Action and Perception Thresholds of Static and ELF Magnetic and Electric Fields and Contact Currents in Humans

Abstracts of a workshop held at the Federal Office for Radiation Protection, Oberschleißheim/Neuherberg, October 26 – 27, 2016

Schriften

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INHALT

ACTION AND PERCEPTION THRESHOLDS OF STATIC AND ELF MAGNETIC AND ELECTRIC FIELDS AND CONTACT CURRENTS IN HUMANS

1 ZUSAMMENFASSUNG

Seit dem Ausstieg aus der Kernenergie und der zunehmenden Nutzung erneuerbarer Energien als Stromquelle wird der Stromnetzausbau bzw. die Umrüstung bestehender Netze in Deutschland weiter vorangetrieben. Diese Entwicklung kann dazu führen, dass die Bevölkerung vermehrt elektrischen und magnetischen Feldern ausgesetzt wird. Um die möglichen Auswirkungen genauer zu untersuchen, wurde vom Bundesamt für Strahlenschutz das Forschungsprogramm „Strahlenschutz beim Stromnetzausbau“ ins Leben gerufen. Ein Forschungsaspekt, der dabei genauer untersucht wird, beschäftigt sich mit Wahrnehmungs- und Wirkungsschwellen niederfrequenter Felder. Als eine der ersten Veranstaltungen im Rahmen dieses Schwerpunktes wurde vom Bundesamt für Strahlenschutz der internationale Workshop „Action and perception thresholds of static and ELF magnetic and electric fields and contact currents in humans“ organisiert.

Felder, wie sie von Starkstromleitungen ausgehen, können unter Umständen wahrgenommen und als unangenehm empfunden werden. Niederfrequente Magnetfelder induzieren im Körper elektrische Ströme, die oberhalb der Grenzwerte zur Reizung von Nerven und Muskeln führen. Statische elektrische Felder können bei hohen Feldstärken direkt wahrgenommen werden. Unter Stromleitungen können sich Metallgegenstände elektrisch aufladen. Bei Berührung durch Personen kann es zu Funkentladungen und Kontaktströmen kommen.

In allen genannten Szenarien ist die wissenschaftliche Datenlage bezüglich Schwellenwerte von biologischen Wirkungen und Wahrnehmbarkeit unzureichend und die Alters-und Geschlechtsabhängigkeit weitestgehend unbekannt.

Ziel des Workshops war es mit international ausgewiesenen Experten den aktuellen Kenntnisstand der Forschung zusammenzufassen und wissenschaftliche Kenntnislücken zu identifizieren, um darauf aufbauend mögliche Forschungsschwerpunkte zu definieren. Die einzelnen Aspekte wurden in Vorträgen von zwölf eingeladenen Rednern aus sechs Ländern zusammengefasst. Insgesamt haben zwanzig externe Gäste teilgenommen, alles Spezialisten auf den Gebieten der Dosimetrie, Biologie und des Strahlenschutzes.

Der Workshop hat im Oktober 2016 im Bundesamt für Strahlenschutz, Ingolstädter Landstraße 1, 85764 Oberschleißheim/Neuherberg stattgefunden.

2 SUMMARY

In Germany, the transition from nuclear to renewable energy sources for power production leads to the expansion of the existing power grid systems and to constructions of several new high voltage AC and DC power lines across the country. This will bring about an increased exposure of the population to static and ELF electric and magnetic fields. Therefore, research activities are planned to follow up the increased exposure and the possible biological effects.

The Federal Office for Radiation Protection (BfS) has launched the research programme "Radiation Protection in Power Grid Expansion". One of the research aspects, which will be examined in more detail, deals with the perception and action thresholds of low-frequency fields. One of the first activities within this topic was the international workshop on „Action and perception thresholds of static and ELF magnetic and electric fields and contact currents in humans“, organized by the German Federal Office for Radiation Protection (BfS).

Fields such as those emanating from power lines can under some circumstances be perceived and considered unpleasant. Low-frequency magnetic fields induce electric currents in the body that cause nerve and muscle stimulation above the limit values. Static electric fields can be directly perceived at high field strengths. Metal objects can charge themselves electrically under power lines. Contact with persons can then lead to spark discharges and contact currents.

In all of these scenarios, the scientific knowledge on threshold values for biological effects and sensations is insufficient and age and gender dependency are largely unknown.

The aim of the workshop was to summarize the recent state of scientific knowledge and to identify research gaps. The various aspects of the topic were covered by twelve presentations of invited speakers from six countries. Altogether, twenty external participants, experts in dosimetry, biology and radiation protection, took part at the workshop. On the basis of the results, further research will be initiated.

The workshop took place in October 2016 at the Federal Office for Radiation Protection, Ingolstaedter Landstrasse 1, 85764 Oberschleissheim/Neuherberg, Germany.

3 PROGRAMM

Wednesday, October 26th,

11.00	Welcome and Introduction to BfS	T. Jung
11.15	Purpose of the workshop	G. Ziegelberger
11.30	Lunch	
Session 1: Magnetic fields (Chairman: G. Ziegelberger)		
12.30	Thresholds for peripheral nerve stimulation by ELF magnetic fields in humans	W.H. Bailey
13.30	Experimental threshold for ELF magnetic field effects on human brain function	A. Legros
14.15	Modelling of ELF modulatory effects on neuronal functions	J. Modolo
15.00	Coffee break	
Session 2: Electric fields (Chairman: B. Pophof)		
15.30	Human perception of static and ELF electric fields	K. Shimizu
16.15	Provocation study on detection thresholds of static electric fields	K. Schmiedchen
Session 3: Dosimetry and modelling (Chairman: D. Geschwentner)		
17.00	Peripheral nerve stimulation – modelling	E. Neufeld
17.45	Thresholds of PNS and CNS stimulation: experiments and modelling	I. Laakso

Thursday, October 27th

Session 4: Electric currents (Chairman: B. Pophof)		
9.00	Electrical sensation and stimulation	J.P. Reilly
10.00	Transcranial Direct Current Stimulation	W. Paulus
10.45	Coffee break	
Session 5: Research perspectives (Chairman: G. Ziegelberger)		
11.15	Experimental human studies: quality requirements and methodological considerations	H. Danker-Hopfe
12.15	Technical requirements on exposure systems for humans	G. Schmid
12.45	Acquisition of physiological data under exposure	H. Dorn
13.15	Discussion: Scientific gaps and Research perspectives	
13.30	End	

4 ABSTRACTS

4.1 MAGNETIC FIELDS

4.1.1 Thresholds for peripheral nerve stimulation by ELF magnetic fields in humans

William H. Bailey

Health Sciences Group

To connect new sources of electricity in the north of Germany to load centers in the south, the Ultranet Plan would reconfigure existing quad AC transmission towers (2 x 110 kV and 2 x 380 kV) by replacing one 380-kV AC line with a ± 380-kV DC transmission line. The implications of this plan for exposure are likely decreased AC electric and magnetic fields on the right-of-way (depending on line phasing) and changes in ambient levels of static electric and magnetic fields. The proposed hybrid (AC/DC) structures will affect calculated levels of electric fields, audible noise, and radio/TV noise. The static field and space charge from the DC line may enhance the sensory perception of the 50-Hz electric field at the surface of the skin but the static magnetic field from the DC line will not affect induction from the AC magnetic field of the three remaining AC lines.

In projecting what levels of AC magnetic field would produce potentially adverse peripheral nerve stimulation by induction of electric fields beneath the skin, multiple sources of uncertainty in human physiology as well as model and dosimetry assumptions need to be considered. Here I describe the approach used to address some of these sources of uncertainty. The assessment of the likelihood of stimulation of peripheral nerves (PNS) by 50-Hertz (Hz) AC magnetic fields was made by reference to experimental measurements of rheobase thresholds for PNS in 84 human subjects reported by Bourland et al. (1999) and Nyenhuis et al. (2001) for pulsed, trapezoidal gradient fields generated by MRI coils. These data were analyzed in combination with dosimetric modeling of the electric field induced by these coils in subcutaneous body fat containing myelinated nerves in two anatomical, heterogeneous human models at locations with the lowest stimulation thresholds (Caputa et al., 2002; So et al., 2004). Rheobase thresholds for rectangular pulses with a chronaxie of 380 ms exceeded in 1% of voxels were converted to the amplitude of sinusoidal 50/60 Hz magnetic fields (Bailey and Nyenhuis, 2005). The median value for detection of nerve stimulation for a field coronal to the body was 47.9 ± 4.4 mT and the threshold for the most sensitive 1% of the population was 27.8 mT. At 50 Hz the thresholds were slightly (2%) lower. Thresholds for uncomfortable and intolerable stimulation and other orientations of magnetic field exposure were considerably higher.

As the allowed limit on public exposure to 50-Hz magnetic fields from transmission lines in Germany is 0.1 mT, there is no expectation that the magnetic field from the AC lines in the current Ultranet Plan would cause stimulation of peripheral nerves in persons walking under the lines.

4.1.2 Experimental threshold for ELF magnetic field effects on human brain function

A Legros[1,2,3], **J Modolo**[4], **D Goulet**[5], **M Plante**[5], **M Souques**[6], **F Deschamps**[7], **G Ostiguy**[5], **J Lambrozo**[6], **AW Thomas**[1]

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7: Service Environnement Réseaux, RTE, Paris, France

Living in our modern environment implies that we are constantly subjected to various types of electromagnetic exposures coming from different artificial sources, such as mobile phones, power-lines or electrical appliances. As a consequence, the question of possible biological effects from this type of exposure arises, and international organizations such as ICNIRP (International Commission on Non-Ionizing Radiation Protection) and IEEE-ICES (Institute of Electrical and Electronics Engineers - International Committee on Electromagnetic Safety) are responsible for issuing limits and recommendations to ensure public health and worker safety. In the context of the so-called Extremely Low Frequencies (ELF, <300 Hz), the time-varying magnetic field (MF) from the exposure induces electric fields and currents within biological structures, possibly leading to biological effects including on neuronal functions. In this frequency range, limits and recommendations are based on the exposure threshold at which acute effects are observed on synaptic communication in humans, hence resulting in modulated functional outcomes.

Our team is working since 2005 towards experimentally establishing these thresholds in human through the study of magnetically induced cognitive (e.g. short term memory) or motor (e.g. tremor, postural stability) modulations, changes in functional brain activity, and acute visual perceptions called magnetophosphenes.

This presentation will give an overview of recent human studies investigating the impact of ELF exposures on neurophysiological outcomes, and will report new results establishing the threshold for an acute neurophysiological response in humans: magnetophosphene perception.

Knowing and understanding the implications of this threshold for an acute neurophysiological response to a time-varying MF is critical from an international guidelines standpoint. Also, since the induced electric fields and current densities resulting from such stimuli are comparable to those produced by tDCS and tACS, possible translational applications will be discussed.

4.1.3 Modelling of ELF modulatory effects on neuronal functions

Julien Modolo[1,2,3]**, Alexandre Legros**[3,4,5,6]

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2: Institut National de la Santé et de la Recherche Médicale (INSERM), France

3: Human Threshold Research group, Lawson Health Research Institute, London (ON), Canada

4: Departments of Medical Biophysics and Medical Imaging, Western University, London (ON), Canada

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The increase prevalence of extremely low-frequency (ELF, < 300 Hz) magnetic fields in our daily environment has raised safety concerns regarding the general public and workers. Despite the accumulation of experimental data during the last decades, effects of ELF exposure on the human central nervous system remain controversial, due to conflicting experimental results and variability in experimental protocols.

One strategy to improve our understanding of the effects of ELF on human brain activity is the use of biophysical models of brain tissue, which combine knowledge from physics (electromagnetic theory from Maxwell) and from biology (neuroanatomy and neurophysiology) into a unique quantitative, predictive framework. Biophysical models enable the simulation of neuronal activity from the single cell to brain-scale activity, and can also account for the impact of electromagnetic stimuli. Such models have become, over the years, an accepted and validated strategy in the field of neuroscience, and are precious tools for integrating and making sense of the growing amount of experimental results.

This talk will first present briefly the different types of biophysical models of brain tissue, each with their strengths and weaknesses. Then, the talk will focus on different examples of real-life exposure in which biophysical models offer potential mechanistic explanations during high-level ELF exposure: modulation of neuronal spike timing potentially impacting synaptic plasticity, the perception of phosphenes (magnetophosphenes), and the effects on the vestibular system (induction of loss of balance). An emphasis will be made on the mechanisms suggested by these models and how these could be confirmed experimentally. Finally, we suggest that biophysical models of brain activity have a critical role to play to understand how electromagnetic fields exposure can impact human brain activity. Furthermore, these models can assist international regulation agencies such as IEEE and ICNIRP in re-evaluating guidelines of ELF exposure based on improved hypotheses regarding the mechanisms of action and corresponding safety factors.

4.2 ELECTRIC FIELDS

4.2.1 Human perception of static and ELF electric fields

Koichi Shimizu[1] **and Hisae O Shimizu**[2]

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To elucidate the mechanisms of biological effects of static and ELF electric fields, the characteristics of human perception were analyzed, and the causes of the perception were investigated. The perception threshold is apparently lower among people with longer and denser arm hairs, which suggests that body hair plays an important role in field perception. We derived the equation of motion to describe body hair movement caused by the electric force, and obtained an analytical solution for body hair movement in an electric field. This solution explains the causes underlying variations in the perception threshold described above and explains the lower perception threshold in an AC than in a DC electric field. To explain the cause of the seasonal perception threshold variation, we devised a technique to measure the dielectric constant of the body hair. Using this measurement method and the analytical solution, we achieved quantitative evaluation of the variation of body hair movement in different humidity conditions. These results verified the effectiveness and usefulness of the analytical technique developed for human perception of static and ELF electric fields.

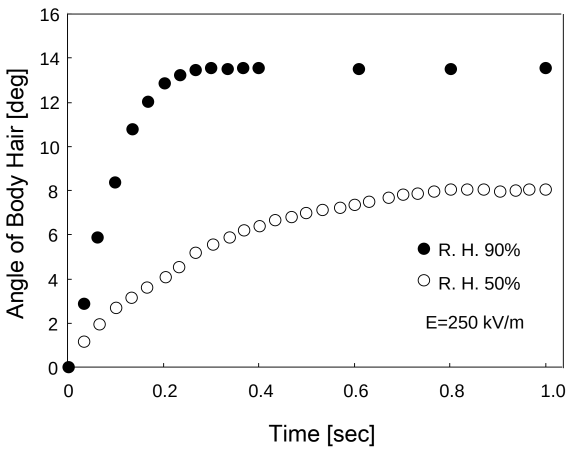

Fig. 1: Measured temporal change of body hair angle during electric field exposure: dependence on relative humidity.

4.2.2 Provocation study on detection thresholds of static electric fields

Kristina Schmiedchen, Dominik Stunder, Sarah Drießen

Research Center for Bioelectromagnetic Interaction, RWTH Aachen University, Aachen, Germany

Institute for High Voltage Technology, RWTH Aachen University, Aachen, Germany

Germany is increasingly shifting from nuclear power and fossil fuels to renewable energies. To connect offshore windfarms in the North Sea to power grids and transmit renewable energy over hundreds of kilometers, high-voltage direct current (HVDC) transmission lines are the technology of choice. With the expansion of these lines, the public has raised questions about exposure to static electric fields and the potential environmental effects.

The aim of this study is to examine the ability of humans to perceive the presence of those fields and to determine detection thresholds for DC fields alone and for hybrid fields (DC fields in combination with AC fields). An exposure chamber has been built for this purpose. Four electrodes produce electric fields and ion currents while air temperature, air humidity and ozone density will be constantly monitored. Two-hundred participants between the ages of 20 and 70 years will be tested in a double-blind study design. They will be exposed to DC fields up to 50 kV/m, AC fields up to 30 kV/m and ion current densities up to 400 nA/m2. Similar to the study by Blondin et al. (1996), the ability to detect static electric fields will be examined both with an adaptive staircase procedure and a rating procedure based on the signal detection theory. Participants are asked after each trial to judge the presence of an electric field. Randomly interspersed sham exposures, i.e. non-signal trials, serve as control condition. To further assess individual parameters for electric field sensitivity, body hair movements during exposure to electric fields, skin hydration level and vibrotactile detection thresholds will be recorded and correlated with detection thresholds for static electric fields.

Reference

Blondin, J, Nguyen, D, Sbeghen, J, Goulet, D, Cardinal, C, Maruvada, P, Plante, M, Bailey, W (1996). Human perception of electric fields and ion currents associated with high-voltage DC transmission lines, Bioelectromagnetics, 17(3), 230-241.

4.3 DOSIMETRY AND MODELLING

4.3.1 Peripheral nerve stimulation – modelling

Esra Neufeld

IT'IS Foundation, Zurich, Switzerland

When studying intended and unintended neurostimulation by electromagnetic fields, the inhomogeneity of the human anatomy not only determines the field exposure strength, but also impacts in a complex manner the resulting neuronal dynamics. Therefore, neuro-functionalized anatomical human phantoms suitable for coupled electromagnetic-electrophysiology computational studies are required. The generation of such functionalized phantoms and their application in exposure safety assessment, stimulation therapy modelling and personalization, and neuroprosthetic device development will be presented. The consequences for peripheral nerve stimulation and related limitations of current safety guidelines will also be discussed

4.3.2 Thresholds of PNS and CNS stimulation: experiments and modelling

Ilkka Laakso

Aalto University, Finland

Thresholds of electrical stimulation of the PNS and CNS form the scientific basis of human exposure guidelines at extremely low and intermediate frequencies. In humans, these thresholds can be measured using non-invasive electrical and magnetic stimulation. The drawback of non-invasive stimulation, because it is delivered externally at some distance from the targeted neural structures, is that the site of activation in the body is difficult to localize. Furthermore, we cannot measure the electric fields induced in the activation site, and these fields also depend on complex individual anatomical features. In recent years, progress in computational dosimetry has made it possible to determine the electric fields in detailed realistic anatomical models, allowing us to make direct comparisons between the electric fields and thresholds of physiologically measured responses. This talk describes recent advances we have made in combining data from electrophysiological measurements and computer modelling to determine the stimulation thresholds in intact humans.

For studying the PNS stimulation thresholds, we developed a computational technique that combines physical and biophysical models on two different spatial scales. This enabled us to model the whole chain of events from delivering the external stimulus, to determining the pattern of current flow in realistic anatomy, to activation of nerve fibers. Our experimental configurations utilized the recently developed technique of magnetic stimulation of motor nerve roots, which permitted reliable measurements of a wide range of responses for testing the model predictions.

In a second study, the thresholds of CNS stimulation were studied using transcranial magnetic stimulation. The study was made possible through the combination of actual electrophysiological findings and induced electric field modelling using actual MR images in nineteen subjects. To our knowledge, this work is one of the largest modelling studies featuring nineteen high-resolution realistic models constructed from individual magnetic resonance images, and the first study to compare the computational modelling results to actual physiological measurements in a large number of subjects.

In a third study, the stimulation thresholds of unmyelinated C-fibers, which convey pain sensation from the skin to the CNS, were studied using specially-designed intra-epidermal electrodes and microscopic modelling of the electric fields.

4.4 ELECTRIC CURRENTS

4.4.1 Electrical sensation and stimulation

J. Patrick Reilly

Silver Spring, USA

Factors responsible for human sensory reactions to electrostimulation are discussed with respect to exposures from power-frequency electric and magnetic fields, sinusoidal current at other frequencies, and pulsed current with arbitrary waveforms. Data are presented from theoretical models and human experiments. Presentation topics are:

A. AC field Induced Shock: Mechanisms of interaction. Electric shock waveforms that can be experienced near high voltage facilities, including brief capacitor discharges and AC contact current.

B. Electrostimulation Basics: Peripheral nerve stimulation principles. Strength-duration and strength-frequency effects.

C. Stimulation Waveform Effects: Factors affecting the stimulation "potency" of arbitrary waveforms, including pulsed currents or magnetic fields. Use of a neuroelectric model to characterize the relative stimulation strength of arbitrary pulsed waveforms on a consistent numerical scale.

D. Dose-Response Relationships: Physiological relationships in electrostimulation. Growth of sensation with increases in stimulus intensity. Effects of AC or repeated pulses. Human reactions from perception to intolerable pain. Reflex reactions.

E. Stimulated Body Location and Electrode Interface Effects. Sensory effects of electrode size and location on the body.

F. Intersubject variability. Inter-subject statistics of electrostimulation thresholds. Subject variables affecting individual thresholds. Application to exposure guidelines.

4.4.2 Transcranial Direct Current Stimulation

Walter Paulus

University Medical Center Göttingen

Transcranial electric stimulation techniques have been developed as cheap and efficient tools for modifying cortical plasticity. Whereas transcranial magnetic stimulation provides the vehicle which allows transferring transcranially short-pulsed (around ~ 100 µs) high electric energy without inducing strong pain perception direct transcranial electric stimulation of the human brain is painless due to it's use of much smaller intensities and less steep voltage gradients.

Transcranial direct current stimulation (tDCS) induces membrane polarization: cathodal stimulation hyperpolarizes, while anodal stimulation depolarizes the resting membrane potential. The induced plastic after-effects depend on polarity, duration, intensity, intervals and other stimulation aspects. A minimum duration of 3 min continuous stimulation at a minimum of 0.4 mA is required for induction of aftereffects. Transcranial alternating current (tACS) (Antal et al, 2008) and random noise stimulation (tRNS) intend to interfere with ongoing cortical oscillations (Terney et al., 2008). Using these techniques, it is possible to induce and modify differently neuroplastic changes with different advantages and disadvantages of tDCS, tACS and tRNS. Plastic aftereffects may reverse with longer stimulation. Whereas in the normal stimulation duration range of about 10 minutes tDCS allows for excitability increase and decrease, tACS and tRNS induce preferentially excitability increases with higher frequencies between 100 and 600 Hz or in the low kHz range. TACS and tRNS induce less skin sensation than tDCS and accordingly can be blinded better. They are also no longer current flow direction sensitive. These effects are strongly modified by neuropharmacological co-application. L-DOPA e.g. leads to a focusing effect of synapse specific plasticity in analogy to its otherwise found U-shaped dose dependency. Dopamine agonists may reverse anodal excitatory tDCS into inhibition, SSRI provide the opposite effect. In conclusion the targeted modulation of cortical plasticity in man by transcranial electrical stimulation techniques is restricted to small windows of physical stimulation parameters and can be further substantially modulated by co-application of neuropharmacological drugs.

4.5 RESEARCH PERSPECTIVES

4.5.1 Experimental human studies: quality requirements and methodological considerations.

Heidi Danker Hopfe

Kompetenzzentrum Schlafmedizin, Charité Universitätsmedizin Berlin, Berlin, Germany

Studies to investigate possible biological effects of magnetic and electric fields and currents in humans comprise both 1) epidemiological studies and 2) human experimental or provocation studies. Both types of studies have its strengths and limitations. The focus of this presentation is on human experimental studies. Among the strengths of this type of study are that exposure and factors that may introduce a large variability in the outcome parameter can be well controlled to enhance the chance of identifying effects – if present at all. Some of the limitations are that only short-term effects can be investigated, that results are specific for the experimental exposure design and that results might not be generalized to whole populations.

Quality requirements of experimental human studies will be discussed in the context of (randomized) clinical trials with special focus on statistical considerations (measurement scales, parametric vs. non-parametric tests, type I and type II errors). Methodological considerations will address studies on sensation and perception, specifically the estimation of thresholds.

4.5.2 Technical requirements on exposure systems for humans

Gernot Schmid

Seibersdorf Laboratories

For a high quality of human provocation studies, adequate exposure facilities are essential. Depending on the considered study endpoint and study design the particular requirements on the exposure system and the challenges in developing them may vary widely.

The most important basic requirements are

- reproducible, well defined exposure conditions
- adequate exposure levels and field vector orientations
- adequate volume with homogeneous field level
- guaranteed low background field levels (monitoring)
- control and recording of all relevant exposure parameters
- evaluation/quantification of potential artifacts (noise, vibration, warmth, etc.)
- double blinded application of exposure

For magnetic field exposure setups one of the main challenges is the physical restriction with respect to achievable exposure level and volume, which is particularly an issue in case uniform whole body exposure is requested. Due to the ohmic resistance of the coil windings not more than a few tens of mT at maximum can usually be achieved over body dimensions, when placing the subjects in a “coil-cage” of approximately 1.5 m in diameter. Correspondingly lower magnetic field strengths can be applied when the study design requires more space for the subjects. Using superconductor technology in order to overcome this problem is typically not feasible due to cost reasons. For exposing subjects to intense static magnetic fields the usage of MRI equipment is possible, however for ELF magnetic field exposure no such (cost-efficient) alternative is available. In practice, this means that a 50 Hz sinusoidal whole body magnetic field exposure above peripheral nerve (PN) stimulation threshold is typically not feasible, i.e., PN stimulation threshold studies are limited to partial body exposure setups or to the use of trapezoidal waveform magnetic fields with adjustable ramp time in order to obtain strengths-duration functions [1]. Head exposure systems enabling sinusoidal magnetic field exposure above CNS and/or retinal stimulation/perception thresholds in the CNS are feasible at reasonable effort. Beside the above mentioned principle limitations other important issues for ELF magnetic field exposure setups are the avoidance of unblinding due to noise, vibration and warmth perception by the subject. Differences in coil warmth development between sham and exposure can be handled either by coil cooling or by counter-current fed coils in sham condition. Keeping vibration and noise reliably below the subject’s perception threshold may require sophisticated mechanical/constructive measures, particularly in settings with intense magnetic fields and high dB/dt. In case of sinusoidal (non-pulsed) magnetic fields slow upregulation of the coil current helps avoiding mechanical forces during switch on. Anyway, a thorough specification/measurement of the remaining noise, vibration and warmth development both during exposure and sham condition is essential.

Electric field exposure facilities for human provocation studies are usually based on the plate capacitor principle, i.e., the subjects are located between a planar top (typically mounted close to the ceiling) and a planar bottom (typically at floor level) electrode between which a high voltage is applied. Due to the fact that a minimum distance between top and bottom electrode of at least 2.5 m is required, and limited lateral space, the ratio between lateral dimensions and distance between the electrodes is typically low which leads to substantial deviations from a uniform undisturbed electric field. Therefore, metallic “guard rings” (connected to a capacitive voltage divider between the electrodes) for control of the electric potential between the edges of the two electrodes are typically required to improve field homogeneity [2]. Particular for ELF electric field exposure facilities corona and connected ionization effects need to be considered. On the one hand the noise connected to it may be perceived by the subjects and therefore may affect blinding, and on the other hand ozone concentration at the subject’s place may be an issue. Therefore, avoiding sharp metallic edges and covering delicate structures with high-voltage putty must be recommended. Finally, as in case of the magnetic field exposure facilities mentioned above, a thorough evaluation of all remaining potential artifacts (noise, corona, etc.) is considered essential also for electric field exposure setups.

[1] J. D. Bourland, J. A. Nyenhuis, and D. J. Schaefer, “Physiologic effects of intense MRI gradient fields,” Neuroimag. Clin. North Amer., vol. 9, pp. 363–370, 1999.

[2] H. D. Cohen, C. Graham, M. R. Cook, J. W. Phelps, “ELF exposure facility for human testing,” Bioelectromagnetics., vol. 13, pp. 169–182, 1992.

4.5.3 Acquisition of physiological data under exposure

Hans Dorn

Kompetenzzentrum Schlafmedizin, Charité Universitätsmedizin Berlin, Berlin, Germany

Research on perception thresholds is (besides assessing subjective data) interested in physiological measurements. In the presence of static or extremely low frequency (ELF) electric or magnetic fields which are strong enough for a possible perception by humans, such measurements may be a challenge. Interactions between the measurement and the investigated field(s) in both directions will have to be minimized: (1) errors or artifacts in the measurement due to field effects or the subject moving in the field and (2) disturbing the field geometry by the measurement sensors/instrumentation. Interaction with the measurement and additionally (3) with other equipment may result in a compromised blinding of experiments.

Measured data include (A) electrical biosignals, (B) non-electrical parameters assessed using electronic sensors/instrumentation and (C) performance/behaviour/mood of the subject. Specially designed sensors and devices may be needed. Essentially, miniaturization, prevention of conductive elements where possible and minimization of loops in signal paths will help to solve problems. For 'B' and 'C' there will be technical solutions for virtually any purpose. Measurements 'A' are complicated but possible in many situations. There is much experience already for e.g. simultaneous EEG-fMRI recordings, which suffer from similar interaction like magnetic field experiments. A combination of special hardware designs and artifact compensation techniques allows for coexistence of EEG acquisition and strong static and varying magnetic fields.

Whole body static or ELF electric fields exposure at sensation strength with Simultaneously performed 'A' measurements (electrical biosignals) will require a high effort for appropriate hardware designs and/or will be affected from limited resolution of the measurement and/or will distort the exposure. Partial body exposure experiments may be much easier feasible of course.

Every biosignal can be measured in almost any environment. It may take a lot of effort though.

Bisher erschienene BfS-Schriften

BfS-SCHR-1/90
Warnecke, E.; Odoj, R.; Simon, R. (Editors)
Requirements for Waste Acceptance and Quality Control.
Proceedings of the 2nd International Seminar on Radioactive Waste Products.
28 May - 1 June 1990, Research Centre Jülich, Federal Republic of Germany.
Salzgitter 1990

BfS-SCHR-2/91
Sicherheitsreihe Nr. 6.
IAEO-Empfehlungen für die sichere Beförderung radioaktiver Stoffe. Ausgabe 1985.
(Diese Übersetzung enthält auch die von der IAEO im Nachtrag 1988 zu den Empfehlungen vorgenommenen Ergänzungen).
Salzgitter 1991

BfS-SCHR-3/91
Schüttmann, W.; Aurand, K.
Die Geschichte der Außenstelle Oberschlema des Kaiser-Wilhelm-Instituts für Biophysik Frankfurt am Main.
Salzgitter 1991

BfS-SCHR-4/91
Bornemann, O. (mit einem Beitrag von *R. Fischbeck*)
Zur Geologie des Salzstocks Gorleben nach den Bohrergebnissen.
Salzgitter 1991

BfS-SCHR-5/92
Herrmann, *A.G.*
Endlager für radioaktive Abfälle Morsleben (ERAM).
Lösungszuflüsse in den Grubenfeldern Marie und Bartensleben: Stoffbestand, Herkunft, Entstehung. Eine Dokumentation.
Zweiter Bericht. Abschlußbericht für den Zeitabschnitt 1. Januar bis 31. Dezember 1991. Clausthal-Zellerfeld, den 29. Februar 1992.
Salzgitter 1992

BfS-SCHR-6/92
Bestandsaufnahme IMIS-IT.
Seminar zum Projektstand IMIS am 3. Mai 1991.
Salzgitter 1992

BfS-SCHR-7/92
Empfehlungen der Reaktor-Sicherheitskommission (RSK) 1987 - 1991 (Band 7).
Zusammengestellt von der RSK-Geschäftsstelle.
Salzgitter 1992

BfS-SCHR-8/92
Radiologische Erfassung, Untersuchung und Bewertung bergbaulicher Altlasten.
Abschlußbericht zum ersten Teilprojekt.
Salzgitter 1992

BfS-SCHR-9/93
Grosche, B.; Burkart, W. (Editors)
Radiation epidemiology after the Chernobyl accident.
Proceedings of a workshop held at the Institute for Radiation Hygiene, Federal Office of Radiation Protection, Neuherberg, October 23-25, 1991

Bisher erschienene BfS-Schriften

BfS-SCHR-10/93
von Borstel, L.E.
Lösungen in marinen Evaporiten.
Salzgitter 1993

BfS-SCHR-11/93
Herrmann, *A.G.*
Endlager für radioaktive Abfälle Morsleben (ERAM).
Lösungsvorkommen in den Grubenfeldern Marie und Bartensleben: Stoffbestand, Herkunft, Entstehung.
Eine Dokumentation.
Abschlußbericht für den Zeitabschnitt 1. Januar bis 31. Dezember 1992. Clausthal-Zellerfeld, den 29. Februar 1992.
Salzgitter 1993

BfS-SCHR-12/93
IMIS-Statusgespräch.
Seminar zum Projektstand IMIS am 1. Februar 1993.
Salzgitter 1993

BfS-SCHR-13/94
Przyborowski, S.; Röhnsch, W.
ICRP-Publikation 65
über den Schutz gegenüber Radon-222 in Wohnung und an Arbeitsplätzen und die Situation in der Bundesrepublik Deutschland.
Salzgitter, 1994

BfS-SCHR-14/95
Kammerer, L.; Peter, J.; Burkhardt, J.; Trugenberger-Schnabel, A.; Bergler, I.
Umweltradioaktivität in der Bundesrepublik Deutschland 1992 und 1993. Daten und Bewertung.
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz.
Salzgitter, Dezember 1995

BfS-SCHR-15/96
Solare terrestrische UV-Strahlung in Deutschland.
Meßergebnisse und strahlenhygienische Bewertung der Daten aus dem UV-Meßnetz des BFS/UBA für den Zeitraum Januar bis Dezember 1994.
Salzgitter, März 1996

BfS-SCHR-16/98
Kammerer, L.
Umweltradioaktivität in der Bundesrepublik Deutschland 1994 bis 1995. Daten und Bewertung.
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz.
Salzgitter, März 1998

BfS-SCHR-17/98
Radiologische Erfassung, Untersuchung und Bewertung bergbaulicher Altlasten.
Abschlußbericht zum zweiten Teilprojekt.
Salzgitter, März 1998

BfS-SCHR-18/98
Sonnek, C.
Die Euratom-Grundnormen für den Strahlenschutz 1996 und 1997.
Ausblick auf zukünftiges Strahlenschutzrecht in Deutschland.
Salzgitter, Juli 1998

Bisher erschienene BfS-Schriften

BfS-SCHR-19/99
Strahlenschutz und Sicherheit in der Medizin.
ICRP-Veröffentlichung 73.
Ein Bericht einer Arbeitsgruppe des Komitees 3 der Internationalen Strahlenschutzkommission.
Von der Kommission angenommen im März 1996.
Salzgitter, Mai 1999

BfS-SCHR-20/99
WORKSHOP
Strahlenüberwachung von Arbeitsplätzen mit erhöhten Konzentrationen von Radon und Radonzerfallsprodukten und Qualitätssicherung der Überwachungsmessungen.
22. bis 24. Juni 1998, Berlin.
Salzgitter, November 1999

BfS-SCHR-21/00
Kammerer, L.
Umweltradioaktivität in der Bundesrepublik Deutschland 1996 und 1997. Daten und Bewertung.
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz.
Salzgitter, Oktober 2000

BfS-SCHR-22/01
Ettenhuber, E.; Gehrcke, K.
Radiologische Erfassung, Untersuchung und Bewertung bergbaulicher Altlasten.
Abschlussbericht.
Salzgitter, März 2001

BfS-SCHR-23/01 (ist nicht als Druck erschienen, nur im Internet)
Steinmetz, M.
UV-Index in practical use
Proceedings of an International Workshop
Institute of radiation hygiene, Munich, Germany, December 4-7, 2000
Salzgitter, 2001

BfS-SCHR-24/02
Peter J.; Schneider G.; Bayer A.; Trugenberger-Schnabel A.
High Levels of Natural Radiation and Radon Areas:
Radiation Dose and Health Effects
Proceedings of the 5th International Conference on High Levels of Natural Radiation and Radon Areas held in Munich, Germany on September 4 to 7 2000
Neuherberg, März 2002

BfS-SCHR-25/02
Brix, J.; Matthes, R.; Schulz, O.; Weiss, W.
Forschungsprojekte zur Wirkung elektromagnetischer Felder des Mobilfunks.
Bundesamt für Strahlenschutz
21. und 22. Juni 2001
Salzgitter, Juni 2002

BfS-SCHR-26/02
Bruchertseifer, F.; Pohl, H.
Fachgespräch
Begrenzung der Strahlenexposition als Folge von Störfällen bei kerntechnischen Anlagen und Einrichtungen.
1. und 2. März 2001
Salzgitter, Juni 2002

BfS-SCHR-27/03
Trugenberger-Schnabel, A.; Peter J.;
Kanzliwius, R.; Bernhard, C.; Bergler, I.
Umweltradioaktivität in der Bundesrepublik Deutschland 1998 bis 2001
Daten und Bewertung
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz
Salzgitter, Januar 2003

BfS-SCHR-28/03
Walter, H.
2.Fachgespräch SODAR
19. u. 20. März 2003
Im Auftrag des Bundesministeriums für Umwelt,
Naturschutz und Reaktorsicherheit
Zusammenfassung der Vorträge
Salzgitter, Juni 2003

BfS-SCHR-29/03
Bergler, I.; Bernhard, C.; Gödde, R.; Schmitt-Hannig, A.
Strahlenschutzforschung
- Programmreport 2001 -
Bericht über das vom Bundesamt für Strahlenschutz fachlich und verwaltungsgemäß begleitete
Ressortforschungsprogramm Strahlenschutz des Bundesumweltministeriums
Salzgitter, Juni 2003

BfS-SCHR-30/04
Lennartz, H.-A.; Mussel, Ch.; Thieme, M.
Beteiligung der Öffentlichkeit bei der Standortauswahl für die Endlagerung radioaktiver Abfälle
Abschlussbericht
Salzgitter, April 2004

BfS-SCHR-31/04
Weiß, D.; Bönigke, G.; Spoden, E.; Warnecke, E.
Übersicht zu stillgelegten kerntechnischen Anlagen in Deutschland und in Europa – Januar 2004
Salzgitter, September 2004

BfS-SCHR-32/04
Bergler, I.; Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2003
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrativ begleitete
Ressortforschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und
Reaktorsicherheit
Salzgitter, Dezember 2004

BfS-SCHR-33/05
Hartmann, M.; Beyer, D.; Dalheimer, A.; Hänisch, K.
Ergebnisse der In-vitro-Ringversuche: S-35 in Urin sowie Am-241 und Pu-Isotope in Urin
Workshop zu den In-vitro-Ringversuchen 2001 und 2002 der Leitstelle Inkorporationsüberwachung
des BfS am 1. Juli 2003 im Bayerischen Landesamt für Umweltschutz, Kulmbach
Salzgitter, Januar 2005

BfS-SCHR-34/05 (nur als CD vorhanden)
Trugenberger-Schnabel, A.; Peter, J.; Kanzliwius, R.; Bernhard, C.; Bergler, I.
Umweltradioaktivität in der Bundesrepublik Deutschland
Bericht der Leitstellen des Bundes und des Bundesamtes für Strahlenschutz
Daten und Bewertung für 2002 und 2003
Salzgitter, Juni 2005

Bisher erschienene BfS-Schriften

BfS-SCHR-35/05 (nur als CD vorhanden)
Bergler, I.; Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2004
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrativ begleitete Ressortforschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, August 2005

BfS-SCHR-36/05 (nur als CD vorhanden)
Steinmetz, M.
200 Jahre solare UV-Strahlung
Geschichte und Perspektiven
Wissenschaftliches Kolloquium
Salzgitter, Oktober 2005

BfS-SCHR-37/05
Facharbeitskreis Probabilistische Sicherheitsanalyse für Kernkraftwerke
Methoden zur probabilistischen Sicherheitsanalyse für Kernkraftwerke
Stand: August 2005
Salzgitter, Oktober 2005

BfS-SCHR-38/05
Facharbeitskreis Probabilistische Sicherheitsanalyse für Kernkraftwerke
Daten zur probabilistischen Sicherheitsanalyse für Kernkraftwerke
Stand: August 2005
Salzgitter, Oktober 2005

BfS-SCHR-39/06
Borrmann, F.; Brennecke, P.; Koch, W.; Kugel, K.; Rehs, B.; Steyer, S.; Warnecke, E.
Management of Decommissioning Waste in Germany
Contribution to the IAEA CRP on „Disposal Aspects of Low and Intermediate level Decommissioning Waste"
Stand: August 2006
Salzgitter, Dezember 2006

BfS-SCHR-40/06
Bergler, I.; Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2005
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrative begleitete Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2006

BfS-SCHR-41/07
*Schkade, U.-K.; Arnold, D. *); Döring, J.; Hartmann, M.; Wershofen, H. *)*
**) Physikalisch-Technische Bundesanstalt*
Gammaspektrometrische Bestimmung der spezifischen Aktivitäten natürlicher Radionuklide in Umweltproben
7. Vergleichsanalyse „Boden 2006"
Leitstelle für Fragen der Radioaktivitätsüberwachung bei erhöhter natürlicher Radioaktivität
Berlin, Dezember 2006
Salzgitter, Januar 2007

BfS-SCHR-42/07
Dushe, C.; Ettenhuber, E.; Gehrcke, K.; Kümmel, M.; Schulz, H. [*)]
[*)] *IAF-Radioökologie GmbH Dresden*
Ein neues Verfahren zur Ermittlung der Radonexhalation großer Flächen
Salzgitter, Februar 2007

Bisher erschienene BfS-Schriften

BfS-SCHR-43/07
Richtlinie für die physikalische Strahlenschutzkontrolle zur Ermittlung der Körperdosis
Teil 2: Ermittlung der Körperdosis bei innerer Strahlenexposition; Inkorporationsüberwachung
(§§ 40, 41 und 42 Strahlenschutzverordnung)
Rundschreiben vom 12.01.2007 RS II 3 – 15530/1 (GMBl 2007 S. 623)
Salzgitter, September 2007

BfS-SCHR-44/07
Bernhard, C.; Gödde, R.; Löbke-Reinl, A.; Schmitt-Hannig, A.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2006
Bericht über das vom Bundesamt für Strahlenschutz fachlich und administrativ begleitete Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2007

BfS-SCHR-45/09
urn:nbn:de:0221-2009011200
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2007
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Januar 2009

BfS-SCHR-46/09
urn:nbn:de:0221-2009082120
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2008
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, November 2009

BfS-SCHR-47/09
urn:nbn:de:0221-2009082154
Die Empfehlungen der Internationalen Strahlenschutzkommission (ICRP) von 2007
ICRP-Veröffentlichung 103, verabschiedet im März 2007
Deutsche Ausgabe
Salzgitter, November 2009

BfS-SCHR-48/10
urn:nbn:de:0221-201009153217
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, C.; Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2009
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, November 2010

Bisher erschienene BfS-Schriften

BfS-SCHR-49/11
urn:nbn:de:0221-201111236640
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2010
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, November 2011

BfS-SCHR-50/12
urn:nbn:de:0221-2012120510259
Beyermann, M.; Bünger, T.; Guttmann, A.; Schmidt, K.; Wershofen, H.; Winterfeldt, I.; Labahn, A.
Ringversuch zur Bestimmung von Radon-222, Radium-226, Radium-228, Uran-238, Uran-234 und der Gesamt-**α**-Aktivität in Trinkwasser – Ringversuch 4/2012
Salzgitter, Dezember 2012

BfS-SCHR-51/13
urn:nbn:de:0221-2013012210275
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.
Strahlenschutzforschung
Programmreport 2011
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2012

BfS-SCHR-52/13
urn:nbn:de:0221-2013110811124
Bernhard-Ströl, C.; Gödde, R.; Hachenberger, Claudia, Löbke-Reinl, A.; Schmitt-Hannig, A.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2012
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit
Salzgitter, Dezember 2013

BfS-SCHR-53/14
urn:nbn:de:0221-2014010911155
Schmitt-Hannig, A.; Peter, J.; Bernhard-Ströl, C.; Trugenberger-Schnabel, A.; Hachenberger, C, Löbke-Reinl, A.; Schulte-Büttner, B.
International Cooperation and Research
Report on International Cooperation and Research Activities at the Federal Office for Radiation Protection
Status 2013
Salzgitter, Januar 2014

BfS-SCHR-54/14
urn:nbn:de:0221-2014081211479
Schmitt-Hannig, A.; Gödde, R.; Löbke-Reinl, A.; Hachenberger, C.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2013
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit
Salzgitter, September 2014

BfS-SCHR-55/14
urn:nbn:de:0221-2015021712440
*Walter, H.; Gering, F.; Arnold, K.; Gerich, B.; Heinrich,G.; Welte,U. *)*
**) Strahlenschutzkommission*
Simulation potentieller Unfallszenarien für den Notfallschutz in der Umgebung von Kernkraftwerken mit RODOS
Salzgitter, Dezember 2014

BfS-SCHR-56/15
urn:nbn:de:0221-2015052612750
*Brendebach,B. *); Imielski P.*); Kühn, K.; Rehs, B.*
**) Gesellschaft für Anlagen- und Reaktorsicherheit*
Stilllegung kerntechnischer Anlagen in Europa
Stand: Dezember 2014
Salzgitter, Mai 2015

BfS-SCHR-57/15
urn:nbn:de:0221-2015082013351
Schmitt-Hannig, A.; Löbke-Reinl, A.; Peter, J.; Gödde, R.; Hachenberger, C.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2014
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit
Salzgitter, September 2015

BfS-SCHR-58/16
urn:nbn:de:0221-2016022414011
Arx, Cyrill von; Glaab, Hubert; Grimm, Christian; Martens, Reinhard; Päsler-Sauer, Jürgen; Scheuermann, Walter; Schnadt, Horst; Schumacher, Peter; Torchiani, Silke; Walter, Hartmut; Wilbois, Thomas
Vergleich aktuell eingesetzter Modelle zur Beschreibung der atmosphärischen Ausbreitung radioaktiver Stoffe
Abschlussbericht zum Arbeitspaket AP 5500 der Arbeitsgruppe „Erfahrungsfluss Fukushima“ des Ausschusses „Notfallschutz“ der Strahlenschutzkommission
Salzgitter, Februar 2016

BfS-SCHR-59/16
urn:nbn:de:0221-2016080114068
Schmitt-Hannig, A.; Löbke-Reinl, A.; Peter, J.; Gödde, R.; Hachenberger, C.; Trugenberger-Schnabel, A.
Strahlenschutzforschung
Programmreport 2015
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit
Salzgitter, August 2016

BfS-SCHR-60/16
urn:nbn:de:0221-2016091214084
*Walter, H.; Gering, F.; Arnold, K.; Gerich, B.; Heinrich,G.; Welte,U. *)*
**) Strahlenschutzkommission*
RODOS-based Simulation of Potential Accident Scenarios for Emergency Response Management in the Vicinity of Nuclear Power Plants
Salzgitter, September 2016

Bisher erschienene BfS-Schriften

BfS-SCHR-61/16
urn:nbn:de:0221-2016091314090
Facharbeitskreis Probabilistische Sicherheitsanalyse für Kernkraftwerke
Methoden und Daten zur probabilistischen Sicherheitsanalyse für Kernkraftwerke
Stand: Mai 2015
Salzgitter, September 2016

BfS-SCHR-62/17
urn:nbn:de:0221-2017102314426
Schmitt-Hannig, A.; Löbke-Reinl, A.; Peter, J.; Gödde, R.; Hachenberger, C.; Trugenberger-Schnabel, A. (Redaktion)
Strahlenschutzforschung
Programmreport 2016
Bericht über das vom Bundesamt für Strahlenschutz fachlich begleitete und administrativ umgesetzte Forschungsprogramm Strahlenschutz des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit
Salzgitter, Oktober 2017

BfS-SCHR-63/18
urn:nbn:de:0221-2018011814498
Action and Perception Thresholds of Static and ELF Magnetic and Electric Fields and Contact Currents in Humans,
Abstracts of a workshop held at the Federal Office for Radiation Protection,
Oberschleißheim/Neuherberg, October 26-27, 2016
Salzgitter, Januar 2018

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