28MAR2014KFJ
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Dear Andris, Jim,

Vasken asked me to comment on the Summary Report so here are some comments. At the end of this note I suggest a design for a generic radhard tile-fiber unit as a discussion aid.

I'll cite from the following sources: The PDG organic scintillator section for a simple explanation of how organic scintillators function; Workshop on Radiation hardness of Plastic Scintillator, (“RADDAM '90”, March 1990, which I'll attach as a pdf file); International Conference on Radiation-Tolerant Plastic Scintillators and Detectors, (“RADDAM '92”, April 1992) - hard to find but Vasken has a copy. There are other sources but these are most familiar to me.

The fact that slow raddam can be worse than fast for a given dose has been frustrating scientists for almost half a century. I believe that it was the Brown's Ferry 1975 nuclear power plant fire – at which “rad hard” polymer insulators had slowly turned to dust and ceased to insulate electrical cables - that really made people take notice.

Results reported at RADDAM '90 by Nikos Giokaris on the CDF beam-beam counters and by Clough et al. on SCIFI confirmed prior observations w.r.t. unexpectedly severe damage from slow irradiation. Point 3 of the RADDAM '90 summary is that we urgently need a model which “predicts, from high-rate irradiations, the long-term, low dose-rate behaviour of scintillator”. We haven't made much progress since then – it's really a question of old fashioned chemical kinetics, and funding is difficult to sustain for such non-cutting edge research.

Since then, the fall-back position has become: design for many times the expected dose.

There are some not completely accurate statements in your summary report which I'd like to address. One is the “common wisdom” being that attenuation length degrades before light yield. This depends on the geometry of the detector, how one defines the losses, and will always depend on the compositions of base material and dopants. If the detector has a 16m fiber optical path, then even a very small decrease in attenuation length will dominate detector performance. But if the photodetector is close to the initial light source, then fluor destruction might dominate.

The effect of oxygen on long-term damage is still unclear. There are measurements which seem to show no difference in damage between anoxic and oxygen-available irradiations over timescales of a month, and measurements which indicate the opposite. Comparing figs 7 and 10 (pp. 92 , 93) of the article by Wallace et al, in RADDAM '92, shows that the annealed states of irradiated PS (polystyrene) in vacuum and air are pretty *similar*, but it takes **much** longer to get there for the vacuum annealing. Whitaker et al., p126 ibid, state in their conclusions that oxygen saturated and oxygen depleted PS have permanent absorption changes within 15% of each other after 25 days of room temp recovery. But these were both (relatively) fast irradiations and do not exclude possible as yet unknown slow damage processes.

It is not necessarily the case that “fiber suffers more radiation damage than the scintillator itself”. Both fiber and scintillator usually have the same base material (PS), just different dopings. The fiber usually transports the light a much longer distance than the scintillator, and base transparency loss has more opportunity to do its evil work. The fiber could be less damaged than the scintillator and still show a larger light loss. An example of how dopant concentration affects damage to local light can be seen in Zorn, RADDAM '90, fig 7 p9. This measurement was done by irradiating fibers with different dopant concentrations simultaneously. A 3 cm section of the fiber was protected by a Pb mask from radiation so that a 3 cm length of fiber has undamaged fluors (and base). When the fiber is scanned and the light output is measured, the output jumps up when the shadowed section is scanned, giving a quantitative measure of the local, undamaged yield and thus allowing to separate attenuation damage from light yield damage (a clever idea of Wick and Holm). It is immediately obvious that heavy doping increases radiation hardness. Conversely, very light doping of a WLS fiber to obtain large attenuation length will make the local light yield of the fiber more sensitive to radiation damage.

I've looked at the Pedro&Shin slides you sent me, but I'm missing a lot of background info, such as how the "laser" and "Vasken" data differ, how the "naive Rochester" and "Wick Rochester" data were obtained etc. which makes it hard to comment. Also, radiation damage is governed by chemical (oxygen) diffusion and kinetics (e.g. strongly temperature dependent). There doesn't seem to be any information on temperature and the actual atmosphere immediately surrounding the tiles.

E.g. how are the HE tiles packaged - wrapped in Tyvek like the HB, perhaps with other wrappers as well? It's relevant because we know that O2 has an influence on the base material transparency; O2 is consumed in multi-step reactions as it diffuses into the base. The wrapper(s) will surely slow down O2 replacement; perhaps the irradiation proceeded under somewhat anoxic conditions if the plates were tightly wrapped. Also, the possibility that outgassing by the plastic wrapper may have a detrimental effect has not been excluded. Studies of color center creation and recovery w. and w/o oxygen present can be found in RADDAM '92 in articles by Trimmer et al., Herod et al., Jahan et al., Wallace et al., Gillen et al., Taylor et al., Whitaker et al, and Werst et al. There's a lot more there than I can summarize here.

Commercial plastic scintillator typically are engineered to have just enough fluor to have an acceptable light yield, but not so much as to significantly degrade the attenuation length through self-absorption of emitted light. If radiation stability is desired, heavy doping is essential. In fact, doping beyond the concentration where self-absorption is significant is advantageous and provides an opportunity to build negative feedback (stabilization) wrt radiation damage into our scintillator.

"Overdoping" a fluor – that is using such a high concentration of fluor that significant self-absorption of the scintillation light occurs can make the scintillator more rad hard because when destruction of fluor through irradiation commences, light output, which normally would decrease due to lost fluor, will instead be stabilized by the decrease in self-absorption. Thus the radiation resistance of the scintillator is extended.

A Generic Tile-Fiber Unit

Since I don't know the geometry of the device you are designing, I will suggest how one might build a "generic" tile-fiber device, using the well known PTP, POPOP, K27 set of fluors.

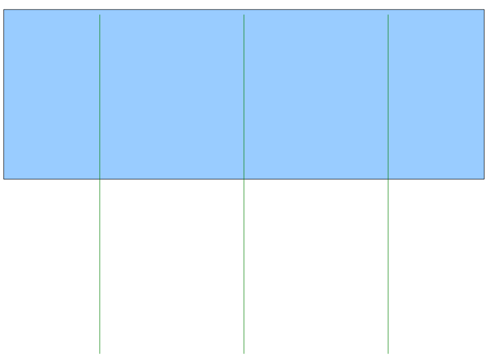
A possible tile-fiber unit can be designed with the three principles in mind:

1) Dope the bejeezus out of the base.

2) Better red than dead.
3) Short optical paths

First, we must recall that for small tile sizes, less than 20cm, we don't really care if the scintillator has a 10m attenuation length and extremely good t.i.r. We can dispense with optically flat, expensive , surfaces and use injection molded plates. Likewise, since we aren't worried about attenuation length diminution from self-absorption, we can crank up the concentration of fluors. As a base one should try both PS, the best studied base and polyvinyltoluene (PVT), for its higher light yield and supposed superior radiation tolerance. Instead of 2% PTP in PS/PVT, go towards the solubility limit (whatever that may be, probably somewhere North of 6%). In fact, you'd like to go well into the self-absorption regime to engender the stabilization of light yield wrt irradiation. Try for 0.2% of POPOP, which is about twice the normal conc in PS-based scintillators.

The same is the case for the WLS fiber. An acceptable – at least to start with - WLS would be a K27 doped fiber. K27 is typically used at ~200ppm concentrations because higher concs shorten the attenuation length. But we don't need 10m attenuation lengths, we will be happy with 2m, so we can try 2000ppm. (The Nova experiment measures >12m at 300ppm).   The distance that the blue, base-emitted light must travel to the WLS should be kept as short as practical. Rather than use a single 1mm fiber, we should use multiple fibers of 0.6mm diameter regularly spaced in the tile. Perhaps thusly:



....where the fibers are 1 to 4 cm apart. For high expected doses, the WLS fiber can be connected to a quartz fiber for further transport of the signal, avoiding the inevitable attenuation of the irradiated WLS fiber.

Place the fibers in grooves, of course, and hold in place with polydimethylsiloxane gel. PDMS will increase the optical contact and is not affected by radiation, unlike epoxies.

For a test slow irradiation, such as those planned by Jim, I would suggest that you avail yourselves of the trick invented by Holm and Wick and occlude a 3cm stretch of the WLS fiber with a slug of lead or tungsten. When you later measure the damage to the fiber this allows to isolate the local light yield damage from the change in attenuation length, as you can see in the RADDAM '90 plot cited. If you have the capability to scan tiles, you can extend this technique to the tile-fiber assembly, Another point to attend to is to have at least some of the irradiated assemblies in the foreseen packaging (e.g. Tyvek etc. wrapper(s)) so that the possibility of wrapper outgassing causing damage can be checked.

I believe Anna Pla at FNAL could whip up a dozen plates in a short time.   The NOvA experiment might be moved to donate a few meters of variously doped K27 fibers. It would be instructive to

compare the radiation tolerance of their most heavily doped (750ppm) with a lightly doped fiber.
To sum up:

1) Make 0.5 liter of PS with 5% PTP, .2% of POPOP and cast into 10 plates of 10x10x0.5 cm^3 each. Mill 3 equally spaced 0.7 mm grooves into which are laid 1m long 0.6mm diameter WLS fibers, perhaps donated by NOVA with different concentrations of K27 and held in place by polydimethylsiloxane.
2)Do the same with 05.L of PVT.
3) Irradiate slowly, with some of the units in the foreseen wrappers and using the Wick&Holm trick to shadow a 3cm section.

I hope my comments will be useful to the RADDAM Taskforce. If you have questions please don't hesitate to email me.

Best Regards,

Kurtis