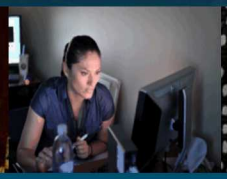
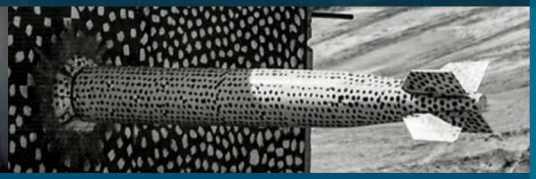
SAND2019-5861C

Reducing Uncertainty in Polyethylene Dosimetry Using Multiple Measurement Techniques





PRESENTED BY

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Presentation Overview

- Background and intended application
- Experimental Setup
- FTIR Analysis of Irradiated Polyethylene Samples
  - Peaks of Interest
  - Time Stability
  - Temperature Stability
- Colorimetric Response of Irradiated Polyethylene
  - Measurement of Discoloration
  - Development of color centers
- Conclusions

Use Case

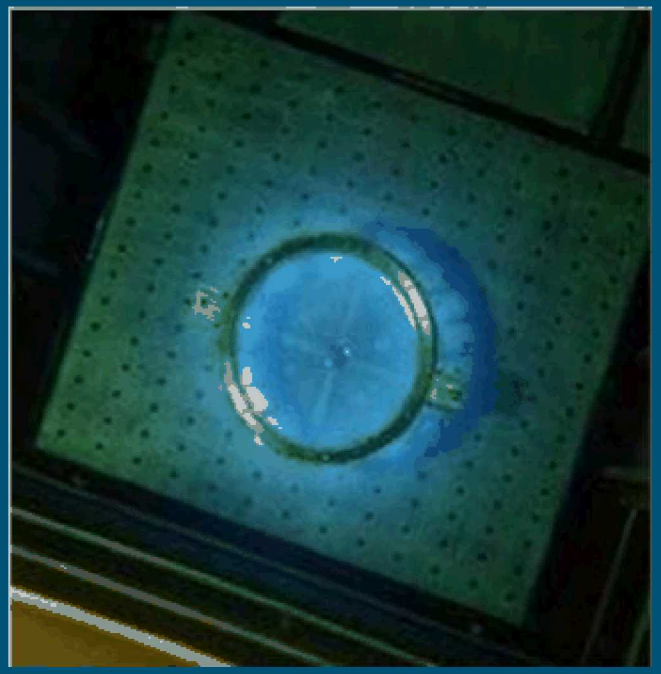
The Radiation Metrology Laboratory provides dosimetry for experiments including, most routinely TLD-400 and less frequently alanine. The upper dose limit on TLD-400 is ~4 kGy

Research efforts into new methods and materials that exhibit measurable response with absorbed dose, such as polytetrafluoroethylene (PTFE) and polyethylene.

Use Case

The Gamma Irradiation Facility houses arrays of intense Co-60 to irradiate experiments in dry cells.

Experimenters are requesting exposures which exceed the upper calibration limits of routine dosimetry and extend may extend for years without any record of the environment in which the experiment occurs. Elevated temperatures and o-zone levels are possibilities.



Desired Dosimeter Properties

Easily obtained, non-hazardous

Passive dosimeter

Higher dynamic range of response than TLD-400

No effects from ambient environment

Good statistical reproducibility

Non-destructive

Historical Polyethylene Dosimetry

The typical application of polyethylene dosimetry has been in electron beam sterilization. The dosimeter itself is frequently tested as a thin film and measured post irradiation using reflectance FTIR.

Reflectance measurements can be highly dependent on the surface quality and thickness of the sample. Reproducibility can be challenging. Unsurprisingly, the literature demonstrates that responses in polyethylene are finicky, which is problematic from a metrology standpoint.

Standard test methods do not address our use case.

Test Methodology

Measure expose positions using ionization chambers and alanine dosimetry where applicable.

Assess dose rate across broad range:

- High Dose Rate: 42.9 Gy/s
- Low Dose Rates: 0.04-1.5 Gy/s

Irradiate under inert atmosphere to assess chemical damage effects.

Monitor temperature and anneal samples post irradiation to assess stability of radiation damage both with and without heat.

Perform irradiations with 4 samples/dose point

Bruker VERTEX 70 FTIR Spectrometer

Thick Polyethylene Dosimeter

The dosimeters consisted of high density polyethylene (HDPE) machine-lathed into discs.

They are easily and affordably mass produced.

Test samples were nominally 25 mm dimeter with a thickness of ~3.175 mm.

40 samples were weighed and found to have an average mass of 1.43 g per sample. The standard deviation of the masses was found to be less than 1%.

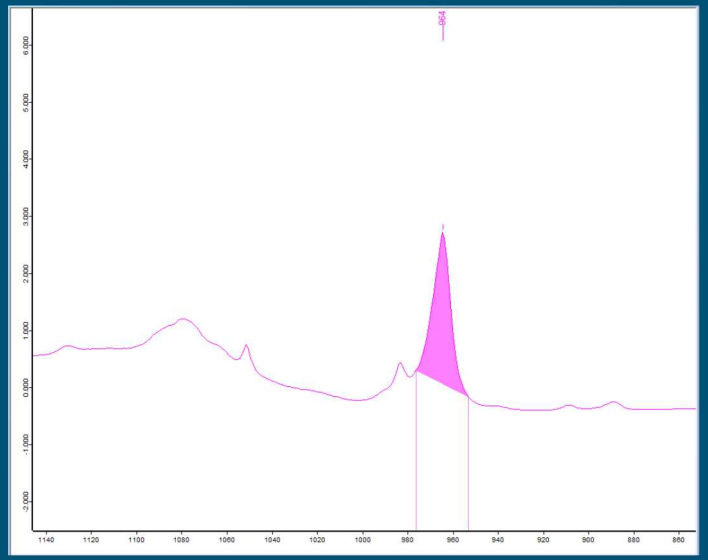
Polyethylene Disks

FTIR Technique

FTIR measurements made in transmission mode, using 64 scans at 2 cm^{-1} resolution.

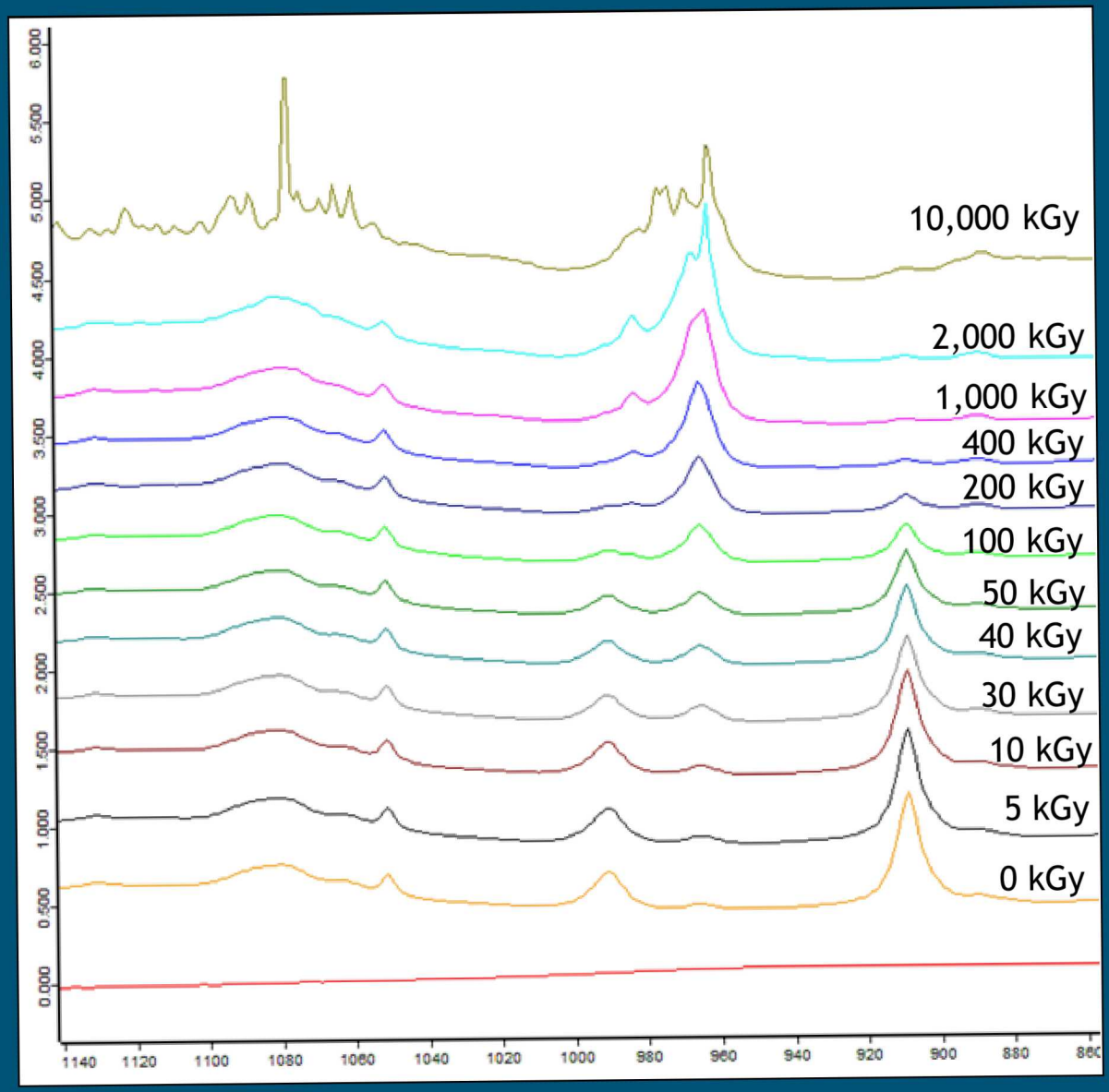
The literature suggested three regions of interest in thinner samples.

Net peak area was the response measured.

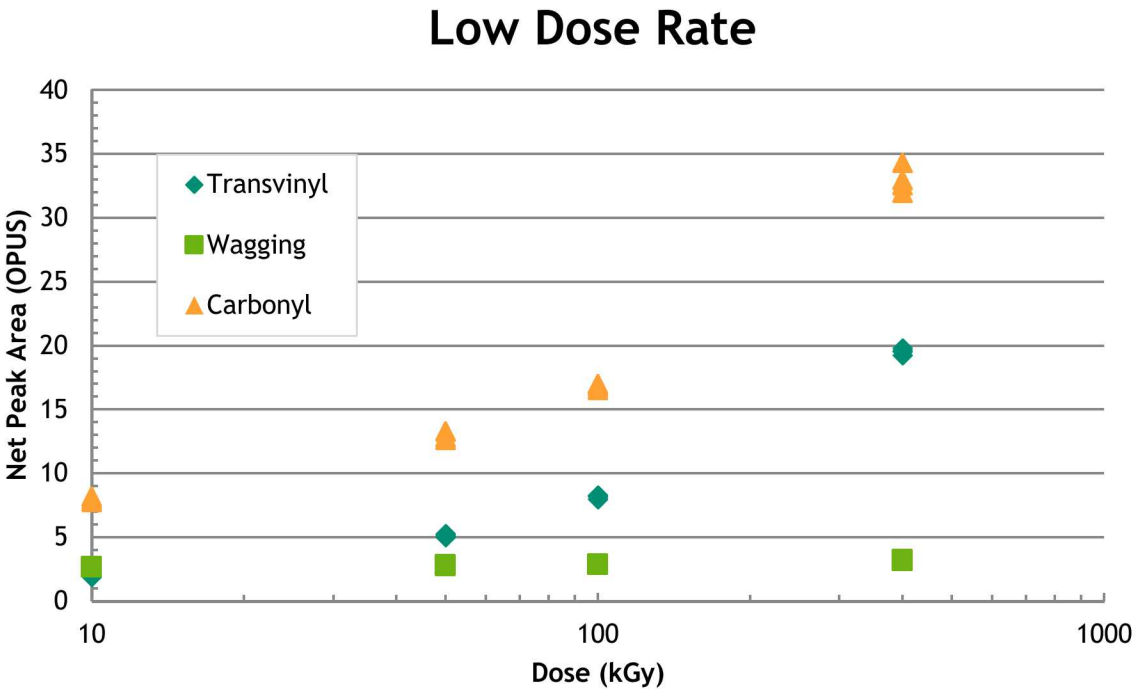


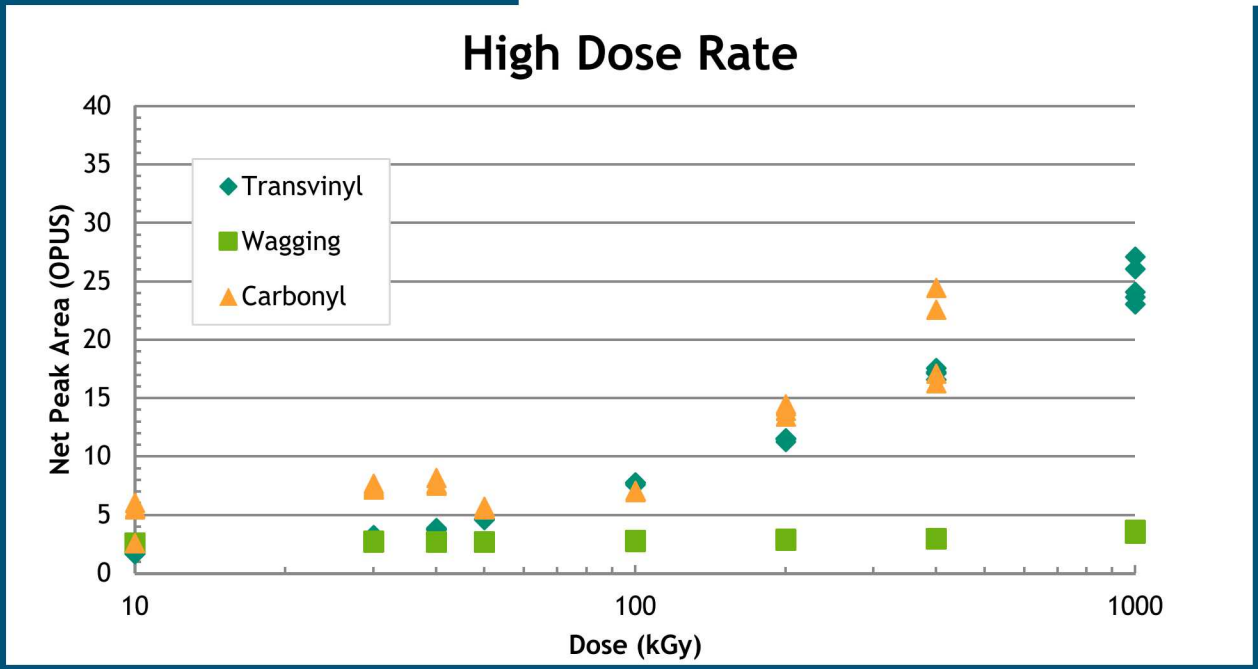
Peak Position (cm^{-1})	Functional Group	Integration Range (cm^{-1})
965	Alkene bend (transvinylene)	954.23 – 975.75
1173	Carbon-Hydrogen wag	1162.22 – 1193.21
1716	Carbonyl stretch	1683.51 – 1734.82

FTIR Transmission Spectra of Irradiated Thick Polyethylene Discs

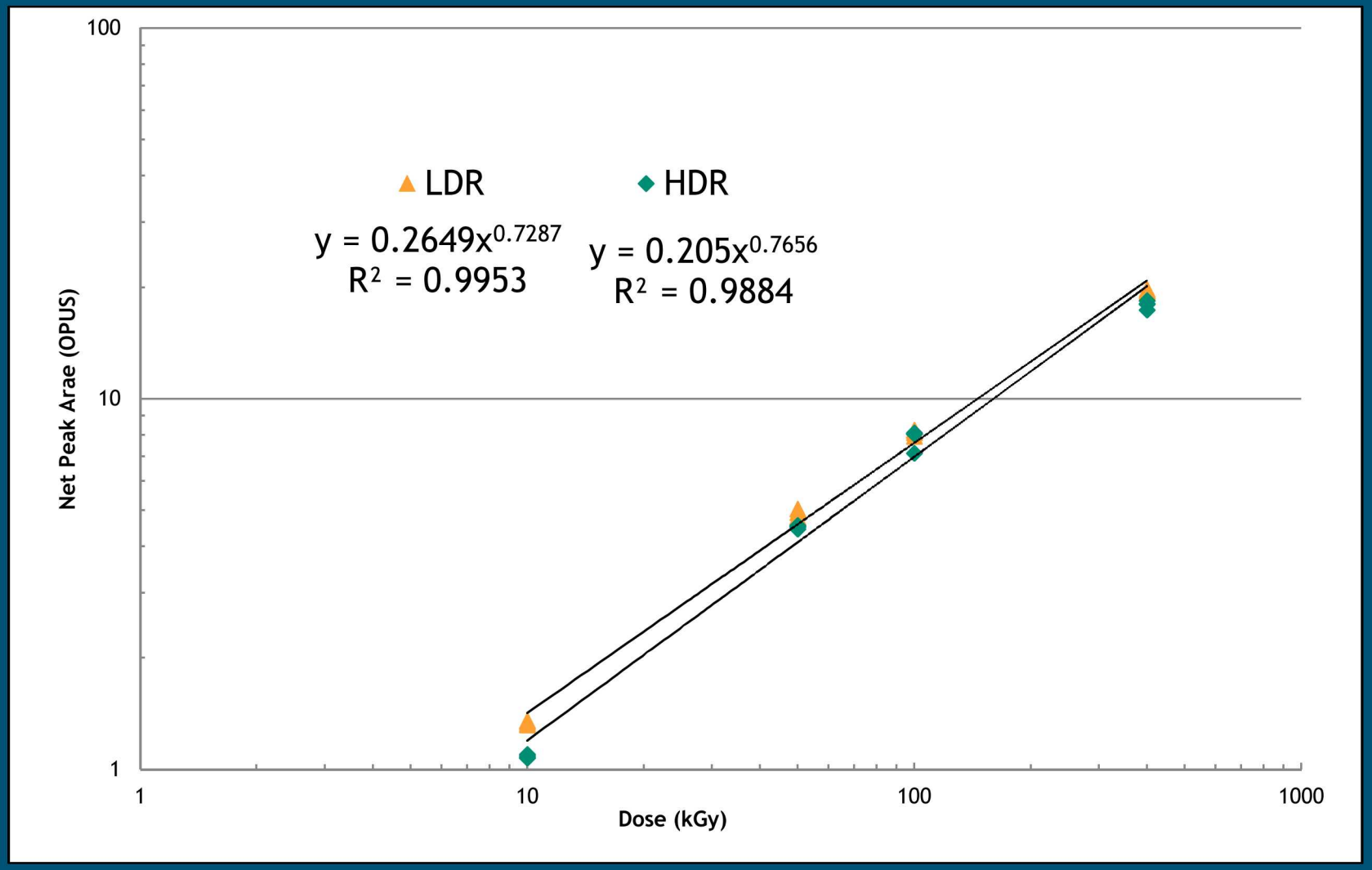


Dose Rate Effects

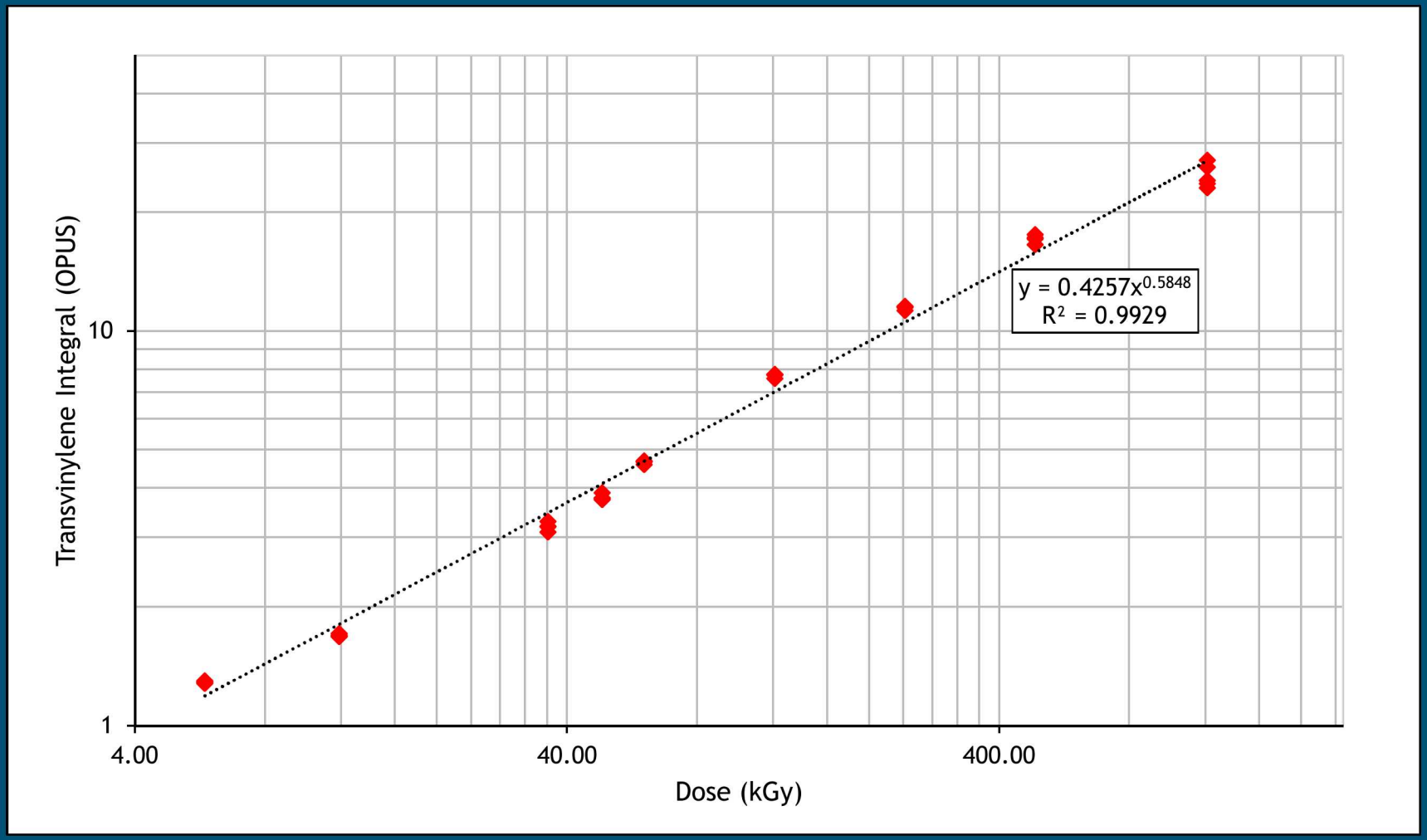




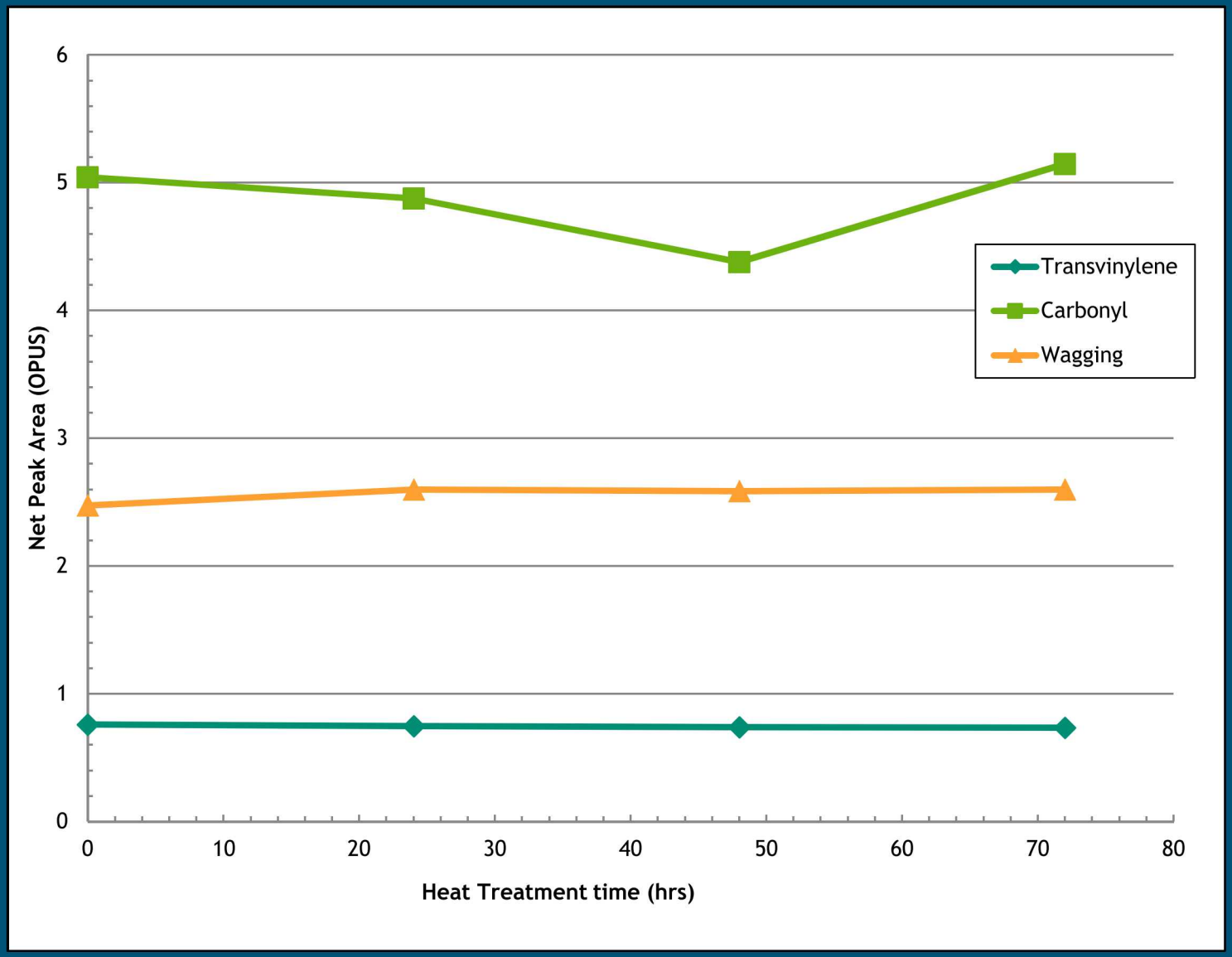
Transvinylene Dose Rate Effect



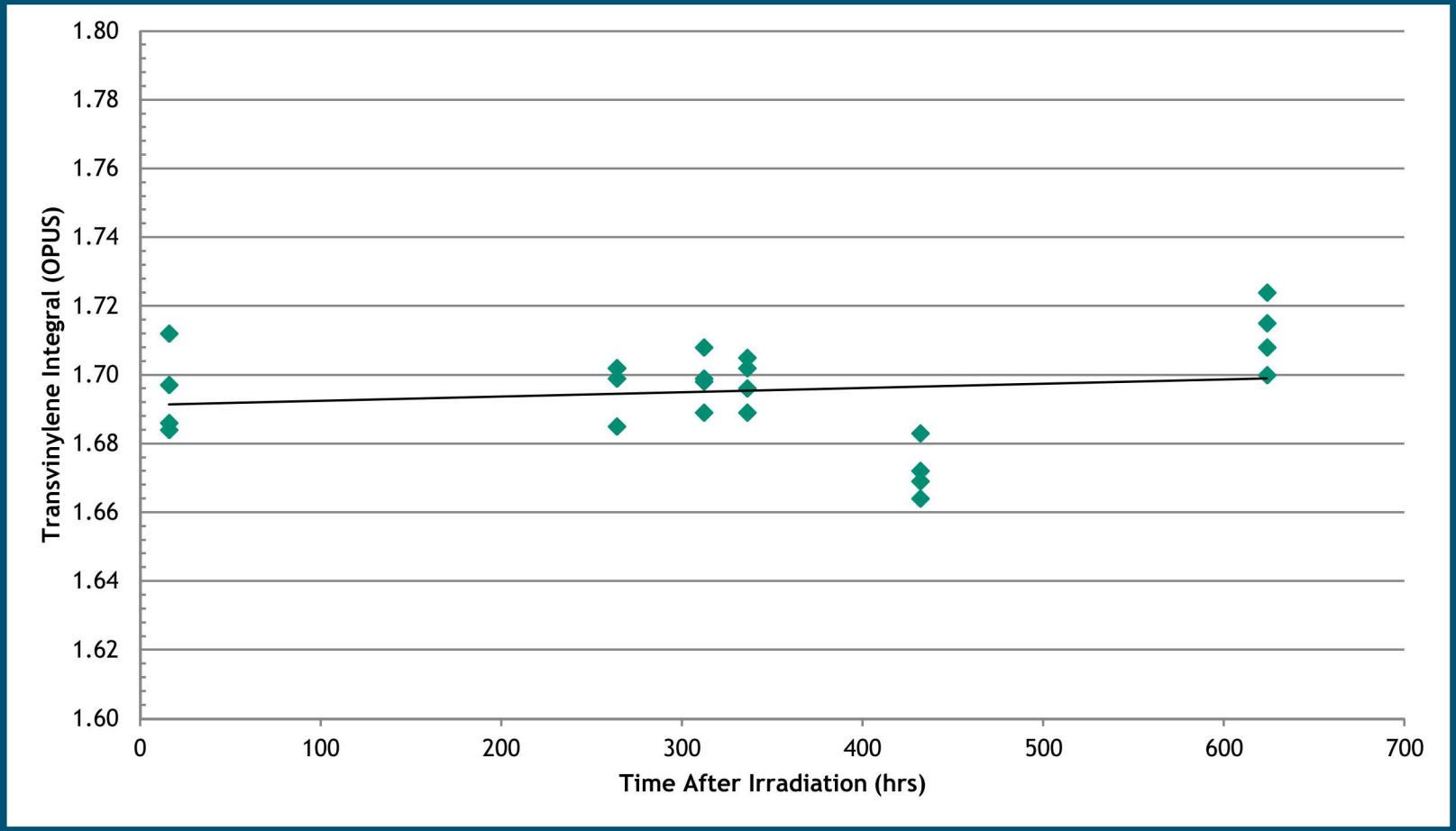
Transvinylene Dose Response



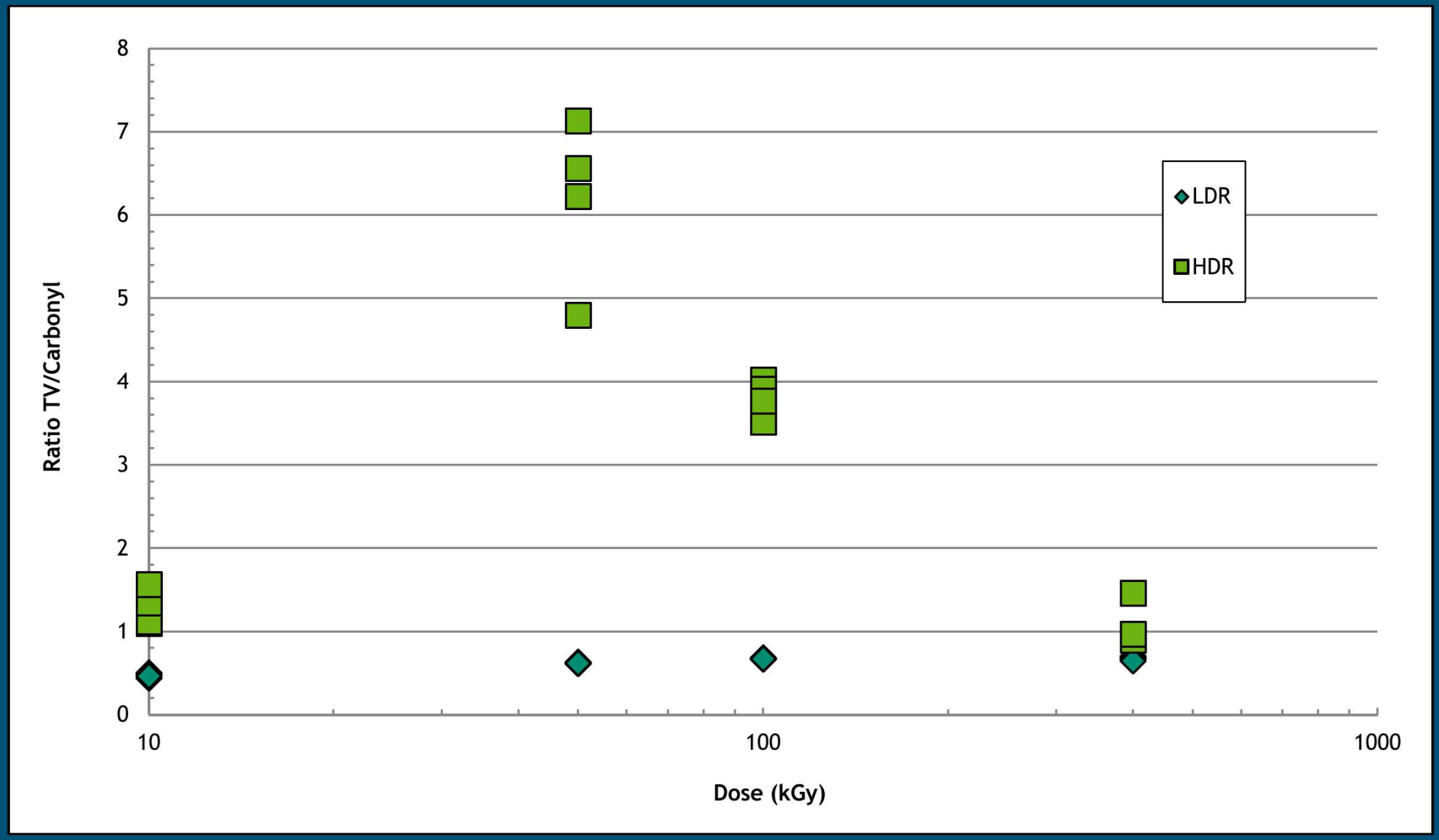
FTIR Peak Stability with Heat Treatment



Transvinylene Peak Stability with Time



Transvinylene to Carbonyl Ratio as a Function of Dose Rate



Feynman's Rainbow

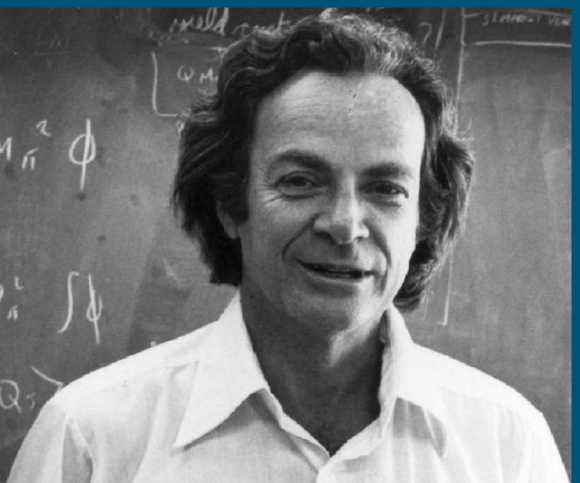
And what do you think was the salient feature of the rainbow that inspired Descartes' mathematical analysis?

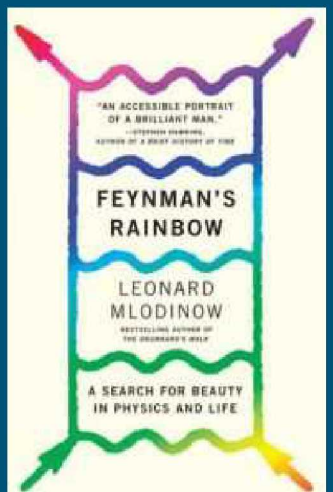
Well, the rainbow is actually a section of a cone that appears as an arc of the colors of the spectrum when drops of water are illuminated by sunlight behind the observer. I suppose his inspiration was the realization that the problem could be analyzed by considering a single drop, and the geometry of the situation.

You're overlooking a key feature of the phenomenon.

Okay, I give up. What would you say inspired his theory?

I would say his inspiration was that he thought rainbows were beautiful.



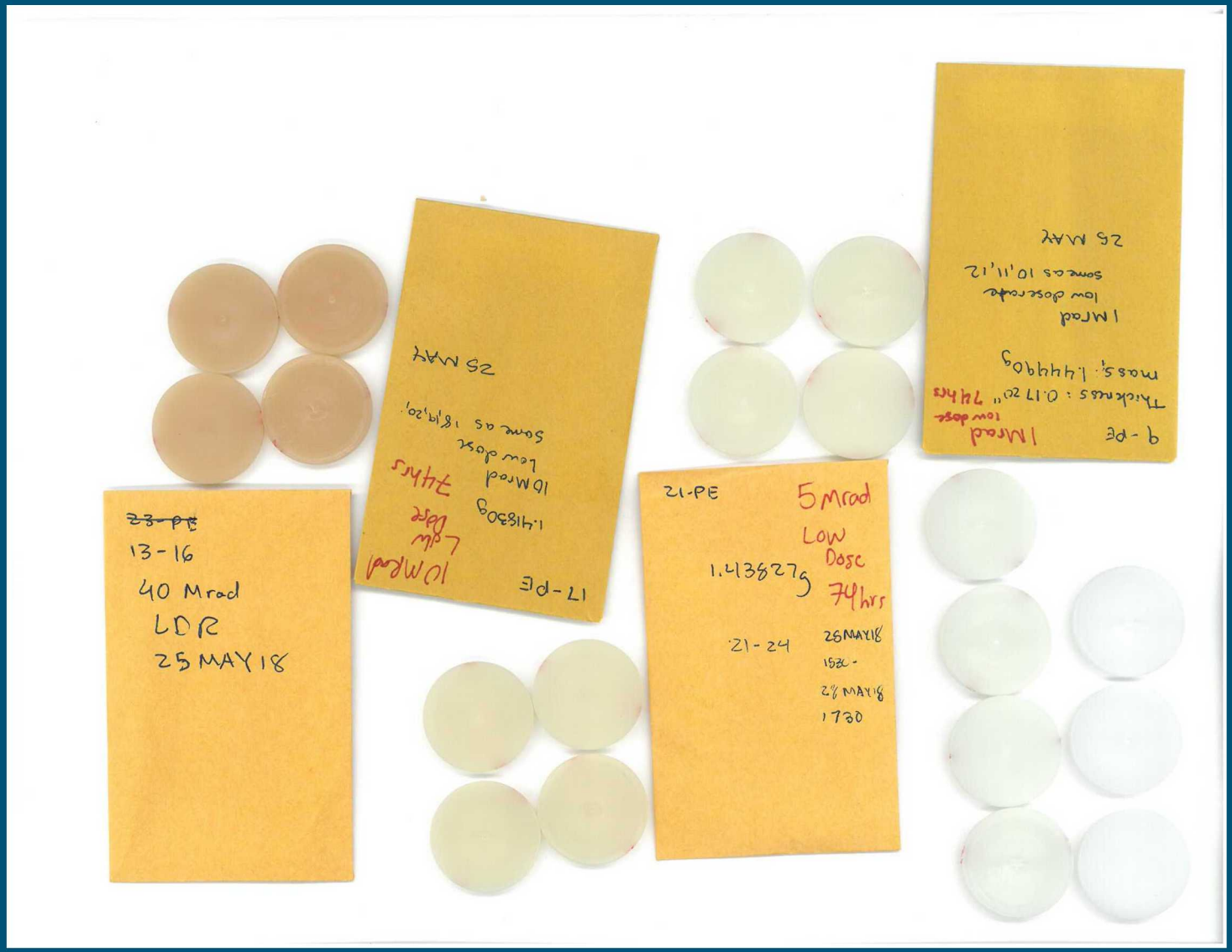


"Salient" Colorimetric Response

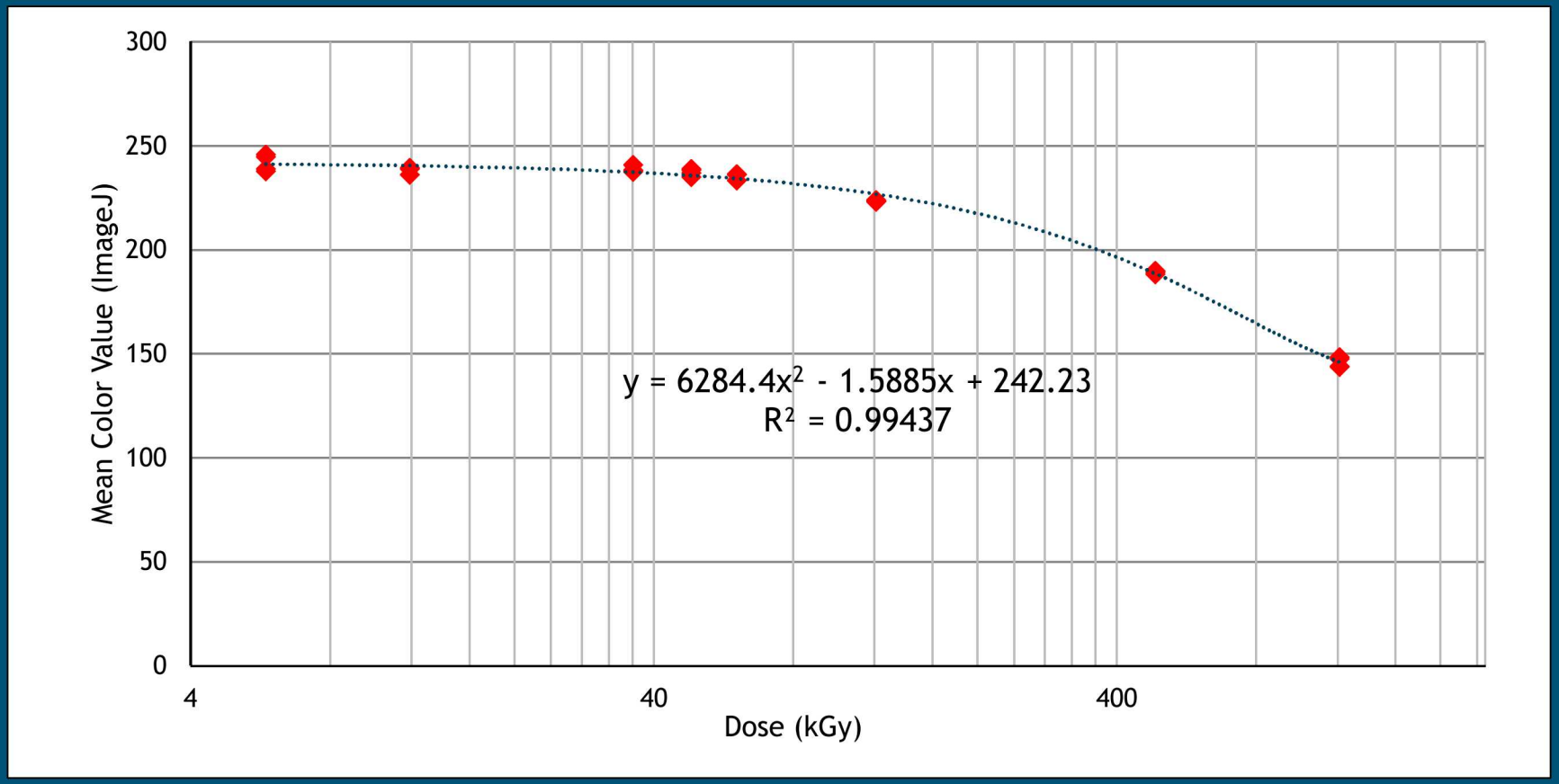
5 kGy 10 kGy 30 kGy 40 kGy 50 kGy

100 kGy 400 kGy 1,000 kGy 2,000 kGy 10,000 kGy

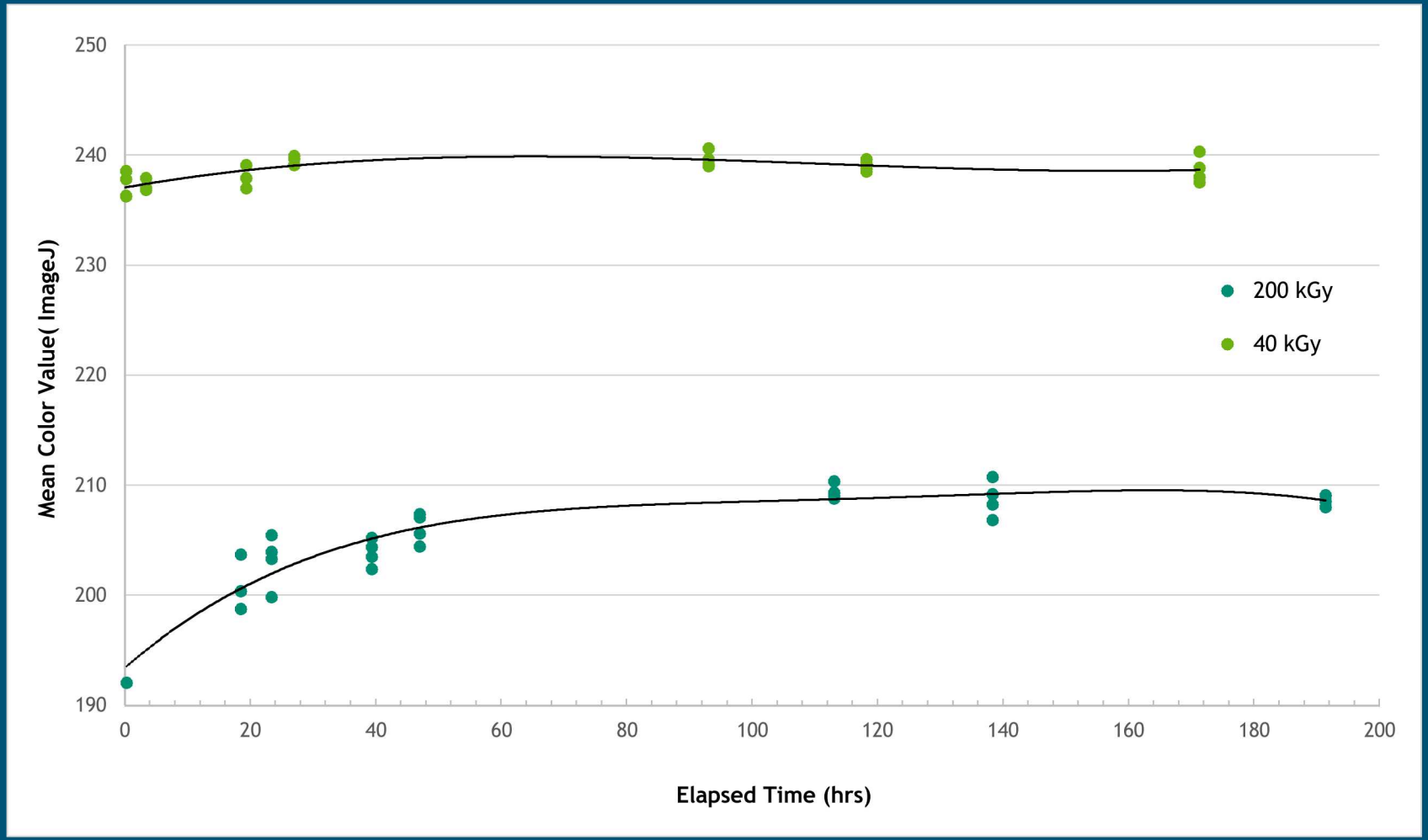
Colorimetric Measurements



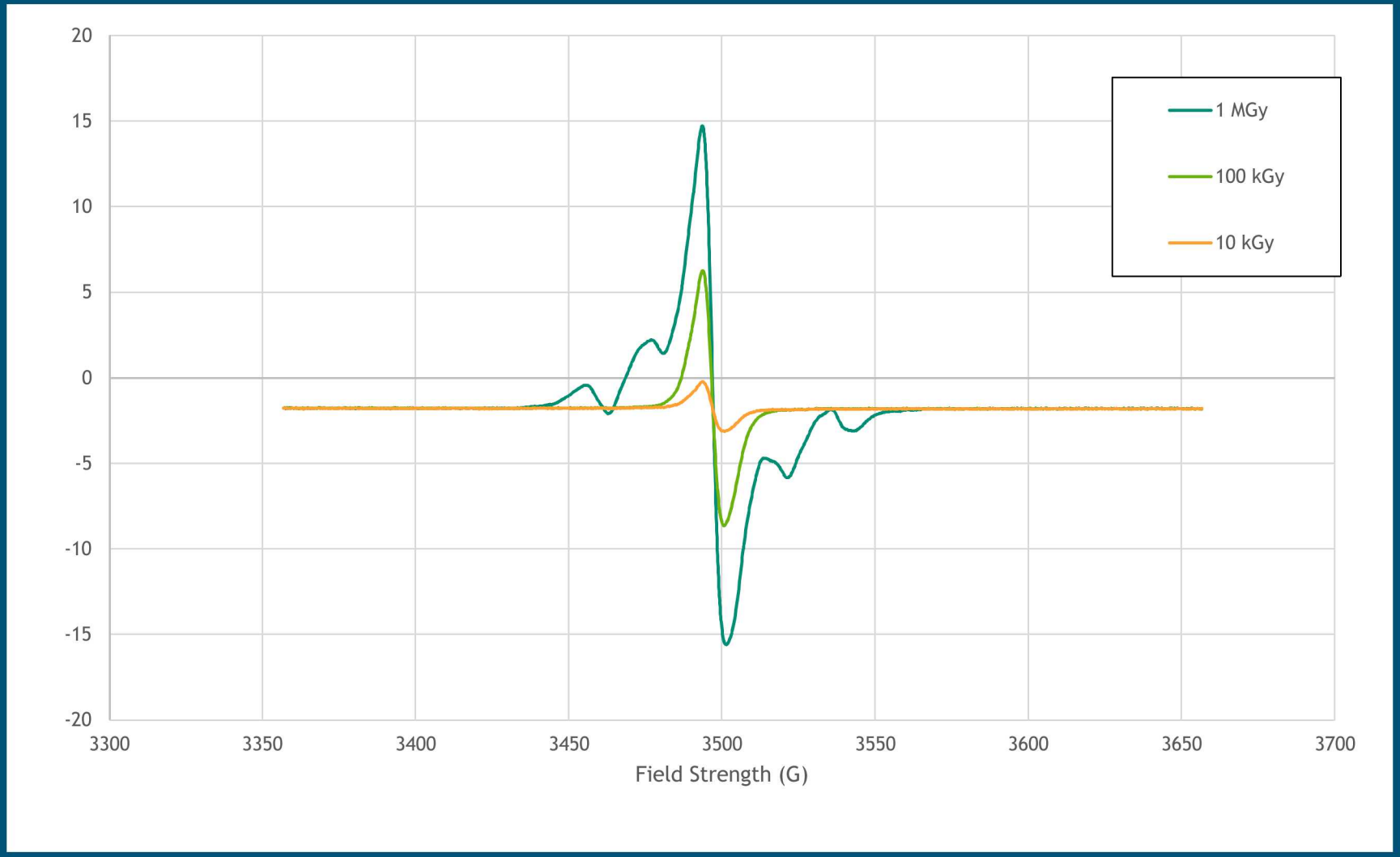
Colorimetric Response with Dose



Color Development



EPR Response in Irradiated Polyethlyene (preliminary)



Questions/Comments?