Small Field Dosimetry & Radiochromic film

Michael Kissick, Ph.D., Assistant Professor, Medical Physics & Human Oncology & Affiliated with the Morgridge Institute for Research

North Central AAPM Chapter Symposium, 10/10/2013
I have no potential conflicts of interest.
Outline and Thesis/Objectives:

I. Small Field Dosimetry – review
II. Radiochromic film (RCF) in general – overview
III. QC/QA for high dose hypofractionated radiotherapy – A few concerns*, many other reasons not to be concerned.
IV. Conclusions – this film will continue to be useful

Learning Objectives:

I. Radiochromic film is fascinating. The topochemical process involved is special in chemistry, and very useful in dosimetry after the vendor has spent decades perfecting it for our use.
II. The QC/QA of the future will likely use this film even more than it is used now, because of hypofractionation and the need for anthropomorphic phantoms with high dose gradients for small fields. Some concerns I have … mostly, RCF is an excellent choice.

I will assume most of you know the basic positives/negatives of RCF.
What is a small field?

According to Alfonso et al. [1] 2008, page 5180, first paragraph:

“A small field is defined as a field with a size smaller than the lateral range of charged particles.”


Loss of charged particle equilibrium for the small field \( \rightarrow \) We need a dosimeter with resolution better than the range of the average charged particle: **FILM IS SUCH A DOSIMETER!**

If charged particle equilibrium:

\[
Dose \propto K_c \propto \mu_{en} \propto T
\]

If no charged particle equilibrium:

Then we are sensitive to unknown aspects of the charged particle spectrum.
RCF does not have the same small field issues that ion chambers have – it does not have an air filled cavity.

1. If one attempts to make a small ion chamber for resolution, and the media are not perfectly matched, then delta-ray equilibrium can be a problem.b

2. Photon energy determines everything, but the proportionality of a ratio of readings to a ratio of absorbed dose is generally robust to the photon spectrum.a

3. This is because it is well-known that ratios of stopping powers are robust to the charged particle energy spectrum.b However, we really need charge particle equilibrium for this.

4. Because RCF is not a gas, the energy dependence resulting from a density effect mismatch is not a concern.

5. It is the tissue equivalence of this film that is a major help for us.


RCF has the spatial resolution needed, and it does not itself change equilibrium.  
(It is tissue equivalent also)

**4 mm** beamlet From:


So, we can image the penumbra from lateral electron motion.
In the context of radiotherapy’s future, small fields pose the following challenges for dosimetry*:

1. Some innovative machines with small fields **CANNOT provide the standard reference field conditions**, i.e., they cannot provide the 10 cm X 10 cm uniform field at 100 cm distance. This is true of helical tomotherapy and the Cyberknife™.

2. Also, there is **no standard for composite fields**, i.e., helical tomotherapy inherently provides dose with composite fields.

3. **For RCF, for composite fields, an issue for me concerns repeated applications of dose – new polymerizations applied on top of previous polymerizations – Note: we have seen fractionation effects, confirmed by David Lewis.**

How does RCF work? It is made up of special crystals: LiPCDA.

Polydiacetylenes in hair-like crystals:

From David Lewis talk, Oct. 20, 2010
The crystals are made up of stacks of monomers that *polymerize in place*:

*topochemical phase change, remarkable!*

H. Gross et al., Chem. Phys. Lett. 95 (1983), p. 584
The polymerization process is inherently nonlinear: the activation energy barrier could respond to local strain for example:

These barriers could change size as the fraction polymerized changes – understudied!

Polydiacetylenes, Editor: Hans-Joachim Cantow, Springer-Verlag, ‘84
Some complications ... known for a long time ... Not perfectly topochemical – strain develops!

Notice the strain this causes!

And rotational strain too:

Both can cause OD Changes!

From: R.W. Carpick et al., Langmuir 16 (2000), page 4639
This local strain, if different from the surrounding crystal, could cause OD changes at low dose ...
There are also temperature phase changes due to the hydrogen bonding to the substrates:


We saw even more worrisome issues: fractionation effects! – scanner or film?


**HS film**

Biggest issues for small doses atop big doses!
David Lewis made me aware of the issue that the field flatness depends on density in the Epson 10000XL flatbed scanner:

![Graph showing normalized pixel value vs. pixel]

Note: I avoided the issue by using small pieces of film here! – benefit for small fields and RCF!

From David Lewis talk, Oct. 20, 2010 … he claims this is due to polarization of light through film!
Now with EBT2,3, there are dyes:

Film looks yellow - red/yellow is NOT absorbed when film UNexposed, but blue is always absorbed. Film looks green - red/yellow and blue BOTH absorbed - leaving only green to get through when exposed.

But, we have seen the scanner Behave oddly for one channel, But not another! McCaw *et al* Med. Phys. 38 (2010) 5771-7
The UW ADCL has developed (Ben Rosen) a new scanning laser densitometer system (LDS)* that eliminates many scanner issues!

From: Ben Rosen talk at the AAPM 55th Annual Meeting
Scientific: Therapy: Dosimetry, Patient Safety and QA Procedures:
Calibration WE-E-141-3
8/7/2013 2:00-3:50 pm

{Would be good to have dual energy, but the laser is adjustable in frequency}

* This will be patented by WARF
I have used RCF in anthropomorphic phantoms to explore interplay for helical tomotherapy: need film for this (small wiggles)!


The Phantoms of Medical and Health Physics, L. DeWerd & Michael Kissick Ed. Springer, 2013
Of great concern to me about the use of film for DQA… can it be used to match DVH type metrics?

- We have to be careful about how we use film for QC/QA on 3D volumes sampled with 2D dosimetry (film).

There is good reason to drop the use of ‘gamma’ as a useful metric for patient-specific QA!


Only this case showed correlations Between DVH based and gamma based Metrics, and it was weak.
In the end, I like this film! It is improving!

1. Gafchromatic film is only made by one vendor.
2. It was invented by David Lewis.
3. It was first used for an image in 1984 for an electron beam recorder.
4. The film activates at about $10^{-3} \text{ J/cm}^2$ versus.
5. Silver halide film activates at $10^{-10} - 10^{-8} \text{ J/cm}^2$.
6. The new yellow dye for EBT2,3 is brilliant!

### Pros

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>high dose capable so competes with EDR film (which has lots of high Z)</td>
</tr>
<tr>
<td>b.</td>
<td>great spatial resolution because its film</td>
</tr>
<tr>
<td>c.</td>
<td>tissue equivalent</td>
</tr>
<tr>
<td>d.</td>
<td>develops itself (solid state polymerization ‘in place’ (topochemical))</td>
</tr>
<tr>
<td>e.</td>
<td>not very sensitive to visible light, but it is to UV like from sun</td>
</tr>
<tr>
<td>f.</td>
<td>now it is mainly energy independent to a large degree</td>
</tr>
</tbody>
</table>

### Cons

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>sensitivity varies with temperature, UV, (and low dose, fractionation issues).</td>
</tr>
<tr>
<td>b.</td>
<td>polarized densitometer light affects OD reading (but EBT model improving this)</td>
</tr>
<tr>
<td>c.</td>
<td>developing takes ~ days, but “saturates” at ~ weeks really: [initial phase = starts &lt; 100 µsec, slow phase = days - weeks, ~log(time)]</td>
</tr>
<tr>
<td>d.</td>
<td>An issue is the nonlinearity at low doses (10% of maximum): seems to be fraction dependent!</td>
</tr>
<tr>
<td>e.</td>
<td>needs to be handled very consistently</td>
</tr>
<tr>
<td>f.</td>
<td>orientation and position dependencies on most scanners - scanners are a big issue!</td>
</tr>
</tbody>
</table>
I am on the new TG-235, representing the UW ADCL.

(I am writing the QA for Tomotherapy and Cyberknife, and MV IGRT QA parts.)
Conclusions:

1. The diacytelene tomochemical phase transition process in radiochromic film is fascinating!

2. There are still unanswered questions from: i. the film, ii. the scanner, and iii. its use for modern QC/QA., i.e., fractionation / composite fields issues.

3. The future appears to be very bright for small field dosimetry with radiochromic film!!