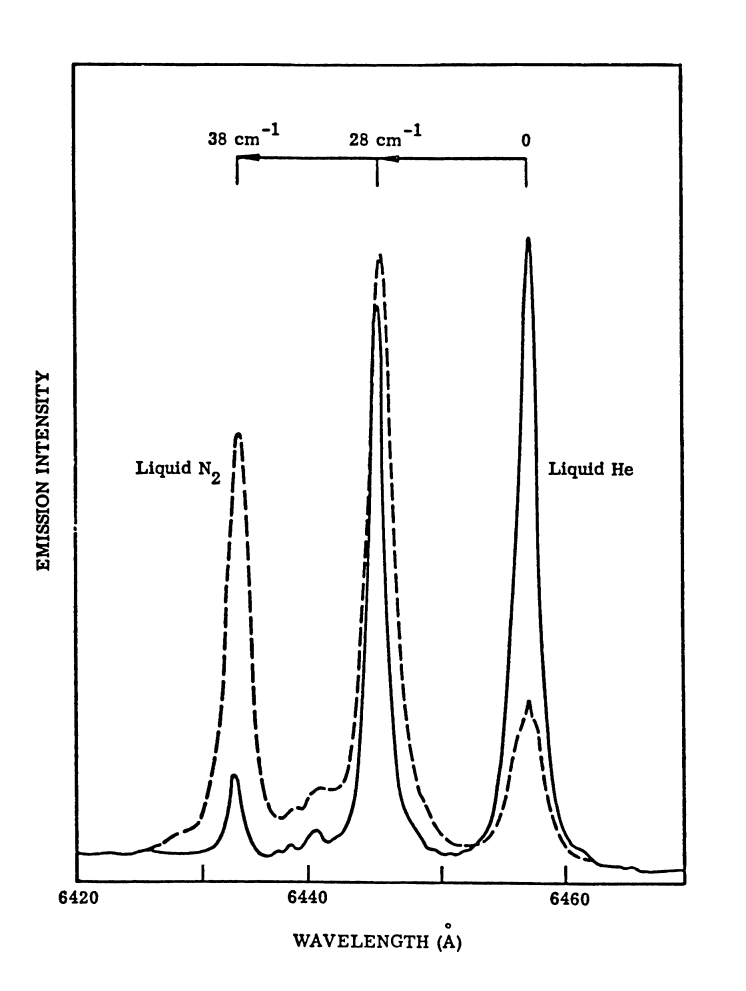
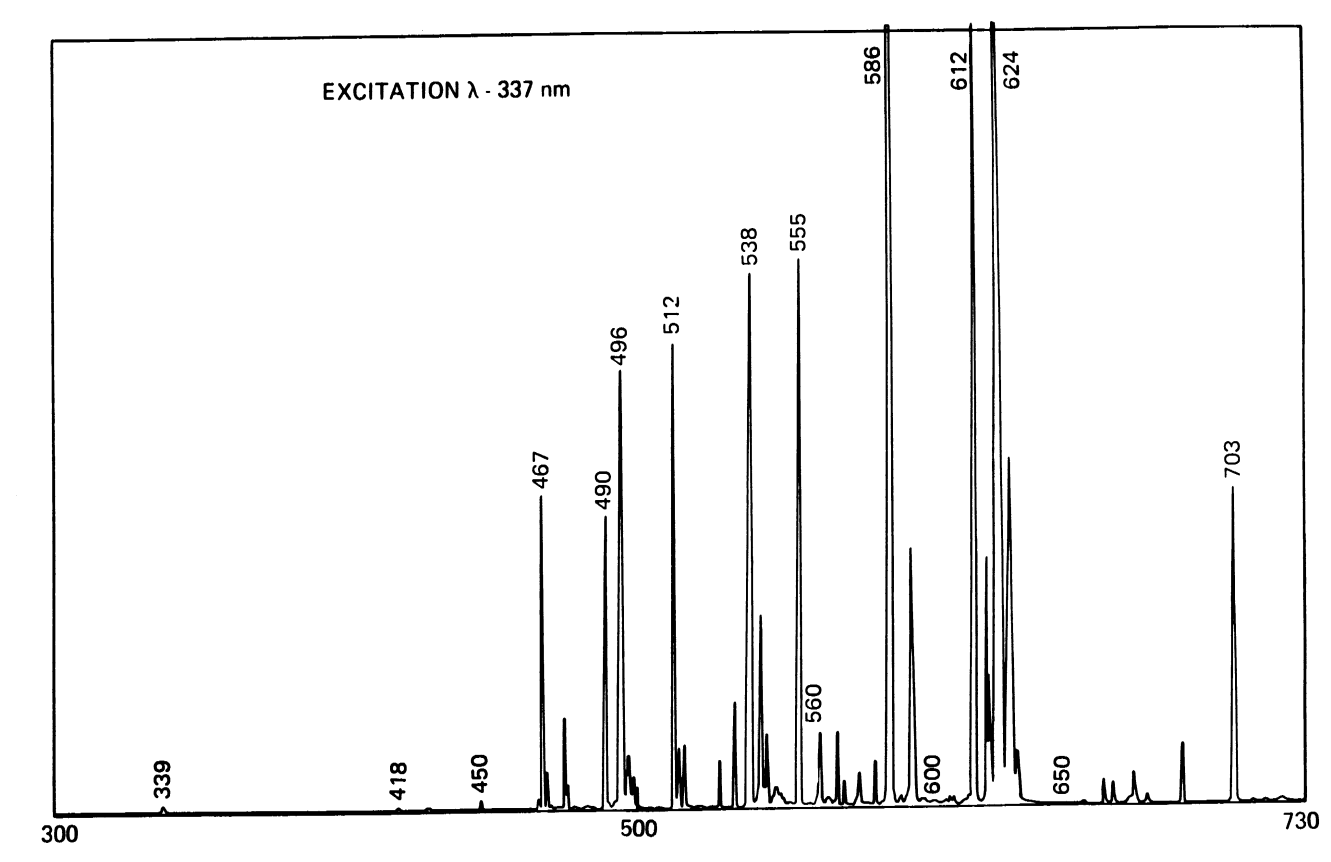
Intensity vs. T



- Change in intensity at cryogenic temperatures

La2O2S:Eu at Low Temperature



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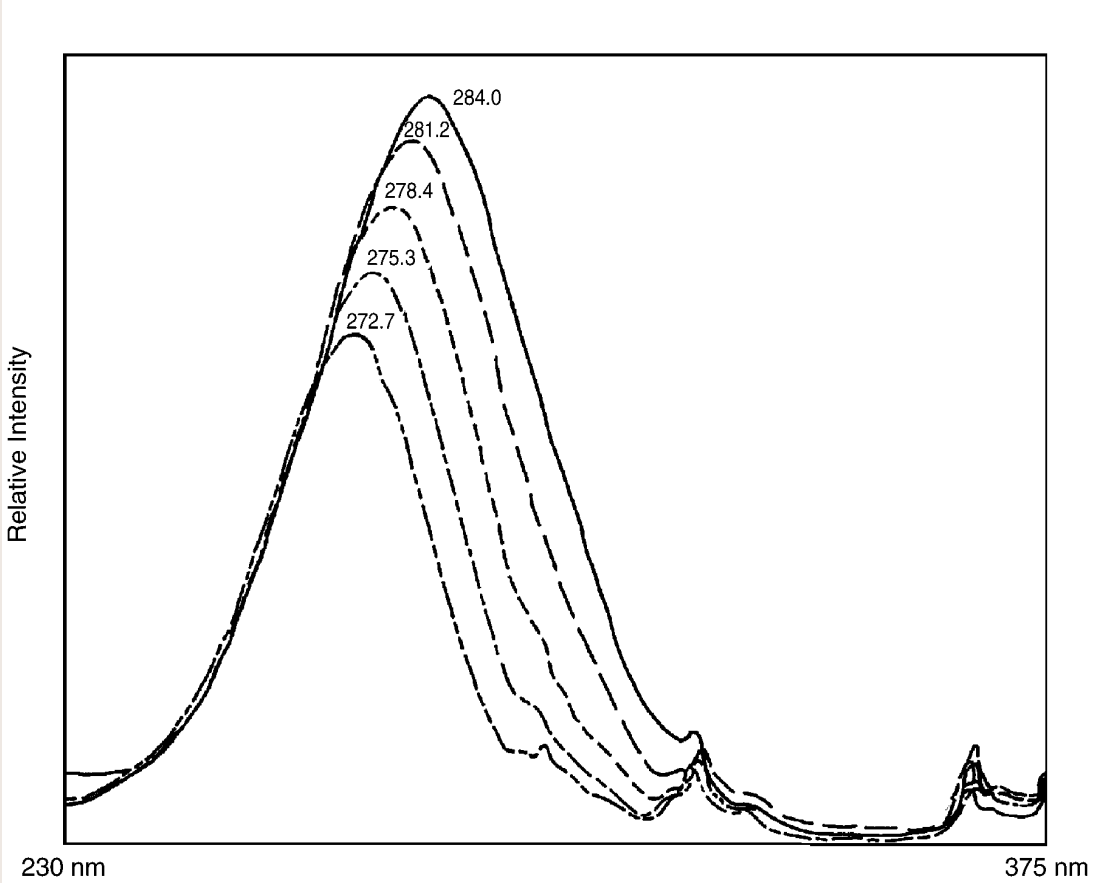
Temperature Dependence of Excitation



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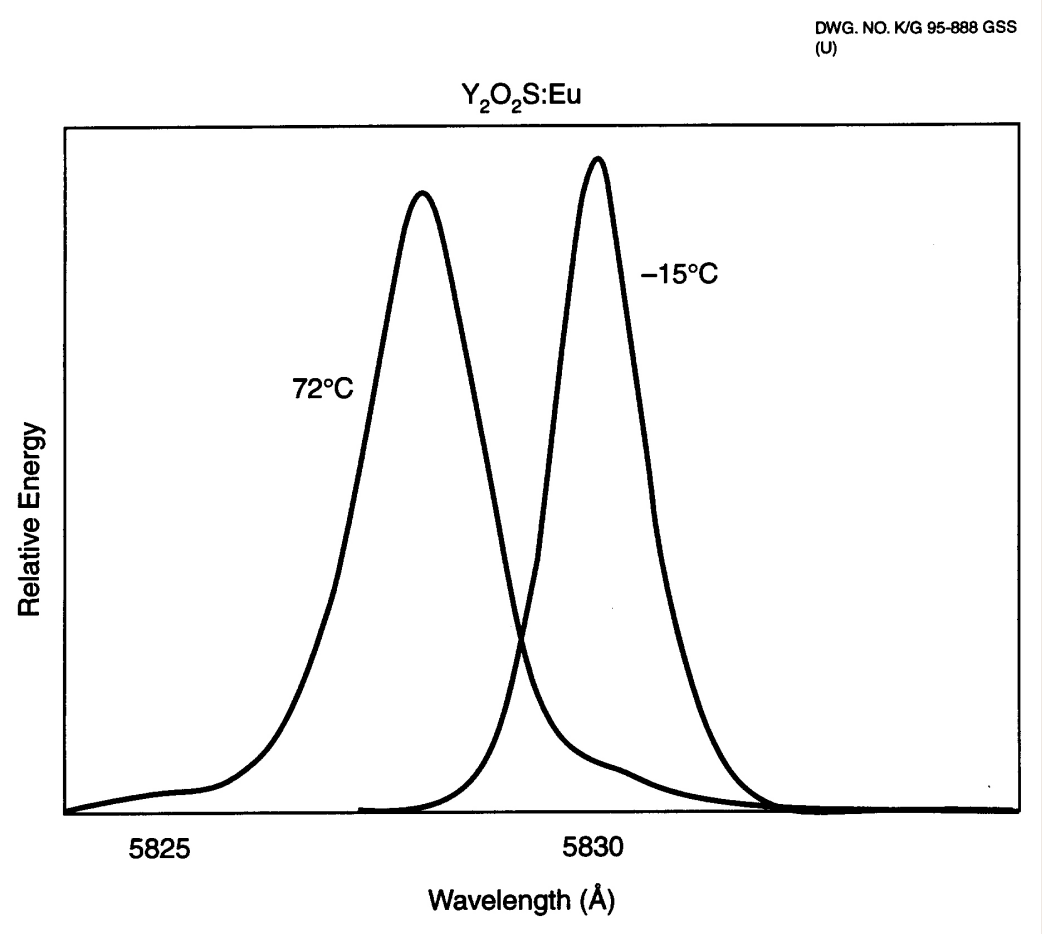
Temperature Dependent Line Position and Bandwidth



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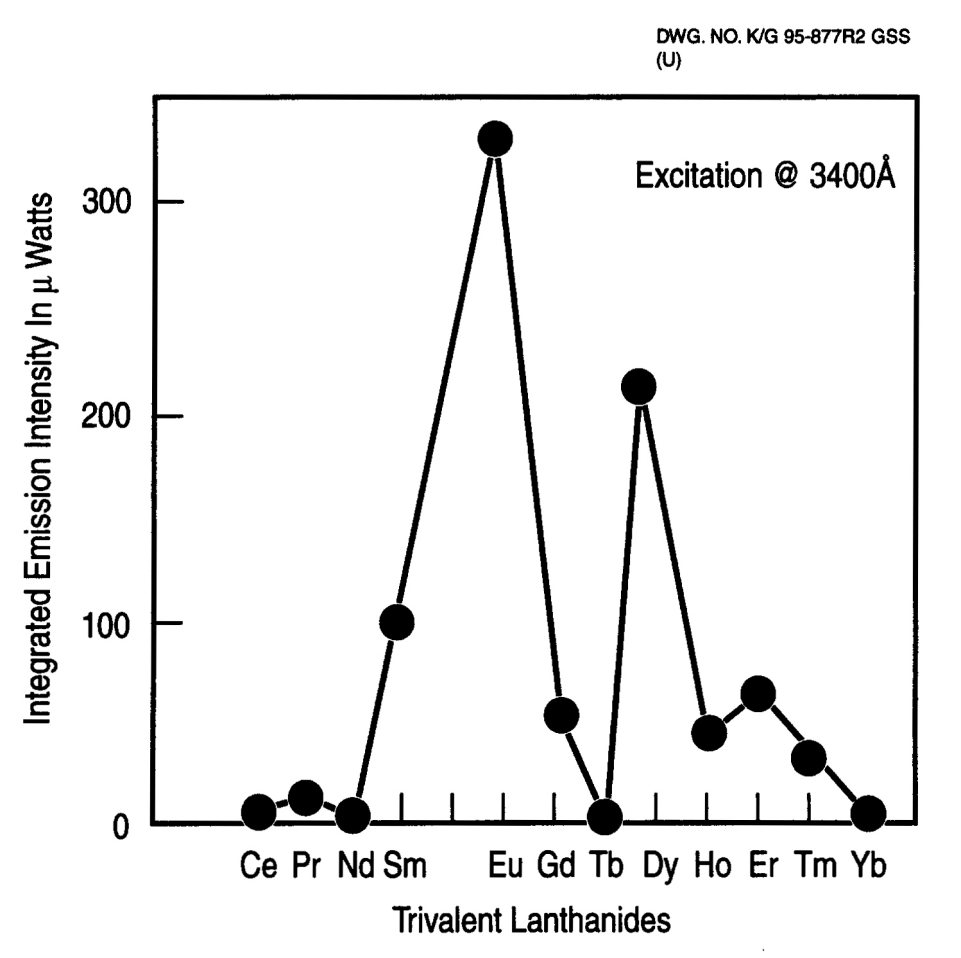
Emission versus Dopant in YVO4



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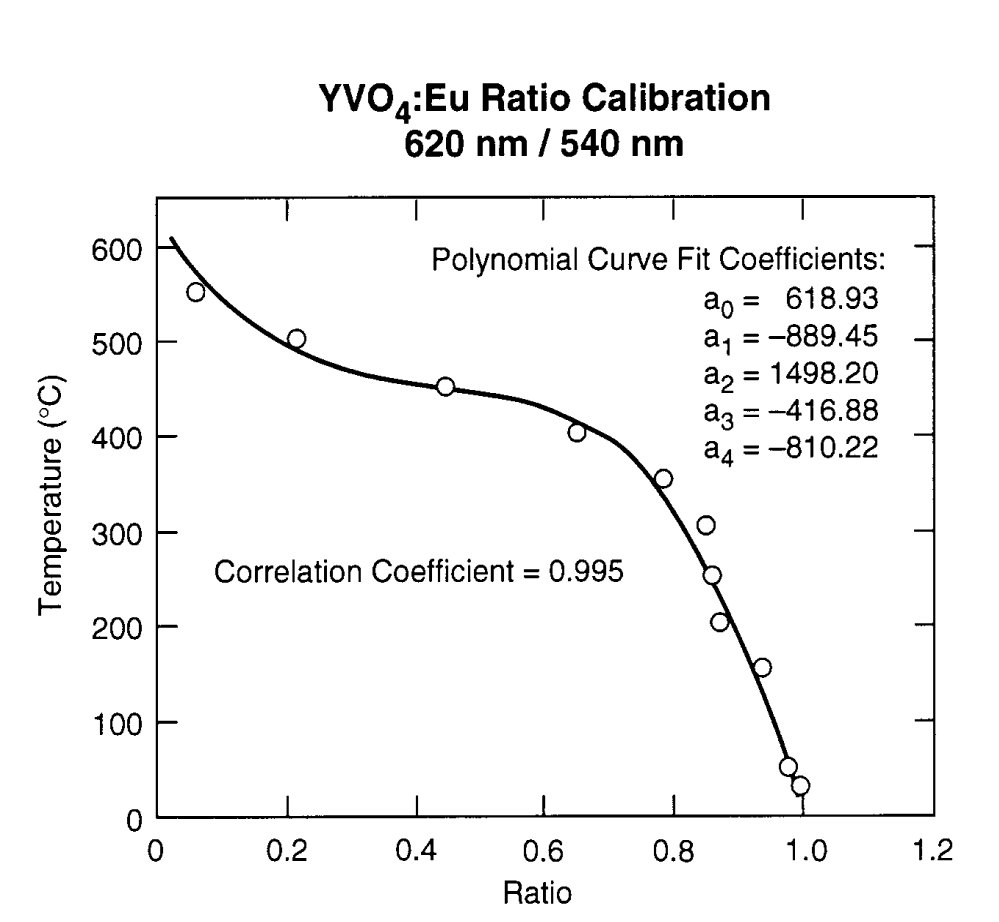
Example of Ratio Data



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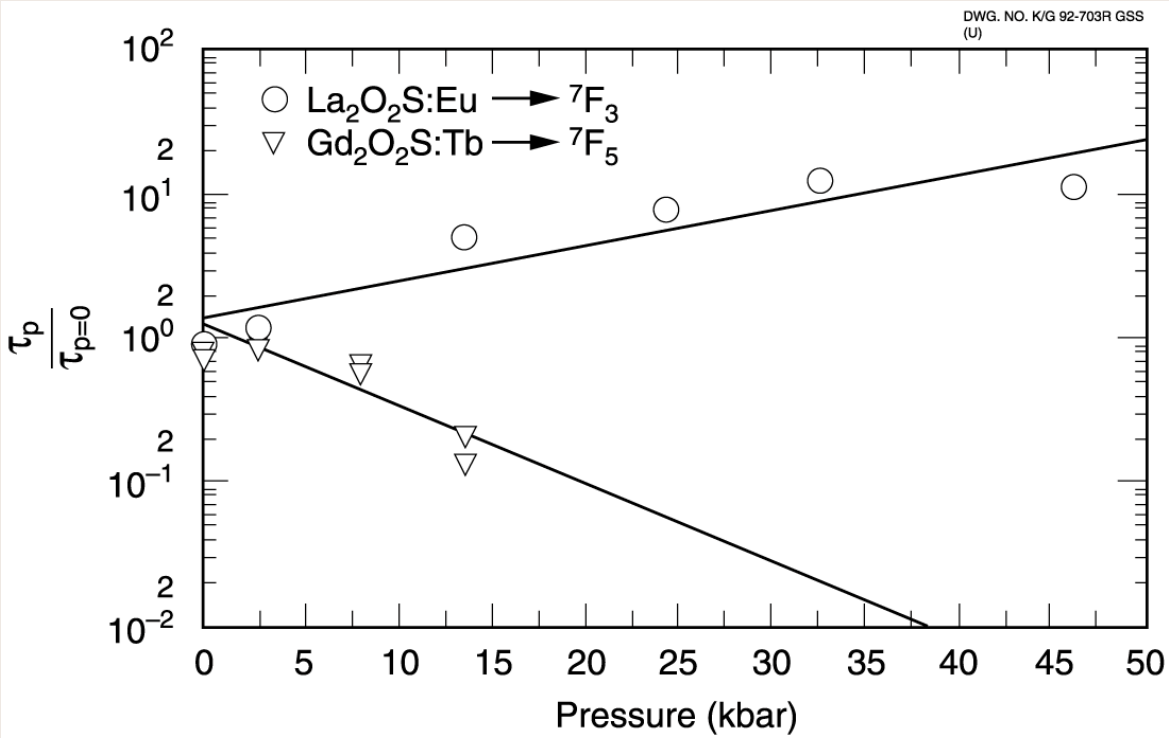
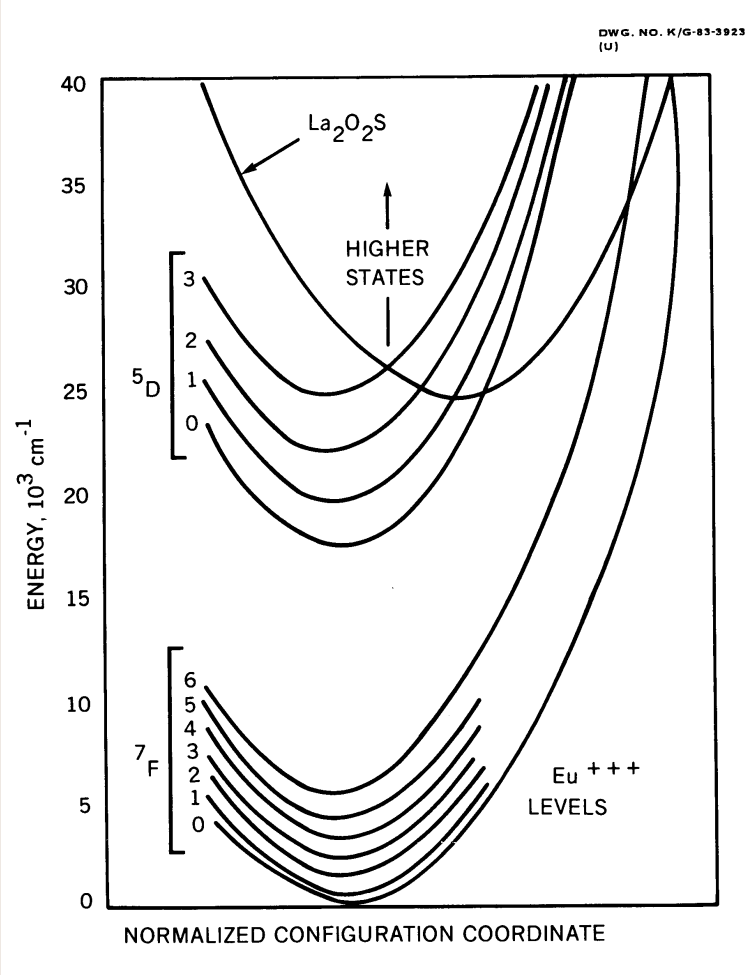
Pressure Dependence of two Pressure-Sensitive Phosphors



- Pressure vs decay time for La2O2S:Eu (top curve) and Gd2O2S:Tb (lower curve)

Origin of Temperature Dependence



- Charge Transfer State Model

Model of Temperature and Pressure Dependence

- A model was developed resulting in the equation above which predicts the decay time, tau, versus both pressure and temperature for La2O2S:Eu. Three of the parameters, a_1, a_2, and Ects; are obtained from fitting to temperature vs decay time data. The reciprocal of the low temperature decay time, a_1, is 6369 sec^{-1}. The transfer rate ratio , a_2, from the excited $^5D_2$ emitting state is 10^{12}; and Ects = 3370 cm^{-1} is the effective energy difference between the $^5D_2$ state and the charge transfer state. k is the Boltzmann constant, h is Planck's constant, and c the speed of light. T is the temperature in kelvin. P is the pressure in psi. q is obtained empirically, it is the slope of the pressure versus decay time curve q = $2.73 * 10^{-3}$ $psi^{-1} * (cm^{-1})^{-1}$.

$$tau := \left[a_1 + a_2 \cdot \left[\exp\left[\frac{-(P \cdot q + Ects) \cdot h \cdot c}{k \cdot T} \right] \right] \right]^{-1}$$

Phosphor Selection Criteria

1. Temperature range of application
2. Chemical compatibility
3. Target stationary or moving
4. Method used: decay time or ratio
5. Surface preparation considerations
6. Imaging or point measurements required

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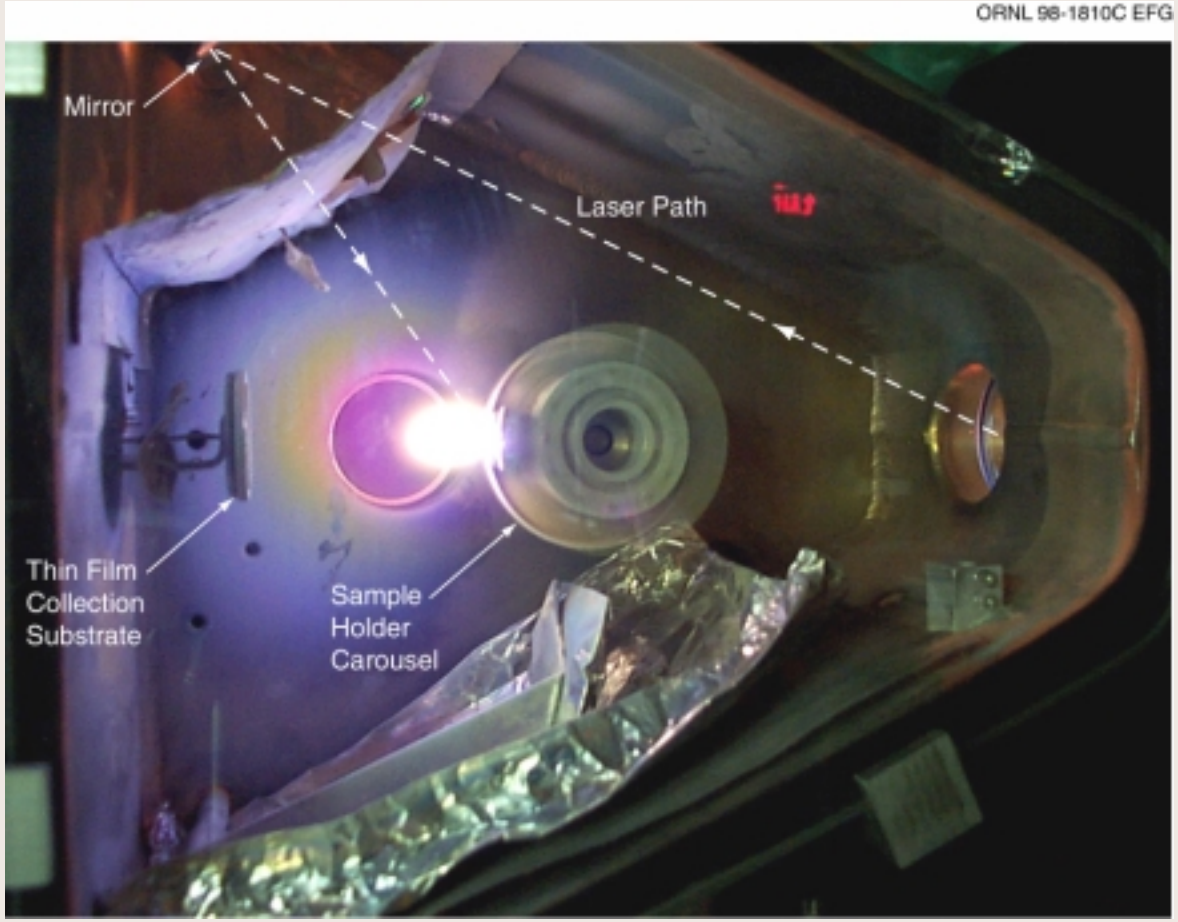
Pulsed Laser Deposition Example



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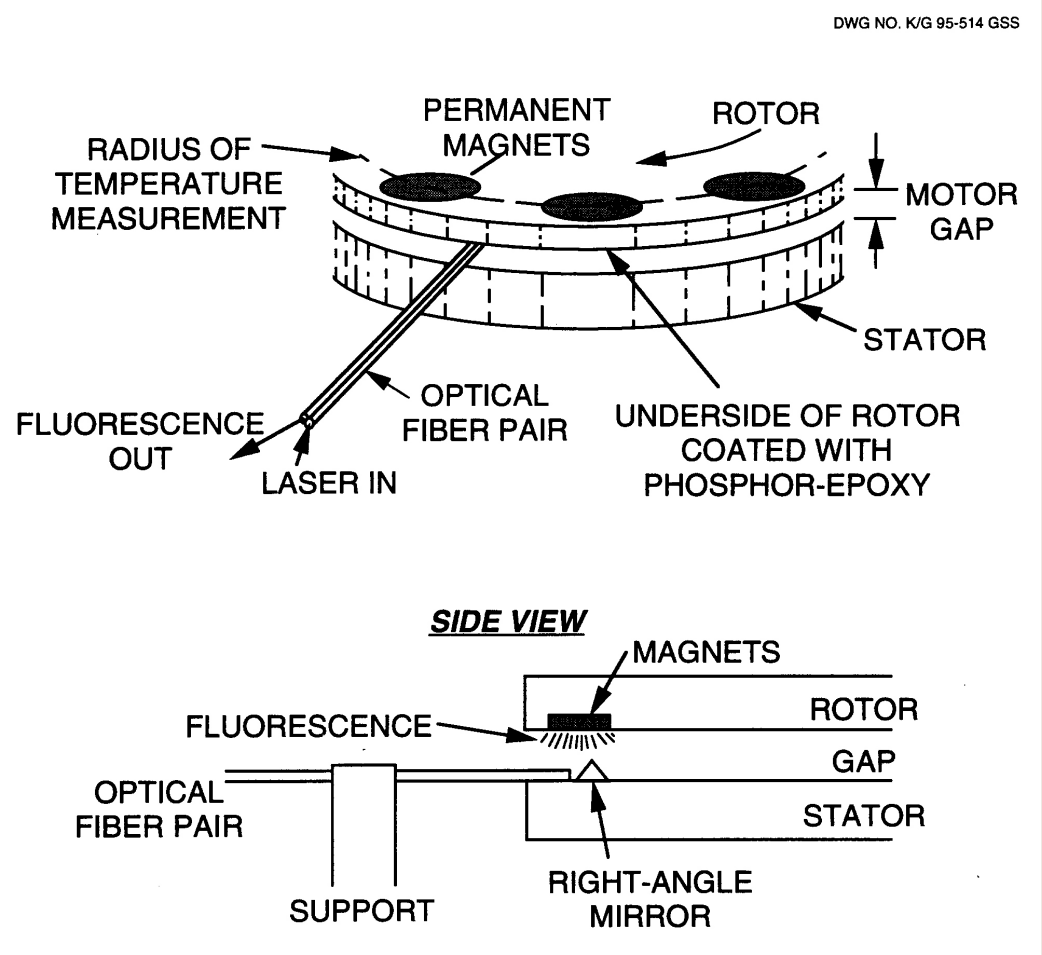
Permanent Magnet Motor



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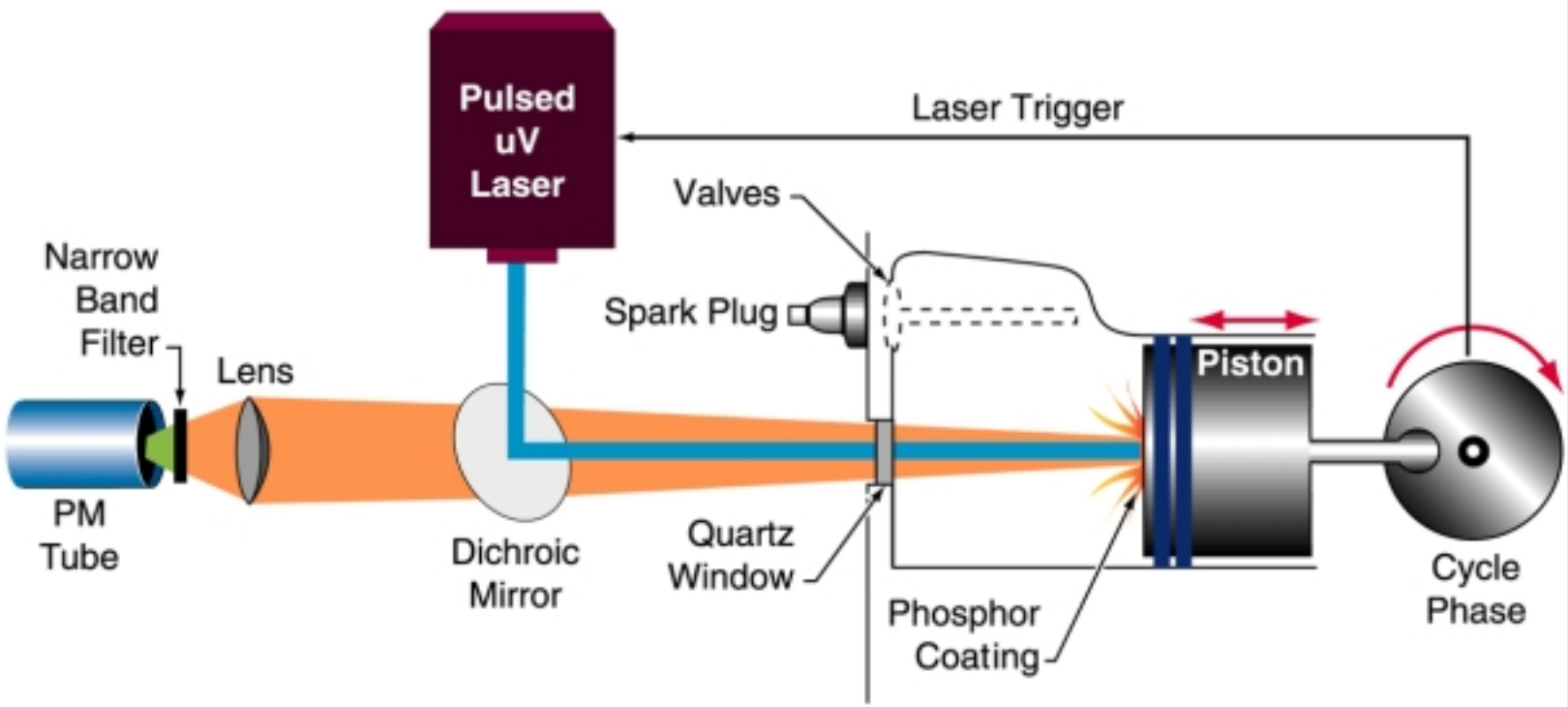
Set-up for Piston Measurement



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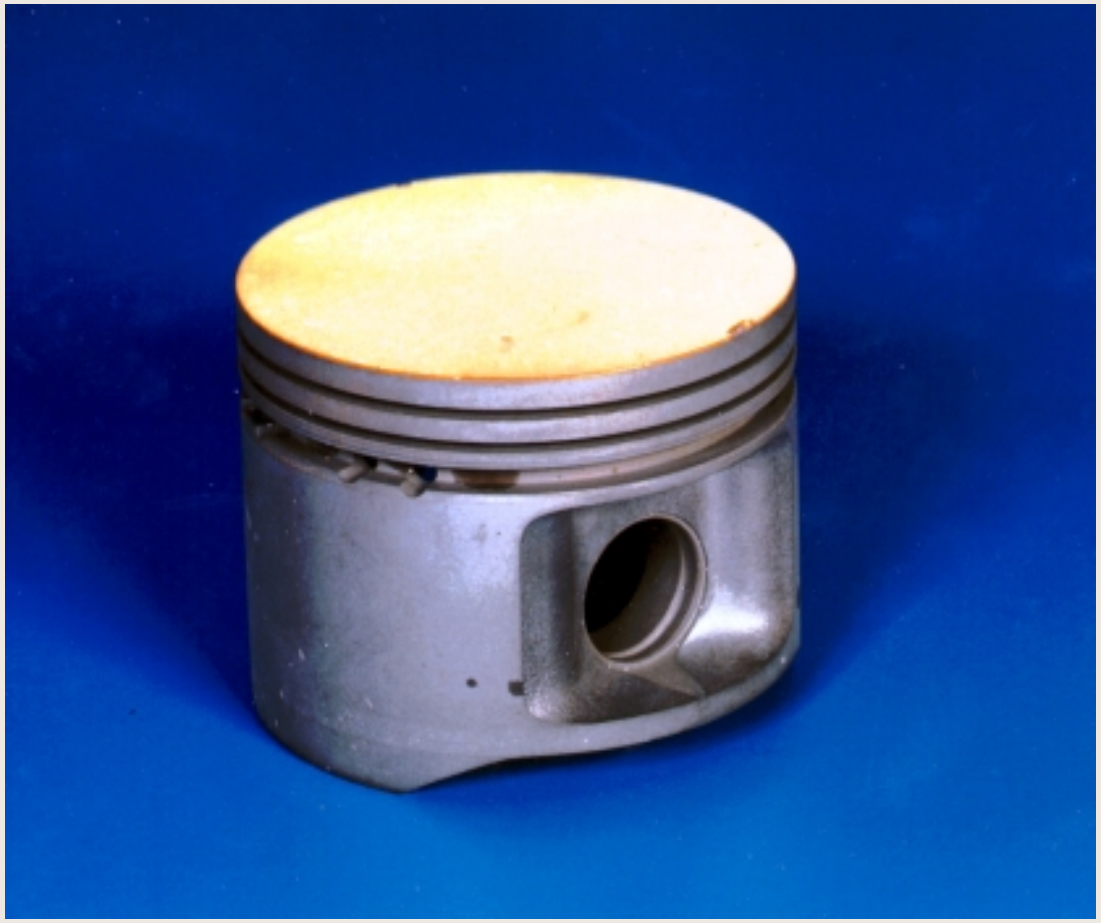
Fluorescing Piston



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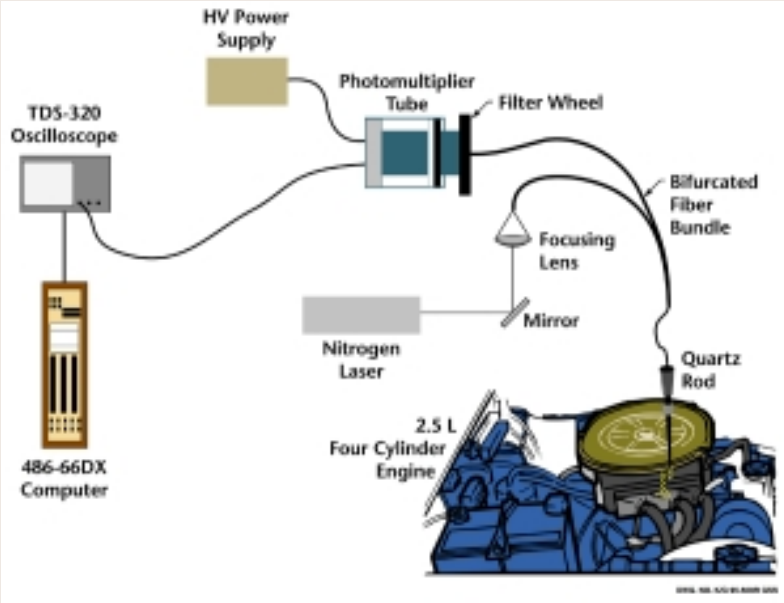
Intake Valve Setup



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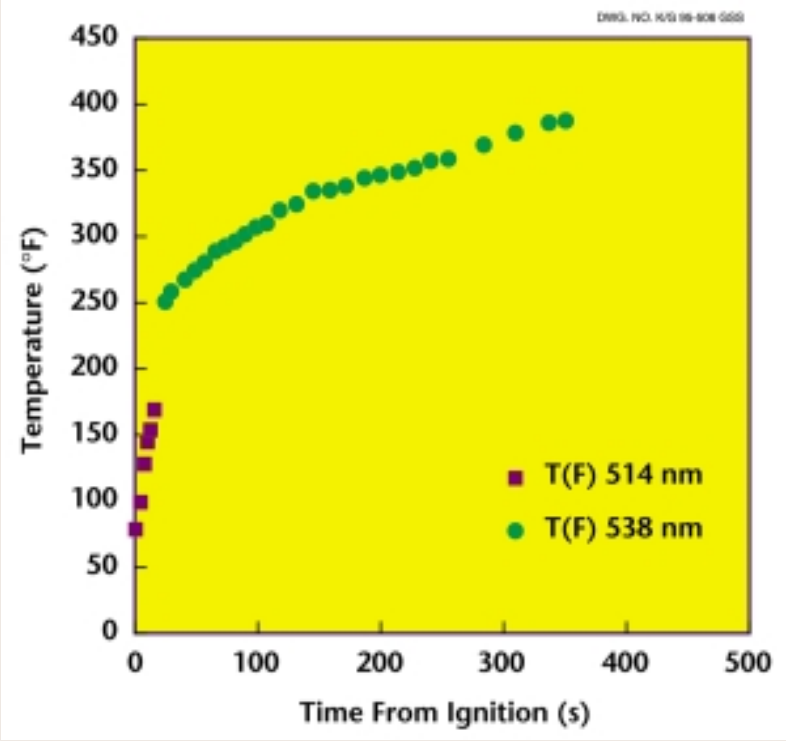
Intake Valve Results



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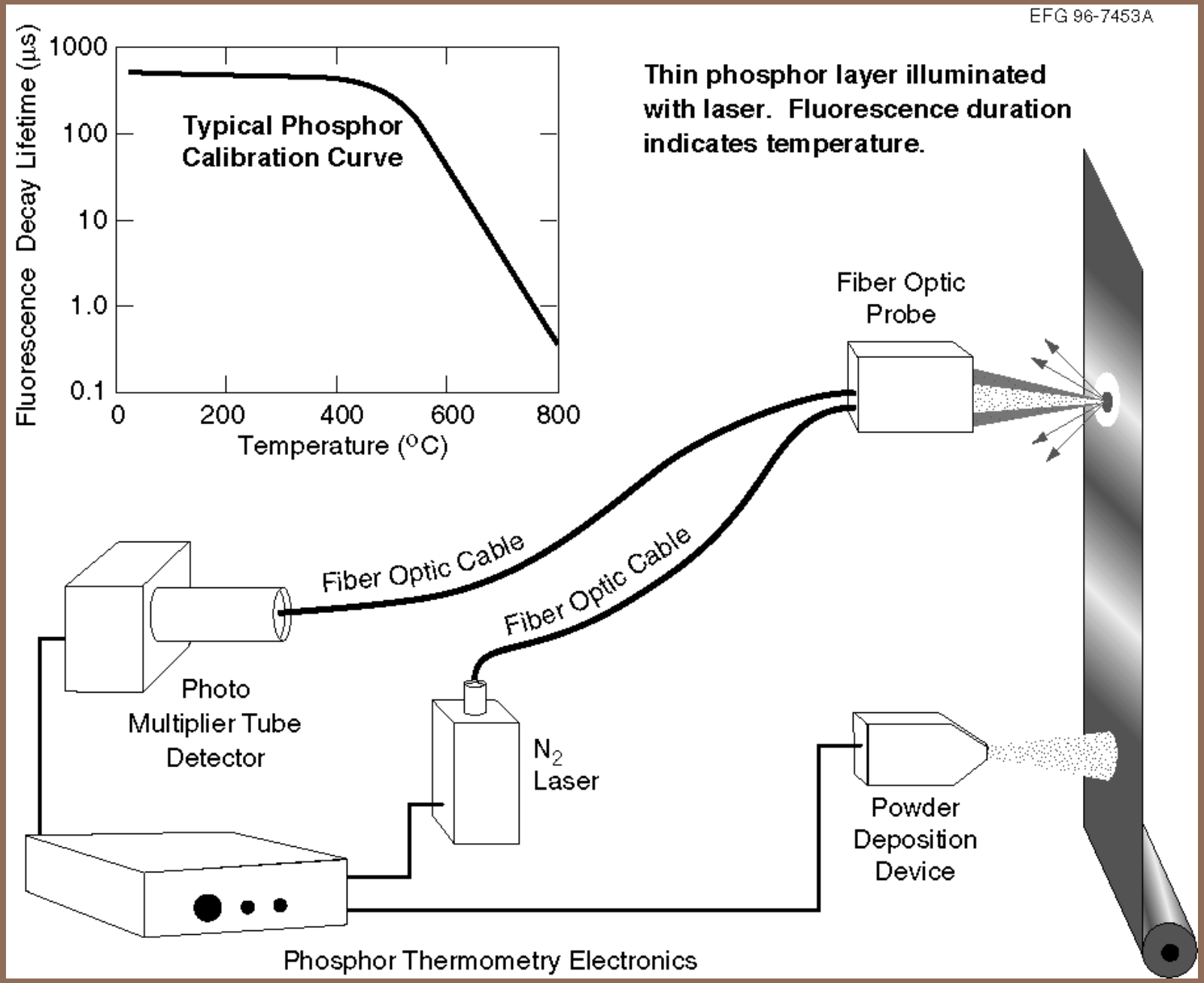
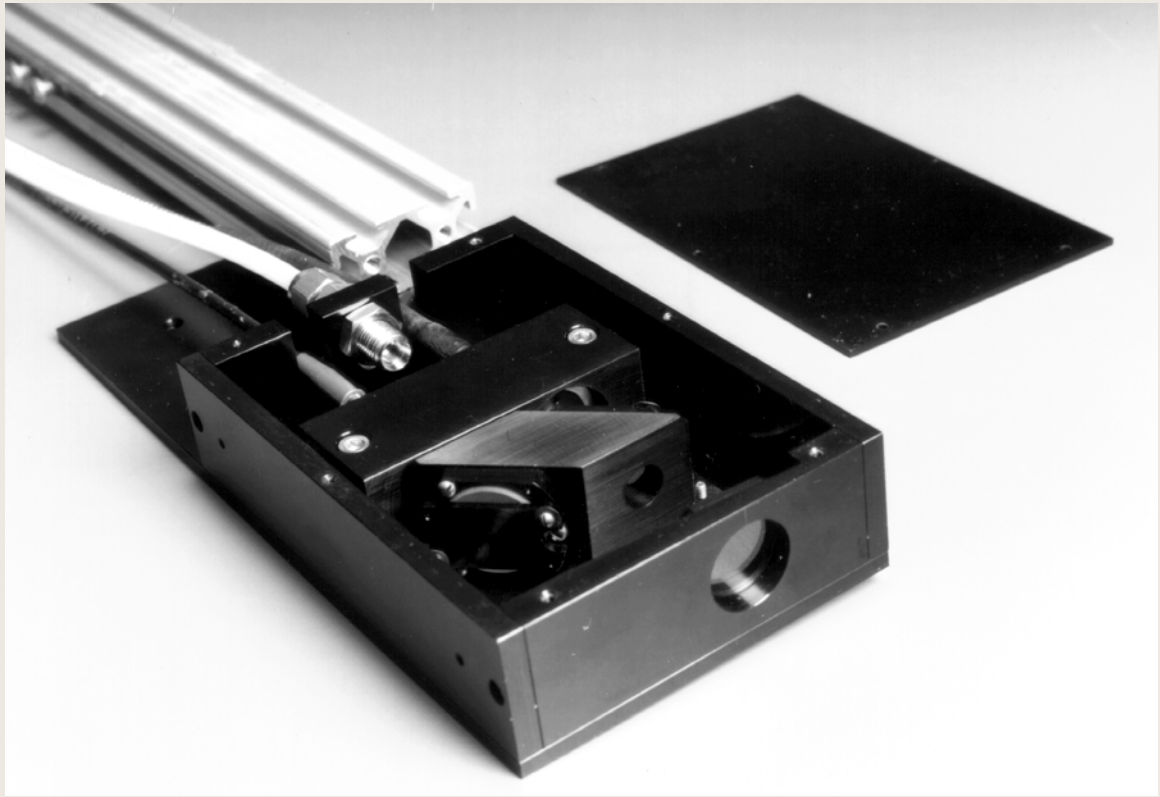

EFG 96-7453A
Thin phosphor layer illuminated with laser. Fluorescence duration indicates temperature.
Typical Phosphor Calibration Curve
Fluorescence Decay Lifetime (µs)
1000
100
10
1.0
0.1
0
200
400
600
800
Temperature (°C)
Fiber Optic Probe
Fiber Optic Cable
Fiber Optic Cable
Photo Multiplier Tube Detector
N_2 Laser
Powder Deposition Device
Phosphor Thermometry Electronics

Optics for Galvanneal Steel



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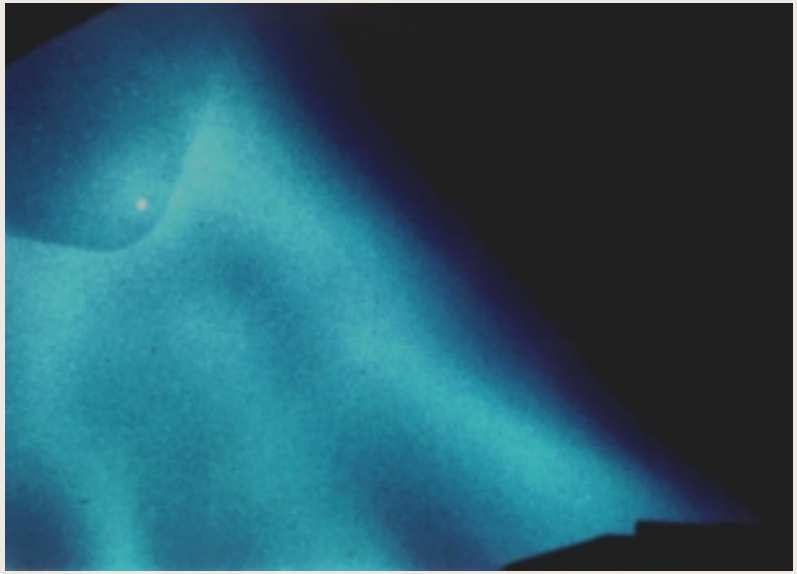
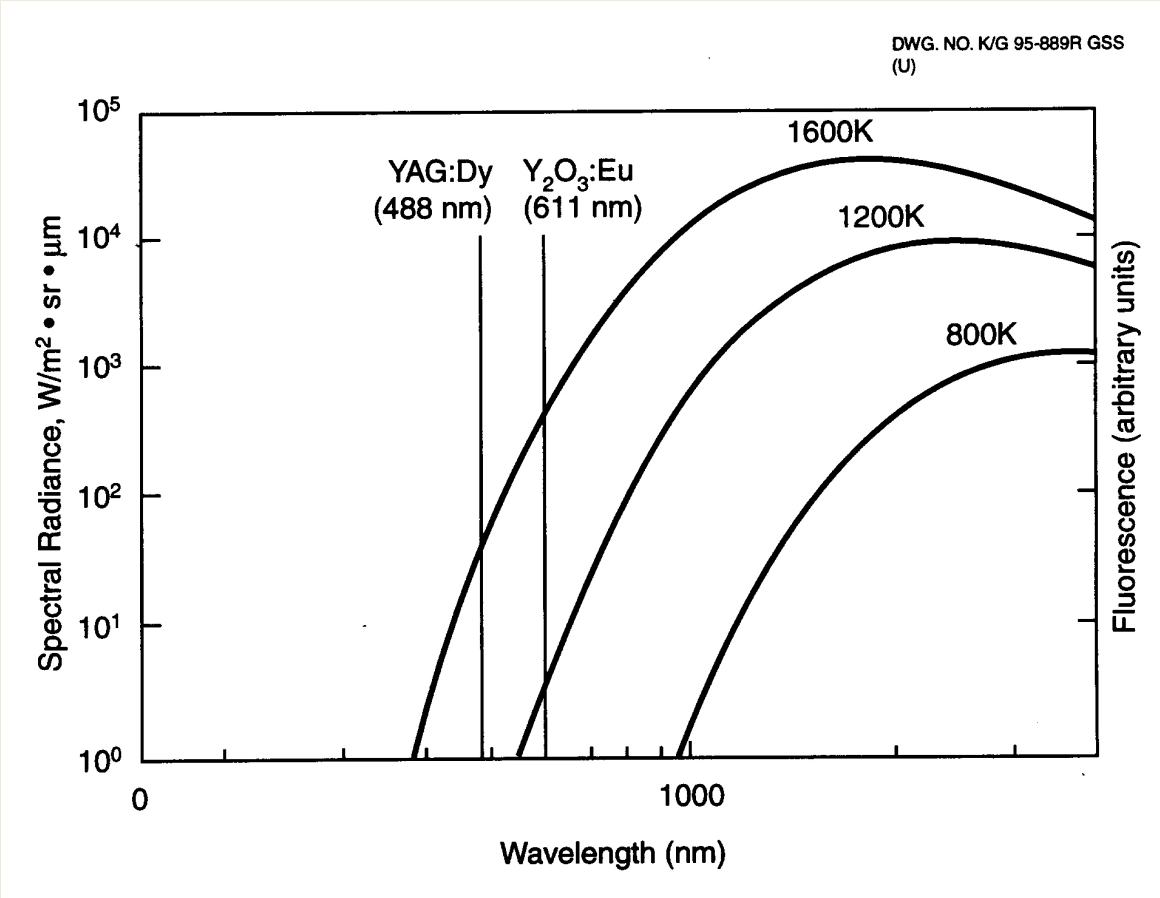
Afterburner/Phosphor LIF



- Afterburner Flame impinging on a variable-area extractor. The white spot is phosphor luminescence.

Blackbody vs. Fluorescence Emission



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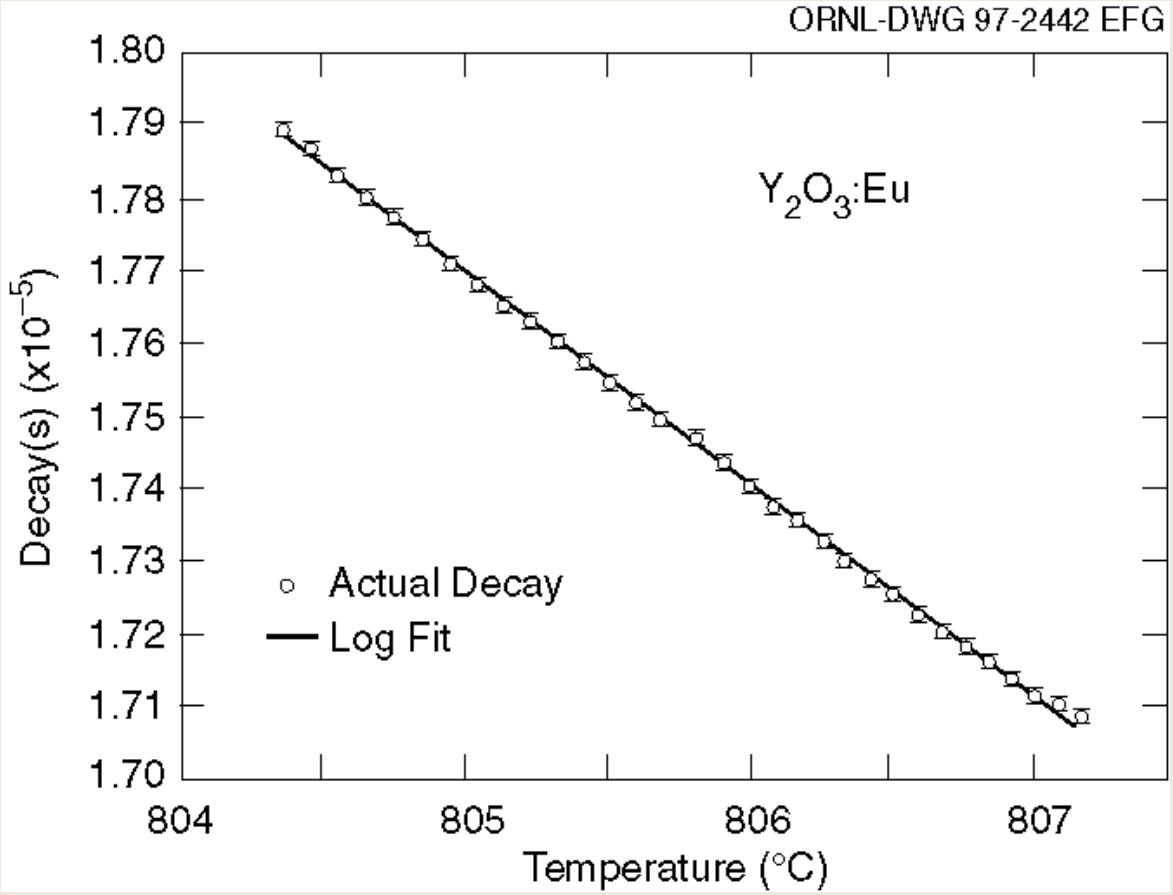
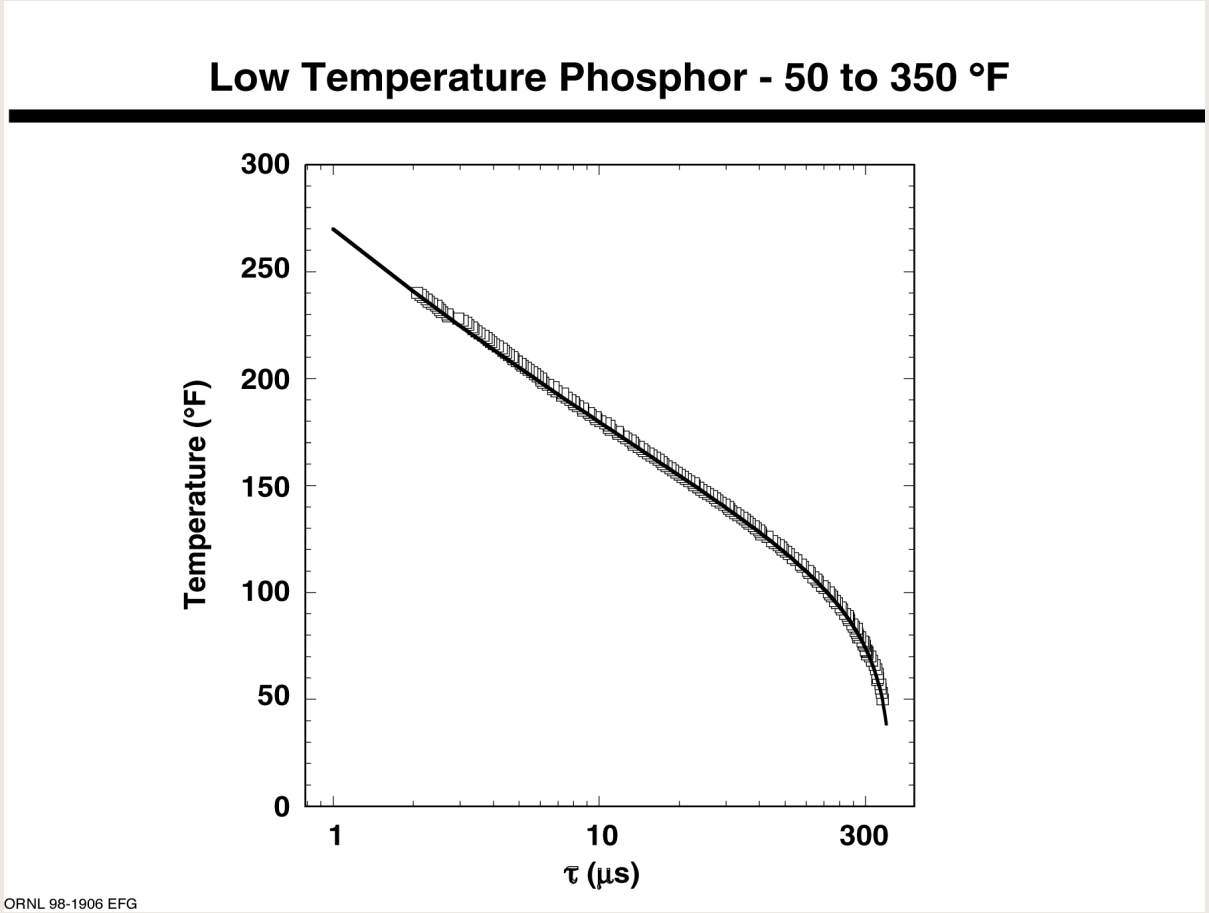
Precision Limits



Gd2O2S:Eu Calibration Curve



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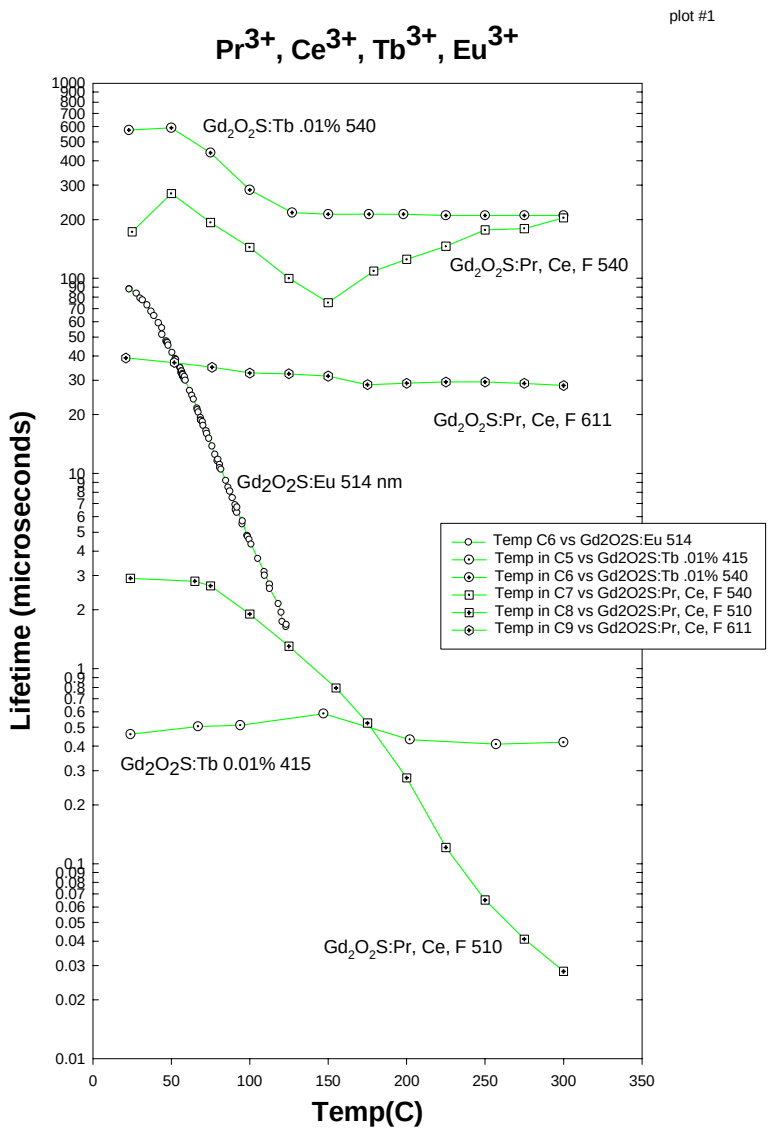
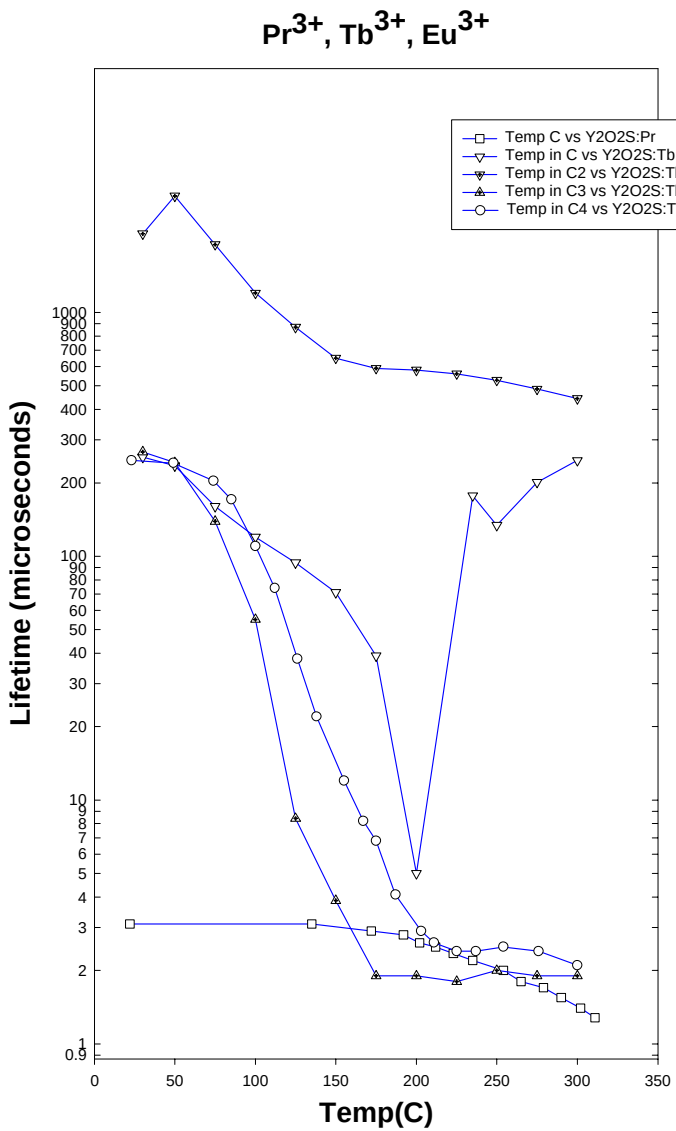
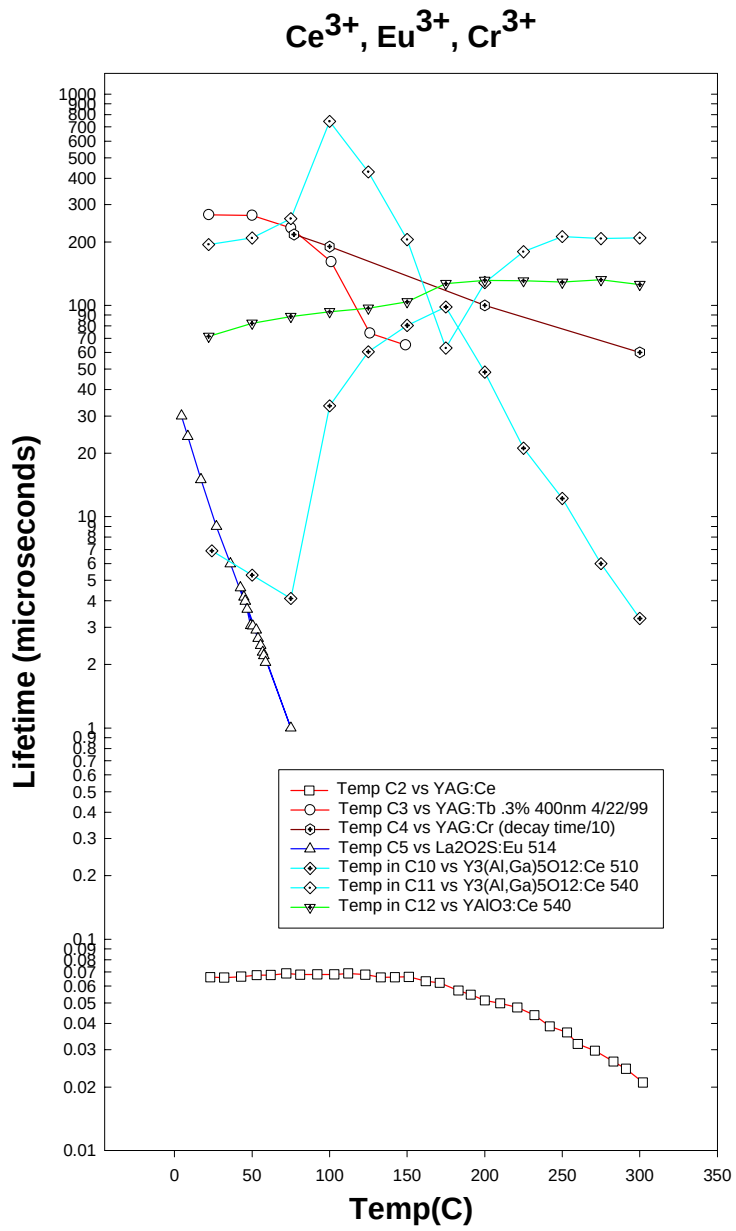
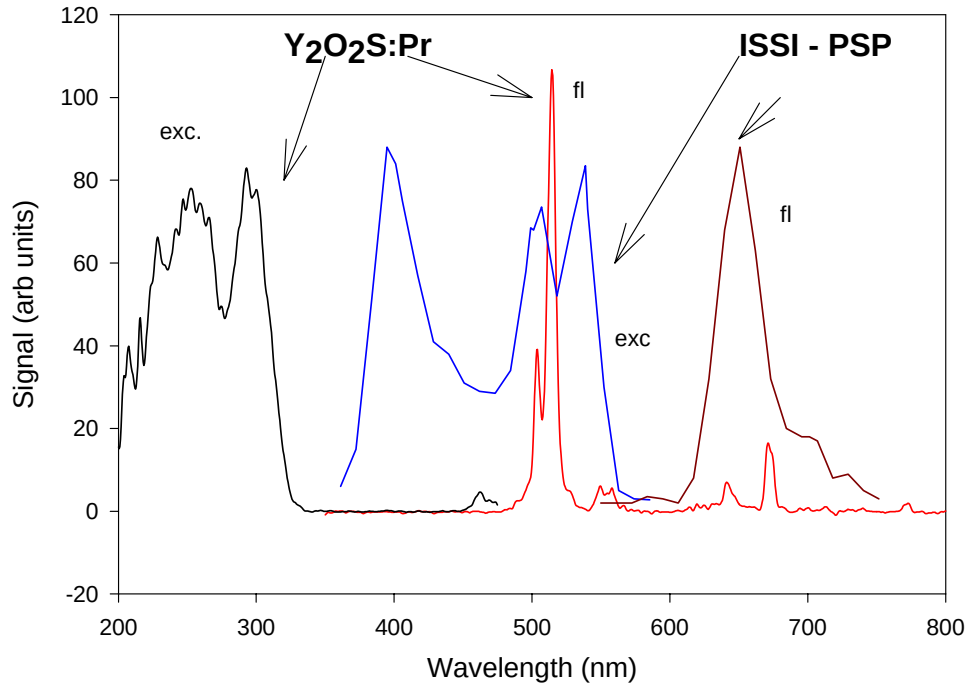

plot #1
Pr3+, Ce3+, Tb3+, Eu3+
Gd2O2S:Tb .01% 540
Gd2O2S:Pr, Ce, F 540
Gd2O2S:Pr, Ce, F 611
Gd2O2S:Eu 514 nm
Gd2O2S:Tb 0.01% 415
Gd2O2S:Pr, Ce, F 510
Temp C6 vs Gd2O2S:Eu 514
Temp in C5 vs Gd2O2S:Tb .01% 415
Temp in C6 vs Gd2O2S:Tb .01% 540
Temp in C7 vs Gd2O2S:Pr, Ce, F 540
Temp in C8 vs Gd2O2S:Pr, Ce, F 510
Temp in C9 vs Gd2O2S:Pr, Ce, F 611
Lifetime (microseconds)
Temp(C)

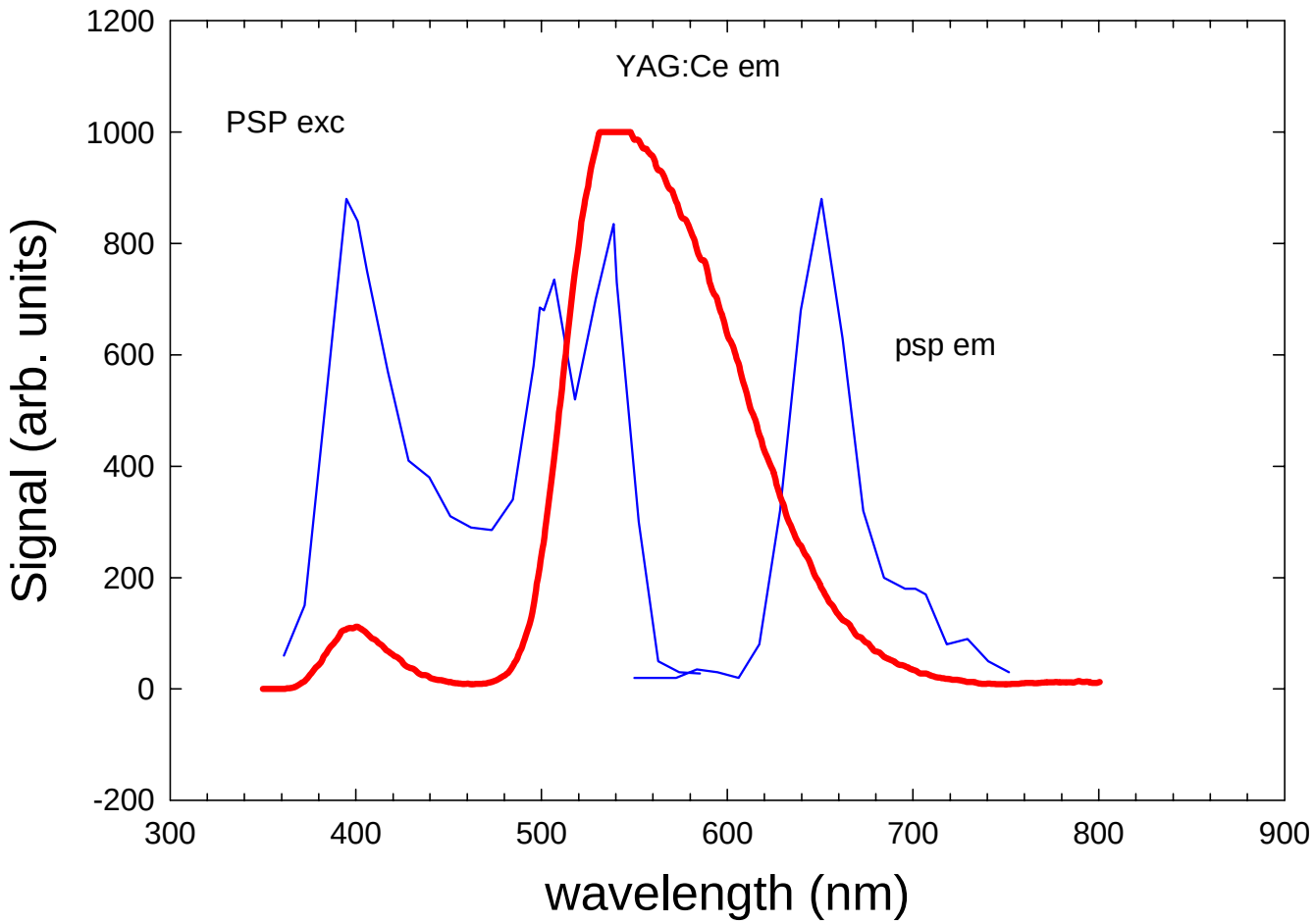

Pr3+, Tb3+, Eu3+
Temp C vs Y2O2S:Pr
Temp in C vs Y2O2S:Tb:Eu 544
Temp in C2 vs Y2O2S:Tb:Eu 544 long
Temp in C3 vs Y2O2S:Tb:Eu 415
Temp in C4 vs Y2O2S:Tb 0.3%
Lifetime (microseconds)
Temp(C)


Ce3+, Eu3+, Cr3+
Lifetime (microseconds)
Temp(C)
Temp C2 vs YAG:Ce
Temp C3 vs YAG:Tb .3% 400nm 4/22/99
Temp C4 vs YAG:Cr (decay time/10)
Temp C5 vs La2O2S:Eu 514
Temp in C10 vs Y3(Al,Ga)5O12:Ce 510
Temp in C11 vs Y3(Al,Ga)5O12:Ce 540
Temp in C12 vs YAlO3:Ce 540

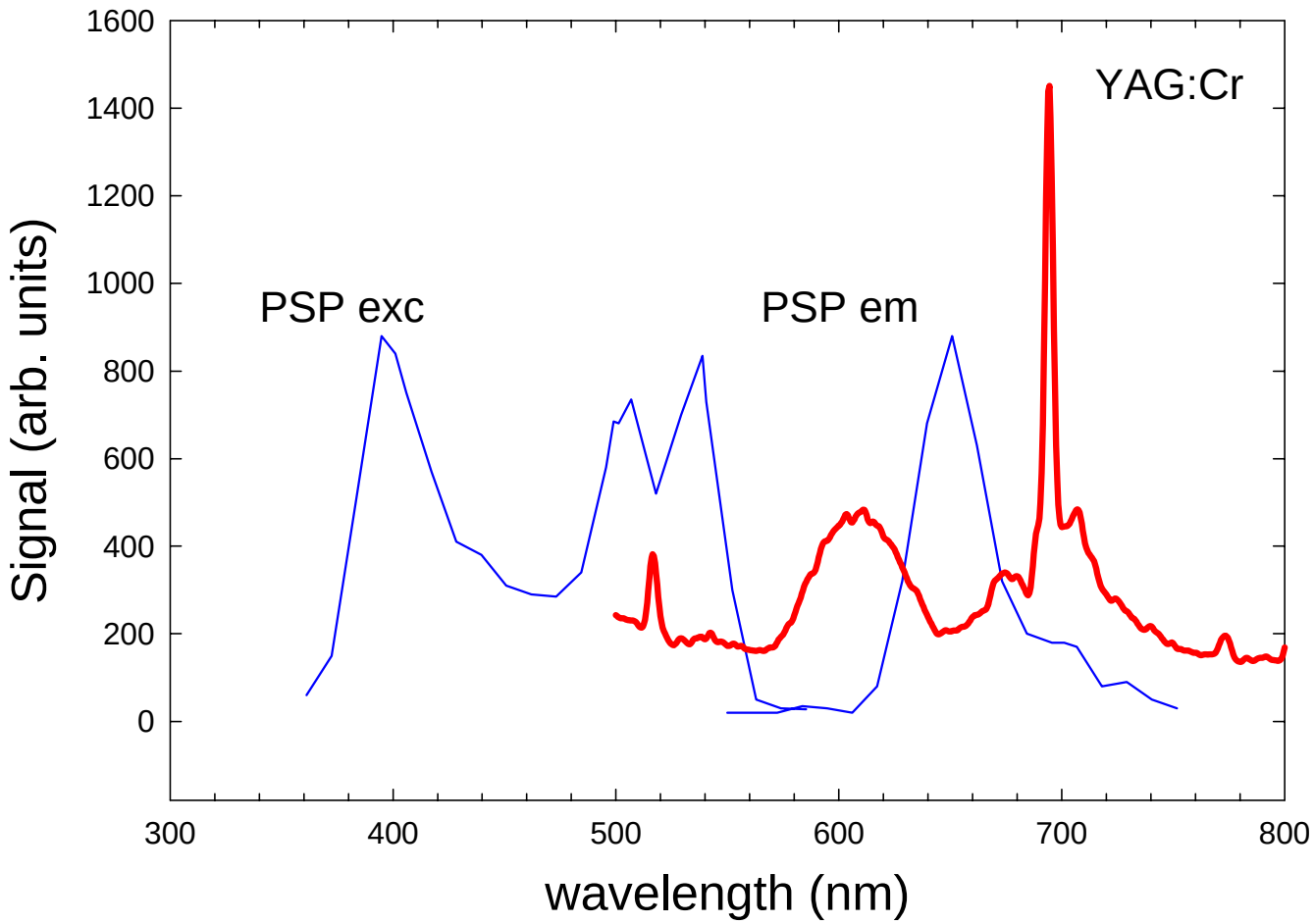
Y2O2S:Pr and PSP



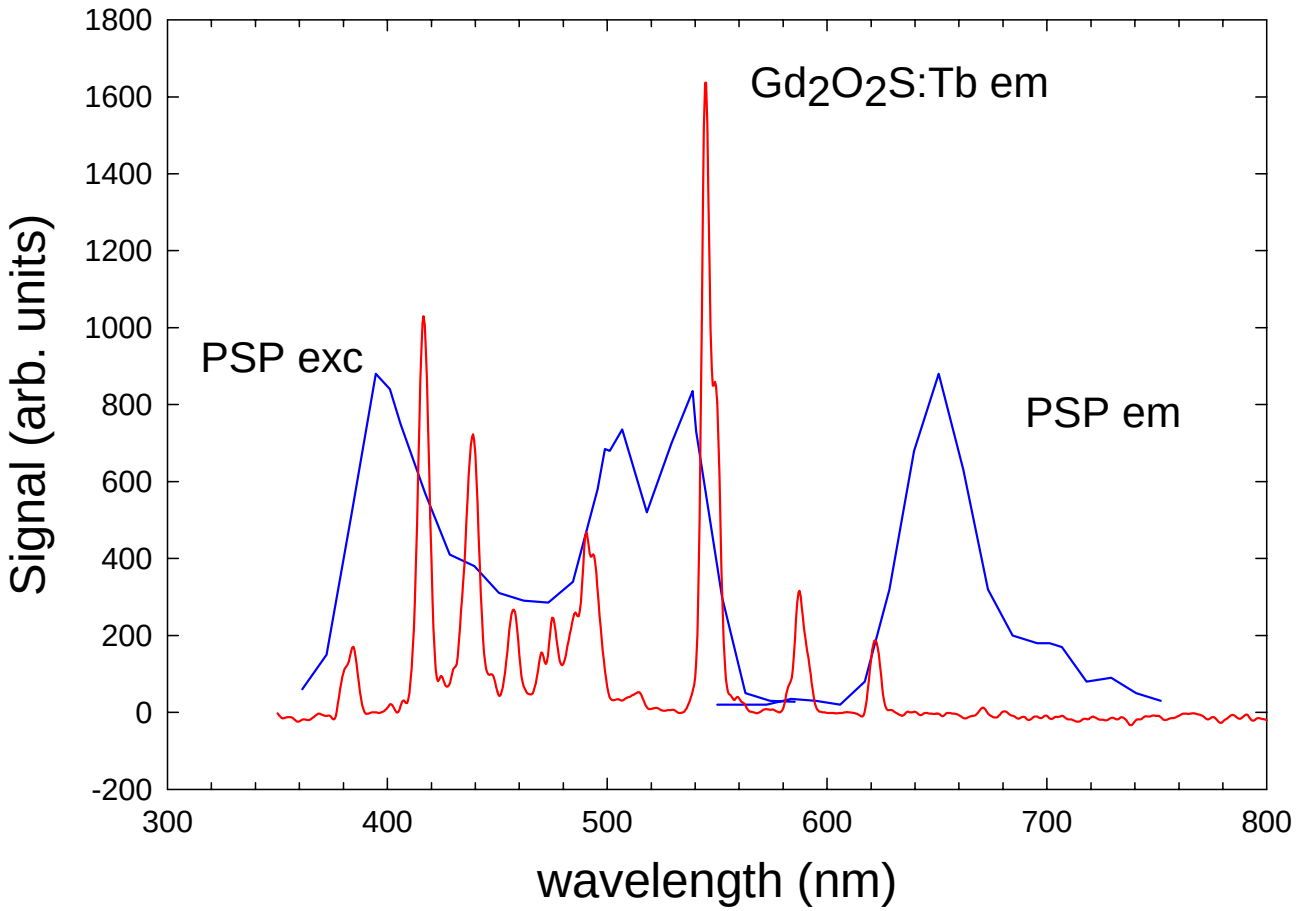
YAG:Ce and PSP



YAG:Cr and PSP



Gd_2O_2S:Tb (low Tb concentration) and PSP



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