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On the use of dental ceramics as a possible second-line approach to accident irradiation dosimetry

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ABSTRACT

Recent development in dental ceramic production has resulted in natural or depleted uranium, used for over half a century to mimic the fluorescence of natural teeth, being substituted in such ceramics by non-radioactive fluorescent materials. This creates the possibility of using dental ceramics incorporating the latter as second-line dosimeters ir cases of accidental irradiation. This pilot study shows the feasibility of such an approach using both thermally stimulated exoelectron and thermoluminescent techniques. *In conclusion*, it is considered that it would be of interest to continue this investigation of dental ceramic materials as second-line accident dosimeters.

RÉSUMÉ

Durant plus d'un demi-siècle la fabrication des céramiques dentaires était réalisée à partir de l'uranium naturel ou appauvri. Ceci avait pour but de simuler la fluorescence naturelle des dents. Le développement récent de la production de nouvelles céramiques tend à substituer à l'uranium des matériaux fluorescents non radioactifs. Cette technologie ouvre la possibilité d'utiliser les prothèses conçues à partir de ces céramiques pour une dosimétrie d'appoint en cas d'irradiation accidentelle. Les résultats préliminaires obtenus montrent que l'on pourrait appliquer les techniques d'émission exoélectronique thermostimulées (EETS) et de radiothermoluminescence (RTL). *En conclusion*, on met en évidence l'intérêt qu'il y aurait à poursuivre l'étude de ces céramiques, utilisées comme « dosimètres secondaires ».

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FOREWORD

The use of biological tissues for irradiation dose measurement purposes in cases of accident provides a major problem for those working in this field of health physics. Methods are available for neutron dose measurement using activated blood sodium or the activity of ^{32}P in hair or nails [1]. However, in the case of gamma irradiation no solution has yet been found which would enable one to make an immediate estimate of an accidental dose received in the absence of a conventional dosimeter.

Although sophisticated methods are becoming increasingly available using chromosome or blood cell abberation techniques [2], these necessarily involve relatively long times in terms of a possible treatment regime for a person who has been accidentally irradiated with a dose close to that considered fatal i. e. approximately 400 rad total body dose.

For this reason, means of measuring a dose using a biological tissue or some other synthetic material normally present in clothes, watches etc. are continually being sought as adjuncts to current patient treatment regimes.

Probably the most commonly solicited biological material for use in accident dosimetry is dental enamel. Its availability without recourse to surgical intervention and its physical characteristics conducive, in theory ([1]), to solid state measuring techniques make it a first-choice material.

However, thermoluminescent studies applied to biological hard tissues in the past [3-5] have not proved successful since the sample heating necessary for measurement damages the biological tissue and at relatively low temperatures irreversibly changes the composition of the material under study. This also applies to thermally stimulated exoelectron emission techniques [6].

Although recent work [7] has shown that some of these problems may be overcome, second-line synthetic materials should nevertheless be investigated.

In the course of a current research programme on the exoelectron properties of synthetic [8], natural and biological apatites, it was decided to carry out a pilot study of the possible dosimetric response of some dental restorative materials.

INTRODUCTION

This paper concerns a pilot study carried out on ceramic material used for dental restoration. Although it is obvious that not everybody wears some form of ceramic dental prosthesis or restoration, the percentage of the total population (which can be estimated following recent publications) who have some form of restoration is sufficiently important to test these materials as possible accident dosimeters. THOMPSON [9] working on

([1]) Approximately 99 p. cent by weight of human dental enamel is a complex crystalline apatite.

previously published national statistics, estimated that in 1971 there were 100 million persons in the U.S.A. wearing a dental prosthesis of which 50 p. cent were made of porcelain ceramics.

Porcelain has been used as a substitute for natural dental tissues since the work of DUCHATEAU in 1776. For a concise early history *see* [10] and references therein. However, in an attempt to mimic the fluorescence of natural teeth, manufacturers of artificial teeth have added uranium salts to porcelain for over half a century [11].

A priori, any material which contains significant levels of radionuclides is unsuitable as an irradiation detection device. However, due to criticism of the use of either natural or depleted uranium in dental ceramics, due to the risk of α and/or β intra-oral mucosal doses [12, 13], manufacturers have concentrated on the development of porcelain products simulating the natural fluorescence of teeth without the inclusion of uranium salts.

Such materials are already available on the market and it is this development which renders possible the use of such dental porcelains as accident dosimeters. Furthermore, during the preparation of dental crowns, these porcelains are heated to approximately 950°C both in vacuum and in air. This treatment will automatically irradicate any spurious tribo-emission due to handling of the crown during preparation and also serve as a pre-heating treatment which has been shown to be so important in the preparation of dosimetric materials [14, 15].

MATERIALS AND METHODS

a) *Materials*

The dental ceramic chosen was BMDK-Metalkeramic made by De Trey Gesellchaft (1). Samples were prepared, comprising both "dentine" and "enamel" porcelains, as discs approximately 1.5 mm thick and 17 mm in diameter. These dimensions were chosen for convenience in mounting in the detection apparatus. The laboratory preparation of these samples from their original powder forms was executed by trained dental porcelain technicians who employed the methods of preparation normally used for the fabrication of crowns. In the case of the enamel samples, this included the final glazing bake given to the finished crown. These materials are usually applied in thin layers to the reduced crown form and great care is taken to avoid distortion. However, the production of flat discs presents unavoidable distortion problems, and therefore some samples were slightly buckled producing discs with one convex and one concave aspect. Although this distortion provided little inconvenience, it did result in some discs cracking during the reading procedure since the sample disc must be securely screwed onto the heating element of the detector apparatus. Twenty discs were prepared for this study.

(1) Kindly supplied and prepared by La Division De Trey of the group Amalgamated Dental (France), 92500 Rueil-Malmaison, France.

b) *Exoelectron emission*

Exoelectron emission may be described as that effect of structure dependent emission of low energy electrons which occurs from surfaces of many insulating solids after mechanical, optical, chemical or ionizing radiation treatment at energy levels below that required to induce photoelectric, thermionic or field emission [16]. After termination of the treatment, heating the sample may produce exoemission maxima at particular temperatures. This effect is known as thermally stimulated exoelectron emission (TSEE) [17], and was first systematically investigated by KRAMER [17, 18].

Figure 1 shows a simple band model explaining this phenomenon and its relation to thermoluminescence. It is thought that the effect is generated within 100 Å of the emitting surface [19].

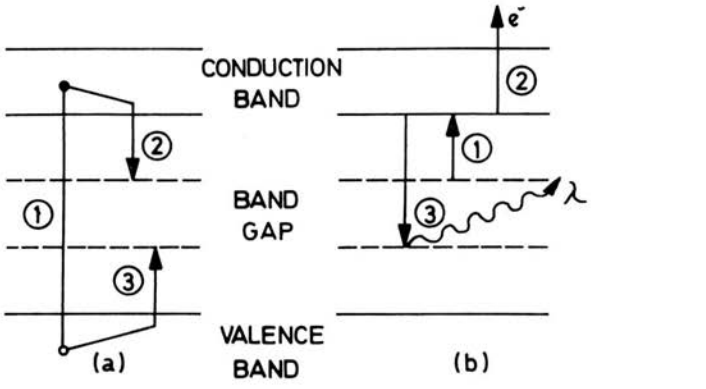

FIG. 1. — Band model.

c) *TSEE measurement*

The apparatus, shown in Figure 2, comprises a point-counter of the proportional type. The high voltage supply provides an electric field in a flowing methane gas atmosphere. The sample irradiation was carried out using a 5 Ci γ^{137}Cs source. A comprehensive account of the development and characteristics of this detector may be found in [14].

d) *Thermoluminescence measurements*

Some samples which had already been used for TSEE measurements and therefore both irradiated and heated in the exoelectron apparatus, were broken into smaller fragments and used for thermoluminescence measurements (TL) using a commercially available LDT20-Saphymo-Strat TL reader. The temperature maximum, using a linear heating rate of 10°C/s was 325°C.

RESULTS AND DISCUSSION

All ceramic discs exhibited electron emission on thermal stimulation whether irradiated or unirradiated prior to reading. In unirradiated samples this first emission is often called "tribo-emission". However, in view of the preheating treatment of the discs during their preparation and the fact that this emission tended to return after keeping the samples in air overnight,

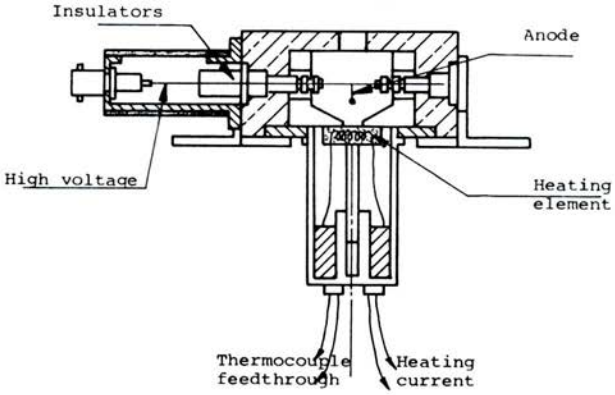

FIG. 2. — The exoelectron detection apparatus, from [14], reproduced with permission.

(*Fig.* 3 *a*), it is most likely that this phenomenon is related to the surface state of the glazed porcelain which would change in the presence of atmospheric impurities. As was mentioned above, exo-emission is a surface phenomenon and therefore may be expected to respond to even small changes in the surface state of the sample. In this case, the term reversible "chemi-emission" is more suitable.

However, as can be seen below, this chemi-emission occuring at 490°C was independent of the irradiation induced changes in the glow curve structure. Figure 3 *a* shows the chemi-emission from an unirradiated glazed enamel porcelain sample. In 3 *b* the glow curve of a second sample, irradiated (100 rad) before reading, shows the appearance of two peak structures at 172 and 350°C induced by the irradiation, and at 490°C the chemi-emission already seen in the unirradiated sample. The second reading cycle of both these samples showed no emission at temperatures below that of the thermionic emission appearing at 500°C. After a second irradiation (*Fig.* 3 *c*) a new peak appears at 85°C together with the two structures at 172 and 350°C. This low temperature peak appears therefore only after the first heating cycle in the detector. Figure 3 *d* shows the response of the same sample used in 3 *b* after having been irradiated with a dose of 45×10^4 rad. Although the low temperature (85°C) peak is not apparent, the peaks at 172 and 350°C can be clearly seen. A further irradiation of 100 rad produced an emission

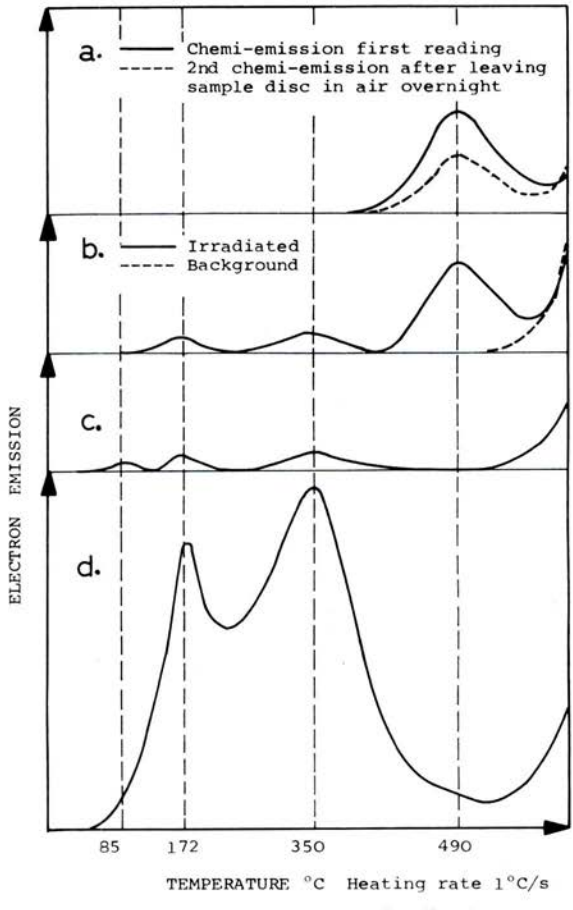

FIG. 3. — Response of unirradiated and irradiated glazed enamel dental ceramics.

response within 2 p. cent of the first 100 rad irradiation. This finding, which was reproducible throughout this short experimental series is important in terms of any eventual use of these materials in accident dosimetry since the first reading, containing the required information, would have to be standardized using known doses and subsequent readings of the same sample.

Within the limited scope of this study no comparison of intersample dose/emission linearity was attempted. However, within the same sample these preliminary results show that a sub-linear dose/emission relationship may exist (*Fig.* 4).

In the case of the TL samples, as they had already been used for TSEE measurements, no comparison could be made between irradiated and unirra-

diated samples. Furthermore, as the fragments were of unequal weight, the response to a given dose could not be compared between different fragments. Figure 5 however shows the response of one enamel porcelain fragment after six successive γ irradiations of 600 rad. A single prominent peak occurs at 175°C which may represent the same trapping mechanism responsible

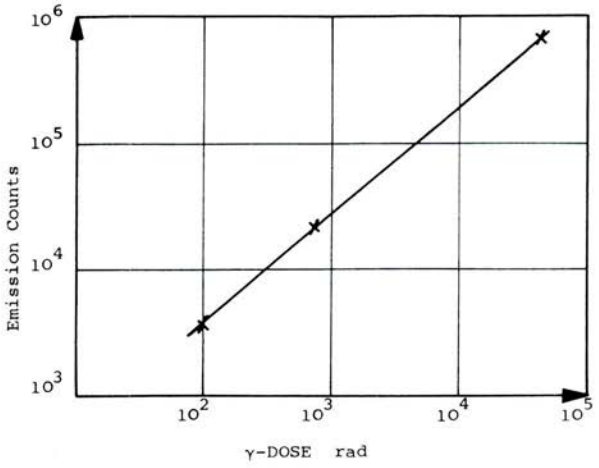

FIG. 4. — Response of a single re-irradiated glazed enamel ceramic.

for the 172°C peak seen in TSEE measurements. An unidentified higher temperature structure beyond the temperature maximum of these readings is increasingly apparent with the successive irradiations since the emission increases with each reading between the peak at 175 and 325°C. Facilities for higher temperature thermoluminescent reading would be necessary to distinguish this structure.

CONCLUSION

It must be stressed that the purpose of this pilot study was to investigate the *possibility* of the use of dental ceramics as second-line accident dosimeters. In this context, these preliminary results may be considered promising since the glazed 'enamel' porcelain ceramic selected was sensitive to both thermally stimulated exoelectron and thermoluminescent investigative techniques and using TSEE, specific differences could be seen between unirradiated and irradiated samples. Furthermore, although reversible chemi-emission occurs, this does not interfere with the monitoring of irradiation induced changes since these emission peaks occur at different temperatures. We consider then, that it would be of interest to continue this investigation of dental ceramic materials as second-line accident dosimeters.

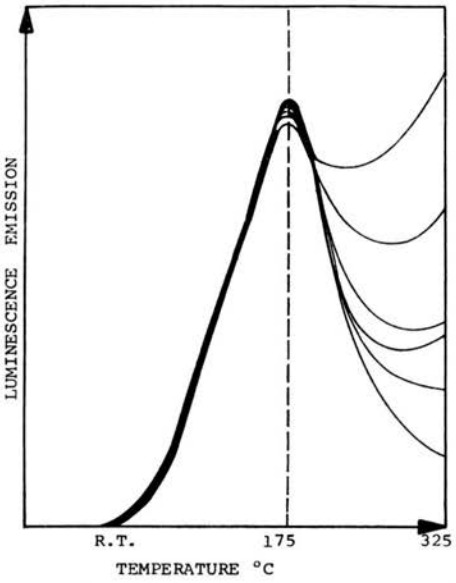

FIG. 5. — Successive TL measurements of an irradiated glazed enamel ceramic fragment.

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