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# RADIATION EXPOSURE OF MEDICAL STAFF: APPLICATION OF HAND PHANTOMS IN EXPERIMENTS AND SIMULATIONS

**Abstract:** *To evaluate extremity doses and optimize radiation protection of medical staff, we investigated examples in nuclear medicine and CT fluoroscopy. In addition to measurements with medical staff on-site and with real hand phantoms, selected scenarios were simulated with hand phantoms. Besides simulations of static hand poses also modeling based on consecutive frames from video recordings during handling scenarios was realized. These procedures are useful tools to reveal highest exposures which in turn could promote initiating optimized radiation protection measures.*

**Key words:** hand phantom, MCNPX, Y-90, CT fluoroscopy, radiation protection, $H_P(0.07)$.

## INTRODUCTION

With the growing use of nuclear medicine therapies and interventional procedures using real-time image control by means of fluoroscopy combined with computed tomography (CT), detailed research concerning the radiation protection for the people working with these emitters becomes more and more important.

The following citation [1] concerning the increased use of CT underlines this: "What is becoming clear … is that the large doses of radiation from such scans will translate, statistically, into additional cancers."

This concerns not only the patient, where medical indications justify its use, but also medical workers, which represent the largest proportion of exposed people worldwide. The handling of high-energy beta-radiators and the CT fluoroscopy are supposed to be among the highest exposure scenarios for medical staff.

One task was to develop a method, to model handling scenarios on the information of images taken and to simulate them with a Monte Carlo code like MCNPX. Simulations using voxel hand phantoms or flexible mathematical hand phantoms are useful tools to investigate the hand exposure [2]. In particular for the case of inhomogeneous radiation fields, where measurements could be difficult, time consuming or not feasible at all, simulations are advantageous. Different scenarios can be simulated and situations with highest exposures can be revealed.

However, measurements performed with phantoms and detector equipment are still necessary in order to validate the simulations. Fig. 1 shows an example of our experimental set-up with the hand phantom [3] as used for our first measurements at a CT device.

**Figure 1.** *Experimental set-up of a wax hand phantom equipped with active (black) and passive (blue) sensors to determine the radiation exposure. The hand phantom was positioned on an anthropomorphic phantom (grey)*

## MATERIALS AND METHODS

The passive detectors shown in Fig. 1 are thermoluminescence detectors (TLDs) wrapped in blue plastic bags. Measurements of the extremity dose $H_P(0.07)$ were performed. Thin layer TLDs [4] were used to measure in mixed beta-gamma radiation fields, while for the X-Ray CT-measurements "Photon-TLDs" of type MTS-N [5] were employed. The "Beta-TLDs" were calibrated with a Beta Secondary Standard 2 [6], while the Photon-TLDs were calibrated according to

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the CT-device tube voltage, in the present case to the N-120 X-ray standard.

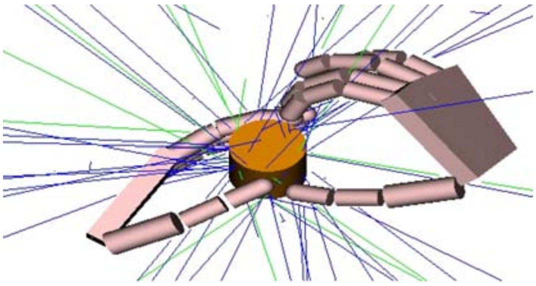

**Figure 2.** *Radiation scenario modeled with the self-developed software using an articulated hand phantom. The blue and green lines illustrate the simulated photon (green) and beta (blue) rays emitted from the fictive cylinder source*

A flexible hand phantom model was developed for simulations (see Fig. 2) [7]. The hand model, consisting of simple geometrical structures, can be moved via an interactive controlling interface. If 3-D coordinates of marked points on the hand, which can be obtained with a multi-camera system, are available, modeling can further be facilitated with an inverse kinematics procedure. In this way, in addition to the measurements, Monte Carlo simulations of different radiation scenarios were performed using the MCNPX code [8]. Fig. 2 shows a few rays emitted from the fictive cylinder source as calculated with MCNPX, together with the articulated hand phantom.


**Figure .3**. *TLDs fixed at different positions on a hand to measure the radiation exposure on-site. Some typical relative exposure values are indicated.*

The simulation results can be verified by measurements with real scenarios (Fig. 3) or e.g. with a wax hand phantom (Fig. 1).

To investigate the CT fluoroscopy we used a CT scanner at the Coimbra hospital. Fig. 4 shows the device. Our first measurements at a CT-device were performed with a "Brilliance CT 16-slice configuration" from Philips.

The wax hand phantom equipped with dosimeters (see Fig. 1) was employed to measure the dose distribution on the hand. To account for scattering effects, the hand phantom was placed on an anthropomorphic phantom.

DICOM files of the CT scans provide the basis to create voxel models or other models of the scenario. For the first test measurements we have chosen simple conditions in order to validate the simulations. The tube voltage was 120 kV, the tube current was 200 mA, and the tube rotation time was 1000 msec. For the measurements we selected a static option (incr=0) to have a simple scenario.

**Figure 4.** *CT scanner at the Coimbra hospital*

## RESULTS AND DISCUSSION

Investigations at KIT assessing medical staff extremity doses focused on selective internal radiation therapy and radiosynoviorthesis (RSO). In these therapies, the beta-emitting nuclide Y-90 is used.

So far measurements and simulations for nuclear medicine therapies employing the beta emitting nuclide Y-90 are almost finished at KIT [9]. As a result the strong inhomogeneous beta-gamma radiation field gives different exposures to different hand positions. In Fig. 3 the highest exposure is indicated at the right forefinger tip (typically measured values are about 1 mSv), while the fingering dosimeters only register 10% of the maximum exposure. As indicated with the question mark at the left thumb, not all exposure positions can be measured due to its complexity. Here the open question remains, if other positions would show a higher value as measured. Furthermore the example shows that the exposure measured with fingering dosimeters could strongly underestimate the "official" dose. Such discrepancies between official measured and real doses were investigated in detail in the ORAMED project [10].

To overcome the limitations by measurements, simulations are a useful tool.

**Figure 4.** *Snapshots taken with four cameras at different perspectives. Top: real pictures of handling a syringe with position markers at the hands (white spots), bottom: the same scenario as given by the articulated hand phantom as determined by the marker positions.*

An example for analyzing handling procedures is given in Fig. 4. Handling a syringe as employed in the RSO case study is presented here. In this laboratory study the fictive handling without use of activity was chosen to illustrate best the procedure (for details see [7, 9]).

In contrast to the measurements, simulations allow determining the dose distribution at all positions (however for the precise determination of $H_P(0.07)$ via energy deposition in so called tally cells simulation with MCNPX is also limited to 100 positions per simulation). Another important point is that measurements determine the integral dose, while simulated dose distributions can be revealed at each moment of interest. Several snapshots can be arranged to a sequence of action. Fig. 5 shows an example for such a simulation result. Employing the articulated hand phantom, the dose rate at the outer side of the distal phalanx of the right hand is shown over a handling interval of 40 seconds. Normalization to the filling volume was performed to account for the decreasing activity in the syringe during an injection [9]. As a result, such a procedure is useful to reveal situations with highest exposures. This knowledge allows thinking about possible measures to reduce the exposure.

The first results of our application of a hand phantom in a CT fluoroscopy device are given in the following. From the DICOM files of the CT scanner we created a voxel model of the scenario as pictured in Fig. 1.

In Figure 6 the voxel model together with the corresponding TLD measurement results are shown. As a conclusion the dose varies strongly. Similarly to the nuclear medicine investigations the radiation field turned out to be very inhomogeneous. This means again that a dose determination with fingering dosimeters could give an incorrect assessment of the real dose. In the given example the dose at the tip of the thumb amounts to 4 % of an annual limit of 500 mSv, while for the base of the ring finger, the typical position to wear a fingering dosimeter, only 0.1% is indicated. The corresponding simulations with the voxel model are in progress.

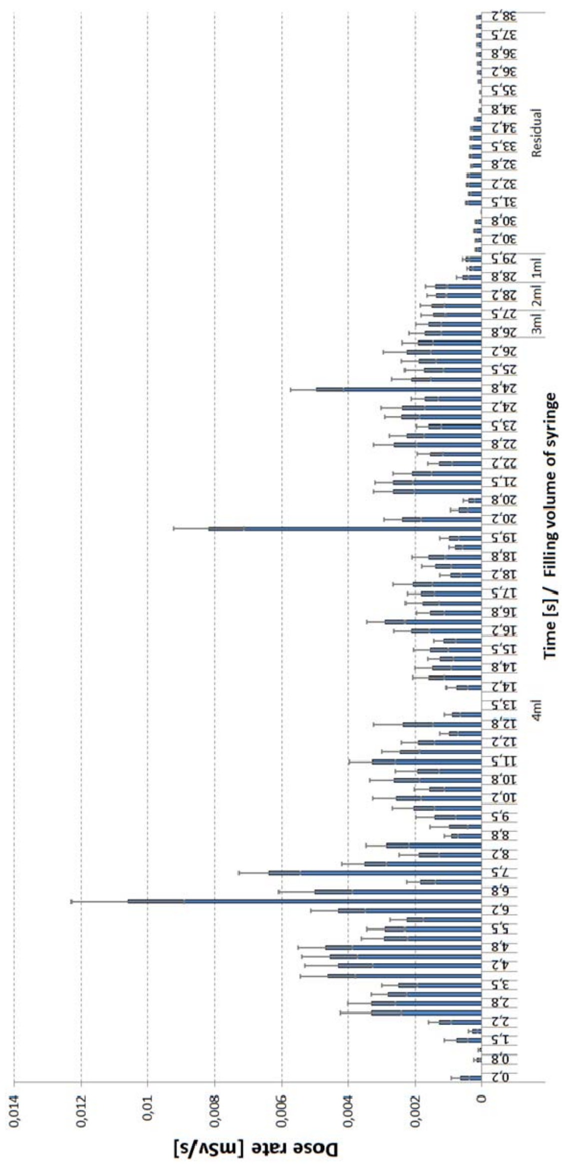


**Figure 5.** *Simulated dose rate at the outer side of the distal phalanx of the right hand against the time of handling*

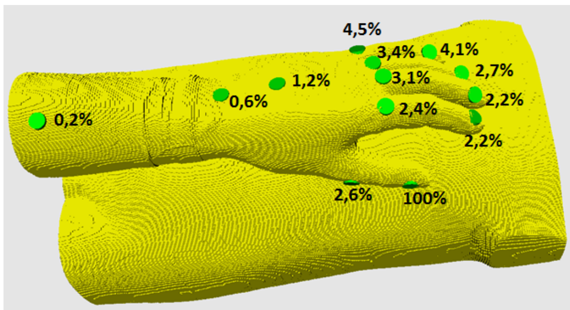


**Figure 6.** *Green disks on the voxel model of the hand phantom show the TLD positions. Next to the positions the relative measured dose is given. 100% corresponds to 20 mSv.*

## SUMMARY AND OUTLOOK

The purpose of this contribution is to point out where and how hand phantoms can be applied in experiments and simulations. We focused on the exposure of medical staff in nuclear medicine therapies and CT-Fluoroscopy. The latter project just started and is part of a EURADOS-project [11] and will be pursued on a European level.

The presented procedures allow searching for the moments of highest exposure. In this way e.g. an investigation of modified handling procedures and different shielding measures could yield an optimum radiation protection with reduced exposures.

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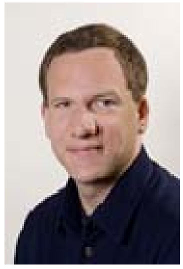

**Frank Becker** graduated from the University of Cologne, Germany and received the diploma in physics and the PhD in science from the Faculty of Mathematics and Natural Sciences.
Since 2006 researcher at the Forschungszentrum Karlsruhe in Germany and since 2009 at the Karlsruhe Institute of Technology (KIT), which was founded by a merger of Forschungszentrum Karlsruhe and Karlsruhe University. He is lecturer at the Baden-Wuerttemberg Cooperative State University Karlsruhe.
His main areas of radiation protection research include external dosimetry, development of methods for individual dosimetry of workers, radiation protection of medical staff, modeling and simulations of scenarios in nuclear waste disposal facilities, and detector development.

# EKSPOZICIJA ZRAČENJIMA MEDICNSKOG OSOBLJA: SIMULACIJA NA FANTOMU RUKE I EKSPERIMENTALNA ISTRAŽIVANJA

**Frank Becker, Christoph Blunck, Catarina Figueira, Bruno Esteves, Salvatore Di Maria, Graciano Paulo, Joana Santos, Pedro Teles, Pedro Vaz**

**Rezime**: *Da bi se utvrdile ekstremne doze radijacije i da bi se postigla optimalna zaštita medicinskog osoblja, analizirani su primeri iz prakse u nuklearnoj medicini i CT fluoroskopiji. Osim terenskih merenja, koriščeni su modeli ruku, kao i različiti scenariji izloženosti. Pored simulacija statičkih položaja ruku, ispitivani su i modeli generisani uzastopnim prikazima na osnovu video snimaka. Ove procedure predstavljaju koristan alat za otkrivanje najvišeg stepena izloženosti, što je od značaja za optimizaciju mera zaštite od elektromagnetnog zračenja.*

**Ključne reči:** fantom model ruke, MCNPX, Y-90, CT fluoroskopija, zaštita od zračenja, HP(0.07).