Radiation Litmus Paper

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Project Goals:

1) Improve detection limits of chemical-based radiation measurements
2) Incorporate these reactions into a generally useable form

- Adjustable Sensitivity
- Lightweight and Portable - Similar to a TLD
- No Power/Cooling Requirements
- Require Little/No Training
- Inexpensive
- Extended Shelf-Life

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Detect Radiation by a Color Change

Potential Uses:

- "First Responder" Badge
- Personal Dosimetry

10 mR	50 mR	100 mR

Before Exposure

10 mR	50 mR	100 mR

After Exposure

- Form and Use Similar to Other Detection Equipment

Anachemia M256A1 Chemical Test Kit

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Background Numbers: ***How Little Can You See ?***

A person can see a 2% change in color

Assume a good colorant (ε=50,000), 1 cm path length, 1 cc volume

$\text{Log}\ (I_o/I) = \varepsilon \times \text{path length} \times [\text{colorant}]$

$\text{Log}\ (100/98) = .009 = 50{,}000 \times 1 \times [\text{colorant}]$

$[\text{colorant}] = 1.7\text{x}10^{-7}$ moles/liter

$= 1.7\text{x}10^{-10}$ moles/mL

$= 10^{14}$ molecules

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Background Numbers: ***Chemical Reactions from Radiation***

Radiation produces ion or radical pairs

G = reactions / 100 eV

Commonly G=3 for gasses, liquids (G=30 for solids)

For a 100 keV $h\nu$: 10^5 eV x 3 rxns/100 eV = 3,000 rxns/$h\nu$

For a $^{10}B(n,\alpha)\,^{7}Li$ reaction: 2.4 MeV x 3 rxns/100 eV = 72,000 rxns/n

Radiation can produce ~10^3-10^5 reactions per interaction

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Historical Problems with Colorimetric Detection: Sensitivity

- Radiation ionizes materials: ~10^3 (γ) to 10^5 (n_{th}) molecules per event
- Common chain reactions give a 10-100-fold amplification
- A person can see ~10^{14} molecules of a colorant
  - So need 10^7-10^{10} captured events to see

Example: 100 keV γ: Assume a 1 mm thick hydrocarbon detector

= (10^{14} rxns) / (10^3 rxns per γ) x (0.1% capture efficiency)

= 10^{14} $h\nu$ / cm^2 to see = ~5,000 R

Example: Neutrons: Assume a 1 mm thick hydrocarbon detector, 10% ^{10}B

= (10^{14} rxns) / (10^5 rxns per n_{th}) x (30% capture efficiency)

= 10^8 -10^9 n_{th} / cm^2 to see

however, thermal neutrons (n_{th}) = 1% of initial flux (n_f)

so to get 10^8 n_{th}, need initially 10^{10} n_f / cm^2

which is a initial dose of 300-400 rem

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Historical Problems with Colorimetric Detection: Stability

Chain reactions can increase the chemical yield from captured radiation

Common chain reactions include decomposition of halogenated materials (RX), including CCl_4, $CHCl_3$, PVC

RX decomposition can yield acid or oxidizers

Can achieve chain lengths of 10-100 (realistically closer to 10)

Problem: *RX is usually unstable to light and heat*

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Methods to Enhance Signal: Autocatalysis

- **Ionization Creates Catalyst**
- **Product of Catalyzed Reaction is Second Catalyst Molecule**

Issues:

- **Sensitivity vs Stability**
- **Stability to Environment (heat, light)**

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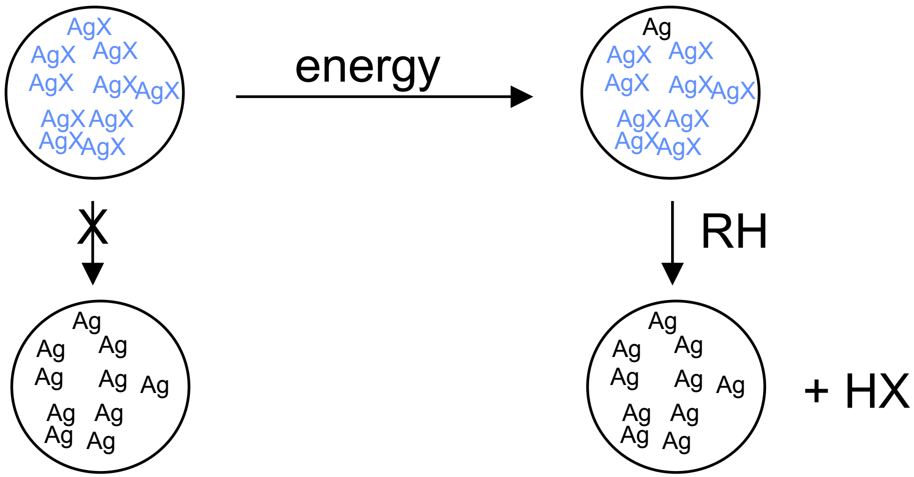
Underlying Chemistry: 10^8-10^{10} *Amplification*

$(AgX)_n$ + RH $\longrightarrow$ no reaction - *device is dormant*

$(AgX)_n$ + radiation $\longrightarrow$ $AgX_{n\text{-}m}\,Ag_m + X_{m/2}$

$(AgX)_{n\text{-}m}\,(Ag)_m$ + nRH $\longrightarrow$ $Ag_n + R_{n\text{-}m} + HX_{n\text{-}m}$

$HX_{n\text{-}m}$ + Indicator $\longrightarrow$ Indicator•HX - *color change*



Need *four* atoms of Ag^0 to activate grain

Typical grains are .25-1 micron diameter = 10^8 - 10^{10} atoms Ag/grain

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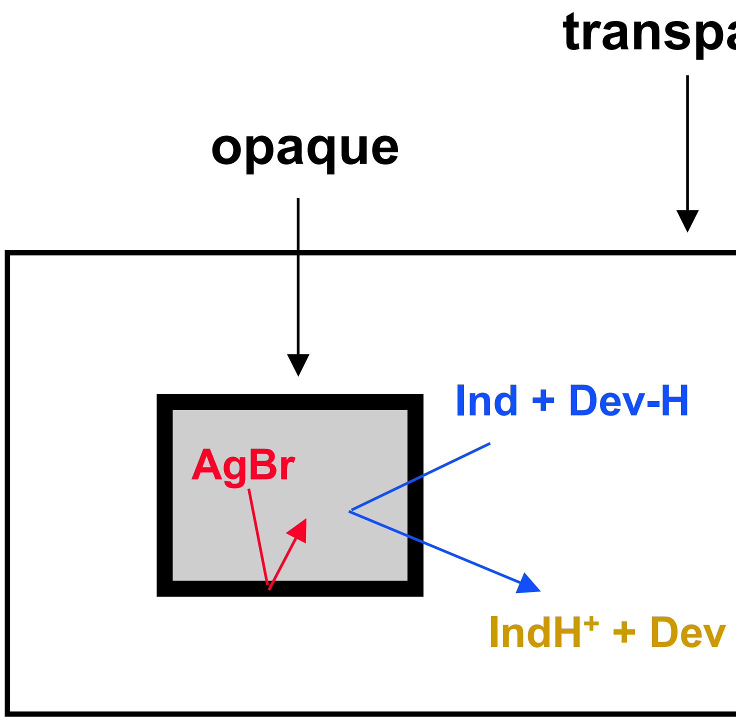
General Schematic Drawing



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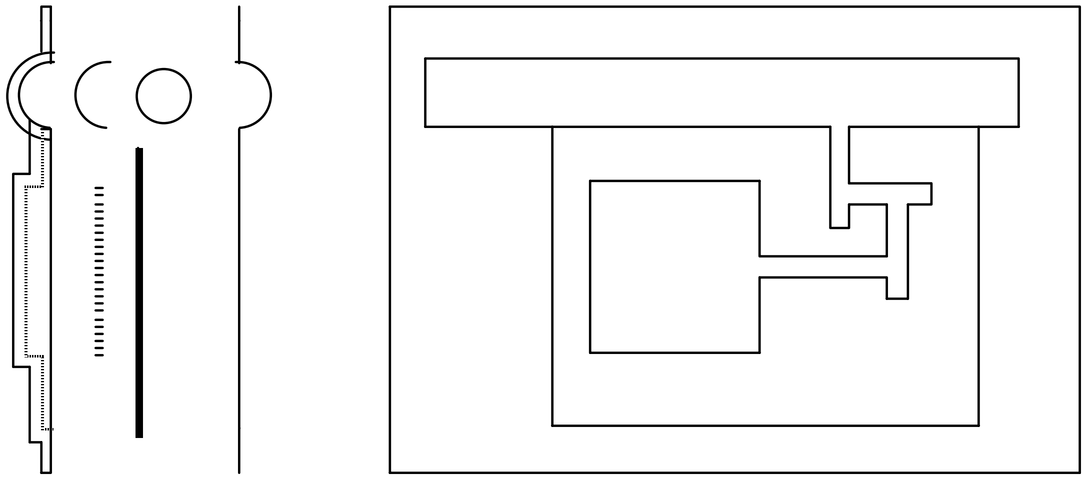
Schematic:



Fieldable form of Radiation Litmus Paper

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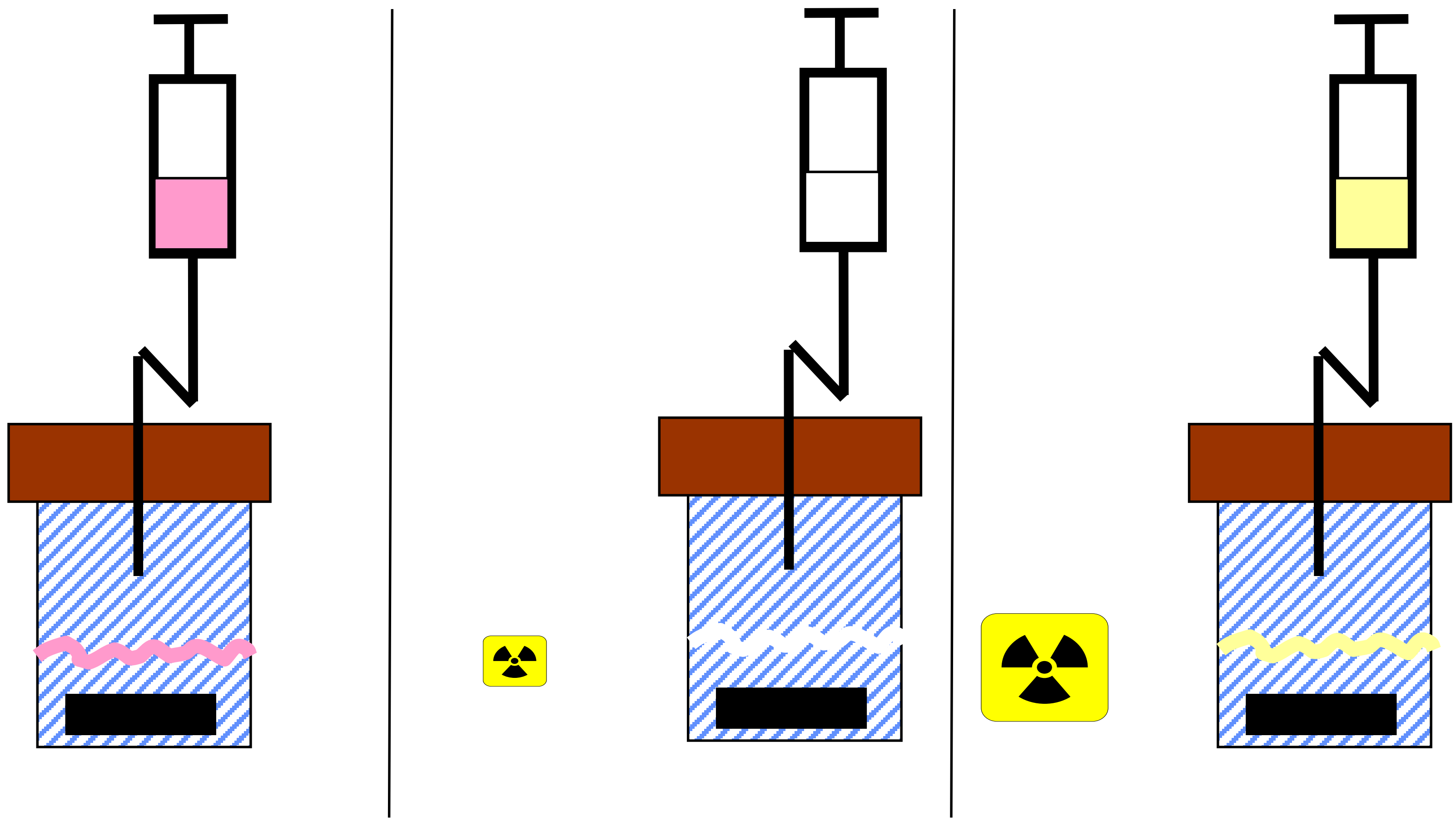
Prototype For Testing Chemistry:



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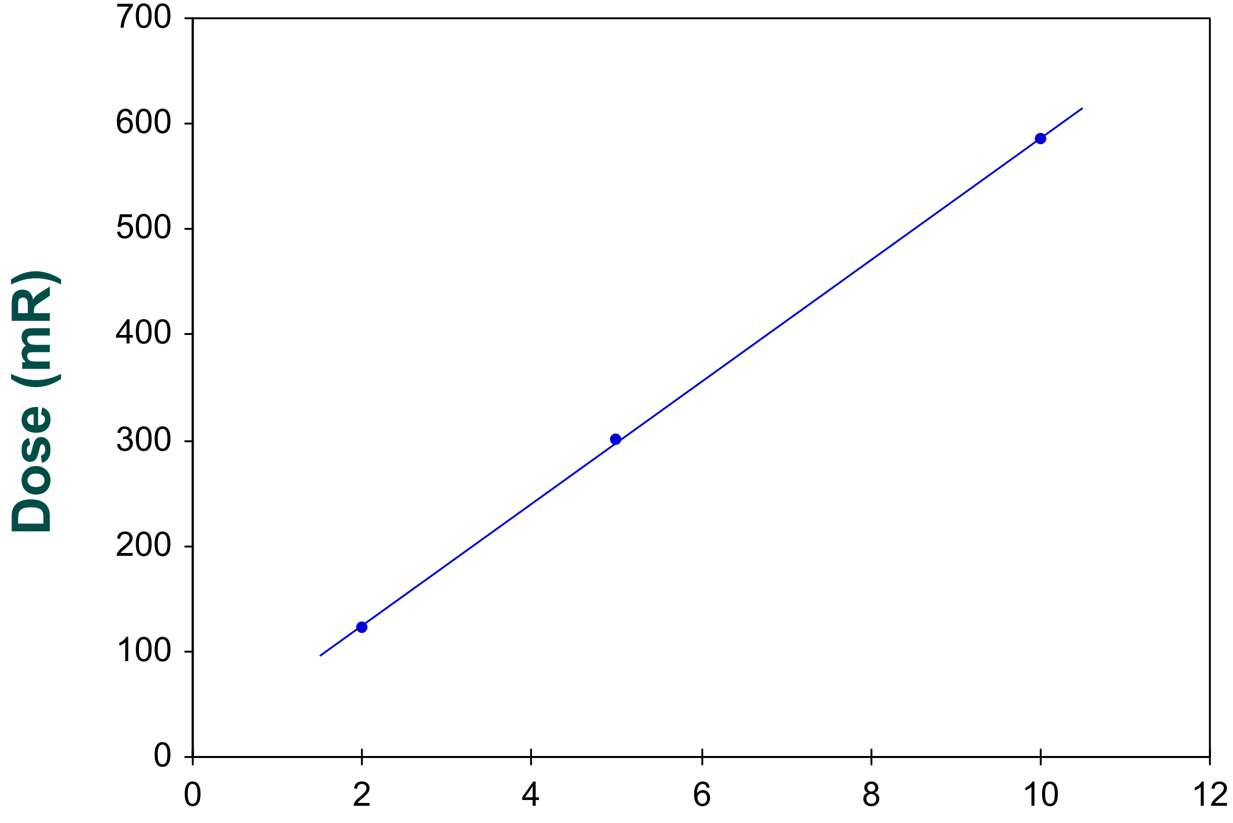
Sensitivity vs Volume of Indicator Phase



Volume of Indicator Phase (mL)

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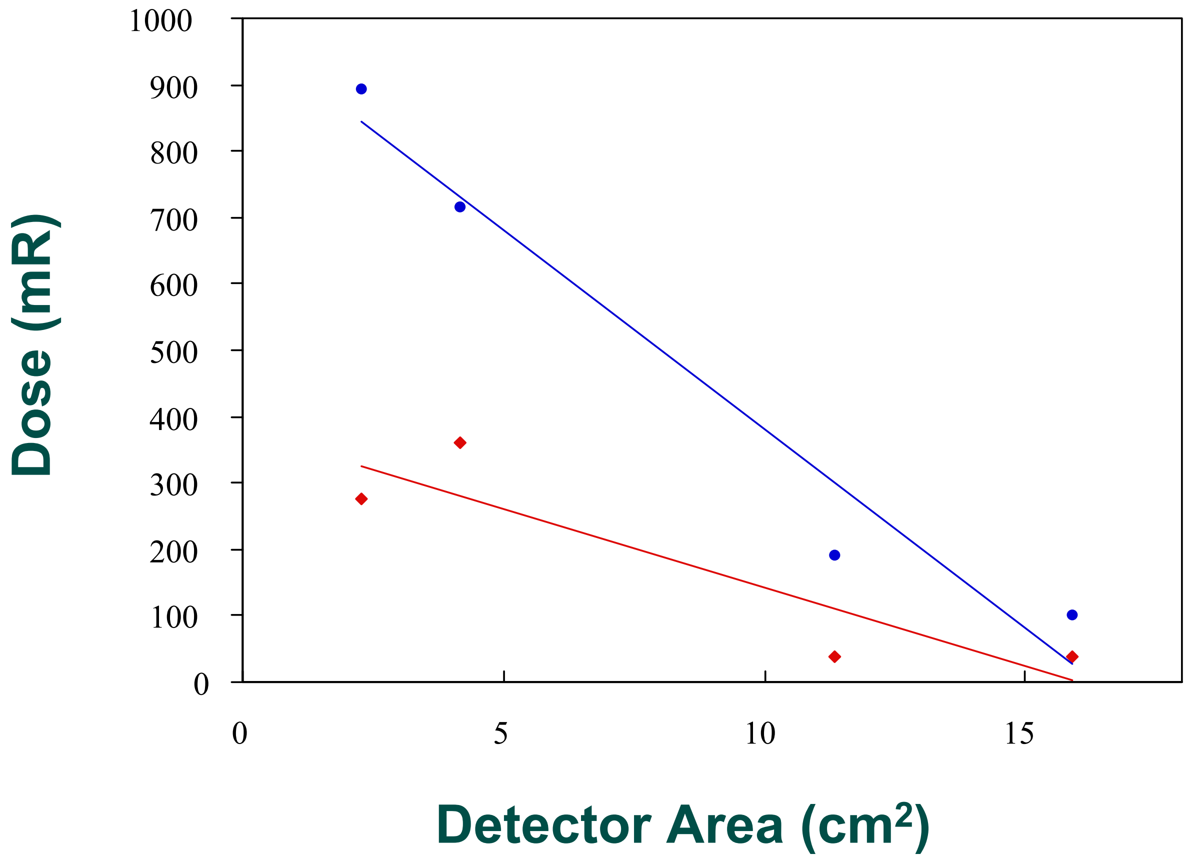
Sensitivity vs Detector Area



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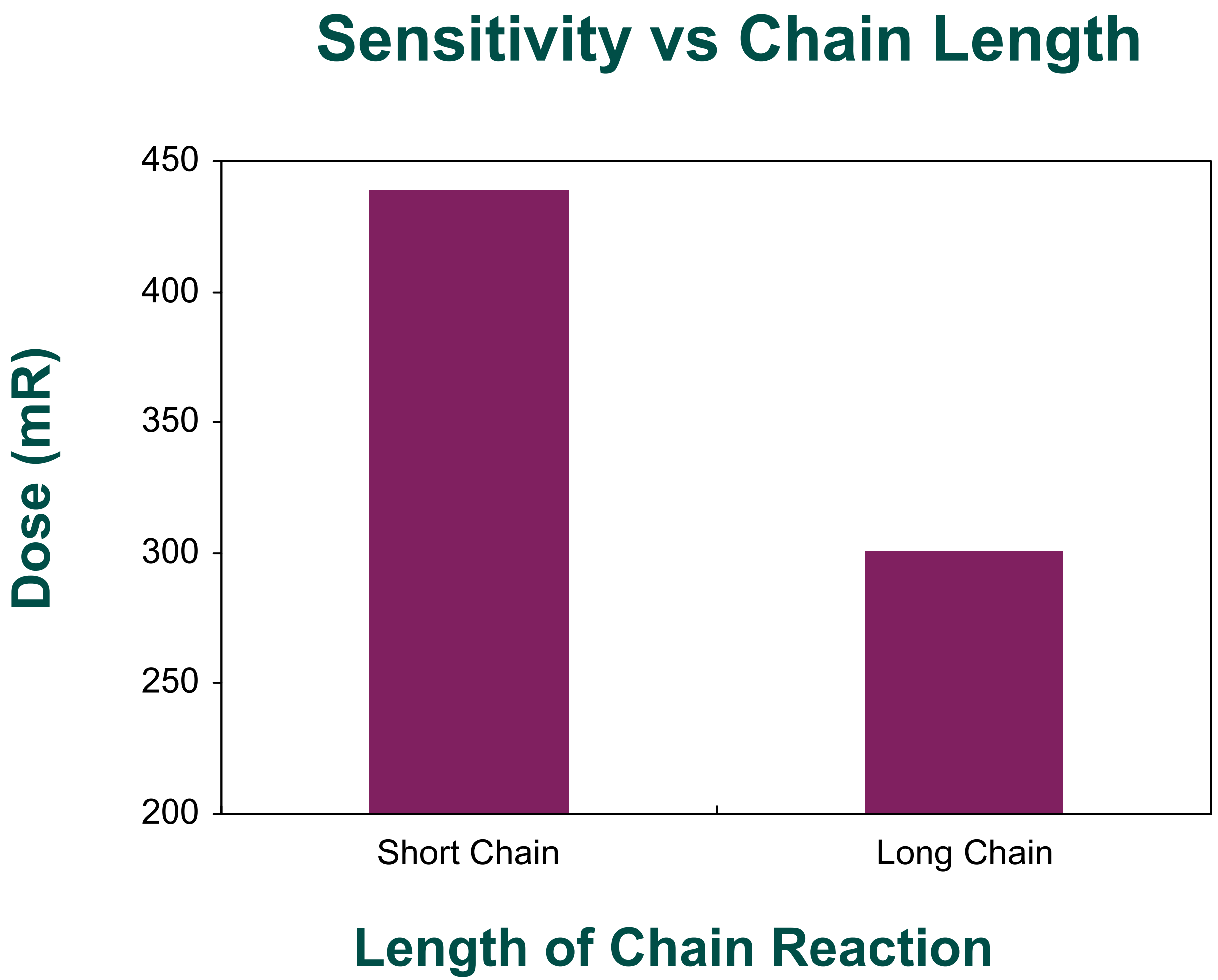

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Features:

Useful Lifetime of Material: Devices function for 8-36 hours

Material Form: Liquid and gel developers

Color Choice: Dark {blue, purple, red} to yellow, or red to blue

Multi-Component System Allows Tuning

Easy to Synthesize

Relatively Stable

Long Shelf Life

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Current Performance:

- Adjustable Sensitivity - 17 to 2000 mR
- Easy to Make and Use
- Small - 17 mR Device ~ 2 cm^3
- Threshold or Continuous Dosimeter
- Inexpensive - Chemicals < $1
- Calibrated for ^{137}Cs γ-Radiation
- Sensitive to β, neutron

Future Work:

- Enhance Color Change Range
- Mass Produce for Field Test

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