A Radio Frequency Radiation Reverberation Chamber Exposure System for Rodents

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Abstract

Reverberation chambers have long been used for EMC measurements on equipment; however, it was only recently that they have been developed as a paradigm for animal exposure to radio frequency radiation. This paper describes the system of 21 reverberation chambers developed for the National Toxicology Program of the National Institute of Environmental Health Sciences for assessing potential toxicity or carcinogenicity of mobile phone radiation and some of the specific decisions that were made and challenges that had to be overcome. Also detailed is the overall performance achieved.

1. Introduction

This paper presents the design and experimental results for a reverberation chamber based exposure setup for individually housed unconstrained rodents suitable for exposure over extended periods. The idea of using reverberation chambers for animal exposure to electromagnetic fields was first suggested by the National Institute of Standards and Technology (NIST) in a special session at BEMS 2001. A preliminary study involving an experimental investigation performed by NIST and a preliminary numerical dosimetry study performed by IT'IS, both funded by the National Institute of Environmental Health Sciences (NIEHS) in the USA. The results of this preliminary study were very encouraging and in January 2006 the main study to evaluate the potential toxicity and carcinogenicity of cell phone RF radiation in laboratory animals was issued by NIEHS under the National Toxicology Program (NTP). These results constitute the out come of the chamber prototype development and evaluation phase of the study.

The guidelines for cell phone RFR are based largely on protection from acute injury from thermal effects [1]. Little is known about possible health effects of long-term exposure to minimally thermal levels of cell phone RFR

The NTP chronic studies will require a total of 21 reverberation chambers, Figure 1.

Figure 1. Half of the 21 chamber installation.

3 power levels for mice exposed to 1900 MHz GSM modulated signals
3 power levels for mice exposed to 1900 MHz CDMA modulated signals
1 mouse sham chamber
3 power levels for male rats exposed to 900 MHz GSM modulated signals
3 power levels for male rats exposed to 900 MHz CDMA modulated signals
1 male rat sham chamber
3 power levels for female rats exposed to 900 MHz GSM modulated signals,
3 power levels for female rats exposed to 900 MHz CDMA modulated signals
1 female rat sham chamber

2. Methods

Reverberation chambers are resonant enclosures where the field structure is continuously altered using stirrers such that they provide a statistically homogeneous field distribution within a specific volume in the chamber [2]. In the NTP studies, rats will be chronically exposed at 900MHz and mice at 1.9GHz, different exposure groups will be subjected to either GSM or IS95 signals at one of three SAR levels or sham, over an entire lifespan. The use of a range of SAR levels will provide the ability to elicit any possible dose response.

The design of the reverberation chamber had to encompass both the electrical design and animal housing issues. To comply with the NTP guidelines non-toxic sterilizable materials must be used, from an electrical point of view the chamber must be fully shielded. The resultant solution was in a fully welded stainless steel design with a standard shielded room door, the stainless steel is slightly less conductive than normal steel so there is a slight compromise with the ultimate Q factors achievable. The tight requirements on the field homogeneity and requirement to be able to place animal racks in the chambers necessitated a design with two near optimal mode stirrers [3]. The first stirrer is placed vertically at the rear of the chamber and the second horizontally on the ceiling, Figure 2. The overall chamber size is w = 2.2m, l = 3.7m and h = 2.6m.

The field at any point in the chambers changes temporally, it is only the target value when averaged over integral number of rotations of the stirrers. The temporal changes in field and hence exposure can be used to mimic the temporal changes in the output power of a mobile phone due to the power control implemented in the GSM or IS95 handset by tuning the speed of the two stirrers (the rotation speeds should always be different).

Figure 2. Internal view of the reverberation chamber showing the two stirrers.

The choice of exposure frequency is based upon two main criteria, firstly frequencies commonly in use in the USA for mobile telephony and secondly based on providing a more uniform SAR distribution in the animal species, Figure 3 right hand side shows from left to right mouse 900MHz, mouse 1900MHz, rat 900MHz and rat 1900MHz, based on the analysis f the SAR distributions 900MHz was chosen for rats and 1900MHz for mice.

The required field strength was determined from numerical dosimetry using the plane wave integral representation of a reverberation chamber [4] and high resolution animal models based on 4 different size models covering the whole life span. Each model has over one hundred different body parts differentiated, the models can be seen in the left hand side Figure 3. Using the models the average field strengths required to produce the target SAR in the animals in each exposure group was determined, Figure 3 right hand side.

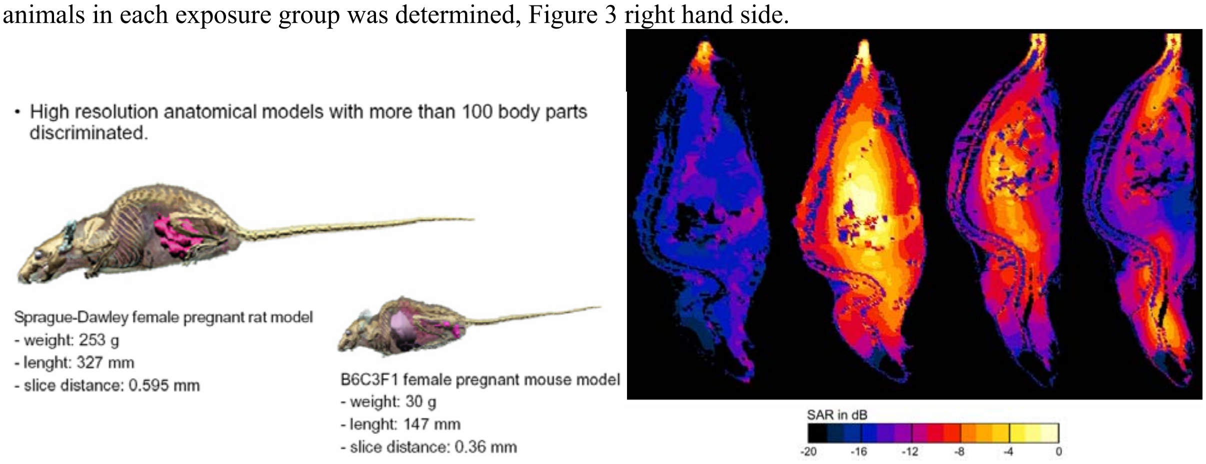

Figure 3. Electromagnetic modelling was performed using anatomical models, left, using SEMCAD X (SPEAG Switzerland) to perform the numerical dosimetry, right.

The rodents have to be supplied with drinking water without energy absorption in the water or increased SAR in or RF burns to the animal whilst drinking. To facilitate the supply of water a new concept had to be developed to prevent the high field strengths that would be present around the lixit if a standard watering system was employed. To this end a choked and shielded automatic watering system was designed. The resultant design can be seen in

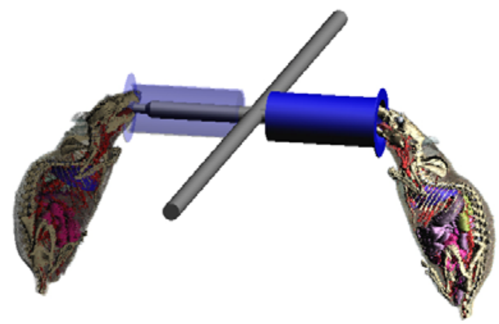

Figure 4. Two rats drinking

Figure 4 it consists of a coaxial quarter wave choke to quench the RF currents that extends beyond the tip of the lixit shielding it from the electric field. The choke is then flanged to both remove the high field region away from the lixit and reduce the intensity by virtue of the increased circumference.

The exposure in the chambers is controlled using a closed loop system. This system is based on the measurement of three orthogonal components of both the electric and magnetic field at two locations in each chamber.

3. Results

The important performance metrics for a reverberation chamber used for animal exposure are: the field uniformity, field isotropy, SAR uniformity and efficiency. Using E-Field probes the measured electric-field uniformity (one standard deviation) in the empty chamber measured on a 300mm 3D grid was 0.6dB and the field isotropy 0.85dB and in the fully loaded chamber, over a reduced number of points, the values were 0.74dB and 1.3dB respectively. Figure 5, shows the E-field uniformity results. The SAR uniformity was measured in the same chamber using rat and mouse phantoms consisting of bottles of tissue simulating liquid optimised to provide the same absorption as an adult rodent. The experimental dosimetry was performed using the final temperature method, and showed that the SAR uniformity between animals was 0.46dB and 0.40dB respectively for rats and mice, the SAR shows better uniformity than that of the field measurements due to the special averaging over the volume of the animal phantom. Additionally, the design of any exposure system needs to consider how much power must be generated to achieve the desired animal exposure, one key metric is the overall efficiency, in this case the chamber approach provides efficiencies of ~70% for adult rats and ~45% for adult mice.

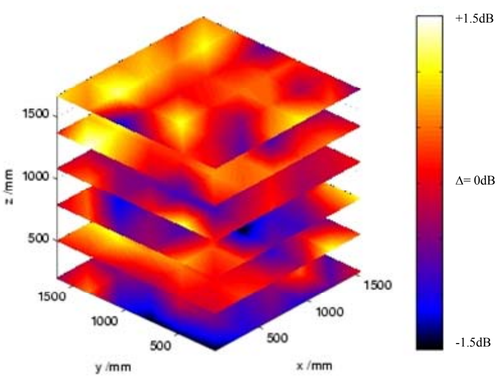

Figure 5. Field Uniformity.

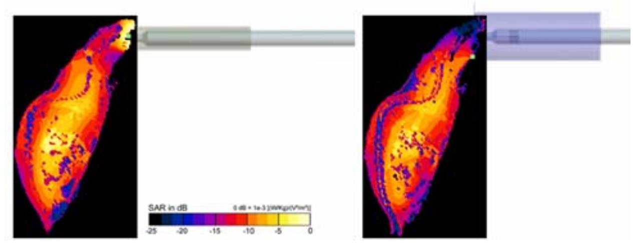

Figure 6. SAR in the mouth of a rat when drinking with and without the special shielded choke design.

The water system was developed that can be installed in the chambers without introducing additional loss by RF absorption in the water by virtue of its fully shielded design. The design can also be used in a reverberation chamber environment with high average RF fields (up to 400 V/m) as it has been shown that it avoids or minimizes:

1) high local SAR peaks in the animal whilst drinking,
2) variations in whole-body average SAR with respect to the animal not drinking,
3) significant distortions in the fields around the water system.

The flanged quarter wave choke design was integrated into a stainless steel automatic watering system. Numerical analysis was performed using SEMCAD X with the high resolution anatomical models, Figure 6 shows the SAR experienced in the animal for a traditional water system and for the RF safe design, it can be seen the excess SAR in the mouth can be completely avoided. An experimental verification was performed using gel animal phantoms and temperature probes in the body head and mouth this also demonstrated that the water system designed provides a safe drinking environment without disturbing the field homogeneity and isotropy within the animal enclosures.

Fundamental to the nature of the reverberation chamber is the fact that the field has temporal and spatial variations. The design of the stirrers can be such that the spatial variations in the average field strength can be minimised, or at least controlled within specified bounds, this work has shown that this can be achieved. The work has also shown that temporal variations introduced by the rotation of the stirrers can be tailored to provide a change in exposure that has some meaningful correlation to real world exposure variations. By taking measurement data of the power control and hence actual exposure of real mobile phones when operated in different propagation environments and performing a Fourier transform the low frequency components of variation of power can be determined. Figure 7 shows the measurement setup and analysed data for a typical GSM mobile phone exposure [5]. The rotation velocities of the two stirrers can then be tuned to provide a variation that has many of the key characteristics of the real signal variation. Individual components can be created by a combination of the beat frequency of the stirrers and the absolute rotational speed. The velocity of rotation and the relative differences is dependant on the mobile communication system to be mimicked as they have different power control characteristics and the mode density in the chamber at a given frequency also impacts the required angular displacement to achieve a given field strength variation at a single point in the chamber.

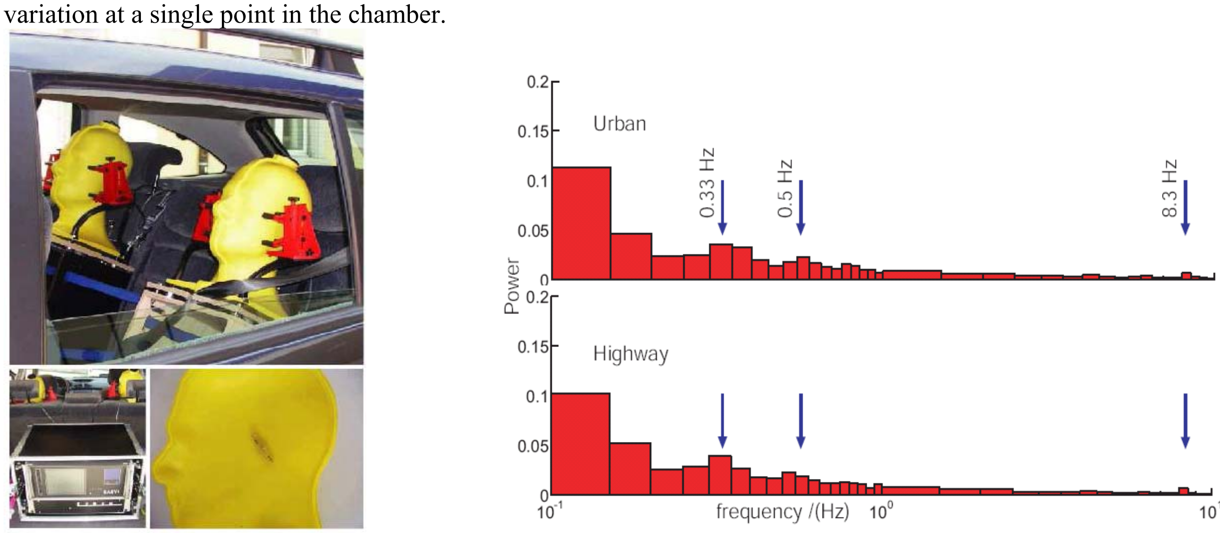

Figure 7. Measurement data for the low frequency spectrum of the temporal variations in SAR exposure from a GSM mobile phone.

4. Conclusions

Overall, the performance across all the criteria of the reverberation chamber for animal exposure is excellent, with all target performance metrics being met or exceeded. A reverberation chamber has the ability to house large numbers of animals where the animals are unconstrained and can be individually housed. Long exposure periods of ≥ 20 hours per day are possible as the animals can be free to feed and drink during exposure. Excellent field uniformity and isotropy can be achieved which in turn provides excellent SAR uniformity and all with good efficiency. The performance of this exposure environment is comparable to the best exposure setups using constrained animals.

5. References

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6. Acknowledgements

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