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ADVANCEMENTS IN PROSPECTIVE DOSIMETRY WITH NACL READ-OUT BY OPTICALLY STIMULATED LUMINESCENCE

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***Abstract*:** In this paper we present the recent improvements for optically stimulated luminescence dosimetry using ordinary salt (NaCl). It is shown that the dosimetric properties of NaCl may be improved by compressing the salt grains to solid pellets. With a linear dose response in, at least, the region <100 mGy, a zero background signal (when pre-bleached) and a minimum measureable dose of 10-20 µGy and high reproducibility, this opens for new applications of prospective OSL dosimetry with NaCl.

***Keywords*:** OSL, NaCl, household salt, dose response, MDD, MMD, dosimetry.

1. Introduction

Proper and accurate dosemeters are essential to control, maintain or improve the protection of workers and the public to ionizing radiation. When no such dosemeters are available, *e.g.* during unintentional exposure to ionizing radiation, other retrospective methods are needed to estimate the radiation dose for proper medical follow-up, if necessary, and for information to stakeholders. Currently there are many different methods for this purpose, based on various assessment methods: biological (e.g. cytogenetic-, genetic and haematological techniques), physical (e.g. thermoluminescent (TL) and optically stimulated luminescent (OSL)), and mathematical methods [1]. High demands are required on such dose registering indicators, or dosemeters, apart from having a reproducible signal which response is specific to ionizing radiation. For this purpose, both the TL- and OSL properties have been investigated in various forms of household and commonplace materials [2]. Several authors have identified ordinary salt (NaCl) as being a radiation sensitive materials that may be found close to man in a situation of unintentional exposure *e.g.* [3-5]. Particularly, household salt has shown dose detection levels below 1 mGy [3] and low fading. However, there are several issues making it complicated to use NaCl alone for individual retrospective dose determinations despite its beneficial dosimetric properties.

It has previously been suggested to use NaCl for prospective dosimetry using special dosemeter holders [6,7]. However, using ordinary salt in its original form as grains or as crystals is time-consuming and associated with several uncertainties during read-out and OSL signal conversion to absorbed dose. In order to improve the overall process of using NaCl for prospective dosimetry, without any degradation of the dosimetric properties, it is suggested to compress the salt grains into solid pellets.

There are several potential benefits of using salt in the form of pellets instead of its original form as grains. One obvious advantage is that the salt is easier to handle when in the form of a pellet, making it possible to position the dosemeters in a dosemeter holder or on/inside phantoms etc. Another advantage would be a higher density of signal producing crystal material per volume unit as well as a more homogenous and reproducible detector unit/sample. Further, as compared to commercial available alternatives of thermoluminescent dosimeters (TLD), and apart from the low cost of each dosemeter, there is potentially no need for any annealing, saving time during each read-out and calibration.

The aim of the current study was to further investigate the possibility of NaCl for OSL dosimetry by pressing the salt grains into pellets. This paper also provides suggestions of applications for these NaCl pellets as a new tool for prospective dosimetry in various exposure situations.

2. Instruments and Methods

Based on previous investigations of the OSL properties of household salt [3], Brand 5 with no additives (Falksalt fint bergsalt, Hanson & Möhring, Sweden) was considered to have the best dosimetric properties of the salt brands investigated. Hence, this type of household salt was used in the current study. For comparison, analytical grade NaCl (Scharlau, Scharlab, Spain) was also used in the current study. These two types of salt were used to optimize the process of manufacturing the salt pellets with the best properties. The specific properties considered were: mechanical stability of the pellet and the thickness and transparency of the pellet, *i.e.* sufficiently thick but at the same time thin enough to avoid self-quenching of the luminescence. This was investigated for various compression forces and for various grain size fractions of the two salts. The salt pellets with the optimal properties were then further investigated in terms of the dosimetric properties.

2.1. Production of NaCl pellets

The salt grains were compressed to pellets using a standard hydraulic hand-press (Hamron, Sweden), with a maximal compression force of 10 T (see Fig. 1).

Fig. 1. The hydraulic hand-press for producing the NaCl pellets. A special made tool (Fig. 2) was developed for this press.

In order to use this hand-press (Fig. 1) for making pellets, a special tool was manufactured (Fig. 2). This tool allows for five cavities of salt grains to be compress at the same time. The size of these cavities was determined in order to comply with the standard size of LiF chips, for convenient readout and use of the NaCl pellets in phantoms, dosemeter holders etc. The diameter of the pellets was fixed to 4 mm, whereas the thickness of the pellets was adjustable by varying the pressure force and the amount of salt in the cavities. For each filled tool, the compression force was equally divided over these cavities allowing simulations production of five NaCl pellets. A more detailed description of the NaCl pellet production may be found in [8].

The optimal grain size for pressing pellets was investigated by sieving the salts into four different fractions: <100 μm, 100-250 μm, 250-400 μm, >500 μm. Depending on the grain size, the weight of salt used for each pellet varied between ~18-22 mg. Each of these fractions were then compressed to pellets using different compression forces from 1 T up to 3 T in steps of 0.5 T.

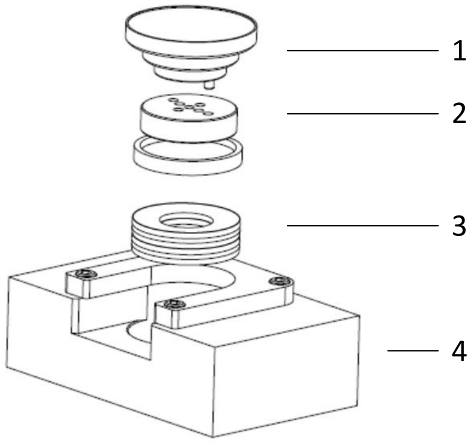

Fig. 2. Schematic outline of the dedicated press tool, with the central part made from brass (2). The tool is configured to simultaneously produce five NaCl pellets during each compression. The individual parts in the figure correspond to: 1.) the top of the press, consisting of a lid with five steel rods; 2.) the central brass piece with five cavities for NaCl; 3.) springs for controlling the compression force; 4.) the block holder where the different parts of the tool are kept at a firm position during compression.

The compression force was assured by the use of a set of precise spring rings (item 3 in Fig. 2) and a pressure gauge on the hand-press. The final pellets were then visually inspected under an electronic magnifier (60×) to examine the degree of inhomogenities within the pellets and to get an impression of the pellet transparency. The pellets with the best combinations, *i.e.* homogenous and transparent, were then tested for mechanical stress.

After deciding the ideal combination of grain size and compression force, the following dosimetric properties of the manufactured pellets were investigated: dose response, signal reproducibility, minimum detectable dose (MDD) and minimum measurable dose (MMD) according to [9,10].

2.2. Irradiation and read-out conditions

All readouts were carried out in a Risø TL/OSL reader (TL/OSL-DA-15, DTU Nutech, Denmark) [11]. This reader was equipped with a 20 MBq (2009-04-09) $^{90}Sr/^{90}Y$ irradiation source with a dose rate to a thin layer of calibrated quartz (DTU Nutech, Batch 101) of 0.79±0.02 mGy s^{-1} (2017-09-01). Using a stopping-power ratio of 0.943 between NaCl and SiO_2 the $^{90}Sr/^{90}Y$ dose rate to a thin layer of NaCl corresponds to 0.75 mGy s^{-1}. The pre-irradiated NaCl pellets were read-out, without any pre-heat, with blue LED light (40% of the total power) and at room temperature for 10 s.

Using the internal $^{90}Sr/^{90}Y$ source, a calibration curve was established in the absorbed dose range from 3.75 mGy to 75 mGy. For each given dose, the absorbed dose to the NaCl pellets was calculated as the average value of five pellets. In order to compensate for variations between individual pellets, the signal was normalized to the weight of the pellet.

Based on the signals in five irradiated NaCl pellets, for each dose in the dose response, the reproducibility was investigated in terms of the OSL signal normalized to the weight of the pellets and to a calibration dose (of the same magnitude).

3. Results and discussion

The best configuration of the NaCl pellets, according to the properties described above, was achieved for a compression force of 2.5 T, using grains in the size range: 100-500 µm, *i.e.* all grains of intermediate size. Hence, NaCl pellets made with those conditions were used during the further investigations of the dosimetric properties. NaCl pellets positioned on a white paper are presented in Fig. 3.

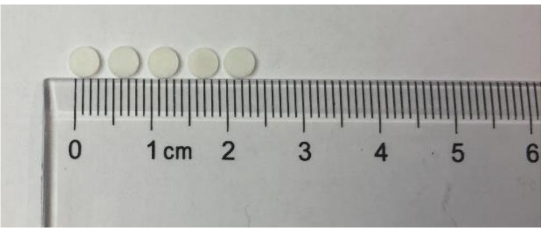

Fig. 3. Photograph of the NaCl pellets after compressing salt grains (250-400 µm) with a force of 2.5 T.

The dose response to $^{90}Sr/^{90}Y$ in the dose interval from 3.75 mGy to 75 mGy is shown in Fig. 4, where the average OSL signal from five individual pellets (for each dose) is normalized to the weight of the pellet.

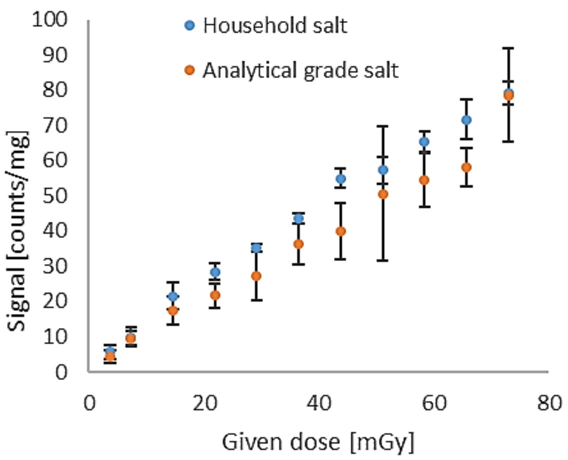

Fig. 4. $^{90}Sr/^{90}Y$ dose response for NaCl pellets made from household salt and analytical grade salt.

The relatively large uncertainty bars of the dose response in Fig. 4, may be further reduced by applying a so called calibration dose to the pellets after the OSL signal acquisition. By normalizing to a calibration dose, the signal from each pellet is weighted to the amount of OSL sensitive material of each pellet. Hence, based on the calibration curve (Fig. 4) the reproducibility of the OSL signal, when normalized to a calibration dose, was 0.2%-2%.
The calculated detection limits for the NaCl pellets made from household salt and chemically pure salt are presented in Table 1. As a further comparison, the specific luminescence, $c_{specific}$ (counts mg^{-1} mGy^{-1}), is also provided for the investigated salts.

Table 1. Statistics for the NaCl pellets in terms of three standard deviations of the background OSL signal (3*SD), minimal detectable dose (MDD) and minimal measurable dose (MMD), together with the specific luminescence ($c_{specific}$) for the two brands of salt investigated and for empty cups as a reference.

NaCl pellet	3*SD (counts)	MDD (µGy)	MMD (µGy)	$c_{specific}$ (counts mg^{-1} mGy^{-1})
Household salt	107	3.7	12	920
Chemically pure salt	155	5.5	19	790
Empty cup	257	N/A	N/A	N/A

N/A: Data not available.

As can be seen from Table 1, the MDDs of 3.7 µGy and 5.5 µGy for the household and chemical pure salts, respectively, are much lower than what has previously been observed for household salt when investigated as grains (a factor of about 100), which is comparable to LiF:Mg, Ti (TLD-100) [12]. This can be explained by the higher density of signal producing crystal material for the pellets as compared to salt as grains and the zero background signal of the pellets. The lower variation in the background signal, as compared to an empty cup, can be a result of the empty pellet blocking reflected stimulation light from the sample cup.

4. Conclusions

In this paper we have demonstrated improvements for OSL dosimetry with NaCl. When compressed as NaCl pellets, it is possible to achieve a reproducibility of the radiation induced OSL signal that is within 2%; the dose-response is linear for doses below 100 mGy; and, the MDD is around 4 µGy, for the household salt investigated. Considering these findings and the overall cost of manufacturing NaCl pellets, the proposed method of using NaCl compressed as pellets provide possibilities in radiation protection measurements that has so far been too expensive or impossible. Some of these applications include:

- Emergency dosimetry: for fast distribution and reporting of individual doses to the general public and emergency workers.
- Environmental monitoring: mass-mapping of the radiation levels in *e.g.* contaminated areas.
- Nuclear industry: carful mapping of special radiation situations for more efficient planning of delicate work *e.g.* when changing parts in compartments with high radiation exposure levels.
- Medical: as a cost-effective alternative to TLDs for the assessment of patient doses for most X-ray diagnostic modalities.
- Epidemiology: potential for measuring individual external doses for any person exposed to elevated levels of ionizing radiation.

- Research: the low price and easy access provide a tremendous potential in various aspects of radiation research and radiation protection.

A few important issues still remains to be studied further in order to fully use the potential of NaCl as a prospective dosemeter. More salts need to be investigated in order to determine the variation between different brands of salt. The read-out protocols and the calibration procedure should be further optimized for the purpose of a one-time use of the NaCl pellets. In addition, the whole concept would benefit from a dedicated OSL reader for NaCl pellets.

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