## A 'molecular dosimeter' which shows a predictable and reproducible change in fluorescence spectrum on exposure to ionizing radiations

## Christopher J. Broan

Company Research Laboratory, BNFL, Springfields, Preston, UK PR4 0XJ

The concept of the loss of a property which depends holistically on the entire structure of a molecule is exploited to prepare compounds which show a predictable and reproducible change in the fluorescence spectrum on exposure to ionizing radiations.

In recent years there has been much interest in the preparation of compounds for optical sensor applications. Whilst a change in the spectrum is usually observed for absorbance based sensors,<sup>1</sup> it would appear that only limited attention has been devoted to fluorescence based sensors with a spectral change,<sup>2</sup> as opposed to the considerable recent work on changes in fluorescence intensity, particularly fluorescence quenching by PET.<sup>3</sup>

An attractive concept for the active element in a system for the measurement of damaging radiations is to prepare a compound with an observable property which depends holistically on the entire structure, such that any damage to the compound, irrespective of its nature or the point at which it occurs, leads to a significant change in that property. An embodiment of this principle could be a compound in which two fluorescent aromatic moieties are held in close proximity by means of a rigid (or semi-rigid) spacer in a face-to-face orientation such that on photoexcitation an excimer can be formed by partition of the excitation energy between the two fluorophores. Damage to one of the fluorophores will, in the great majority of cases, eliminate the possibility of excimer formation. Likewise, damage to the linking unit will allow the two fluorophores to diffuse further apart and again greatly reduce the probability of excimer formation.

An example of the utility of such compounds would be the simple detection of radioactive 'hot spots' in areas of a nuclear reprocessing plant by means of readily detectable changes in a coating or paint. This could be of value in minimizing the amount of uncontaminated material wrongly classified as nuclear waste during decommissioning.

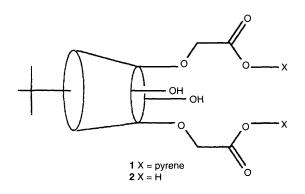
The preparation of compounds is described herein where we also report radiolytic degradation by a substantial change in the fluorescence spectrum, based on the principle of destruction of an excimer forming compound to yield one or more fragments with intact fluorophores. These fragments will, of course, emit as the monomer. Using pyrene fluorophores a wavelength shift in the emission maximum of more than 80 nm is readily achievable.

One of the major advantages of fluorescent reporter molecules is that they can be utilised at micromolar concentrations, in which case the predominant mode of damage will be *via* free radicals generated from the medium by radiolysis. The advantage of the excimer-breaking concept is that the nature of the response is essentially independent of the nature of the damaging radiation and of the medium because at least one fragment containing an intact fluorophore will be generated irrespective of the point within the original molecule where the damage occurs. In a dosimeter compound whose response is dependent on the cleavage of a specific bond, or upon formation of a long-lived free radical, the nature and free energy of the radicals generated in the medium might change the nature of the response as well as its intensity. In the case of dosimeter systems based on free radical generation, the apparent dose measured may decline over time as the radicals recombine. In contrast, the system described here can, in principle, be read out at any time to obtain the total integrated dose over the history of the sample.

Compound 1 was prepared from the diacid 2 (prepared by potassium carbonate catalysed condensation of 2-chloroacetamide with tetra-tert-butyl calixarene followed by alkaline hydrolysis) by DCCI-DMAP catalysed condensation with 1-hydroxypyrene in THF. Dicyclohexylcarbodiimide-4-dimethylaminopyridine (DCCI-DMAP) catalysed condensations of 2 with other alcohols and amines could be used to produce a variety of related putative excimer forming compounds. It would appear that attempts to prepare the acid chloride of 2 lead only to acid-catalysed decomposition of the calixarene unit. We found it advantageous to treat the crude product mixture with aqueous acetic acid for approximately 1 h to convert the excess DCCI used to the more easily removed dicyclohexylurea (DCCU). Compound 1 gave satisfactory IR, <sup>1</sup>H and <sup>13</sup>C NMR (CDCl<sub>3</sub>) spectral data with integrations consistent with the disubstituted compound only. The monosubstituted compound and the 1-hydroxypyrene were shown not to be present in detectable quantities by TLC.

Pyrene fluorophores are known to suffer from photodegradation in the presence of UV light, which might prove to be a limiting factor in the exploitation of these particular compounds. Compound 1 shows particularly rapid photodegradation which might be due to intramolecular energy transfer from the pyrene chromophore to the adjacent chemically fragile ester unit. The evidence to support this interpretation comes from the rapid loss of excimer emission on exposure to light compared to the rate of decrease in the intensity of the monomer emission in the photodegraded material and also of the 1-hydroxypyrene.

The facility to prepare a wide variety of related excimer forming compounds by means of DCCI–DMAP catalysed condensation of 2 with many different alcohols and amines will enable more photochemically robust compounds with similar functionality to be prepared. Similar compounds incorporating anthracene, naphthalene or stilbene fluorophores might be expected to also show some excimer emission, although it is well known that pyrene excimer formation is particularly facile.



Chem. Commun., 1996 699

The fluorescence spectrum of 1 (as a 1.0  $\mu$ mol dm<sup>-3</sup> solution in HPLC grade hexane) as a function of dose (gamma irradiation, 1.17 and 1.33 MeV, cobalt-60 source) is shown in Fig. 1. The large change in the overall fluorescence spectrum can be clearly seen as the relative intensity of the structured pyrene monomer emission increases with respect to the broad, structureless excimer emission centred at 470 nm. The sharp

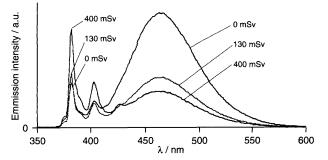


Fig. 1 Fluorescence spectra of 1 in hexane  $(10^{-6} \text{ mol dm}^{-3})$  as a function of gamma dose. Excitation is at 340 nm, emission intensity is on arbitrary scale.

and structured nature of the monomer emission shows that it is due to fragments containing an isolated and intact pyrene fluorophore rather than an ensemble of many different fluorescent fragments, as would be generated by radiolysis and/or radical reactions of a compound initially containing only one fluorescent unit.

This work is the subject of Patent No. PCT/GB94/02676.

I would like to acknowledge the support of my management and co-workers at the Company Research Laboratory and the assistance of Simon Cooper and Rod Bilton at Liverpool John Moore's University in carrying out the irradiation experiments.

## References

- 1 Y. Kubo, S. Marugama, N. Ohhara, M. Nakamata and S. Tokita, J. Chem. Soc., Chem. Commun., 1995, 1727.
- 2 D. Y. Sasaki, D. R. Shnek, D. W. Pack and F. H. Arnold, Angew Chem., Int. Ed. Engl., 1995, 34, 905; T. Jin, K. Ichikawa and T. J. Koyama, J. Chem. Soc., Chem. Commun., 1992, 499.
- 3 T. D. James, K. R. A. S. Sandanayake, R. Iguchi and S. Shinkai, J. Am. Chem. Soc., 1995, 117, 8982.

Received, 4th December 1995; Com. 5/07884I