A mm-Scale Dosimetry System Based on Optically Stimulated Luminescence of Beryllium Oxide for Investigation of Dose Rate Profiles in Constricted Environments - 12219

Marian Sommer[*], Axel Jahn[*], Reiner M. Praetorius[**], Dora Sommer[*], Juergen Henniger[*]
[*]Technische Universitaet Dresden , Institute for Nuclear and Particle Physics,
Radiation Physics Group, D-01062 Dresden, Germany
[**]Wiederaufarbeitungsanlage Karlsruhe Rückbau- und Entsorgungs- GmbH,
POB 1263, D-76339 Eggenstein-Leopoldshafen, Germany

ABSTRACT

The dismantling of the former German fuel reprocessing research center Wiederaufbeitungsanlage Karlsruhe requires extensive investigations of contamination and dose rate inside of the shielded areas. Particularly for first the exploration of radiation field existing thermoelement pipes may offer access to the tanks and to other interesting points without the risc of contamination. Because of their small dimension, almost no active dosimetry systems are able to measure inside the pipes. New mm-scale luminescence dosimeters in combination with a packing and transport technique are presented. The dosimeters could measure doses from 0.1 mGy up to more than 100 Gy. Hence, over the possible exposure time durations, dose rates from μGyh^{-1} up to 1000 Gyh^{-1} are ascertainable. For potential users the system opens the opportunity for investigation of dose rates inside of shielding and in contaminated environments. Particularly in constricted environments the technique is a unique solution for dose and dose rate measurement tasks.

INTRODUCTION

For planning of the plant dismantling of the former German fuel reprocessing research center Wiederaufaufbeitungsanlage Karlsruhe (WAK), extensive investigation of contamination and dose rates must be done. Dose rate profiles inside the high activity waste concentrate tanks, as well as in the vitrification plant, have been measured through access gained through small thermoelement pipes that were available. These pipes provided a pathway to arrive at the points of interest without penetrating the tanks and without risc of contamination. These pipes have diameters of only 8 mm, but with lengths of up to 30 m. In practice, manufactured dosimeter must be smaller than 3 mm in diameter, hence the bare detectors must not be more than 2 mm in diameter. No active and only a few passive dosimetry systems meeting such requirements are available.

For more than ten years a valuable dosimetric method employing optically stimulated luminescence (OSL) of the material beryllium oxide (BeO) has been developed at Technical University Dresden (TU Dresden) [1],[2]. Since 2006, with the BeOmax reader, a semi-commercial dosimetry system has been available for scientific as well as industrial users. The system has been continuously upgraded and adapted based on the requirements of the users. As a result, several forms of encapsulated dosimeters and handling techniques for bare BeO detectors are now available for dosimetric use. One detector form is a cylindric BeO substrate with a diameter and a height of 1 mm each, which is very useful for dosimetry within small or restricted spaces.

Due to the near tissue equivalence of the material BeO, the method promises to be useful for personal dosimetry, too. A collaboration of HelmholtzZentrum Muenchen, TU Dresden and IBA Dosimetry GmbH Schwarzenbruck developed the modular personal dosimetry system iBeOx

according to the requirements of IEC 62387-1 for the evaluation of $H_P(10)$ and $H_P(0.07)$ photon doses [3]. Actually, iBeOx is established in Germany and Belgium as one of the personal dosimeters with official approval.

EXPERIMENTAL METHOD

Detector material

The BeO detector material is offered as Thermalox 995® by Materion Ceramics, Tucson, AZ (former known as Brush Wellmann Inc.). According to the intensive use of BeO in electronic industries, the BeO-chips are clearly cheaper than standard luminescence materials. Square chips of 4.7 mm edge length and 0.5 mm thickness are used as standard detectors for most applications. For special applications, detectors with very small dimensions of 1 mm each in diameter and height were developed, optimized and produced. All detectors are dry pressed and sintered. As result they have a very good mechanical, thermal and chemical stability. Due to this and to insensitivity to humidity, it is even possible to irradiate bare detectors directly in liquid or radioactive environments and measure the dose with high accuracy after the decontamination, cleaning and drying procedure. The poisonous character of BeO powder can be eliminated for the sintered material.

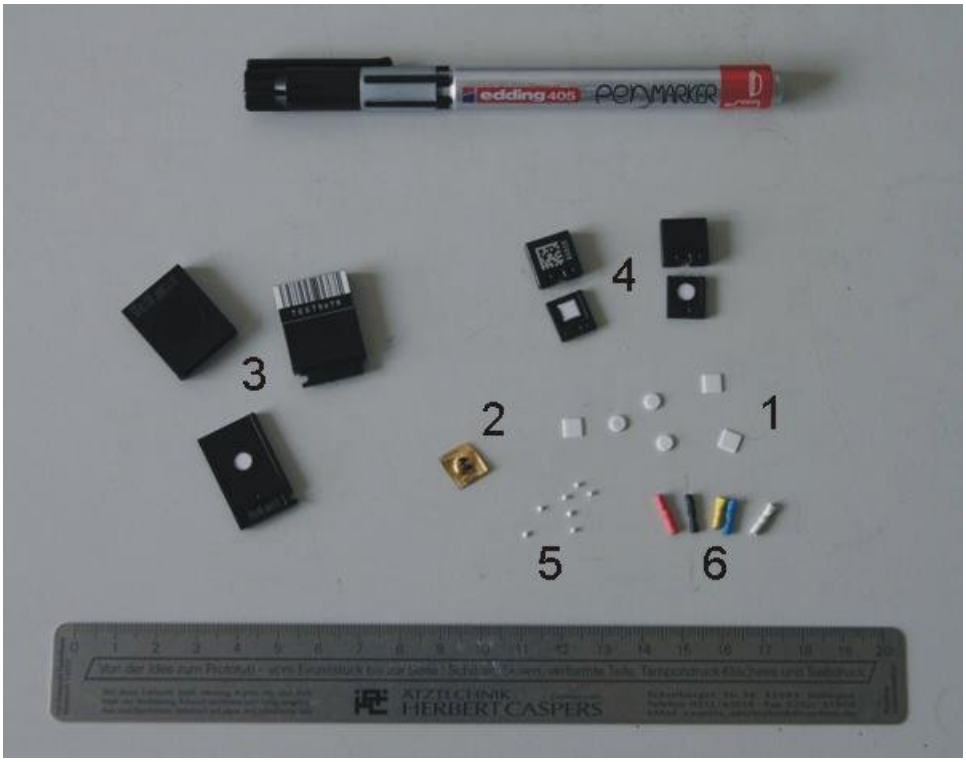

Fig 1. Different detector and dosimeter forms: 1 Square and circular chips for standard investigations, 2 Jig-welded bare detector, 3 and 4 Encapsulated dosimeters with different dimensions (26 x 19 x 5 mm³ resp. 12 x 12 x 4 mm²) and barcode or data-matrix-code for identification, 5 Small cylinders with 1 mm dimensions, 6 Shrink-wrapped 1 mm-scale detectors for the investigations at the WAK.

The physical effect used for the OSL dosimetry is contemporaryly the most important practical disadvantage of the technique – the light sensitivity of the luminophor. That's why encapsulated dosimeters, automatically opened only inside the reader, are preferred in practice (see figure 1, number 3 and 4). But for some applications like Beta dosimetry or dosimetry in constricted environments, the use of dosimeters is not possible. Then bare detectors must be shrink-wrapped or jig-welded in light-impermeable foils (number 2 and 6). While wrapping of unexposed detectors may be done in light, unpacking must be performed under light protected conditions. An advantage of BeO compared to other OSL materials like Al_2O_3 or quartz is the weaker light sensitivity, so that handling can occur under weak indirect illumination or under red light.

Reading concept

The physics of the OSL is comparable to well-established thermoluminescence techniques except for the stimulation procedure. The passive BeO detectors positioned in the radiation field store part of the absorbed radiation energy inside the crystal. This storage is an integral process. It is linear with absorbed dose over a wide range of doses. After the end of exposure detectors are removed from the irradiation point and read out. In the BeO*max* reader, irradiated detectors are positioned between a blue stimulation light source and a photosensor module consisting of photomultipiler tube, high voltage supply and preamplifier. The blue stimulation of BeO releases a dose proportional luminescence emission of UV-light.

The stimulation LED is a focussed royal blue Luxeon Star/O (455 nm) with electric power of 1 W. Its current can be free regulated between 2 mA and 350 mA. The small UV part of LED emission is removed by simple UV absorption foils, the red part is suppressed by a Schott BG39 filter. So, the stimulation spectrum is limited between 390 nm and 650 nm with highest power between 400 nm and 500 nm. The luminescence light is detected by an Hamamatsu photo sensor module (PSM) H5784-03. Hoya U340 or Schott DUG11 filters in front of the PSM prevent the light of the stimulation spectrum from reaching the photomultiplier. As result the LED light cannot be directly monitored on the PSM signal.

The voltage output of the sensor module is amplified in three channels of different gains and time constants, which are digitized in a parallel way. A self-developed software selects the best fitting channel and converts the OSL-signal via the known gain factors into an unified value of OSL measure. The decay curve integral over a defined time interval (typically 4 s) results into the OSL-signal used to specify the dose (see figure 2). A comfortable software controls the reader, manages data and dosimeter information and calculates doses.

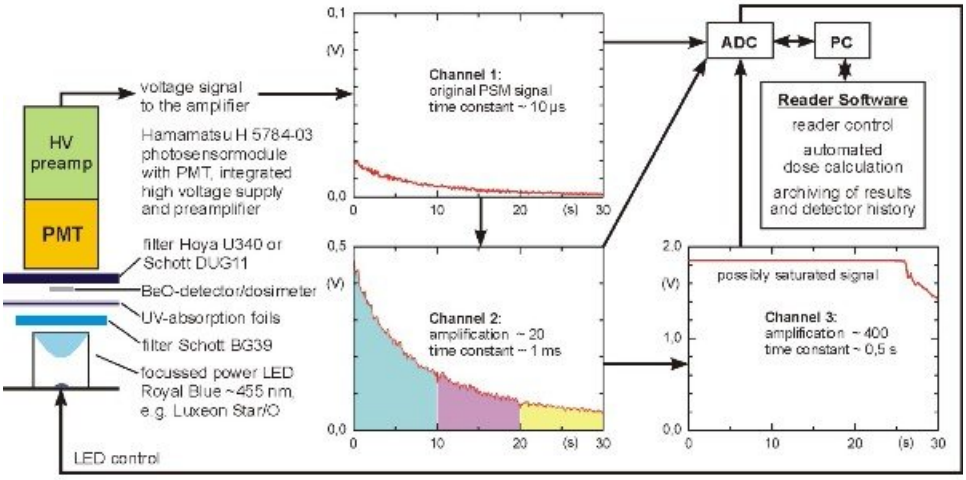

Fig 2. Reader concept and data acquisition of the BeO*max* system.

Dosimetric properties

The dosimetric properties of BeO are excellent for use in all dosimetric fields. Due to the effective atomic number (Z_{eff}=7.14) BeO can be qualified as tissue equivalent in dosimetric practice. The absorption of photon doses in BeO fits well the energy response of tissue. For low energy radiation only weak underestimated values could be observed.

Furthermore, after storage for some minutes, long-term fading is negligible under environmental conditions. The loss of OSL signal after storage of one year is less than 5%. Temperature dependence of the OSL-signal could not be monitored up to storage temperatures of about 120°C and up to reading temperatures up to 40°C. Illumination of bare irradiated detectors with office-typical light densities (e.g. with fluorescent lamps) induce a signal bleaching of percents per minute. Pure red illumination cause no light-induced fading. Weak and indirect white lighting allows fast unpacking of wrapped detectors with negligible signal loss.

All investigated detector forms show nearly the same dosimetric properties. Due to the individual response of each detector as well as the influence of detector volume, thickness and surface area the absolute response distinguish between the different detectors. This is the reason why either an individual calibration or a classification of detectors into sensitivity badges is needed. in the BeO*max* system the individual calibration is used for all dose calculations.

The standard detector (4.7 x 4.7 x 0.5 mm³) shows a wide range of linearity of the dose characteristic from about 1 µGy up to a few Gy. For higher doses the signal saturates. This effect can by described with a saturation function which permits to specify well doses up to about 100 Gy. For the miniaturized mm-scale detectors the lowest detection level is about 0.1 mGy and the linear dose range reaches up to several 10 Gy. Within the linear dose range, the uncertainty of the results is less than 5%. 100 Gy-doses can be specified within 20%, with individual high dose calibration of the detectors even better than this value (see figure 3). For higher doses the saturation dominates the OSL. Then an unique dose specification becomes more difficult. It is not possible to measure doses higher than 300…500 Gy.

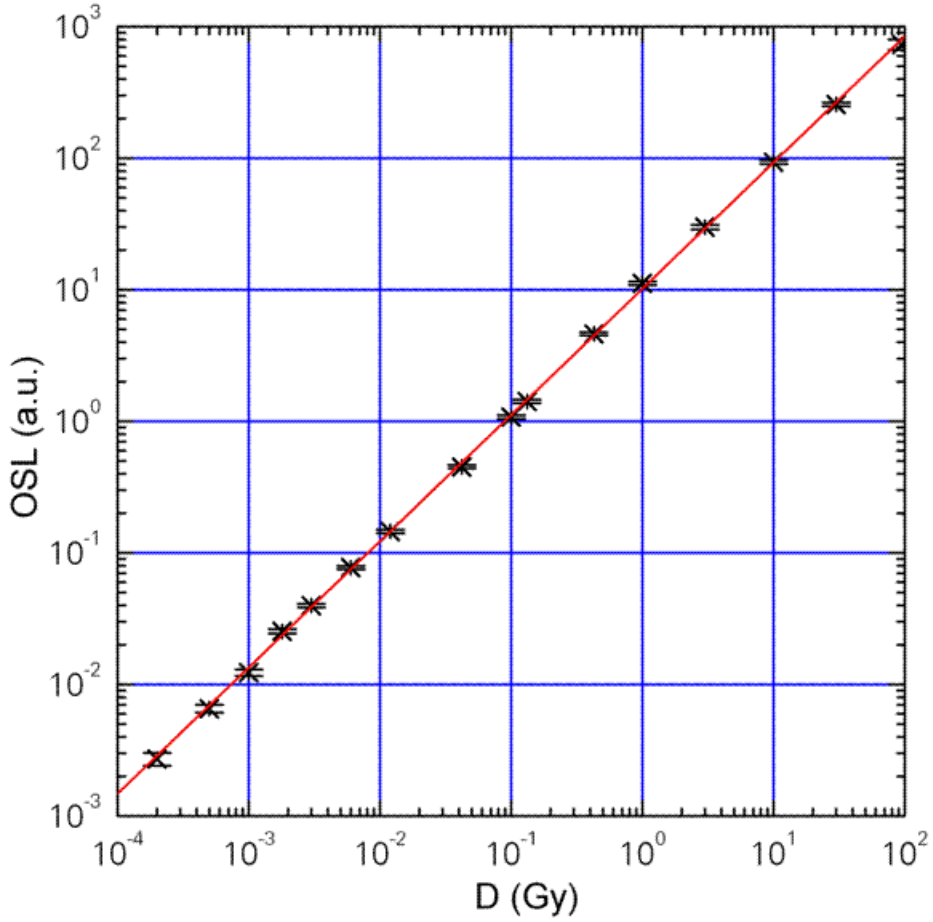

Fig 3. Dose characteristics of the mm-scale BeO detectors. The ratio between OSL signal and dose is constant within less than 1 mGy up to several 10 Gy. In this range the uncertainty is less than 5%.

RESULTS AND DISCUSSION

Beside a variety of standard applications during the last two years a special technique has been developed, tested and applied to the WAK. For planning of the plant dismantling extensive investigation of contaminations and dose rates must be done. Particularly dose rate profiles inside the high activity waste concentrate (HAWC) tanks as well as the vitrification plant have been measured through access gained through small thermoelement pipes that were available. These pipes provided a pathway to arrive at the points of interest without penetrating the tanks and without risc of contamination. These pipes have diameters of only 8 mm, but with lengths of up to 30 m.

The mm-scale dosimeters were packed into short heat-shrinkable tubings. The ends were bunged with carbon rods. Different tubing colors provide distinction of individual detectors (see figure 1, number 6). The dimensions of these wrapped dosimeters are about 5 mm in length and 1.5 mm in diameter. The next steps were achieved at WAK. The dosimeters were stringed as a chain on a wire and were shrink-wrapped then a second time. This chain was threaded into an up to 18 m long spring with outer diameter of 6 mm. For irradiation this spring could be slid-

ed into the thermoelement pipes very fast. The transport time for a 18 m long chain is less than 15 s. Hence, minimum exposure time of about 2 min is connected with acceptable errors.

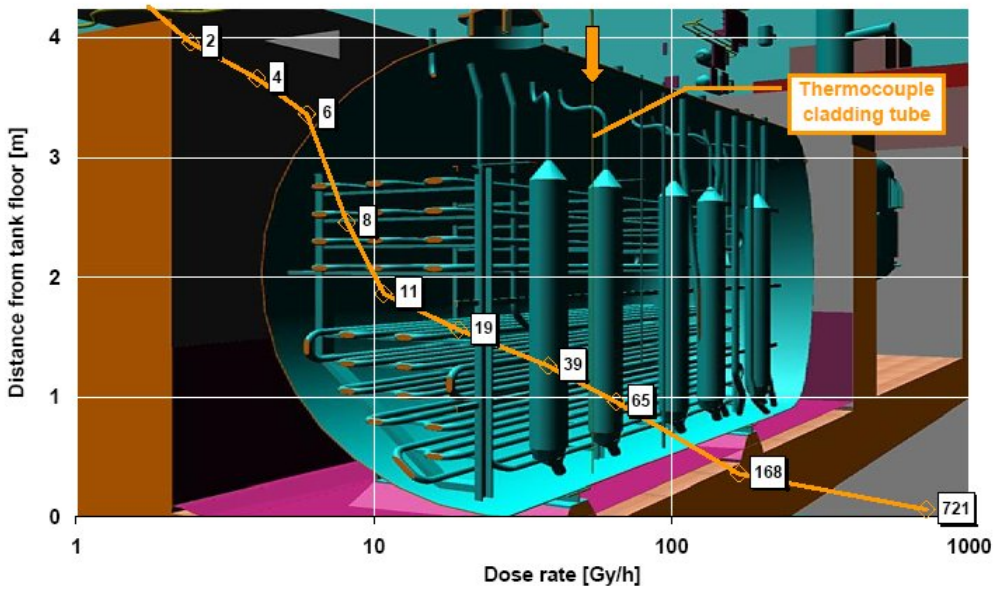

Fig 4. Dose rate profiles of an empty HAWC tank measured with miniaturized BeO OSL detectors. The HAWC was stored there for more than 20 years. Particularly on the bottom of the tank strong deposition of precipitates are found. The exposure time was 10 min, the maximum measured dose was about 120 Gy.

Up to now more than ten chains with several hundred dosimeters were measured for WAK. Depending on expected dose rate maximum exposure times from minimum 2 min up to several hours were specified. Doses from the lowest detection level of about 0.1 mGy inside the shielding walls up to more than 100 Gy near to the deposition of fission products were observed. These values are related to dose rates up to about 1 $kGyh^{-1}$.

Some of the chains show very inhomogeneous dose rate profiles. Particularly for these cases, OSL dosimetry offers an advantage to actually developed fibre-coupled radioluminescence techniques. The measured dose is not influenced by the Cherenkov effect and intrinsic luminescence of the fibre.

The performed measurements show that the most expensive part of the process is the packing and unpacking of the dosimeters as well as the preparation of the chains. The processing time of a chain with typically 35 dosimeters is about 8 h. Beside this the costs for the raw detectors are negligible. TU Dresden offers the complete system and a measuring service.

CONCLUSION

Doses from 0.1 mGy up to more than 100 Gy could be measured with the mm-scaled OSL dosimeters. Hence, over the storage time dose rates from μGyh^{-1} up to 1000 Gyh^{-1} are ascertainable. Within the linear dose range up to several ten Gy, the uncertainty of the results is less than 5%. 100 Gy-doses can be specified within 20%, with individual high dose calibration of the detectors even better. For WAK and other potential users the system offers the opportunity to

investigate dose rates inside of shieldings and in contaminated environments. Particularly in constricted environments the technique is an unique solution for dose and dose rate measurements.

REFERENCES

[1] Sommer, M., Freudenberg, R. and Henniger, J. (2007). New aspects of a BeO-based optically stimulated luminescence dosimeter. *Radiation Measurements, 42*, 617-620.
[2] Sommer, M., Jahn, A. and Henniger, J. (2008). Beryllium oxide as optically stimulated luminescence dosimeter. *Radiation Measurements, 43*, 353-356
[3] Sommer, M., Jahn, A. and Henniger, J. (2011). A new personal dosimetry system for $H_P(10)$ and $H_P(0.07)$ photon dose based on OSL dosimetry of beryllium oxide, *Radiation Measurements, 46,* 1818-1821