Meetings

Progress in Luminescence Dosimetry

After two highly successful previous conferences on this subject in 1965 (*1*) and 1968 (*2*), a third international conference on luminescence dosimetry took place at the Research Establishment of the Danish Atomic Energy Commission (AEC) in Risö, near Copenhagen, from 11 to 14 October 1971. It was cosponsored by the Danish AEC and the International Atomic Energy Agency (IAEA). The increasing worldwide interest in integrating solid-state radiation measurements and their many applications was reflected in the attendance of scientists from 27 nations and 3 international organizations; 75 papers were presented.

The first two sessions were devoted to the progress made during the last 3 years in understanding the mechanism of thermoluminescence (TL). Among many interesting investigations are some studies on the TL peaks in LiF: Mg,Ti (TLD-100) in the temperature range 100° to 660°K, which revealed an increase in "supralinearity" (more than proportional radiation response) with increasing peak temperature as well as an anomalous breadth of some low-temperature peaks (E. B. Podgorsâk *et al.*, University of Wisconsin, Madison, and C. M. Sunta *et al.*, Bhabha Atomic Research Center, Trombay, India). The properties of high-temperature glow-peaks in this material have also been studied by a group from the United Kingdom (E. W. Mason and G. S. Linsley, National Radiation Protection Board, Glasgow). The hydroxide anion was shown to have a strong effect on the TL properties of LiF (L. A. DeWerd and T. G. Stoebe, University of Washington, Seattle) and CaF_2, but not on phosphors containing oxygen, such as $CaSO_4$, BeO, or Mg_2SiO_4 (T. Nakajima, National Institute of Radiation Sciences, Chiba, Japan). The effects of a large number of other impurities and their potential use as activators in LiF were studied by M. E. A. Robertson *et al.* (United Kingdom) and by M. J. Rossiter (National Physical Laboratory, Teddington, U.K.). The latter made a strong case in support of Ti (approximately 10 parts per million) as the only important coactivator for Mg (approximately 80 parts per million) in TL-grade LiF.

Abnormally rapid fading, probably due to nonradiative electron leakage from the traps, has been observed in a wide variety of TL phosphors (Z. Spurny and J. Novotny, Technical University, Prague) and geologic materials (A. G. Wintle *et al.*, Oxford University, U.K.). This complicates TL dating. Various new or modified TL models were suggested, for example, the possibility of a Gaussian trap-depth distribution instead of a single trap depth (R. Abedin-Zadeh, IAEA, and S. Watanabe and P. S. Morato, Institute for Atomic Energy, São Paulo, Brazil). In particular, the TL kinetics of CaF_2 : Mn have been studied (G. Adam, Beer-Sheva, Israel). Electron spin resonance studies helped to clarify the TL mechanism in lithium borate glasses (D. R. Shearer, St. Williams Hospital, Rochester, U.K.) and in natural CaF_2 (K. S. V. Nambi and T. Higashimura, University of Kyoto, Kyoto, Japan).

Closely related to some of the more basic studies were reports given during two sessions on new or modified TL materials. A particularly important development is the emergence of BeO as a TL material of low atomic number, with properties equal or superior to those of LiF : Mg,Ti. Toxicity problems have been solved either by sealing BeO : Na in special glass capillaries (Y. Yasuno and T. Yamashita, Matsushita Co., Osaka), or by using extremely hard and chemically resistant sintered disks (G. Scarpa *et al.*, Comitato Nazionale Energia Nucleare, Rome), which are also becoming very popular for use in thermally stimulated exoelectron emission (TSEE) dosimetry (R. B. Gammage *et al.*, Oak Ridge National Laboratory). Two approaches designed to avoid the time-consuming, complicated post-irradiation annealing procedure for the widely used LiF : Mg,Ti have been successful. It can be done either by a special preparation of the phosphor (K. Naba, Vienna, and G. Portal *et al.*, Comité Energie Atomique, Paris), or by a special short annealing added to the reading cycle (G. A. M. Webb and H. P. Phykitt, Teledyne Isotopes, Westwood, N.J.).

Natural fluorites (CaF_2) from India (C. M. Sunta, BARC, Trombay) and Brazil have also been used for ultraviolet dosimetry (E. Okuno and S. Watanabe, University of São Paulo). Quartz can be used for measuring high "accident" doses (D. J. McDougall, Loyola College, Montreal), and even naturally occurring Kapis shells exhibit TL (N. T. Bustamente *et al.*, Philippine AEC, Manila). Other studies were devoted to TL enamels (M. Mihailović, Ljubljana, Yugoslavia), sintered TL materials (T. Niewiadomski *et al.*, Institute for Nuclear Physics, Cracow, Poland, and D. Uran *et al.*, Ljubljana), and $Li_2B_4O_7$ activated with Ag, Fe, Co, and Mo (A. Moreno, University of Mexico, Mexico City).

In a session on TL instrumentation, it was pointed out that a-c heater currents can, in some readers, produce substantial changes of the TL readings (J. E. Saunders, Ontario Cancer Foundation). A better knowledge of the emission spectra of TL materials permits optimal reader design (K. Konschak *et al.*, Technical University, Dresden). Photon counting can improve the sensitivity (T. Schlesinger *et al.*, Israel AEC, Yavne), and heating of the dosimeters with a hot air stream in a new commercial instrument reduces the disturbing infrared emission (H. Onishi *et al.*, Matsushita Co.). Automatic or semiautomatic TL readers for routine personnel dosimetry have been developed in Chalk River, Canada (A. R. Jones) and in Risö (L. Bøtter-Jensen and P. Christensen).

A fresh look has been taken of numerous dosimetric properties of TL materials. The effect of dosimeter size on the response was studied for CaF_2 : Mn (M. Ehrlich, National Bureau of Standards, Washington, D.C.) and granulated LiF incorporated in silicone (P. Bassi *et al.*, CNEN, Bologna). Closely related is the problem of measuring steep dose gradients at interfaces (G. A. Carlsson and C. A. Carlsson, University of Linköping, Sweden). Very fine TL powders were used for preparing extremely thin TL foils (G. A. M. Webb and G. Badin, Teledyne Isotopes). Like natural CaF_2, $CaSO_4$: Tm and $CaSO_4$: Dy can be used for ultraviolet dosimetry (K. S. V. Nambi and T. Higashimura, Kyoto University). The linear energy transfer response and the parameters that affect it, in particular in LiF : Mg,Ti, have been the subject of several studies (C. A. Carlsson and P. Spanne, University of Linköping; J. R. Harvey and S. Townsend, Berkeley, U.K.; T. Nakajima, Chiba; and B. Jähnert, Hahn-Meitner Institute, Berlin). The dependence of various detector materials on dose and energy was studied by two Belgian groups (G. Eggermont *et al.*, University of Ghent, and S. K. Dua *et al.*, Mol, Belgium). The consistency of the properties of LiF-Teflon disks over repeated use cycles can be remarkably good (T. O. Marshall and K. B. Shaw, National Radiation Protection Board, Belmont, U.K.). Thermoluminescence measurements at very low temperatures were reported by R. D. Jarrett *et al.* (Natick, Massachusetts), and M. R. Mayhugh *et al.* (University of São Paulo) described the dosimetry of thermal neutrons by "self-dosing" of the phosphor due to its activation.

Concerning practical applications of TL, it has been pointed out that within a few years about half of the world's personnel dosimeters will consist of, or be supplemented by, TL (F. H. Attix, Naval Research Laboratories, Washington, D.C.). Since TL personnel dosimetry is already routine, most of the reports focused on other applications. Thermoluminescence dosimetry is also widely used on a routine basis in clinical dosimetry (B. I. Rudén, Radiumhemmet, Stockholm; D. S. Gooden and T. J. Brickner, Jr., St. Francis Hospital, Tulsa, Oklahoma; and N. Suntharalingam and C. M. Mansfield, University Hospital, Philadelphia). Among the special applications are precise area monitoring (measurement of the background dose), which became possible with the development of more sensitive phosphors such as $CaSO_4$: Dy, $CaSO_4$: Tm (K. Becker *et al.*, ORNL and Hsinchu, Taiwan), and CaF_2 : Dy (D. E. Jones *et al.*, Livermore), and archeological dating, with accuracy increased by the use of more sophisticated techniques (S. J. Fleming and D. Stoneham, Oxford University; V. Mejdahl, Risö; M. C. Han and E. K. Ralph, University Museum, Philadelphia).

Almost one-quarter of the papers were devoted to phenomena other than TL, in particular to the related process of exoelectron emission. In two studies, a comparison was made between the TL and TSEE characteristics of various phosphors, including CaF_2 and LiF : Mg,Ti (K. J. Puite, Wageningen, Netherlands, and A. E. Nash *et al.*, NRL, Washington, D.C.). It was concluded that different centers are frequently involved in the two processes. Instrumentation for TSEE, in particular the use of proportional counters, was the subject of other investigations (L. D. Brown, London Polytechnic, and T. Niewiadomski, Cracow). Optical instead of thermal stimulation offers advantages in the use of organic emitters or carriers, such as paper (J. Kramer, Physik.-Techn. Bundesanstalt, Braunschweig). When heated to very high temperatures, Al_2O_3 becomes quite sensitive (G. Holzapfel and E. Chryssou, PTB, Berlin and Athens). However, most of the work was devoted to the use of certain ceramic beryllium oxides first studied at Oak Ridge. Silicon was identified as activator in these materials, but the characteristics might be modified by activation with Li or by particle irradiation (R. B. Gammage *et al.*, ORNL); Li activation was also studied by D. F. Regulla and G. Drexler (Neuherberg). E. Rotondi (CNEN, Rome) further investigated the effect of the detector's environment on its photon response, and M. Euler *et al.* (University of Giessen, Giessen, West Germany) added other oxides such as ZnO to the BeO/SiO_2 system in attempts to further increase its sensitivity.

Another main topic of the conference was radiophotoluminescence (RPL) in glasses. E. W. Claffy *et al.* (NRL, Washington, D.C.) used RPL and optical absorption changes in LiF for measurements at high doses. L. Westerholm and G. Hettinger (University of Umeå, Umeå, Sweden) studied the response of commerical dosimeter glasses to 10- to 30-Mev electrons, and laser pulse excitation, first suggested by J. Kastner, helps to reduce the background effect called "predose" (R. Yokota *et al.*, Toshiba, and F. Hillenkamp and D. F. Regulla, Neuherberg). Most important, new systems have been developed for routine personnel dosimetry by means of RPL glasses in Finland (M. Toivonen, Institute of Radiation Physics, Helsinki) and Germany (M. Dade *et al.*, Berthold-Friesecke, Karlsruhe). The latter permits an energy-independent measurement down to about 15 kev as well as an effective energy reading from the same small glass plate.

Another, more exotic technique of potential interest for high-level fast neutron dosimetry, based on triplet exciton annihilation changes induced in anthracene, was described by D. Pearson *et al.* (University of Wisconsin).

From the papers, the final panel discussion (with K. Becker as moderator and F. H. Attix, C. Carlsson, J. F. Fowler, R. Maushart, and A. Scharmann as participants), and many informal discussions, the following conclusions can be drawn:

1) Thermoluminescence dosimetry, which was still generally considered an experimental technique a few years ago, is now firmly established in routine personnel and clinical dosimetry as well as in archeological dating.

2) The theory of TL, even for such highly complex materials as LiF : Mg,Ti and natural CaF_2, is finally better understood, but there are substantial gaps in our knowledge of the mechanism of TSEE and its relations to TL.

3) Other TLD phosphors that combine either higher sensitivity ($CaSO_4$: Tm,Dy) or better energy response (BeO: Na), or both, with simpler dosimetric and annealing properties offer attractive alternatives to the widely used LiF : Mg,Ti. Also, the complicated annealing of conventional LiF can be simplified by different preparations of the material, or by a modified heating cycle.

4) Thermally stimulated exoelectron emission emerged as an important research tool and potentially interesting dosimetric technique, with some materials such as BeO : Si combining very high sensitivity and stability with an extremely thin sensitive layer (solid-state "microdosimetry").

5) With the development of more sophisticated dosimeters and readers, RPL (glass) dosimetry has also matured so that its use in large-scale personnel dosimetry as a replacement of the usually insufficient film badge can be considered.

At the suggestion of J. H. Schulman (Washington, D.C.), a standing committee has been formed to decide on the location and date of a possible fourth conference, perhaps in 1974. The proceedings of the third conference have been published in three volumes as Risö Report 249 and are available on exchange from the library of the Danish AEC, Risö, Roskilde. The sales distributor is J. Gjellerup, 87 Solvgade, Copenhagen, Denmark.

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References and Notes

1. C. J. Karzmark, F. H. Attix, C. L. Wingate, *Science* **150**, 391 (1965).
2. K. Becker and J. A. Auxier, *ibid.* **164**, 974 (1969).

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