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Fire Science & Technology

HEAF Workgroup
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Semi-Empirical Cable Fire Conceptual Model Methods

Alexander L. Brown; albrown@sandia.gov; (505)844-1008
Jeffrey D. Engerer; jengere@sandia.gov; (505)284-6555
Fire Science and Technology Department
Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration
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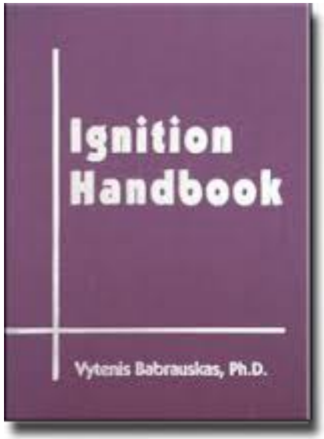
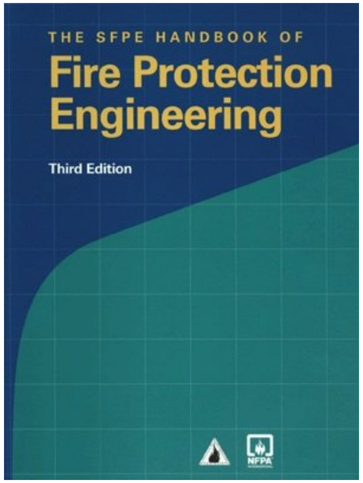
High Flux Current Ignition Literature

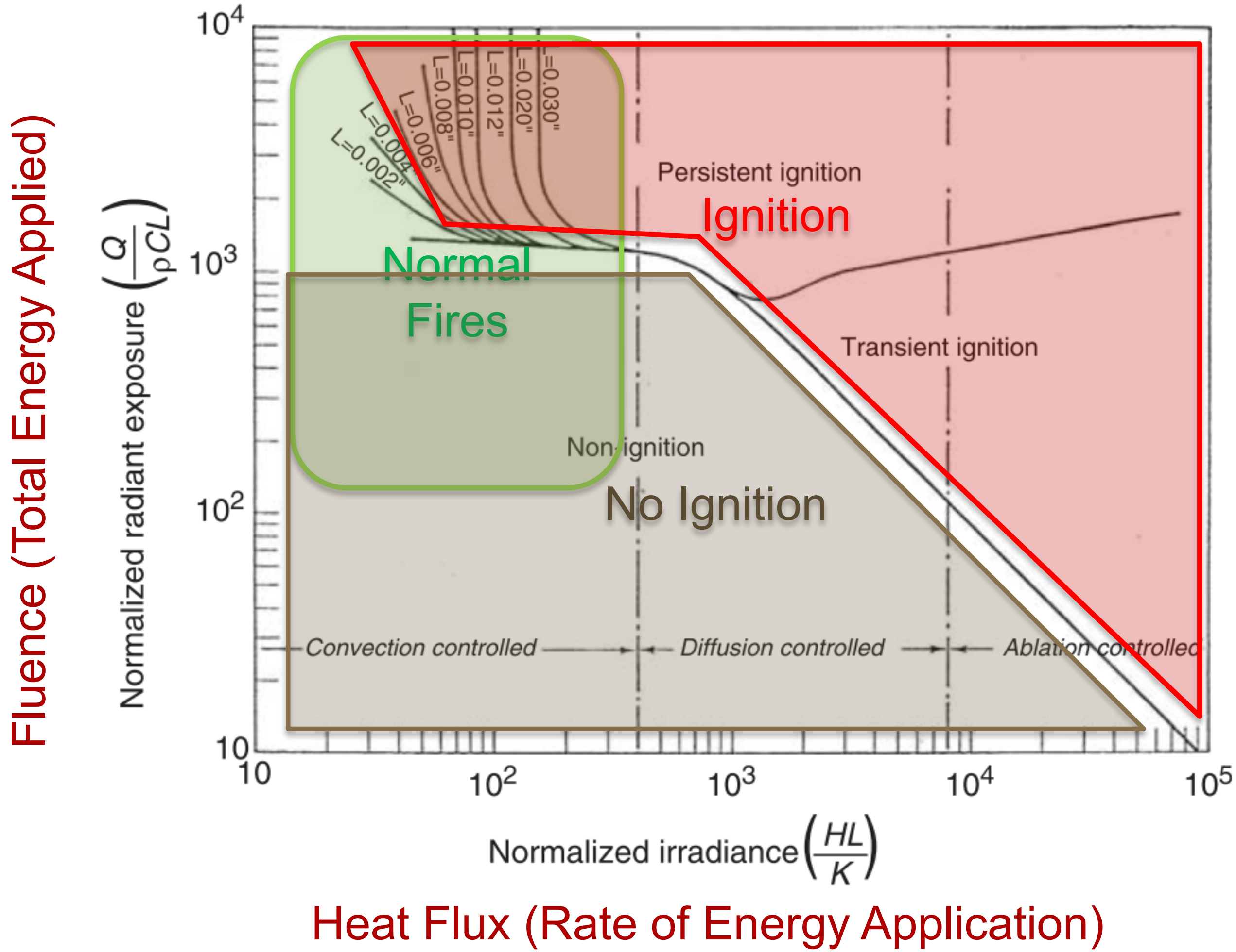
- Ignition Handbook (Babruskas, 2003)
  - Cites Glasstone and Dolan (1977) as main source
  - We believe their ignition data are based on the historical data from the 50's-60's.
- SFPE Handbook (Chapter 11, third edition)
  - Ignition section written by Kanury, heavily references Martin's work
  - "Martin and his collaborators had honed the technique of ignition measurement to such a fine art that their measured ignition thresholds of drapes, typing paper, dry rotted wood and leaves were included in the newer printing of Glasstone's Effects of Nuclear Weapons"—Kanury, A. M. (2009). SFPE Classic Paper Review: Diffusion-Controlled Ignition of Cellulosic Materials by Intense Radiant Energy by Stanley B. Martin. Journal of Fire Protection Engineering, 19(2), 125-131.
- Most current recommendations for high flux ignition go back to the same dated sources (Martin et al.)





Martin et al. (1965) Ignition Regimes

- Stan Martin summarized his ignition data for blackened cellulose in terms of flux/fluence regimes



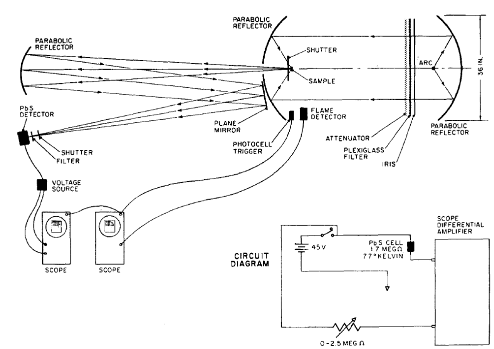
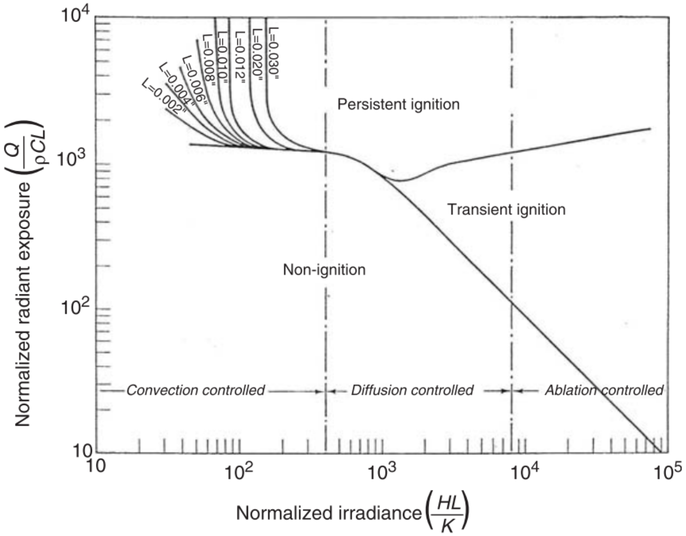


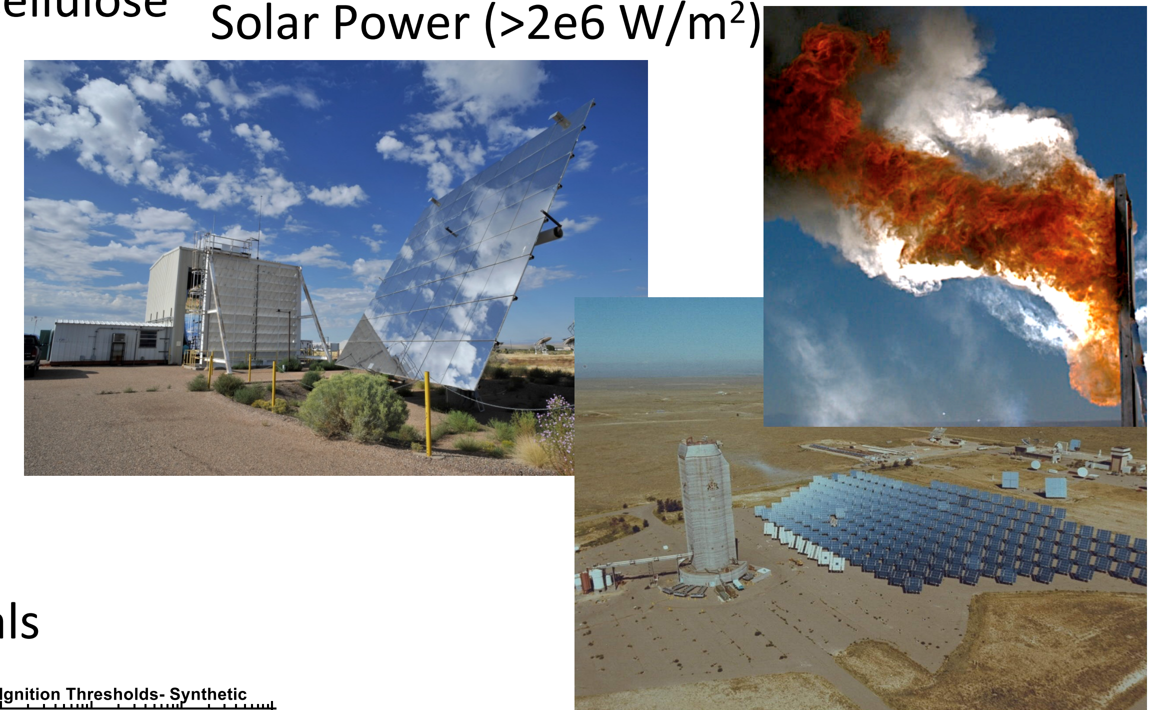
Fig. 4. Apparatus for the measurement of temperatures of the irradiated surface of cellulose.

Recent Ignition from High Heat Flux

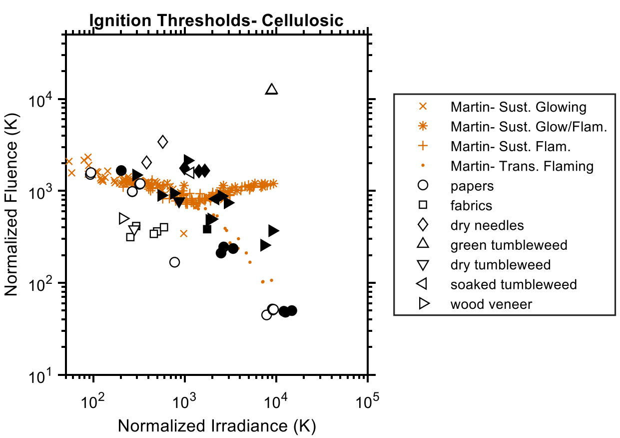
Prior Martin Ignition Data-mostly cellulose

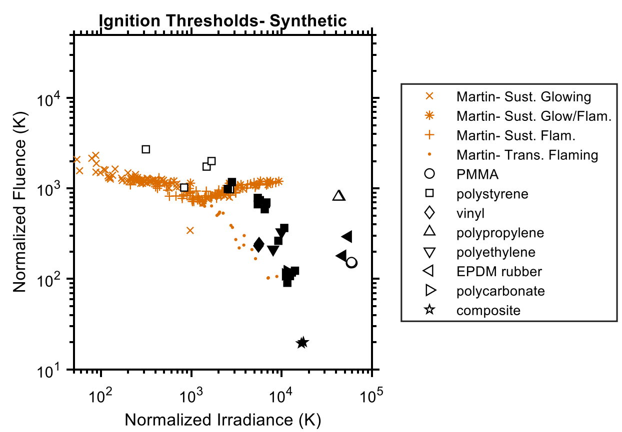


New Testing using Concentrated Solar Power (>2e6 W/m^2)



Emerging Data for More Materials





- Orange = historical data
- Solid black = new ignition thresholds
- Open = non-ignition

Martin's Ignition Model: Critical Surface Temp.

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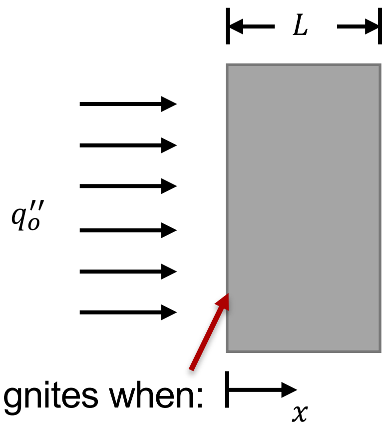
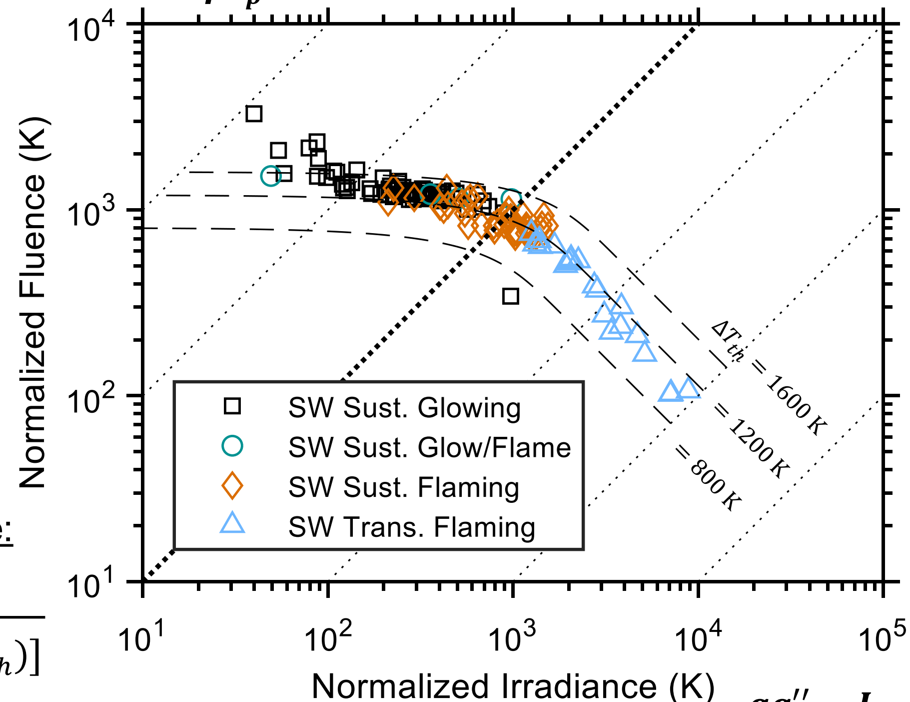


Ignites when:
$\Delta T_s = \Delta T_{th}$

- Thermal diffusion into a radiantly heated slab.
  - Ignore other effects (pyrolysis, losses, etc.)
  - Solid temperature has well-defined sol'n:

$$Q^* = \frac{aQ''}{\rho c_p L}$$

Engerer, et al., AIAA/ASME Joint Thermophys. H. Transf. Conf., Atlanta, GA, 2018. DOI: 10.2514/6.2018-3764



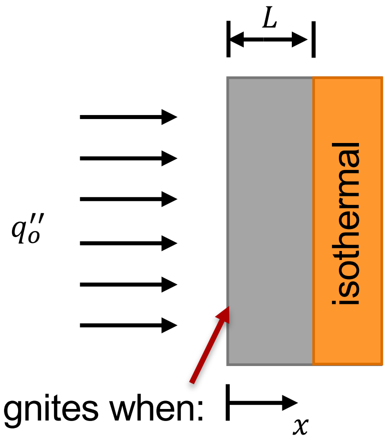
$$q^* = \frac{aq''_{peak}L}{k}$$

<u>Empirical Ignition Model based on critical surface temperature:</u>

$$Q^*_{th} = q^*_{th}Fo_{th} = \Delta T_{th}\frac{Fo_{th}}{Fo_{th} + \frac{2}{\pi^2}\sum_{m=1}^{\infty}\frac{1}{m^2}\left[1 - \exp(-m^2\pi^2 Fo_{th})\right]}$$

$$Q^*_{th} = \Delta T_{th}\, f(Fo_{th})$$

Proposed Cable Ignition Model



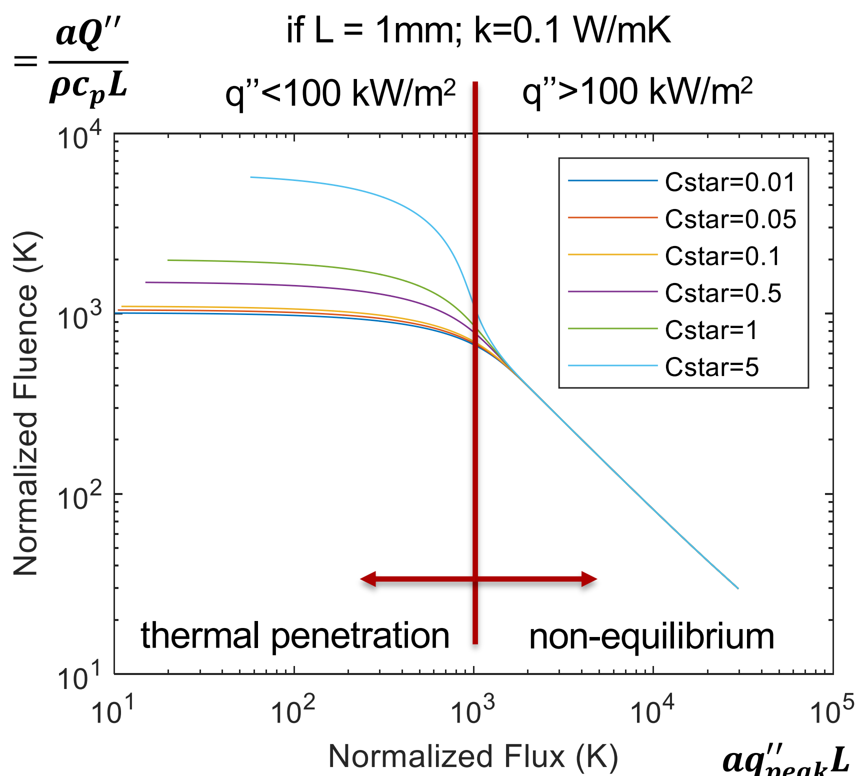
Ignites when: $\Delta T_s = \Delta T_{th}$

- Lumped-material model.
  - Ignore other effects (pyrolysis, losses, etc.)
  - Conductor is isothermal.

$$C^* = \frac{(\rho c_p L)_{cond}}{(\rho c_p L)_{insul}}$$

- Ignition prediction unchanged for:
  - Small/Thin Conductor
  - High normalized heat flux.
- Conductor augments curve if:
  - C*>0.1, Low flux, & long exposure

$$\boldsymbol{Q^* = \frac{aQ''}{\rho c_p L}}$$



$$\boldsymbol{q^* = \frac{a q''_{peak} L}{k}}$$

Recent References

- Brown, A.L., Engerer, J.D., Christian, J.M., and Tanbakuchi, A., "NW Fire Material Effects Solar Furnace Phase 1 Test Results Report," SAND 2017-9869, OUO, September 2017
- Engerer, J.D., Brown, A.L., Christian, J.M., "Mass-loss measurements on solid materials after pulsed radiant heating at high heat flux," Paper 2FI-0319, 10th US National Combustion Meeting, College Park MD, USA, 2017.
- Brown, A.L., Engerer, J.D., Ricks, A.J., and Christian, J.M., "Scale Dependence of Material Response at Extreme Incident Radiative Heat Flux," The 2018 ASME/AIAA Joint Thermophysics and Heat Transfer Conference, Atlanta, Georgia, June 25-29, 2018. SAND2018-5209C.
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- J.D. Engerer, Brown, A.L., "Pyrolysis under Extreme Heat Flux Characterized by Mass Loss and Three-Dimensional Scans," 4th Thermal and Fluids Engineering Conference (TFEC) April 14–17, 2019 Las Vegas, NV, USA. (SAND 2018-11381C)
- Brown, A.L., Engerer, J.D., Ricks, A.J., and Christian, J.M., (2019) "Ignition from High Heat Flux for Flat Versus Complex Geometry", 9th Symposium on Fire and Explosions Hazards, April 21-26, St. Petersburg, Russia, pp. 970-979. (SAND2018-10277C).

Majority of Historical Data

Martin's Test Apparatus

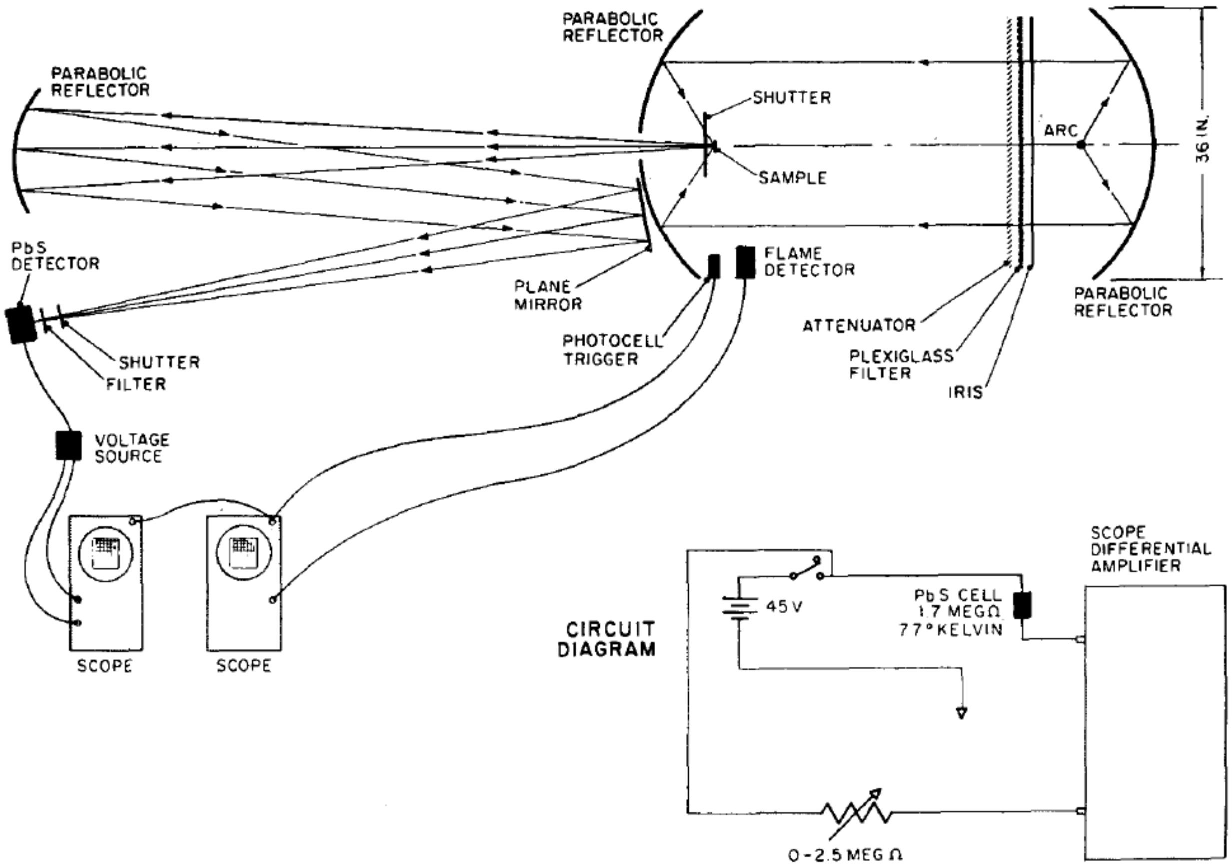

FIG. 4. Apparatus for the measurement of temperatures of the irradiated surface of cellulose.

Martin S.B., Diffusion-controlled ignition of cellulosic materials by intense radiant energy. In Symposium (International) on Combustion 1965 Jan 1 (Vol. 10, No. 1, pp. 877-896). Elsevier.