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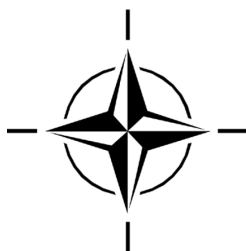
**STO TECHNICAL REPORT**

**TR-HFM-189**

# **Electromagnetic Fields Exposure Limits**

(Limites d'exposition aux champs électromagnétiques)

The NATO Research Task Group 189 "Bioeffects and Standardization of Exposure Limits of Military Relevant High-Energetic Electromagnetic Pulses (HEEP)" was organized to research the possible bioeffects and health risk to military personnel and workers exposed to unique military technologies employing high-peak-power ultra-short pulsed electromagnetic fields. A secondary task was to determine if the reductions in allowed contact current exposure limits were scientifically justified. This report documents the findings and the consensus reached.



Published January 2018





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- AVT     Applied Vehicle Technology Panel
- HFM     Human Factors and Medicine Panel
- IST     Information Systems Technology Panel
- NMSG    NATO Modelling and Simulation Group
- SAS     System Analysis and Studies Panel
- SCI     Systems Concepts and Integration Panel
- SET     Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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## List of Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACT	Allied Command Transformation
AFB	Air Force Base
AFRRI	Armed Forces Radiobiology Research Institute
ARES	Advanced Research Electromagnetic Simulator
BBB	Blood Brain Barrier
BEL	Belgium
CA1	Cornu Ammonis CA1 Subarea
CF	Center Frequency
CSMWG	Civil Standards Management Working Group
CW	Continuous Wave
DNA	Deoxyribonucleic Acid
DoD	Department of Defense (United States)
DoDI	Department of Defense Instruction
DOL	Department Of Labor
DRL	Dosimetric Reference Limit
Dstl	Defence Science and Technology Laboratory (United Kingdom)
E3-RADHAZWG	Electromagnetic Environmental Effects Radiation Hazards Working Group
E3P	Electromagnetic Environmental Effects to Personnel
EC	European Commission
<i>E</i> -field	Electric field
EG	Exploratory Group
EMF	Electromagnetic Field
EMP	Electromagnetic Pulse
EMPRESS	Electromagnetic Pulse Radiation Environment Simulator
ERL	Exposure Reference Level
ET	Exploratory Team
EU	European Union
FOB	Functional Observational Battery
FRA	France
GBR	Great Britain
GFAP	Glial Fibrillary Acidic Protein
HEEP	High-Energetic Electromagnetic Pulse
HEMP	High-Altitude Electromagnetic Pulse
HFM	Human Factors and Medicine (Panel)
HPM	High Power Microwave
HPMP	High-Power Microwave Pulse
HPPCES	High-Peak-Power Counter Electronic System
HPPP	High-Peak-Power ultra-short Pulsed
HPW	Human Performance Wing
HQ	Headquarters
HUN	Hungary

ICC	Induced and Contact Currents
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
INERIS	Institut National de l'Environnement Industriel et des Risques
KAFB	Kirtland Air Force Base
LPTT	Limited Participation Technical Team
LTCR	Long-Term Capabilities Requirement
MAP	Mean Arterial blood Pressure
MC	Military Committee
MedStds	Medical Standards
MPE	Maximum Permissible Exposure
NaCl	Sodium Chloride
NATO	North Atlantic Treaty Organization
NIR	Non-Ionizing Radiation
NLD	Netherlands
NSA	NATO Standardization Agency
OSHA	Occupational Safety and Health Administration
PBM	Panel Business Meeting
PEL	Permissible Exposure Limit
PEP	Primate Equilibrium Platform
PfP	Partnership for Peace
PI	Propidium Iodide
POL	Poland
POW	Program Of Work
pps	pulses per second
PS	Phosphatidylserine
PTZ	Pentylene-tetrazol, Pentylene-tetrazole, Pentetrazol, Pentamethylene-tetrazol
R&T	Research and Technology
RF	Radio Frequency
RFR	Radio Frequency Radiation
RHD	Bioeffects Research Division
ROM	Romania
RSM	RTO Specialists' Meeting
RTA	Research Technology Agency
RTB	Research and Technology Board
RTG	Research Task Group
RTO	Research and Technology Organisation
RUS	Russia
SA	Specific Absorption – expressed in joules-per-kilogram (J/kg)
SAMSO	Space And Missile Systems Organization
SAR	Specific Absorption Ratio – expressed in watts-per-kilogram (W/kg)
SDO	Standards Developmental Organization
SEMCAD	3D Electromagnetic (EM) Simulation Software
SHAPE	Supreme Headquarters Allied Forces Europe
SIEGE	Simulated Electromagnetic Ground Environment

SLED	Stanford Linear Energy Doubler
SME	Subject-Matter Expert
SOH	Safety and Occupational Health
STANAG	Standardization Agreement
STO	Science and Technology Organization
SVN	Slovenia
SWE	Sweden
TAD	Technical Activity Description
TAP	Technical Activity Proposal
TEMPO	Transformer Energized Megawatt Pulsed Output
TER	Technical Evaluation Report
TERP	Transmitted Electromagnetic Radiation Protection
TOR	Terms Of Reference
TORUS	Toroidal Omnidirectional Radiating Unidistant and Static simulator
TT	Technical Team
U.S./USA	United States of America
USAF	United States Air Force
USAFSAM	United States Air Force School of Aerospace Medicine
USP	Ultra-Short Pulse
UV	Ultraviolet
UVA	Ultraviolet A (Long-Wave) Ray
UVB	Ultraviolet B (Short-Wave) Ray
UWB	Ultra-Wide-Band
VIRCATOR	Virtual Cathode Oscillator
VTC	Video Teleconference
WBA	Whole-Body Average
WG	Working Group

### List of Unit Symbols

A	Ampere
GW	Gigawatt
Hz	Hertz
MV	Megavolt
V	Volt

## Technical Activity Description

<b>Activity reference number</b>	HFM-189	<b>Activity Title</b>	<b>Approval</b>
<b>Type and serial number</b>	RTG	Bioeffects and Standardization of Exposure Limits of Military Relevant High Energetic Electromagnetic Pulses (HEEP)	2009
<b>Location(s) and Dates</b>		1st Mtg at RTA, Paris (FRA) 25-26 May 2009 and Ineris, Paris (FRA) 27 May  2nd Mtg San Antonio (USA) 9-10 November 2009 , Brooks City Base 3rd Mtg Ljubljana (SLV) 20-21 May 2010, postponed to September 2010 4th Leuven Dstl Porton Down, Salisbury (GBR), 23-24 September 2010 TBC, 5th Budapest (BUL) TBD 6th Ankara (TUR) TBD 7th Warsaw (POL) TBD	<b>Start</b>  April 2009
<b>Coordination with other bodies</b>		NONE	<b>End</b>  April 2012
<b>NATO Classification of activity</b>		UU	<b>Non NATO Invited</b> Yes
<b>Publication Data</b>		TR	UU
<b>Keywords</b>		Non-Ionizing, Peak Pulses, High Energetic Pulses, Exposure Limits, Health & Safety, Dosimetry, Electromagnetic, Standardization, Commonality, Emerging Technologies	

### I. BACKGROUND AND JUSTIFICATION (RELEVANCE TO NATO)

Current and emerging military technologies use electromagnetic pulses ranging from milliseconds (e.g. radars) to micro- and nano-seconds (e.g. HPMP – High-Power Microwave Pulse). Bioeffects research provides the basis for establishing appropriate exposure limits, which protect military personnel (e.g. NATO STANAG 2345). Emerging military relevant High-Energetic Electromagnetic Pulses (HEEP) research database must be evaluated and scientific bases for exposure limits developed establishing safe military operational exposure limits. No standards have addressed areas of military relevance of HEEP. NATO STANAG 2345 is undergoing revision and through the NATO Civil Standards Management Working Group (CSMWG) is serving as the first transition of a NATO STANAG to a civil Standards Developmental Organisation (SDO). The CSMWG will select in October 2008 an SDO to work with the NATO Custodian of STANAG 2345 to develop a Military Workplace Specific Standard that would incorporate non-civil aspects such as high power pulsed fields, and induced and contact current exposure limits for which existing standards have been shown to result in unnecessary impacts to military operations. Interoperability of electromagnetic-based systems throughout NATO is based on commonality of exposure limits. The RTG HFM-189 will focus on garnering sufficient scientific bioeffects data to support development of safe exposure limits for personnel to HEEP. The roles of exposure parameters such as frequency, modulation, polarization, duration, and intermittence of exposure must be elucidated. Solving these questions would greatly benefit from the knowledge of biophysical mechanisms of Electromagnetic Environmental Effects to Personnel (E3P).

## **II. OBJECTIVE(S)**

Coordinate and leverage multi-national research into the possible bioeffects and health risks in military personnel and workers exposed to unique emerging military technologies employing High-Energetic Electromagnetic Pulses (HEEP). Develop risk assessment code matrices for emerging technologies E3P. Develop appropriate safe Maximum Permissible Exposures (MPE). Develop improved methods of assessment of exposure for these technologies. Develop exposure safety standards for milli- and sub-millisecond RF pulses. Establish experimental supporting protocols for sub-millisecond HEEP: metrology, dosimetry, and instrumentation in experimental studies. Establish sufficient bioeffects database through direct laboratory experimentation or from existing literature to develop safe operational exposure limits for HEEP.

## **III. TOPICS TO BE COVERED**

- 1) Information Exchange regarding the development and use of national and NATO HEEP experimental instrumentation, measurement tools, and techniques.
- 2) Bioeffects-based risk assessment of modern and emerging HEEP technologies.
- 3) Bioeffects of induced and contact currents (40 mA to 100 mA).
- 4) Standardization of exposure limits.

## **IV. DELIVERABLE (E.G. S/W ENGAGE MODEL, DATABASE, ...) AND/OR END PRODUCT (E.G. FINAL REPORT)**

Technical Report.

Other deliverable(s): None.

## **V. TECHNICAL TEAM LEADER AND LEAD NATION**

Chair: Dr. B. Jon. KLAUENBERG (United States).

Co-Chair: Dr. Jill S. McQUADE (United States).

Lead Nation: United States.

## **VI. NATIONS REALLY PARTICIPATING**

France, Hungary, Netherlands, Sweden, Turkey, United Kingdom, United States.

## **VII. NATIONAL AND/OR NATO RESOURCES NEEDED (PHYSICAL AND NON-PHYSICAL ASSETS)**

National resources are needed to provide manpower, travel funding and meeting venues.

## **VIII. RTA RESOURCES NEEDED**

Administrative: RTA Author instructions/guidelines, publication release forms.

Funding travel: Funding of consultants. Support for the 1<sup>st</sup> meeting at RTA, publishing and distribution of the TR.

# Terms of Reference

## I. ORIGIN

### A. Background

Radio Frequency (RF) Non-Ionizing Radiation (NIR), defined as part of the electromagnetic spectrum which cannot ionize biomaterials, includes Electromagnetic Fields (EMF) in the spectrum range of 0 – 300 GHz. NIR has wide application in modern technologies, including military operations. Current and emerging military electromagnetic technologies mostly use short RF pulses ranging from milliseconds (e.g. radars) to micro- and nano-seconds (e.g. HPMP – High-Power Microwave Pulses). NIR can produce biological responses at given characteristics including power, frequency, duration, and pulse shape.

Bioeffects research provides the basis for establishing appropriate exposure limits, which protect military personnel (e.g. NATO STANAG 2345 “*Evaluation and Control of Personnel Exposure to Radio Frequency Fields, 3 kHz to 300 GHz*” Edition 3 (CU: US) Ref: NSA (ARMY) 0120-MED/2345: 13 February 2003).

Emerging military relevant High-Energetic Electromagnetic Pulses (HEEP) research database must be evaluated and scientific bases for exposure limits developed establishing safe operational exposure limit standards. No standards have addressed areas of military relevant HEEP.

The current research database for HEEP is insufficient to support establishing spectrum-wide safe operational exposure limits. NATO STANAG 2345 is undergoing revision and through the NATO Civil Standards Management Working Group (CSMWG) is serving as the first transition of a NATO STANAG to a civil Standards Developmental Organization (SDO). Interoperability of electromagnetic-based systems throughout NATO is based on commonality of exposure limits. The Task Group will focus on garnering sufficient scientific bioeffects data to support development of safe exposure limits for personnel to HEEP.

Another unresolved area of NATO relevance is bioeffects and health risks of Induced and Contact Currents (ICC). New international standards have significantly reduced exposure limits from 100 mA and now have action levels of 40 mA (EU Directive 2013/35/EU [34]) or 50 mA (IEEE C95.1<sup>TM</sup>-2005). These action levels are being interpreted as more restrictive limits and have been shown to have non-mitigatable impacts to military operations. Additionally, no rationale for the recently introduced more restrictive limits have been presented. While there are no reports of health effects of 100 mA, research into human perception of ICC and determination of startle and pain thresholds is needed to resolve the standardization issue. Research into safety practices that may mitigate startle effects is needed; such as grasping versus touch. ICC will be a secondary project that will be addressed and scheduled as time permits and as laboratories are found to have ongoing research in this area requirement.

### B. Justification (Relevance for NATO)

Commonality of standards is required for NATO interoperability. NATO Nations are developing new capabilities of extremely high-peak-power ultra-short electromagnetic pulses. Coordination of international laboratory expertise will ensure NATO Nations are leveraging research efforts and will expedite establishing appropriate safety guidance. NATO STANAG 2345 should be updated to include personnel exposure limits for these newly emerging technologies. As Custodian of STANAG 2345, USA has led three revisions of the standard over a 15-year period and recognizes the importance of the STANAG to continued interoperability. Recent NATO Nation reports to the Custodian have identified areas of impact to operations resulting from new civil standards. Scientifically based input to the newly formed NATO-SDO working group under the NATO Standardization Agency (NSA) CSMWG will facilitate development of a Military Workplace Specific Standard that is protective yet has minimized impacts to operations.

## **II. OBJECTIVES**

- 1) Bioeffects research at the sub-cellular level to the whole animal is underway in several NATO participating Nations. These research efforts will be coordinated to leverage efforts. The project will focus on emerging military relevant High-Energetic Electromagnetic Pulses (HEEP). A secondary effort that may be undertaken will be initiation of a research protocol to obtain sufficient bioeffects data to characterize risk of induced and contact currents.
- 2) Goals: Coordinate research efforts and obtain sufficient data to either establish safety guidelines or point to additional research that will need to be accomplished.
- 3) Deliverables: RTO Specialists' Meeting, publication of meeting report. Annual reports on literature review and research conducted in support of project, report to the RTA on RTG program results and to the NATO Standardization Agency on proposed HEEP personnel exposure limits.
- 4) Duration: Three-year work effort with final report on RTO Specialists' Meeting delivered 6 months after.

## **III. RESOURCES**

### **A. Membership**

Willing: BEL, FRA, GBR, HUN, NLD, POL, ROM, RUS, SWE, SVN, TUR, USA.

Invited: All NATO, PfP including Russian Federation, and Australia.

### **B. National and/or NATO Resources Needed**

The Technical Team (TT) is composed of internationally recognized leading researchers in bioelectromagnetics and safety of EM Fields (EMF), who represent different philosophies of possible health risks of the EMF, including participants from Russian Federation. The critical review of available data and experience should result in elaborating a consensus in evaluation of risks from exposures of military personnel to RF pulses and possibly, in a proposal of safety levels for such exposures. Travel funding is limited and organizers will attempt to combine meeting dates with other meetings especially for those traveling overseas.

### **C. RTA Resources Requested**

Administrative: RTA Author instructions/guidelines, publication release forms, site support (first meeting at RTO-HQ), publish and distribution of report.

Funding travel for one consultant and Technical Evaluation Report (TER) Author.

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## Acknowledgements

The Chairman, Dr. B. Jon Klauenberg wishes to thank each of the participants for their contributions of knowledge and time. Additional thanks go to Drs. Tattersall and Scott, Dr. de Seze, the USAF Tri-Service Research Laboratory and Brigadier General Dr. Debouzy for serving as excellent hosts. The Chairman would also like to thank the STO for their assistance and use of the Neuilly-sur-Seine HQ for the ET preparatory meeting and the RTG HFM-189 kick-off meeting. Finally, we thank Professor Marek Janiak for his mentorship and patience while we completed the standardization development which incorporated the results of this Research Task Group review.



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# Electromagnetic Fields Exposure Limits

## (STO-TR-HFM-189)

### Executive Summary

#### Problem and Purpose

Increasingly, current and emerging military technologies employ High-Peak-Power ultra-short Pulsed Electromagnetic Fields (HPPP-EMFs) ranging from milliseconds (e.g. radars) to micro- and nano-seconds (e.g. high-power microwave and directed-energy devices). The peak (temporal) value of the Maximum Permissible Exposure (MPE) in terms of the electric field (*E*-field) for exposures to pulsed Radiofrequency (RF) fields, in the range of 100 kilohertz (kHz) to 300 gigahertz (GHz), had been 100 kilovolt per meter (kV/m) since 1971 when it was established as a “provisional” limit by the United States Air Force. That exposure limit value was set in place during the initial “hardness” tests of electronic systems exposed to simulated nuclear blast Electromagnetic Pulse (EMP). This ultra-conservative limit was an overly cautious action taken due to the limited data at the time although no adverse health effect had been found. Unfortunately, the “provisional” limit has remained for over 40 years and has been adopted by numerous standardization organizations without any supporting scientific data. The third edition of NATO Standardization Agreement (STANAG) 2345 raised the exposure limit for a single pulse to 200 kV/m. The NATO Science and Technology Organization (STO) Human Factors and Medicine (HFM) Research Task Group HFM-189 conducted a thorough evaluation of the research to determine whether the limits were supported or should be removed. Secondly, NATO Electromagnetic Environmental Effects Radiation Hazards Working Group (E3-RADHAZ) had identified a problem which impacted operations with newly reduced contact current limits. Contact with metal surfaces energized by exposure to high frequency emissions can lead to shock and burns. The Institute of Electrical and Electronics Engineers (IEEE) C95.1<sup>TM</sup>-2005 standard reduced contact current limit from 100 milliampere (mA) to 50 mA and the limit was proposed to be reduced to 40 mA by European Union Directive 2013/35/EU [34]. These reductions were deemed by a majority consensus of the HFM-189 to be unnecessary (based on no adverse health effects in the work environment).

#### Scope

The STO HFM-189 RTG was formed to review the scientific data and to develop appropriate operational exposure limits for HPPP *E*-field. A second task was to review the literature on contact currents to determine if the reduction in the limits in the proposed EU Directive 2004/40/EC [33] from 100 mA to 40 mA and the IEEE C95.1<sup>TM</sup>-2005 50 mA limit was scientifically supported. Specific issues were to address military aspects of high-peak-power ultra-short pulsed *E*-fields and contact current exposure limits for which existing standards and the proposed EU Directive had been shown to result in unnecessary impacts to military operations.

#### Analysis/Results

HFM-189 found no published and replicated adverse health effects or biological mechanisms, beyond thermal interaction, for pulses shorter than 100 ms which suggested that neither the peak *E*-field limit in the IEEE C95.1<sup>TM</sup>-2005 safety standard nor the proposed limit in the Directive 2004/40/EC [33] (subsequently promulgated as 2013/35/EU [34]) have scientific basis. The group noted that physical laws governing the propagation of *E*-fields in air already limit the maximum allowable peak *E*-field at ~3 MV/m (air breakdown). Current research efforts by members to expose biological organism(s), tissues, and cells to environmental fields up to this magnitude have been unable to elicit an acute biological response.

## Recommendations

A consensus statement was drafted which recommended that the exposure limitation based on HPPP *E*-field be eliminated. The recommendation of the HFM-189 was adopted by the IEEE International Committee on Electromagnetic Safety (ICES) TC-95 in IEEE Standard C95.1-2345<sup>TM</sup>-2014, “*Military Workplaces-Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz*”. This standard has been adopted by NATO under STANAG 2345 Edition 4-2015.

# Limites d'exposition aux champs électromagnétiques

## (STO-TR-HFM-189)

### Synthèse

#### Problème et objectif

Les technologies militaires actuelles et émergentes utilisent de plus en plus des champs électromagnétiques à impulsion ultra-courte et puissance de crête élevée (HPPP-EMF) qui vont de quelques millisecondes (par exemple, les radars) à quelques microsecondes et nanosecondes (par exemple, les dispositifs à énergie dirigée et les dispositifs à hyperfréquence de haute puissance). La valeur de crête (temporelle) de l'exposition maximale admissible (MPE) du point de vue du champ électrique lors d'une exposition à des champs de radiofréquences (RF) pulsées comprises entre 100 kilohertz (kHz) et 300 gigahertz (GHz) est de 100 kilovolts par mètre (kV/m) depuis 1971, date à laquelle les forces aériennes des Etats-Unis ont établi une limite « provisoire ». Cette valeur limite d'exposition a été mise en place pendant les essais de « résistance » initiaux des systèmes électroniques exposés à une impulsion électromagnétique (IEM) nucléaire simulée. Cette limite ultra prudente était une mesure de précaution excessive, prise en raison du manque de données, bien qu'aucun effet nocif sur la santé n'ait été décelé. Malheureusement, la limite « provisoire » est demeurée pendant plus de 40 ans et a été adoptée par de nombreux organismes de normalisation sans qu'aucune donnée scientifique ne vienne l'étayer. La troisième édition de l'accord de normalisation de l'OTAN (STANAG) 2345 a relevé la limite d'exposition à 200 kV/m pour une seule impulsion. Le groupe de travail HFM-189 de la Commission sur les facteurs humains et la médecine (HFM) de l'Organisation pour la science et la technologie (STO) de l'OTAN a mené une évaluation minutieuse des recherches pour déterminer si les limites étaient justifiées ou devaient être supprimées. D'autre part, le groupe de travail de l'OTAN sur les effets de l'environnement électromagnétique et les dangers du rayonnement (E3-RADHAZ) avait identifié un problème relatif aux opérations avec des limites de courant récemment réduites. Le contact avec les surfaces métalliques mises sous tension par l'exposition à des émissions à haute fréquence peut provoquer des chocs et des brûlures. La norme C95.1<sup>TM</sup>-2005 de l'*Institute of Electrical and Electronics Engineers* (IEEE) a réduit la limite de courant de contact de 100 milliampères (mA) à 50 mA et une directive de l'Union européenne 2013/35/UE [34] a proposé de réduire la limite à 40 mA. La majorité du HFM-189 a jugé ces réductions inutiles, en raison de l'absence d'effet sanitaire nocif dans l'environnement de travail.

#### Portée

Le HFM-189 de la STO a été constitué pour examiner les données scientifiques et développer des limites d'exposition opérationnelle appropriées pour le champ électrique HPPP. La seconde tâche du RTG était de passer en revue la littérature sur les courants de contact pour déterminer si la réduction des limites de la directive européenne 2004/40/CE [33] de 100 mA à 40 mA et la limite de 50 mA de la norme C95.1<sup>TM</sup>-2005 de l'IEEE se justifiaient sur le plan scientifique. Les points à traiter en particulier étaient les aspects militaires des champs électriques à impulsion ultra-courte et puissance de crête élevée et des limites d'exposition actuelles, pour lesquels il avait été prouvé que les normes existantes et la directive européenne proposée avaient des effets inutiles sur les opérations militaires.

#### Analyses et résultats

Le HFM-189 n'a découvert aucune publication ni mention d'un effet sanitaire ou d'un mécanisme biologique nocif, au-delà de l'interaction thermique, pour les impulsions de moins de 100 ms, ce qui suggère

que ni la limite de champ électrique maximal de la norme de sécurité IEEE C95.1<sup>TM</sup>-2005, ni la limite proposée dans la directive 2004/40/CE [33] (promulguée ensuite sous la référence 2013/35/UE [34]) n'ont de fondement scientifique. Le groupe a noté que les lois physiques régissant la propagation des champs électriques dans l'air limitaient déjà le champ électrique maximal admissible à environ 3 MV/m (claquage dans l'air). Les travaux actuels de recherche des membres du groupe visant à exposer des organismes, des tissus et des cellules biologiques à des champs environnementaux de cette amplitude n'ont pas provoqué de réaction biologique aiguë.

## Recommandations

Une déclaration consensuelle a été rédigée, recommandant la suppression de la limite d'exposition reposant sur le champ électrique HPPP. La recommandation du HFM-189 a été adoptée par le Comité international sur la sécurité électromagnétique (ICES) de l'IEEE TC-95, dans la norme IEEE C95.1-2345<sup>TM</sup>-2014, « *Military Workplaces-Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz* » (Lieux de travail militaires – Protection sanitaire des forces concernant l'exposition du personnel aux champs électriques, magnétiques et électromagnétiques, de 0 Hz à 300 GHz). Cette norme a été adoptée par l'OTAN dans le cadre du STANAG 2345, édition 4-2015.

## **Chapter 1 – INTRODUCTION**

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### **1.1 ORIGIN OF THE TECHNICAL ACTIVITY**

#### **1.1.1 Initial Proposal**

A proposal for establishing an Exploratory Team (ET) or Exploratory Group (EG) for “Biomedical Aspects of Non-Ionizing Radiations” was forwarded by Dr. Stanislaw Szmigielski (POL) at the October 2006 meeting of the Research Technology Organization (RTO). Subsequently, a Technical Activity Proposal (TAP) was prepared.

The original TAP was submitted by Dr. Szmigielski for consideration during the April 2007 meeting of RTO Human Factors and Medicine (HFM) Panel in Heraklion, Crete, Greece. Col. Marek K. Janiak, M.D., Associate Professor, agreed to serve as a mentor.

The proposal topics included:

- Assessment of bioeffects and health risks from long-term environmental and occupational exposures to electromagnetic (0 – 300 GHz), infrared, visible light and UVA/UVB radiation.
- Assessment of health risks from multi-year occupational exposures to strong Radiofrequency (RF) radiation.
- Improvement of methods for assessment of individual occupational and environmental exposures to RF radiation on base of dosimeters.
- Assessment of bioeffects and health risks of High-Energetic Electromagnetic Pulses (HEEPs).

#### **1.1.2 First ET-089 Meeting**

The group was assigned ET-089 and held its first meeting, chaired by Professor Szmigielski, at NATO RTA Headquarters, Neuilly-sur Seine, France, in October 2007.

In early 2008, the Program Of Work (POW) “Bioeffects of RF Pulses from Current and Emerging Military Equipment” (ET-089) was prepared by Dr. Szmigielski.

Topics to be covered were:

- Improvement of methods for assessment of occupational and/or environmental exposure to RF pulses.
- Pooled analysis of health risks and cancer morbidity in joint groups of workers with multi-year exposure to RF pulses from different countries.
- Epidemiological studies of military populations exposed to RF pulses.
- Assessment of bioeffects and health risks from modern and emerging technologies, including HEEP.



## INTRODUCTION

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### 1.1.3 Original Technical Activity Proposal (TAP)

The original TAP was determined by the ET group consensus to be too ambitious and it was recommended that a revision be prepared focusing on two immediate issues:

- Bioeffects and health and safety concerns related to High-Peak-Power ultra-short Pulsed Electromagnetic Fields (HPPP-EMFs); and
- Hazards to personnel from contact current.

In March 2008, Dr. B. Jon Klauenberg was asked by ET-089 Co-chair Dr. Michael Murphy to join ET-089 and prepare a revised TAP, Program Of Work (POW) and Terms Of Reference (TOR) focusing on HPPP-EMF and contact currents for the next HFM Panel Business Meeting (PBM).

### 1.1.4 Panel Business Meeting (PBM)

These revised TAP, POW and TOR documents were submitted to the NATO HFM for the April 2008 meeting. The TAP entitled “*Bioeffects and Standardization of Exposure Limits of Military Relevant High Energetic Electromagnetic Pulses (HEEPs)*”<sup>1</sup> (below) reflected concerns from ET members to provide focus on a few topics and to ensure the military relevance. The HFM PBM decided not to “fast track” the proposal at the Spring 2008 review, deciding to wait until reviewed by the Human Protection Area of the HFM Panel. That group met in Antalya, Turkey (October 13-17, 2008) and unanimously voted for its support to the HFM PBM. The project was approved at the Spring 2009 HFM PBM.

The focused topics of the HFM-189 RTG were:

- Information exchange regarding the development and use of national and NATO HEEP experimental instrumentation, measurement tools, and techniques.
- Bioeffects-based risk assessment of modern and emerging HEEP technologies.
- Bioeffects of induced and contact currents (40 mA to 100 mA).
- Standardization of exposure limits.

### 1.1.5 Terms of Reference (TOR)

The TOR reviewed the background for the proposed work providing a brief look at how current and emerging military electromagnetic technologies mostly use short RF pulses ranging from milliseconds (ms) (e.g. radars) to micro- ( $\mu$ s) and nano-seconds (ns) (e.g. HPPP-EMFs). Safety guidelines and standards limiting exposure levels from HPPP-EMFs were not supported by the scientific database. Interoperability of electromagnetic-based systems throughout NATO is grounded within commonality of exposure limits. The TOR noted that the scientific database for both HPPP-EMFs and contact currents needed to be reviewed.

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<sup>1</sup> The term High Energetic Electromagnetic Pulse (HEEP) is replaced with High-Peak-Power ultra-short Pulsed Electromagnetic Field (HPPP-EMF) from this point onward.



## **Chapter 2 – PARADIGM SHIFT FOR ESTABLISHING EXPOSURE LIMITS FOR HIGH-PEAK-POWER ULTRA-SHORT PULSED ELECTROMAGNETIC FIELDS (HPPP-EMFs): THE HISTORY OF AN ANOMALOUS SAFETY PARADIGM**

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### **2.1 HISTORY OF HIGH-POWER ULTRA-SHORT PEAK PULSE ELECTROMAGNETIC FIELD (HPPP-EMF) BIOEFFECTS**

Over half a century ago, Radio Frequency Electromagnetic Fields (RF-EMFs) were still a novel environmental physical agent with respect to biological effects, especially with very high-powered, very short rise-time and short-duration pulsed systems. At that time, occasionally, when new technologies were developed that emitted RF-EMFs having novel characteristics of forward power, shape, duration, power density, frequency and other parameters of the spectrum, limits were placed on exposure to humans that were “precautionary” and not based on any, or insufficient, scientific biological rationale. Subsequent research efforts, aimed at determining the HPPP-EMP levels at which biological effects occur, have shown that this precautionary approach was overly restrictive.

Once exposure limits are incorporated into health and safety standards, albeit occasionally without scientific foundation, a paradigm for doing so can become established based on an anomaly. The paradigm for establishing the anomalous exposure limit can become entrenched and extremely difficult to modify or eliminate. The paradigm becomes one of precautionous resistance to change. Over-precaution can lead to unnecessary restrictions on the allowed personnel exposure EMF environment and in turn negatively impact system operations and mission. Without assessing the entire risk environment increased restrictions can, in some cases, lead to decrements in safety. This chapter describes the history of the HPPP-EMF standard, and how the paradigm used was flawed from the beginning, and how the approach to standard setting required a paradigm shift.

### **2.2 ELECTROMAGNETIC PULSE (EMP) SIMULATORS**

Baum [9] reviewed the progression of technological development from nuclear Electromagnetic Pulse (EMP) to high-power electromagnetic emissions including High-Power Microwaves (HPMs). The EMP generated by a high-altitude nuclear detonation that can cover a continent is termed High-altitude EMP (HEMP) [9]. The immense amount of energy liberated by a nuclear explosion changes the surrounding environment through conversion of the weapon gamma-ray energy in the earth’s ionosphere to RF electromagnetic energy which propagates toward the earth’s surface [76]. These EMPs can extend well beyond the thermal or ionizing radiation components, especially for HEMPs and represent a threat to electronics and communications. HEMP has been of scientific interest since 1989 [89].

Electromagnetic emitters capable of delivering 100 Gigawatt (GW) pulses to a transmitting antenna producing hundreds of kV/m peak electric ( $E$ ) fields had been developed by the 1990’s [2]. EMPs are broad in frequency, from 1 – 1000 MHz, and 100 – 300 ns. EMP simulators were introduced in the early 1960’s to study the intense

electromagnetic transient that accompanies a nuclear explosion which may exhibit field densities of  $10^5$  V/m with nanosecond rise and fall times. The peak external field arising from EMP simulators can be up to 600 kV/m, while those occurring due to nuclear blast rarely reach 100 kV/m [36]. The typical pulse repetition rate attainable by most EMP simulators was rather low, i.e. one pulse every several minutes [14]. The EMP simulators included the United States Air Force (USAF) Weapons Laboratory Horizontal Dipole Facility and the Advanced Research Electromagnetic Simulator (ARES), Kirtland Air Force Base, New Mexico, and the Navy's Electromagnetic Pulse Radiation Environment Simulator (EMPRESS) in the Patuxent River at the Naval Ordnance Laboratory, Solomon's, Maryland. The USAF began conducting EMP and lightning simulation testing in 1965. The EMPs were considered to be analogous to that of natural lightning with field strengths of up to 20 kV/m measured under thunderstorm clouds [87].

The original goal for HPPP-EMF emission was to establish safe exposure levels for personnel working with EMP simulators. The hypothetical concern was that the extremely high peak power may interact with personnel in a manner differing from the established thermal-biological basis. Studies carried out on both animals and humans for over 40 years failed to provide support for this hypothesis to limit HPPP-EMPs, yet the limits remained.



**Figure 2-1: E-6B Under the Horizontally Polarized Dipole EMP Simulator.**



**Figure 2-2: ARES Simulator.**  
(Source: Air Force Research Laboratory, Phillips Research Site Historical Information Office)

## **2.3 BIOLOGICAL EFFECTS**

### **2.3.1 Biological Effects: Animals**

Several reviews and discussion papers of biological effects of HPPP-EMFs and UWB EMFs have been published [9], [62], [65]. Early research using multiple species and humans consistently failed to find bioeffects, let alone health impacts. Bioeffects from high-voltage atmospheric events have been studied. The EMPs were considered to be analogous to that of natural lightning where field strengths of up to 20 kV/m were measured under thunderstorm clouds. As early as 1941, Wagner and Beck [90] investigated lightning pulses and thunderstorm build-up preceding such pulses with 3 – 5 Megavolts (MV) field strengths several kilometers from the point of lightning discharge. No biological effects were reported, nor were they inferred (cited in Ref. [87]).

Mattsson and Oliva [64] exposed a monkey for a total of 18,700 pulses over one hour to 266 kV/m (188 MW/m<sup>2</sup>) peak *E*-field, 11 ns rise time, 550 ns fall time and 5 pulses per second (pps). No differences between control and exposed were seen on an avoidance behavior test and post exposure electroencephalogram.

The Armed Forces Radiobiology Research Institute (AFRRI) conducted several chronic EMP experiments using rats, mice, and dogs. Baum *et al.* [12] reported that rodents exposed to EMPs at five pulses per second at peak *E*-field of 447 kV/m (530 MW/m<sup>2</sup>) with a 5 ns rise time and a 550 ns (1/e) fall time, 22 hours/day, 5 days/week, 38 weeks for a total of 108 pulses (conditions in excess of the exposure of human who operate EMP facilities) did not show any injuries. They concluded that EMP was not hazardous to rodents and that “... *humans exposed under similar conditions would show no acute injurious biological effects*”. Extending the exposure period to 94 weeks also showed no effects [11]. He did not find any effects up to one year on hematological and hemapoiesis in four male and five female beagle dogs exposed to 447 kV/m EMP for eight hr/day for 45 days a total of  $5.8 \times 10^6$  pulses [10]. Baum and his team also found no changes in fertility and reproductive capacity in dogs following EMP exposure [10].

Diachenko and Milroy [32] performed experiments on the effect of EMP modulated at 2450 MHz on the operant behavior of rats at 125 kV/m at a rate of 4 to 10 pps for one hour per day, followed by performance testing each day for five days. No effects could be detected between performance before exposure (control) and after exposure to the EMP.

Hirsch and Bruner conducted studies [38], [39] involving a naive and a highly over-trained monkey as well as four Dalmatian dogs. These experiments employed high-density pulsed electromagnetic fields up to 600 kV/m. No behavioral or physiological effects were seen including negative results from very extensive blood chemistry examinations.

Cleary *et al.* [18] studied several biological endpoints in rabbits exposed to 100 to 200 kV/m peak *E*-field intensity, 0.1  $\mu$ s rise time, and an exponentially cosine decay pulse with 50% pulse duration at 0.4  $\mu$ s. They studied sodium pentobarbital induced sleeping time in rabbits exposed to 140 kV/m at 100 pps, 190 kV/m at 24 pps, 90 kV/m at 10 pps. They also studied EMP effect on serum chemistry immediately and 24 hours following 150 kV/m at 39 pps for 2 hours. None of the tests showed consistent statistical differences between sham exposed and EMP exposed rabbits.

Klaunberg *et al.* [55] conducted the first bioeffects studies on the Transformer Energized Megawatt Pulsed Output (TEMPO) microwave Virtual Cathode Oscillator (VIRCATOR). They exposed rats to a single 85 ns pulse with 1.3 GHz center frequency and estimated incident power density of 0.75 – 0.99 kW/cm<sup>2</sup> producing a calculated 15  $\mu$ J/kg whole-body Specific Absorption (SA) per pulse. Exposure to a single pulse caused a startle-like response in some animals as measured on a stabilimeter. In the same study, exposure to 1 pps for 10 s produced significant alterations in baseline activity and marked disruption of performance of the rotarod task. The apparently greater effect observed in the rotarod task was discussed in relation to the greater workload that task requires. The possibility that noise associated with the internal electronics and/or perturbations of the field by the Plexiglas apparatus may have acted as intervening variables was shown to be a contributing factor in a later study [56].

Exposure to pulses with 200 MW 80 ns duration and 3.0 GHz CF over about 25 minutes altered performance in a subsequent time discrimination task. Raslear *et al.* [79] also reported that the coincident acoustic stimulus from the TEMPO may be an intervening variable.

In a joint laboratory TEMPO study of rats (Los Alamos National Laboratory, Hjeresen *et al.* and United States Air Force School of Aerospace Medicine, Klaunberg *et al.*) [41], exposure to pulses with 85 ns duration, up to

50 pulses with peak power density averaging 10.8 kW/cm<sup>2</sup> delivered over 5 minutes at 2.11 GHz caused no change in subsequent performance in an operant task or in tests of avoidance behavior.

D'Andrea *et al.* [21] found no effect on behavior of rhesus monkeys performing a vigilance task exposed to TEMPO high-peak-power microwave pulses at 2375 MHz. They evaluated whether short-duration (93 ns) high-peak-power microwave pulses can alter behavioral performance, four rhesus monkeys were exposed to peak powers of 7.02 – 11.30 kW/cm<sup>2</sup> while they performed a vigilance task. The behavior consisted of two components:

- Responding on a variable interval schedule on one lever; and
- Reaction time on a second lever.

Correct response on each lever was signaled by auditory stimuli. Trained monkeys performed the task during exposure to microwave with short pulse durations (80 – 100 ns) delivered concurrently with the auditory signals. The estimated peak whole-body Specific Absorption Rate (SAR) for each pulse was between 582.7 and 937.9 kW/kg (54 – 87 mJ/kg per pulse). Compared to sham treatment, significant changes in behavioral performance were not observed.

Akyel *et al.* [3], [4] conducted a series of behavioral studies (memory consolidation, general motor activity, behavioral despair, and preference of electromagnetic pulses) with rodents which each failed to show effects following exposure to EMP produced by a parallel plate EMP simulator; 100 kV/m peak pulse 7 ns rise time, 20 ns pulse duration and 6 pps for 20 or 30 minutes.

Lu and de Lorge [62] conclude an extensive review of the biological effects of high-peak-power RF pulses stating that other than the unconfirmed report of maze performance disruption by a single EMP pulse of several hundred kV/m [40] “*most studies indicated no observable effect with EMP pulse with peak electric fields less than 100 kV/m.*”

D'Andrea *et al.* [22] trained four male rhesus monkeys on an operant task for food pellet reward to investigate behavioral effects of very high-peak-power pulsed 5.62 GHz microwaves. They compared microwave pulses of two different peak powers but equal total energy per pulse. While performing the behavioral task, the monkeys were exposed to microwave pulses produced by either a military radar (FPS-26A) operating at 5.62 GHz or the same radar coupled to a Stanford Linear Energy Doubler (SLED, ITT-2972) pulse-forming device that enhanced peak power by a factor of nine by adding a high-power pulse to the radar pulse. Peak field power densities tested were 518, 1270, and 2520 W/cm<sup>2</sup> for SLED pulses and 56, 128, and 277 W/cm<sup>2</sup> for the radar pulses. The microwave pulses (radar or SLED) were delivered at 100 pps (2.81Js radar pulse duration: ~50 ns SLED pulse duration) for 20 minutes and produced averaged whole-body SARs of 2, 4, or 6 W/kg. SLED peak power was 2.552 MW, 6.273 MW or 9.838 MW with peak power densities of 0.518 kW/ cm<sup>2</sup>, 1.27 kW/ cm<sup>2</sup> and 2.52 kW/ cm<sup>2</sup>. Compared to sham exposures, significant alterations of lever responding, reaction time, and earned food pellets occurred during microwave exposure at 4 and 6 W/kg, but not at 2 W/kg. There were no differences between radar or SLED pulses in producing behavioral effects.

Postow and Swicord [78] in an extensive review of modulated field effects concluded that pulsed microwave produce by radar transmitters could not cause biological effects other than those caused by exposure to Continuous Wave (CW) radiation at the same average power density of pulsed microwaves. In other words, the thermal bioeffects were no different.

A few studies have reported bioeffects, however, each has been shown to have significant design or interpretation difficulties. Moore [67] studied the orientation behavior of captured migratory birds after exposure



to EMPRESS II EMP pulses. The orientation behavior was observed 2.5 hours after exposure to a single 50 or 100 kV/m EMPRESS pulse. Differences in orientation between sham and exposed were observed in one of three observation periods in spring of 1992, but not during spring or fall of 1991. These observations were criticized due to lack of data on magnetic field intensities and other pulse characteristics [62]; however, the authors nevertheless suggested that individual birds may experience difficulty selecting seasonally appropriate direction following a single EMP of 50 kV/m or higher. Additionally, Moore studied natural remanent magnetization and isothermal remanent magnetization of heads of three bird species and did not find any effect of EMP pulses of the EMPRESS II type. These findings and the aforementioned results led the authors to conclude that no discernible effect on orientation was expected.

These peer-reviewed literature reports are examples of the overwhelming number of studies where no noticeable effect findings leads one trained in these exposures and performing deep science review to the conclusion that animal data does not support setting a HPPP *E*-field human exposure limit.

### **2.3.2 Biological Effects: Humans**

Since EMP site personnel were routinely in the vicinity of these unique electromagnetic fields, concern about potential injurious effects was raised [36]. One of the first reviews [14] on the worker exposure environment and the medical surveillance programs conducted on this workforce showed no documented human or animal injury from EMP. The Space And Missile Systems Organization (SAMSO) used several pulsers including the Simulated Electromagnetic Ground Environment (SIEGE 1.2) system which produced peak pulse power in the High Frequency (HF) range and delivered 40-50 kV/m in single pulses over the Minute Man silo.

Martin, in a monograph on biological effects of exposure to SIEGE Array EMP fields [63], reviewed several studies which failed to show any biological effects. He also cites a three and one half year study of 11 power linemen exposed to fields as large as the corona threshold (3 kV/m) which showed no evidence of malignancies or any other ill effects on health. Another simulator was the Toroidal Omnidirectional Radiating Unidistant and Static (TORUS) simulator which produced an HF component, 50 kV/m measured at 50 meters. The report concluded that EMP produced by the SIEGE pulse Array generator ( $9.6 \times 10^4$  W/cm<sup>2</sup> peak) did not appear to be hazardous to man and that exposures to pulses did not produce changes in the threshold for perception of voltages. Another example of system study was a large volume simulator (Atlas 1) called the Trestle (Figure 2-3) used to test electrical hardness of large aircraft such as the B-52, 747, B-1 that produced a higher power 50 – 100 kV/m (single pulse). No health hazards were reported for either system [17]. Additionally, multiple studies conducted at the Air Force Weapons Laboratory from 1968 to 1969 on human exposures from 5 – 88 kV/m that did not show any effects.



**Figure 2-3: B-52 Stratofortress on Atlas-1 “Trestle” Kirtland AFB – World’s Largest EMP Simulator.**

Bruner [14] reported personal communications from Bartl that Boeing carried out the most extensive medical surveillance of personnel working with three USAF EMP facilities from 1970 to 1975. Over 400 Boeing employees were examined following annual physicals, with some having six repeat annual examinations. Daily exposure logs were maintained on each employee showing the number of pulses and the approximate maximum intensity measured at the worker's station. The occupational health physicians concurred that no adverse health effects were identified.

Bell Laboratories [13] reported that over 10 people were exposed at their facility for thousands of times to pulses with peak intensities of 1 – 10 kV/m, hundreds of times to pulses of 10 – 50 kV/m and several instances at pulses near 100 kV/m. No noticeable or unusual effects were reported.

In summary, no noticeable adverse health effects following exposure to HPPP-EMPs were reported for the reviewed studies which included years of medical follow-up.

### **2.3.3 Biological Effects: Ultra-Wide-Band (UWB)**

Conventional radar operates a narrow band mode in which the fractional bandwidth is less than 1% of the center (carrier) frequency. UWB emitters are relatively new technology with a multitude of applications such as electronic security sensors and automobile warning devices. UWB radar has increased the fractional bandwidth more than 25% ([85] cited by Lu and deLorge [62]). Since the UWB has no center carrier frequency it is characterized as “carrierless”. Lu *et al.* [60] noted that UWB devices with an extremely high-peak electric field and very low duty cycle, the energy absorption rate per pulse in humans can be extremely high (temporal peak Specific Absorption Ratio – SAR), but the average SAR can be very low if a time-average procedure is applied. The ratio of peak to average SARs will be much greater than those of narrowband.

UWB sources can produce ns repetitive pulses with 100 – 300 ps rise times and peak EMF intensity in 100s of kV/m. [2]. Theoretical assessment of potential biological effects has been forwarded suggesting that the ultra-short pulses can produce electromagnetic transients resulting in tissue damage [5]. Albanese *et al.* [5] described the expected propagation of ultra-short electromagnetic pulses in biologic tissue and made recommendations for limitation of human exposure to these pulses. They hypothesized that these ultra-short pulse width electromagnetic events would be expected to produce Brillouin-Sommerfeld transients at the leading and trailing edges of the pulse in tissue. They proposed four possible mechanisms that could be responsible for precursor damage to tissue; viz., molecular conformational changes, alterations in chemical reaction rates, membrane effects, and thermal damage. Merritt *et al.* [65] provide counter arguments to each of the postulated proposals [5]. They reviewed several studies that are directly relevant to the issue of tissue damage by ultra-short pulse width electromagnetic pulses [19], [20], [21], [56]. Additional studies on EMP simulators in which test animals were exposed to *E*-fields up to 600 kV/m [11], [12], [39], [64] have included both narrow band width, high-peak-power microwave pulses with pulse widths of a few tens of nanoseconds, as well as ultra-wide-band pulses with pulse widths of 1 ns or less. None of these investigations revealed effects that indicate exposure is hazardous. Other basic bioeffects research [50], [52], [53], [66], [81], [83] has failed to provide support for Albanese's multiple theoretical postulates [5]. Adair [1] also debated the basis of Albanese's theses. He suggested that “*a 1 MV/m pulse with a width of 1 ns should be quite safe*”.

Adair made three major points:

- 1) As a consequence of shielding from external static electric fields by induced surface charges, low-frequency components of pulsed fields do not enter the body. Thus, even for long external pulses, the internal pulse will be no longer than 20 ns.

- 2) The significant exposure factor for an electric field pulse is  $E - \tau$ , where  $\tau$  is the duration of the internal pulse and  $E$  the average internal field.
- 3) The Brillouin precursors (initial and trailing edge transients) postulated [5] to be generated as a pulse enters tissue are not so much generated by the passage of the pulse through the water as they are a residual that remains after the rest of the pulse was strongly absorbed.

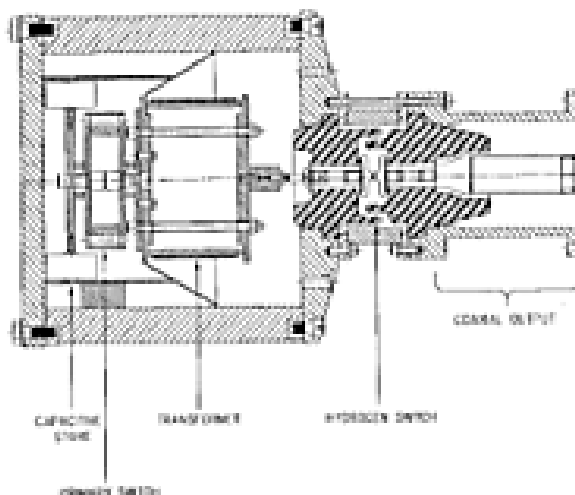
Adair also proffered:

*“... that the energy of the pulse at a depth of 1 cm is about 0.8% of the initial energy; the maximum electric field strength,  $E$  is reduced by a factor of about 12, and the maximum rate-of-change of the field,  $dE/dt$ , is reduced by a factor of 20. Every characteristic of the pulse at depth is contained, albeit attenuated, in the initial pulse. Consequently, we do not find it credible that the strongly attenuated pulse – albeit with a different shape – can induce biological effects beyond that of the initial pulse.”*

Erwin and Hurt [35] reviewed numerous studies conducted by the United States Air Force (USAF) at Philips laboratory, Kirtland Air Force Base (KAFB), New Mexico and Armstrong Laboratory Brooks AFB, Texas. Exposures were with a Hindenburg-2 (H-2) device producing 250 kV/m (166 MW/m<sup>2</sup>) peak  $E$ -field, rise time 310 ps, 60 pulses/s. Endpoints measured in rats were:

- Functional Observational Battery (FOB, 29 physiological and behavioral measures;
- Blood chemistries;
- Brain  $C$ -fos protein activation;
- Metrazole seizure activity; and
- Equilibrium task for monkeys.

Metrazol (also known as pentylenetetrazol, pentylenetetrazole, pentetrazol, pentamethylenetetrazol, Cardiazol or PTZ) is used as a circulatory and respiratory stimulant, but in higher than therapeutic doses is a convulsant). None of the measures showed the animals were affected by UWB.



**Figure 2-4: Hindenberg 2 (H2) UWB Transmitter.**

Sherry *et al.* [83] examined the effect of acute exposure to UWB on the Primate Equilibrium Platform (PEP) task, where the monkey's task was to manipulate a joystick control to compensate for the random perturbations in the pitch plane that are generated by a computer at unpredictable intervals. The duration of the UWB exposure was 2 minutes at a pulse repetition rate of 60 Hz (total of 7200 pulses). The bandwidth of the pulse was 100 MHz to 1.5 GHz (peak power between 250 – 500 MHz) with a peak *E*-field strength of 250 kV/m. Each monkey was exposed twice. The interval between exposures was 6 days. The exposure to UWB electromagnetic radiation had no effect on PEP performance when tested immediately after exposure.

Walters *et al.* [91] studied the bioeffects of an acute high-peak-power UWB exposure (2 minutes of pulsed frequency: 60 Hz, pulse width: 5 – 10 ns, bandwidth: 0.25 – 2.50 GHz) electromagnetic emissions produced by an H-2 transmitter. No effects (i.e. differences between UWB and Sham-exposed rats) were seen following a functional observational battery, swimming test, or a complete panel of blood chemistries or a determination of c-fos protooncogene expression in immunohistologically-stained sections of the brain. The H2 produced peak *E*-field of 250 kV/m pulses (far-field equivalent peak power density =  $1.7 \times 10^9$  W/cm<sup>2</sup>) which was 2.5 times the IEEE safety guidelines (100 kV/m) at the time (IEEE C95.1<sup>TM</sup>-1991). These factors coupled with the close proximity of the animals to the antenna (12 cm), by definition, represent the worst case of a possible accidental exposure.

Several studies by Jauchem *et al.* [50], [51], [52], [53] on the acute cardiovascular effects of UWB pulses found no effect during exposures up to 100 kV/m. Jauchem *et al.* [51] reported that exposure to a Bournlea UWB device (21 kV/m, 318 – 337 ps rise time, 1000 pulses/s, 2 min and Whole-Body Average (WBA) 28 mW/kg) did not cause any significant changes in Heart Rate (HR) or Mean Arterial blood Pressure (MAP). Jauchem *et al.* [52] utilized the Sandia system with rats. Exposure conditions were:

- 50 pps (104 kV/m peak *E*-field, 117 ps rise time, 0.97 ns pulse duration, and 7.4 mW/kg estimated WBA SAR);
- 500 pps (102 kV/m peak *E*-field, 174 ps rise time, 0.97 ns pulse duration and 71 mW/kg estimated WBA SAR; and
- 1000 pps (87 kV/m peak *E*-field, 218 ps rise time, 0.99 ns pulse duration, and 114 mW/kg estimated WBA SAR.

Heart rate and mean arterial pressure were unchanged by exposures to UWB.

Jauchem *et al.* [52] similarly did not find changes in Heart Rate (HR) or Mean Arterial blood Pressure (MAP) following Ketamine (150 mg/kg) administration in cannulated rats exposed for less than 2 minutes to a Bournlea UWB device (21 kV/m, 327 ps rise time, 6 ns pulse duration). Three exposure protocols were used for a total of 2 minutes:

- 2,000 pulses/s for 0.5 s;
- 2,000 pps for 5 s; and
- 1,000 pps pulse train for 2 s and off for 2 s.

No effects were seen. However, Lu and deLorge [62] point out that the average heart rate was considered low and that any effects may have been missed since it may take more than 2 minutes for HR to change [60].

Lu *et al.* [61] used a non-invasive protocol (non-invasive tail-cuff photoelectric sensor sphygmomanometer) to study UWB cardiovascular effects in conscious restraint adapted rats. Exposure parameters were 500 Hz (93 kV/m, 180 ps rise time, 1 ns pulse duration, and 70 mW/kg estimated WBA SAR) and 1000 Hz (85 kV/m,



200 ps rise time, 1.03 ns pulse width, and 121 mW/kg estimated WBA SAR) UWB pulse for 6 minutes. Cardiovascular endpoints were determined 3 – 4 days before exposure and 0.75 h, 24 h, 72 h, 1, 2, 3 and 4 weeks after exposure. No significant changes in HR were found. However, Lu's group did find significant hypotension at 2 weeks that had not resolved by 4 weeks. Lu *et al.* [61] report that the UWB radiation-induced hypotension was a robust, consistent, and persistent effect. The temporal peak SAR of the high UWB pulse used in the experiment was 117 kW/kg (duty cycle  $\approx 10^{-6}$ ). Due to an extremely short pulse (pulse width = 1.03 ns), the SA per pulse from the high UWB pulses was around 0.12 mJ/kg, which was one order-of-magnitude lower than the known auditory threshold in rats. Therefore, the UWB-induced delayed hypotension would not be expected a sequela of an audiogenic (microwave hearing) effect.

Pakhomova *et al.* [74] reported not finding any effects of Sandia spark gap generated UWB on the *saccharomyces cerevisiae* D7 strain of yeast which carries a specific gene marker that facilitates identification of mutagenic damage. Three different 30-minute exposure treatments were used at 102 – 104 kV/m with repetition rates from 165 pps to 600 pps. No effects were seen in yeast cells colony forming nor did it cause mutations or gene recombination. Pakhomova *et al.* [75] in a follow-on study pre-treated the yeast cells with Ultraviolet (UV) light known to cause mutations requiring repair. Using the same protocol as in the previous study they found no effects.

Pakhomova *et al.* [74], [75] irradiated yeast cells with CW or extremely high-power pulses at the same frequency (9.3 GHz) and average power (1.25 W) for 6 h producing peak SAR up to as high as 650 MW/kg (local maximum at the exposed gel surface). They reported the high-peak-power microwave pulses did not produce specific bioeffects as compared to CW exposure at the same average SAR. The peak transmitted power was 250 kW (0.5  $\mu$ s pulse width, 10 pps) producing the *E*-field of 1.57 MV/m in the waveguide. The peak SAR, peak *E*-field in the incident wave and the exposure duration in this study exceeded by far the respective values found in various safety standards [46], [47], [80] and do not support the existing restrictions. Exposures of 950 kV/m pulses to the frog heart [73] revealed no special effects of pulses; all observed effects were due to SAR heating.

Seaman *et al.* [81] tested mice on several measures in an evaluation of the potential effects of exposure of mice to a Sandia UWB. The experiments were very well controlled with cage control, sham exposure, low repetition rate UWB (30 min, 60 pps, 100 – 105 kV/m, 165 – 168 ps rise time, 0.97 ns pulse duration and 3.7 mW/kg estimated whole-body average SAR) and high repetition rate UWB exposure (30 minutes, 600 pps, 100 kV/m peak, 168 ps rise time, 0.97 ns pulse duration and 37 mW/kg estimated whole-body average SAR). Nociception measured as latency to paw lick after placement on a 49.5 – 50.5 °C metal surface was unchanged by UWB. No UWB effect was observed.

Miller *et al.* [66] injected rats with PTZ at 99% effective dose (ED99, 89.17 mg/kg) to re-evaluate the effect of UWB pulses on drug-induced convulsions previously examined by Erwin and Hurt [35]. UWB pulses (40 kV/m (4.24 MW/m<sup>2</sup>) peak *E*-field) were produced by a Kentech PBG3 device into a parallel plate transmission line. Pulses were 176 ps rise time, 1.92 ns pulse duration and 1,000 pps for 2 minutes. No interaction between morphine-induced analgesia and UWB exposure effects was found.

As with the animal and human studies discussed in the previous sections, UWB effects were not observed beyond the single study reporting hypotension that developed two weeks after exposure [61].

### **2.3.4 Biological Effects: Direct Cellular and Sub-Cellular Application of HPPP-EMFs**

Electropermeabilization of the plasma membrane as indicated by an influx of large membrane impermeable molecules (such as DNA binding dye, Propidium Iodide (PI)) has been studied [42] with *E*-field pulse. These

studies of electrical pulses direct to sub-cellular structures are typically of  $\mu\text{s}$  to  $\text{ms}$  duration and have applied voltages in the  $\text{kV}$  range resulting in delivered  $E$ -fields up to  $1 \text{ MV/m}$ . These levels would not be expected as a result of exposure to environmental levels [1].

Jiang and Cooper [54] carried out studies directed at examining TASER biological effects using direct stimulation of rat sensory and pain nerve fiber nociceptor sub-types at a critical threshold ( $E_c$ ) of  $403 \text{ V/cm}$ . There was no evidence of electroporation at field intensities near the  $E_c$  for nociceptor activation. USP bursts activated a late, persistent  $\text{Ca}^{++}$  flux that was identified as a Dantrolene (antispasmodic)-sensitive  $\text{Ca}^{++}$ -induced  $\text{Ca}^{++}$  release (CICR).

Chemeris *et al.* [15] investigated the genotoxic effects of multiple  $65 \text{ kW}$ ,  $8.8 \text{ GHz}$ ,  $180 \text{ ns}$  pulses ( $50 \text{ pps}$ ) on both erythrocytes and white blood cells and saw no effects on DNA integrity or morphology. They later also failed to find a lack of direct DNA damage in human blood (strand breaks, alkali-labile sites, and incomplete excision repair sites) using an alkaline comet assay [16] and using the same exposure parameters as the earlier 2004 study [15].

It remains unclear if field-dependent effects from EMP-like exposures, such as electropermeabilization of deep tissue are possible, however, Adair [1] suggested “*The energy of the pulse at a depth of 1 cm is about 0.8% of the initial energy; the maximum electric field,  $E$  is reduced by a factor of 12, and the maximum rate-of-change of the field,  $dE/dt$ , is reduced by about a factor of 20. Every characteristic of the pulse at depth is contained, albeit attenuated.*” Therefore, caution must be exercised when attributing direct cellular effects to effects expected from environmental HPPP-EMFs.

## **2.4 HIGH-PEAK-POWER PULSED EMF (EMP) EXPOSURE STANDARDS**

### **2.4.1 EMP Simulator Concerns**

The United States Occupational Safety and Health Act [72], employer concern for worker safety, and the rapid development of EMP simulators in the 1960’s and 1970’s led to efforts to establish worker health and safety EMP exposure standards. Experiments were being conducted by the United States military on the effects of EMP that would occur with nuclear events. The EMP simulators included the Air Force Weapons Laboratory Horizontal Dipole Facility and the Advanced Research Electromagnetic Simulator (ARES), KAFB, New Mexico, and the Navy’s Electromagnetic Pulse Radiation Environment Simulator (EMPRESS) in the Patuxent River at the Naval Ordnance Laboratory, Solomon’s, Maryland. The effects they were looking at were those on electrical and electronic materiel. The ultra-short HPPP-EMF limits that were inserted into standards over 40 years ago were set because of concerns that were not scientific in nature, but rather overly cautious concerns of program managers, policy makers and some scientists who believed any limit was better than none. Lin [59] noted that studies on comparisons of biological effects between high peak power, but low-average pulsed RF and CW of equal average intensity (absorption) are sparse and recommended protection guidance and exposure standards should include potential hazards of pulsed RF fields.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) noted that the biological database for pulsed RF was inadequate for setting safety guidelines [46]. However, ICNIRP limited SA to 10 and  $2 \text{ mJ/kg}$  for occupational and general public to prevent occurrence of microwave-induced auditory effect (microwave hearing).

## 2.4.2 United States Air Force Issues First “Provisional” Guidance

The first guidance for limiting exposure to EMP “Provisional Safety Criteria for Use in Electromagnetic Pulse (EMP)” was published by the Radiobiology Division United States Air Force (USAF) School of Aerospace Medicine (USAFSAM) in 1971 [87]. As a highly conservative measure, a “provisional” arbitrary limit of 100 kV/m was established. The “provisional” interim standard stated:

*“No hazardous effects of fields now in use in EMP simulators have been documented or calculated. Pulsed microwave exposures four orders of magnitude greater than those being used in current EMP simulators have given no demonstrable ill effects to several species of animals including man. The recommended standards should be conservative at least one order of magnitude, but are conservative by three orders of magnitude based on experimental data.”*

<b>DEPARTMENT OF THE AIR FORCE</b> Headquarters US Air Force Washington DC 20330		<b>AF REGULATION 161-42</b>  <b>1 November 1973</b>
<b>Aerospace Medicine</b> <b>RADIOFREQUENCY RADIATION</b> <b>HEALTH HAZARDS CONTROL</b>		
<b>Table 1. Permissible Exposure Levels (PELs).</b>		
	<b>Frequency greater than or equal 10 MHz</b>	<b>Frequency less than 10 MHz</b>
<b>Exposure time greater than 1 min (360 sec)</b>	10 mW/cm <sup>2</sup>	50 mW/cm <sup>2</sup>
<b>Exposure time less than 1 min (360 sec)</b>	3600 mW-sec/cm <sup>2</sup>	18,000 mW-sec/cm <sup>2</sup>
<b>NOTE: All exposures limited to 100 KV/M maximum (peak E-field)</b> d. For example if a known exposure is: Exposure time = 180 sec Exposure average power density = 50 mW/cm <sup>2</sup> Frequency = 2.6 GHz		
		To determine if an overexposure would result: (1) Since the frequency is greater than 10 MHz and the time less than 360 sec, the PEL (table 1) is: 3600 mW-sec/cm <sup>2</sup> .

Figure 2-5: First Revision of Provisional 1971 Guideline.

This “provisional” EMP safe-tolerance limit was based on acute thermal burden and related to the 10 mW/cm<sup>2</sup> (100 joules meter<sup>-2</sup> seconds<sup>-1</sup>) that would later become the 1974 ANSI standard [7]. The limit was reissued in 1975 [26] and in 1987 [27]. The limit of 100 kV/m fit well with the measured fields occurring due to nuclear blast which rarely reach 100 kV/m [36].

The proposed criteria were considered conservative by factors of 70 to 100 based on simple power deposition calculations [87]. Retention of this large safety margin was at the time considered to be dictated by the uncertainties in biological response to chronic fields and to uncertainty about how the fields may or may not sum in humans [77]. These Permissible Exposure Limits (PELs) could be applied up to a single pulse (1 per second) maximum *E*-field intensity of 100 kV/m. However, at the time there was additional confusion about how to set the general public level. The “provisional” document stated that pacemakers implanted in eight dogs were unaffected by 5, 25, and 50 kV/m. The “provisional” guidance recommendation for the general public limit was set at 5 kV/m for a single pulse, one per minute. Never-the-less, the “provisional” guidance also stated:

*“Because of the occurrence of these devices (cardiac pacemakers) in the general population, pulse rates greater than one (1) per minute at levels above 200-300 V/m (peak) must be considered to be hazardous.”*

This further reduction was based on USAFSAM research that showed no adverse effects would be expected below peak pulses of 2 – 3 kV/m (pulse repetition rates of greater than 20 per second and pulse widths of 1.5 msec). Additionally, the Command Surgeon, USAF Systems Command [37] recommended the general public limit be set at 50 kV/m (single pulse, one per minute). This may be a typo (50 instead of 5 as in the “provisional”), but as we will see neither the general public nor the occupational limits were justified.

The limit was not based on science, but was basically a policy decision. Today we know that setting exposure limits without sufficient data, a precaution against imaginable effects, can be problematic later as the data-base is expanded. Unfortunately, there is resistance by some to remove these unnecessary limits. Safety and occupational health exposure limits should only be instituted when sound science supports identifiable and established adverse health effects levels. As reviewed by the RTG HFM-189, no adverse health effects from exposure to non-thermal levels of HPPP-EMP have been found all the way up to levels of air breakdown which is the limiting exposure factor. Air breakdown (where air becomes ionized and conductive) occurs at 1 – 1.5 MW/cm<sup>2</sup> for pulses longer than 1 ms. Shorter pulse widths increase the air breakdown threshold, thus allowing greater instantaneous power to be transmitted to a target [65].

In 1975, the United States Department of Army issued Army Regulation 40-583 [8], which established the maximum field strength limit for single-pulse human exposure at 100 kV/m ( $\approx 2.65$  kW/cm<sup>2</sup>), irrespective of the EMP frequency content of the pulse. In 1986, the Department of Defense (DoD) issued DoD Instruction 6055.11-1986 [28] which set the maximum permissible exposure limit to 100 kV/m without attention to frequency content. The American Conference of Governmental Industrial Hygienists (ACGIH) also set a 100 kV/m exposure threshold limit value in 1983 [6]. Recognizing that the limit was not scientifically justified, the third edition of NATO STANAG 2345 [69] raised the exposure limit to 200 kV/m in a single instantaneous pulse. This change, which was still overly precautionary, was subsequently adopted as a PEL by the DoD in DoD Instruction (DoDI) 6055.11-2009 [29].

#### **2.4.3 Proposals to Not Set an *E*-Field Limit for HPPP-EMP**

The USAF Deputy Surgeon General concluded in a letter to the Department of Labor – Occupational Safety and Health Administration (DOL-OSHA) dated March 27, 1974 (cited in Ref. [87]), that “... *it would not be prudent to propose standards that are not based on scientific data, particularly when all known exposure experience shows no cause-effect relationship. A strong recommendation was made not to develop an EMP standard under the provisions of the Occupational Safety and Health Act until there is sufficient scientific data, including cause-effect relationships, to warrant development of a standard.*”

In 1974, the USAF Hospital (KAFB) and the Aerospace Medical Division (Brooks, AFB) conducted a thorough review of all available occupational health records and the results of a continuous EMP exposure study conducted by the Armed Forces Radiobiology Institute [12]. Rodents were subjected to a “worst-case situation” of continuous EMP exposure, 447 kV/m, 5 pulses per second over 38 weeks, for a total of 10<sup>8</sup> pulses. There were no injurious findings and the authors concluded that “...*humans exposed under similar conditions would show no acute injurious biological effects.*” Subsequently, the USAF discontinued the annual EMP physicals (May 1975) on Kirtland AFB personnel and this position is reflected in the USAF Regulation 161-42, Radiation Health Hazards Control [26].

Bruner [14] reviewed the literature on occupational safety and health aspects of electromagnetic pulse exposure. He reported that the DOL-OSHA [30] invited comment on the proposed standard [87] and on the issue of whether any new standard on occupational exposure to EMP’s should be issued at all. Bruner [14] noted that the comments to OSHA acknowledged that the thermogenic hazards normally associated with microwave frequencies



would be miniscule. In response to a petition to the U.S. Occupational Safety and Health Administration, a notice was published in the Federal Register on 26 February 1976 detailing the U.S. Air Force provisional standard and requesting comments. Thirty-one responded that the need for a standard was doubtful. All commenters indicated that they had no evidence of any injuries or illnesses which were attributable to EMPs [71], [72]. The consensus of the responses was that no new standard could or should be issued on occupational EMP exposure based on then current knowledge [71].

The OSHA Consensus conclusions were summarized in the Federal Register NOTICE Determination Not To Propose Standard: *“Experience with EMP worker exposure has accumulated for more than 20 pulser projects, some of which have been in operation for over ten years. No adverse health effects of such exposures have been determined from either the repeated physical examinations performed or the personal observations of nearly 600 individuals covered in this review.”* Based on consensus from the 31 respondents, in 1975 OSHA [72] ruled that *“...the need for a standard regulating employee exposure to EMPs has not been shown and that the scientific information necessary for the development of a standard currently does not exist.”* The OSHA determined *“... that a proposed standard on exposure to electromagnetic pulses should not be issued ...”*.

Patrick [76] reviewed the EMF bioeffects literature and concluded that there was little evidence of permanent damage from a single EMP up to 50 kV/m peak electric field intensity on cardiac pacemakers. However, since the pacemakers could not be accurately assessed prior to implantation, Patrick recommended precautionary measure of restricting access of pacemaker wearers from EMP spaces.

The RTG HFM-189 members similarly agreed that it is inappropriate to set limits without scientific rationale and member Tattersall stated *“it should not be necessary to gather evidence to remove a limit which was not based on any evidence in the first place.”* [84]. Ibey similarly stated *“Many UWB studies have investigated >100 kV/cm fields at or near 1-100ns in duration and yielded no significant results. Additional studies by groups across the world have looked into single frequency high peak power microwaves in the 100’s of ns in duration up to 3MV/m and found no effects as well. Given this evidence, I do not believe we would establish a peak electric field standard today; therefore, it is unclear why we would maintain the one currently in place. In short, the peak field standard should be removed as it has no historical precedence, no published support, and also little to no impact on safety as the thermal standard is already in place and well supported”* [44].

#### **2.4.4 Development of IEEE C95.1 Standard**

The IEEE C95.1<sup>TM</sup>-1999 [47] standard continued the provisional limit for EMP simulator broad-band systems of 100 kV/m for a single instantaneous pulse first set in 1972 by the USAF. With the advent of HPM narrow-band systems, the exposure limit for any single pulse or series of pulses lasting less than 10 seconds was first set at the higher limit of 200 kV/m with NATO STANAG 2345-2003 [69] and later Department of Defense DoDI-6055.11 [29]. No distinction between types of pulsed EMFs was made; high-peak and electromagnetic pulse were not distinguished and both were set at 200 kV/m.

The IEEE C95.1<sup>TM</sup>-2005 [48] standard limits pulsed RF exposure using two independent criteria. First, time averaged SA is limited to protect against a cumulative thermal rise within a tissue volume through repetitive pulse exposures. The body resonance range results in energy deposition, averaged over the entire body mass for any 6-minute period of about 144 J/kg or less. This SA corresponds to an SAR of about 0.4 W/kg or less, as spatially averaged over the entire body mass. The IEEE C95.1<sup>TM</sup>-2005 SA-based restriction of 144 J/kg applies to all pulse exposures. This limit is based on 10% of 4 W/kg, the SAR shown to disrupt animal behavior [24], [25]. However, because that limit is based on a six-minute average, an exposure of closely spaced high-energy pulses could be performed that would average over six minutes under 144 J/kg total SA. For this reason,

the thermal-based standard was modified to conservatively restrict the SA to  $1/5 \times 144 \text{ J/kg}$  (28.8 J/kg), the maximum permissible exposure limit for any 100 ms period. It is important to note that this further restriction reduces the safe limit to  $1/50$  of the known biological endpoint at 4 W/kg. Second, while systems were in use or in development that emitted 100 kV/m or higher, little bioeffects research had been done on these types of emissions. The peak electric field limit was termed “ultra-conservative” and has no underlying biological mechanism to support its existence, unlike the thermal-based standard.

#### **2.4.5 Dissenting Opinions Based on Single Study with Ionizing Cross-Contamination**

A unanimous consensus (see Chapter 7) was obtained at the final meeting (following around the table accounting). The consensus statement [68] drafted by all was later rescinded by two nations entering abstentions. Turkey member, Dr. Seyhan stated that *“complete removal of the standard is not appropriate unless we have more data from experiments on the subject. I think that it is reasonable to keep the current standards as they are”* [82]. French member, Dr. Debouzy [23] cited an unpublished study by RTG HFM-189 member Dr. de Seze and wrote that *“presently it is not possible to build currently systems able to obtain systems strong enough to reach biological deleterious effects; however, the results mentioned by René preclude for us to remove at national level the corresponding measurements until these results are published, replicated and infirmed or confirmed. Consider that our abstention is included in your general consensus process.”* Here again it is evident that it is difficult to remove an exposure limit shown by over 50 years of research as unnecessary. A paradigm once set is truly difficult to shift.

Dr. de Seze submitted to RTG HFM-189 a summary of the unpublished research conducted in his laboratory. The study referred to by France and Turkey was conducted by RTG HFM-189 member de Seze and presented as a conference paper [31] (see also Chapter 4). They reported exposing Sprague-Dawley rats to 3.8 GHz pulses at 1MV/m and reported some significant changes in brain inflammatory markers, but no marked changes in animal behavior. Rats were exposed to the highest possible power level available (1 MV/m) for short duration (1 to 2.5 ns) from two different carrier frequencies of 10 GHz and 3.8 GHz, repetition rate (100 pps) and the duration of pulse trains lasted from 10 s to 20 min under single acute and repetitive long-term conditions for eight weeks (five days/week = 40 days.) The reported results were that only one behavioral effect was observed with the rotarod test after either acute (improved performance) or repetitive exposure (decreased performance); an avoidance reflex was shown with acute exposure, only at very high thermal levels (22 W/kg). This thermal level is above 50 times the occupational/worker limit of 0.4 W/kg and an additional factor of 5 for the public level of 0.08 W/kg. An increase of Glial Fibrillary Acidic Protein (GFAP), in this study interpreted as a brain inflammation marker, was shown at 2 and 7 days after acute exposures. A four month decrease in survival time was found with 6 of 24 exposed animals exhibiting large sub-cutaneous tumor, as there was only 1 of 23 in the sham exposed animals.

A residual x-ray exposure was also present in the de Seze *et al.* study [31] (20 mGy/day, 0.8 Gy (80 rad) in total). Presence of x-ray is a potential contaminant. Transient inflammatory changes can occur after 0.1 Gy exposure [92]. One cannot rule out that an exposure to 0.8 Gy of x rays would cause up-regulation of neuronal Glial Fibrillary Acidic Protein (GFAP). Contamination from 60 mGy/hr acute or 1 mGy/hr average, is known to possibly increase tumor incidence, but it has never been shown to reduce survival time; therefore the observed effect may be related to the EMF exposure.

The de Seze study [31] stands isolated from the plethora of studies reviewed herein (Chapters 2, 5 and 6) that failed to show any effects; however, de Seze notes that none of these studies were performed *in vivo* at such high levels and chronically. This unpublished (abstracted) study concluded that high-power microwaves can lead to cancer and decrease survival time, with few effects on behavior. However, as noted above the thermal levels

were extremely high (22 W/kg). Detailed anatomopathology examination had been performed, showing that the observed macroscopic tumors were in the conjunctive tissue, with different levels of malignancy:

- Well-differentiated fibroma (2 tumors in one animal);
- High-grade fibrosarcoma;
- Mammary fibro-adenoma;
- Low-grade mammary adenocarcinoma;
- High-grade fibroblastic osteosarcoma; and
- One adenoma of the Zymbal gland (on the cheek).

Certain strains of rats such as the Sprague-Dawley used may be prone to certain tumors when stressed. This singular study served as the rationale for participants from two Nations to withdrawal support previously given for the RTG HFM-189 consensus document [68] and abstain. Studies reviewed in Chapters 2, 5 and 6 conclude that there are no adverse health effects or biological mechanisms beyond thermal interaction for high-peak-power ultra-short pulsed *E*-field and the ultra-short *E*-field limit has been deleted from the new IEEE C95.1-2345<sup>TM</sup>-2014 standard [49] adopted by NATO [70]. However, based on the abstracted study [31], de Seze recommended that additional complimentary studies be carried out to determine if the observed effects can be replicated without the identified contaminants. If the study in question is replicated and validated it may again be necessary to establish exposure limits. Science is provisional, it evolves and new data should then promote paradigm shifts unless long-held tenets prevail. The scientific weight of evidence should guide the paradigm not principles/beliefs.

## **2.5 PROVISIONAL NATURE OF SCIENCE AND PARADIGM SHIFT**

Clearly, science is provisional [86]. A Kuhnian paradigm shift [57] usually occurs when anomalous results are obtained and they persist following much scientific discussion and work and then a new paradigm emerges. Typically, however, an existing paradigm is supported and the anomaly is revealed to be pathological [58]. In the case of HPPP-EMFs, the long-held paradigm that HPPP-EMFs were a potential health hazard was itself pathological. The very few studies that have yielded results (“anomalies”) that would point to a possible health hazard have not been scrupulously investigated or in some cases have not been published in peer reviewed literature and therefore replicated. The scientific reality is that the paradigm that has existed for almost half century, setting a limit at 100 kV/m is the “anomaly”. The overwhelming direction of research results on HPPP-EMFs reviewed here supports a paradigm shift back to the original position of no exposure limit is necessary as stated over 40 years ago: “*it would not be prudent to propose standards that are not based on scientific data...strong recommendation was made not to develop an EMP standard*” (USAF Surgeon General letter to OSHA dated March 27, 1974; cited in Ref. [14]). In other words, de Seze *et al.* [31] is an “anomaly” until replicated and validated (and published) with sufficient documentation of exposure conditions and control for ionizing contamination. In order to change the “true” and current paradigm of no HPPP-EMF limit (IEEE C95.1-2345<sup>TM</sup>-2014), actually many, additional “anomalies” must accumulate. Otherwise we fail the pattern of paradigm-guided scrutiny Turro calls the First Law of Parodynamics [86].

One final caution: To the demand “*to eliminate a limit value, we should have many peer reviewed researches in our hands.*” [82] One must consider the large number reviewed here and those studies failing to find any biological effect are oftentimes not submitted for publication beyond the abstract, or are rejected for publication due to a “positive effects bias” or are published in obscure non-peer reviewed journals and therefore virtually lost to the scientific database. This bias pushes the scientific community to look again and again for a proposed

effect that is not there. Such is the Cheshire Fact [43]. It also skews the body of literature to give greater weight to the few positive effects studies. How many times and over how many years must we accumulate data showing no effects before we can remove an erroneous factor from a standard? It is therefore necessary that a paradigm shift be made from prudently avoiding or being precautionous based on insufficient scientific data to establishing exposure guidelines in accordance with sound scientific data.



## **Chapter 3 – HFM-189 REPORT SUMMARY**

**René de Seze**  
FRANCE

### **3.1 BACKGROUND**

High-power microwaves are used to inhibit the electronic systems of threatening military or civilian vehicles, and could also be used in the future to frighten and thus inhibit people in demonstrations.

### **3.2 PURPOSE**

The aim of this work is to evaluate the health hazards of high-peak-power microwaves for the operators of emitting systems and personnel exposed to beams. Rats were exposed to the highest possible power level, under single-acute and repetitive long-term conditions for 8 weeks (5 days/week = 40 days).

### **3.3 METHOD**

Very intense microwave electric fields at 1 MV/m and of very short duration of 1 to 2.5 ns were applied from two different sources at two different carrier frequencies of 10 and 3.8 GHz. The repetition rate was 100 pps, and the duration of train pulses lasted from 10 s to 20 minutes.

The effects were studied on the central nervous system, by labelling brain inflammation marker GFAP and by performing different behavioural tests:

- Avoidance test;
- Rotarod;
- T-maze;
- Beam-walking; and
- Open-field.

Survival time was measured after long-term repetitive exposure.

### **3.4 RESULTS**

Few effects were observed on behaviour after acute and repetitive exposure; an avoidance reflex was shown with acute exposure, but only at very high thermal levels (20 W/kg). Most importantly, an increase of GFAP was also shown at 2 and 7 days after acute exposures. A 4-month decrease of survival time was found, with some exposed animals exhibiting a large sub-cutaneous tumour. A residual X-ray exposure was also present in the beam (20 mGy/dy, 0.8 Gy in total).

### **3.5 CONCLUSION**

High-power microwaves below thermal level can lead to cancer and decrease survival time, without clear effects on behaviour. The parameters of this effect need to be explored further, and a more precise dosimetry to be performed.

## **Chapter 4 – RELATIONSHIP BETWEEN DURATION OF HEATING AND TEMPERATURE THRESHOLD IN RAT HIPPOCAMPAL SLICES**

**Stuart J. Armstrong, A. Chris Green and John E.H. Tattersall**  
UNITED KINGDOM

### **4.1 INTRODUCTION**

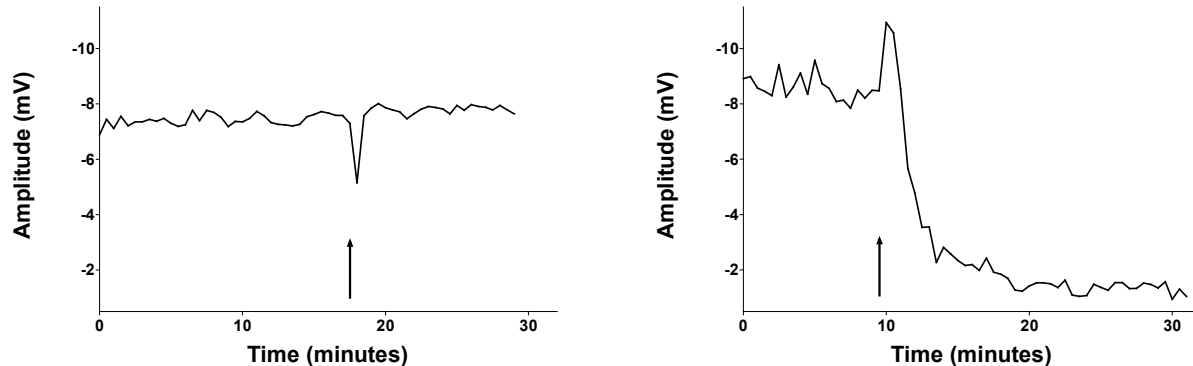
Previous studies have shown that changes in electrical responses in rat hippocampal slices *in vitro* [94] caused by exposure to low-intensity Radiofrequency (RF) fields are due to localised heating produced by interaction of the RF fields with the recording and stimulating electrodes [95]. This electrode-mediated heating artifact can be used to explore the effects of short pulses of localised heating on neurotransmission in brain tissue [96]. This chapter describes experiments to determine the relationship between duration of heating and the temperature rise required to produce changes in electrophysiological responses in brain slices.

### **4.2 MATERIALS AND METHODS**

Porton Wistar rats were anaesthetised with halothane and decapitated; parasagittal slices of brain tissue (300  $\mu\text{m}$  thick) containing the hippocampus were prepared using a Vibratome. The slices were maintained at  $32.0 \pm 0.1^\circ\text{C}$  and perfused with artificial cerebrospinal fluid in a Haas type interface chamber. Responses were evoked every 30 s by constant current pulses (70  $\mu\text{s}$  duration) delivered by a concentric bipolar stainless steel stimulating electrode placed in *stratum radiatum*. Extracellular field potentials were recorded in CA1 stratum pyramidale using glass microelectrodes filled with 2M NaCl. The slices were exposed to 380 MHz RF fields in a parallel plate transmission line. An infrared camera (Cedip Infrared Systems Jade) was used to image the brain slice and the electrodes in order to measure the heating produced during RF exposure. This camera has a theoretical thermal resolution of  $0.025^\circ\text{C}$  and each pixel on the sensor corresponded to approximately 200  $\mu\text{m}$  at the brain slice target. The acquisition rate was 50 – 1000 frames  $\text{s}^{-1}$ . Copper/constantan microthermocouples (Omega Engineering) were also used to record the heating produced during RF exposure.

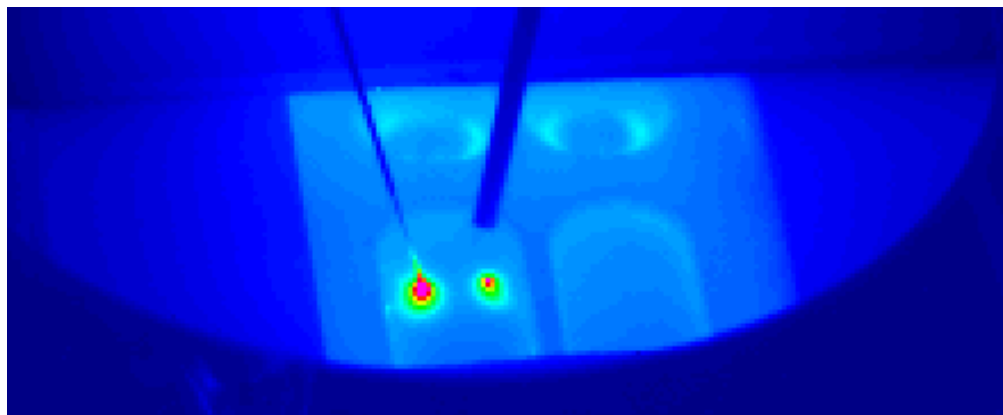
### **4.3 RESULTS**

Exposure to RF fields produced localised tissue heating around the tip of the stimulating electrode [95], which produced a decrease in the amplitude of the evoked field potential response in CA1 (Figure 4-1). At lower levels of RF exposure (smaller temperature increase), the change in the field potential was reversible, but at higher levels of exposure (greater temperature increase), the decrease in amplitude persisted after the end of the exposure. Shorter durations of exposure required higher intensities of RF (greater temperature increase) to produce the effects. The relationship between duration of heating and threshold temperature increase to produce changes in field potential response is being explored for durations of exposure between 1 ms and 10 minutes.



**Figure 4-1: Reversible (Left) and Persistent (Right) Decreases in Evoked Field Potential Amplitude Produced by RF-Induced Heating Through the Stimulating Electrode (indicated by the arrows).**

The possibility of using microthermocouples both to induce the heating artifact and to measure the resulting temperature rise has been investigated. Infrared camera images showed that the RF-induced heating in the tissue slice around the tip of the microthermocouple was similar to that seen around the tip of the stimulating electrode (Figure 4-2).



**Figure 4-2: RF-Induced Heating in Tissue Around the Tip of the Stimulating Electrode (Left) or Around the Tip of a Microthermocouple (Right).**

## 4.4 CONCLUSIONS

RF-induced heating artifacts can be used to characterise the effects of short pulses of localised heating on neurotransmission in brain tissue. The results of this study show that, for shorter durations of heating, higher temperature rises are necessary to produce changes in electrophysiological response. Characterisation of this relationship will help to provide a scientific evidence base for exposure standards for RF pulses.

Microthermocouples can be used both to induce the heating artifact and to measure the temperature rise in the tissue. This offers a lower cost alternative to the infrared camera system, which also has faster time resolution and is not limited to surface measurements.

## **4.5 ACKNOWLEDGEMENTS**

This work was carried out as part of the Electronics Systems Research Programme for the Ministry of Defence.  
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## Chapter 5 – OPINION ON THE CURRENT HIGH-PEAK-POWER PULSED RADIO FREQUENCY (RF) STANDARD

**Bennett L. Ibey, Jason A. Payne and B. Jon Klauenberg**  
UNITED STATES

*“For exposures to pulsed RF fields, in the range of 100 kHz to 300 GHz, the peak (temporal) value of the MPE for the instantaneous peak E-field is 100 kV/m.*

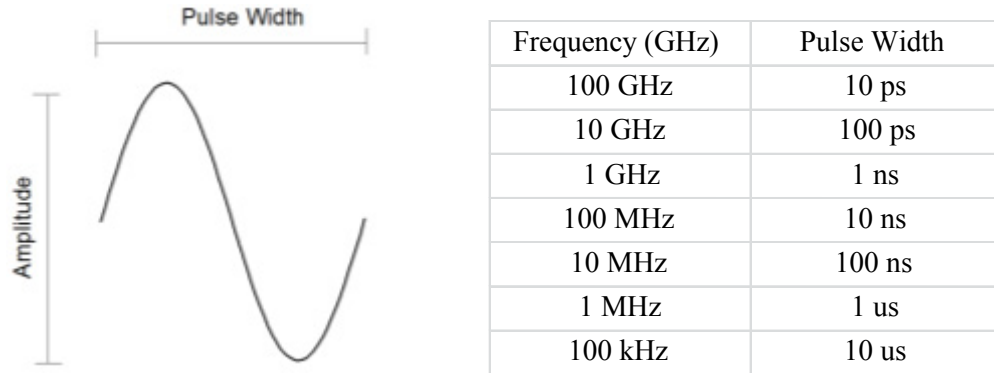
*For exposures to pulsed RF fields in the range of 100 kHz to 300 GHz, the peak pulse power densities are limited by the use of time averaging and the limit on peak E-field, with one exception: the total incident energy density during any one-tenth second period within the averaging time shall not exceed one-fifth of the total energy density permitted during the entire averaging time for a continuous field (1/5 of 144 J/kg), i.e. [48]:*

$$\sum_{0}^{0.1s} (S_{pk} \times \tau) \leq \frac{MPE_{avg} \times T_{avg}}{5} \leq 28.8 \text{ J/kg} . \quad ”$$

The IEEE C95.1<sup>TM</sup>-2005 [48] standard limited pulsed Radiofrequency (RF) exposure using two independent criteria. First, time averaged Specific Absorption (SA) is limited to protect against a cumulative thermal rise within a tissue volume through repetitive pulse exposures. Exposures equivalent to the IEEE C95.1-2345<sup>TM</sup>-2014 [49] Dosimetric Reference Limit (DRL) in the body resonance range result in energy deposition, averaged over the entire body resonance range results in energy deposition, averaged over the entire body mass for any 6-minute period of about 144 J/kg or less. This SA corresponds to a Specific Absorption Ratio (SAR) of about 0.4 W/kg or less, as spatially averaged over the entire body mass. The IEEE C95.1<sup>TM</sup>-2005 [48] SA-based restriction of 144 J/kg applies to all pulse exposures and is based on a 10% modifying factor applied to 4 W/kg, the SAR shown to disrupt animal food-motivated behavior [25]. However, because that limit is based on a 6-minute average, an exposure of closely spaced high-energy pulses could be performed that would average over 6 minutes under 144 J/kg total SA and was considered a possible health risk due to the large energy deposition relative to pulse width. For that reason, the thermally-based standard was modified to conservatively restrict the SA by a factor of five reducing the maximum permissible exposure limit to 28.8 J/kg for any 100 ms period. This further restriction reduces the exposure limit to 0.08 W/kg, 1/50 of the 4 W/kg established adverse health effects limit. Second, to protect against any potential adverse health effects from exposure to high instantaneous power, peak electric field amplitude of any exposure was limited to 100 kV/m [97]. This arbitrary peak E-field limit was set as an “ultra-conservative” limit solely due to the paucity of research data at the time. Unlike the thermally-based exposure limits, continued research has failed to find any adverse health effects for short pulse peak E-fields at any frequency or power, indicating the limit is unnecessary.

For explanation of the true impact of the standard across this broad frequency range, we must first define a pulse. If we consider a single frequency pulse (Figure 5-1 (left)), then the minimal pulse width would be defined as a single bipolar cycle of that fundamental frequency. The chart below depicts the minimal pulse width necessary to generate a single bipolar pulse. We can see that for 100 kHz the smallest possible pulse is 10 μs agreeing very well with the thermal limit imposed by the SA portion of the pulse RF standard. This implies that it is nearly impossible to violate the standard at this frequency with a single frequency pulse.

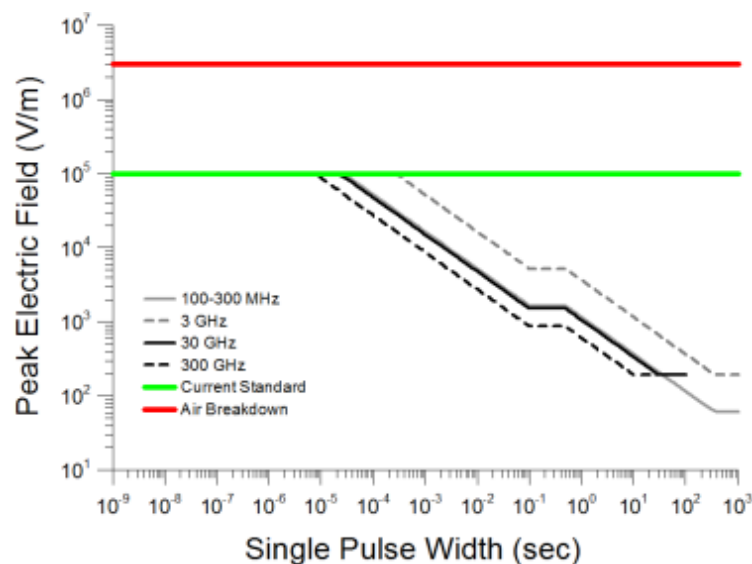




**Figure 5-1: A Simple Depiction of a Single Bipolar RF Pulse (Left) is Shown to Illustrate the Measures of Amplitude and Pulse Width; The Chart (Right) Details the Minimum Pulse Width to Capture a Single Bipolar Pulse Across the Frequency Range of the Standard.**

Wide or Ultra-Wide-Band (UWB) RF pulses contain a broad range of frequencies from kHz to GHz. These pulses are typically lower amplitude than single frequency pulses and distribute that power across a wider frequency range. The rationale in Figure 5-1 depicted in the chart holds true for the fundamental frequency of the wideband pulse and therefore the width of the UWB pulse dictates the fundamental frequency (the point of highest power). Neither single frequency nor UWB pulses have been mechanistically connected to any biological effect that were not determined thermal in nature and therefore human exposures would be protected under the SA-exposure limit.

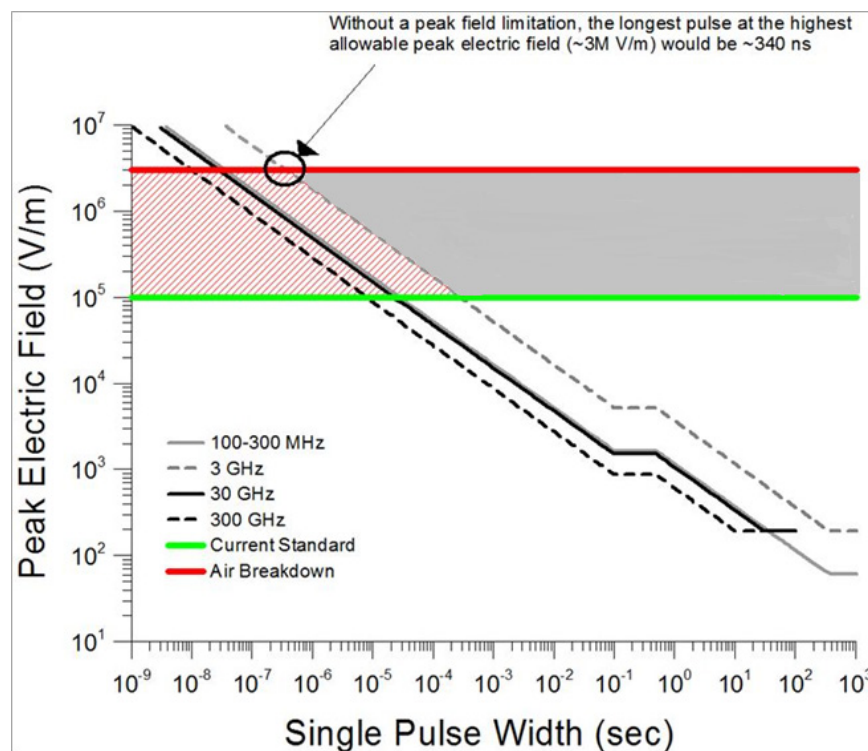
Figure 5-2 illustrates the two-pronged pulse standard based on a single RF pulse exposure. This figure depicts the current safety standard for pulsed RF exposures from 100 KHz to 300 GHz using pulse width and electric field as measureable exposure metrics. A single pulse represents the worst-case exposure scenario (for peak electric field) and therefore the standard limits have been described the in terms of a single RF pulse.



**Figure 5-2: Graphical Depiction of the IEEE C95.1™-2005 Pulse RF Standard.**

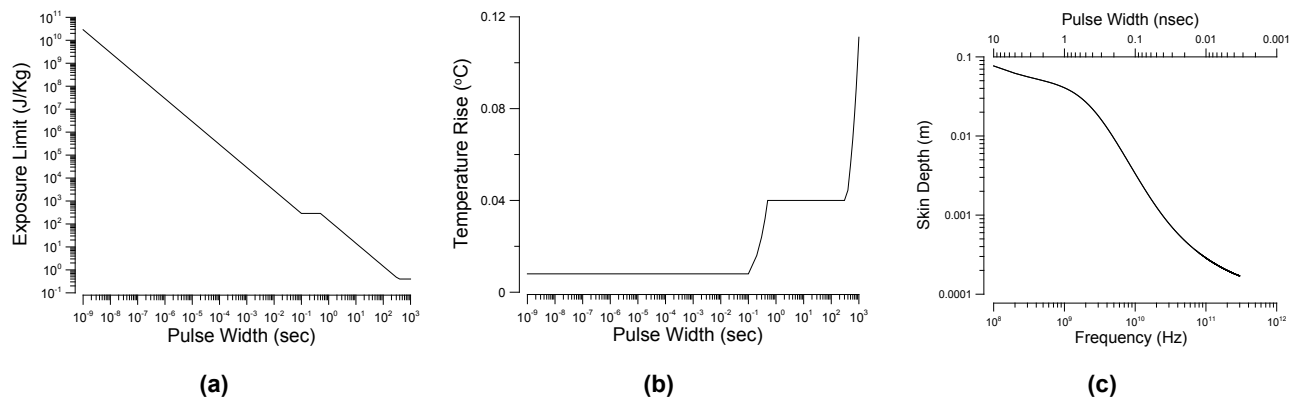
The pulse width is plotted for pulses from 1 ns to 1000 s (beyond the 6-minute average). Four frequencies were selected to depict the SA-based exposure limit. A plateau occurs between 1 s and 100 ms illustrating the transition from 144 J/kg to 28.8 J/kg imposed by the 1/5 modifying factor. The second part of the standard criteria is illustrated by the solid line extended for all pulse widths limiting the peak field of any single pulse to less than 100 kV/m. The uppermost solid line illustrates the voltage typical of air breakdown in which transmission of RF pulses through the air would be unlikely (3 MV/m). Under the C95.1<sup>TM</sup>-2005 standard [48], the maximum allowable exposure would be a single 300  $\mu$ s pulse at 100 kV/m at 3 GHz. For a frequency of 300 GHz, this allowable pulse width is reduced to 10  $\mu$ s, and for 30 GHz and 100 – 300 MHz it is roughly 30  $\mu$ s. This suggests that the only area of concern for peak electric field limitations is pulse widths of less than 300  $\mu$ s given the 100 kV/m limit.

Extension of the SA-based exposure limit for single pulses with amplitudes above 100 kV/m is illustrated in Figure 5-3. The shaded region between the current safety limit and the level of air breakdown, at standard atmospheric humidity and pressure, represents the only portion of the parameter space that the peak electric field limit is relevant. By choosing air breakdown as a limiting point beyond (3 MV/m) the highest achievable electric field could be no longer than 340 ns at 3 GHz. Correspondingly, a single pulse of 100 – 300 MHz or 30 GHz would be limited to 30 ns and 300 GHz would be limited to 10 ns. The necessity of this peak electric field limit is not supported based on the lack of scientific evidence of repeatable adverse non-thermal bioeffects of single radiated 3 GHz pulses below 340  $\mu$ s duration at an amplitude of 100 kV/m (worst-case scenario) [10], [11], [12], [16], [45]. All other frequency ranges are more restrictive suggesting that the current thermal limit further restricts the amplitude within such pulses. As the pulse width shortens in a single pulse, the allowed instantaneous energy density increases accordingly.



**Figure 5-3: Graphical Depiction of the IEEE C95.1<sup>TM</sup>-2005 Pulse RF Standard with Thermally-Based Standard Extended.**

The black circle represents the parameters of the HPPM source used in this study. The IEEE C95.1<sup>TM</sup>-2005 standard is plotted versus pulse duration for single pulse exposures between 1 ns and 1000 s (beyond the 6-minute average) to illustrate the separate roles of the SA and peak electric field standards. The SA exposure limit for frequencies ranging from 100 MHz to 300 GHz is shown plotted by the gray. Between 1 s and 100 ms, a flat line exists illustrating the transition from 144 J/kg to 28.8 J/kg, as imposed by the 1/5 added safety margin. The peak pulsed electric field limit is illustrated by the solid green line extended for all pulse widths, which limits the peak field of any single pulse to under 100 kV/m. The solid red line illustrates the voltage typical of air breakdown, at which transmission of RF pulses through the air would be unlikely (3 MV/m). As the single pulse width shortens, the instantaneous energy density increases accordingly. Figure 5-4(a) depicts the allowable energy density in a single pulse of a specific duration. For example, a 10 ns pulse can have  $2.88 \times 10^9$  W/kg, but the temperature within the tissue would still not exceed 0.008°C (Figure 5-4(a)). For pulses even shorter than 1 ns, the allowable instantaneous energy density climbs even higher, but the frequency components grow increasingly high, which results in very superficial tissue penetration and the lessening impact of the received energy into deeper tissues within the body (Figure 5-4(c)).



**Figure 5-4: Graphical Depiction of the Possible W/kg in a Single Pulse (a) and the Corresponding Temperature Rise within Tissue (b); Additionally, the Skin Depth per Frequency in Muscle is Presented to Illustrate the Lessening Concern Attributed to Higher-Frequency Pulses (c).**

Figure 5-4(a) depicts the allowable energy density in a single pulse of a specific duration. For example, a 10 ns pulse can have  $2.88 \times 10^9$  W/kg, but the temperature within the tissue would still not exceed 0.008°C above initial temperatures (Figure 5-4(c)). For pulses even shorter than 1 ns, the allowable instantaneous energy density climbs even higher; however, the frequency components grow increasingly high resulting in very superficial tissue penetration lessening the deposition of the energy into deeper tissues within the body (Figure 5-4(c)).

In conclusion, the lack of an adverse health effect or biological mechanism beyond thermal interaction for pulses shorter than 100 ms suggest that peak electric field limit in the IEEE C95.1<sup>TM</sup>-2005 [48] safety standard is set excessively low and creates overly-restrictive research and operational conditions. It is important to note that while the standard applies to all fields of any length; it only impacts the shortest pulses, which are likely the least capable of eliciting an exposure to merit a safety concern. Physical laws dictating the propagation of electric fields in free space already limit the maximum allowable peak electric field at  $\sim 3$  MV/m. Current research efforts to expose biological organism(s) and tissues to fields of such magnitudes have been unable to elicit a biological response even at exposures beyond the current thermal limit (see Chapter 2). Since no evidence of non-thermal biomechanism attributed to either single frequency or UWB pulses have been found, the peak electric field limit is unnecessary and has been deleted after expert IEEE review [49].

## **Chapter 6 – MEETING AGENDA, MINUTES AND REPORTS**

**Jill McQuade**  
UNITED STATES

### **6.1 MEETING MINUTES**

#### **6.1.1 NATO Research Task Group HFM-189**

NATO Research and Technology Organization (RTO) HQ  
7 rue Ancelle  
F-92200 Neuilly-sur-Seine  
FRANCE

Monday, 25 May 2009, 9:00 AM – 5:00 PM.

##### **6.1.1.1 Participants**

FRA: Dr. Jean Claude De Bouzy

FRA: LTN David Crouzier

FRA: Dr. René de Seze

HUN: Dr. György Thuroczy

NLD: Mr. Maarten Huikeshoven

SWE: Dr. Mårten Risling

TUR: Dr. Nesrin Seyhan

USA: Dr. B. Jon Klauenberg (Chair)

USA: Dr. Jill McQuade (Co-Chair)

USA: Dr. Michael Murphy

NLD: LtCol Ron Verkerk: (NATO RTO, Wise Observer)

##### **6.1.1.2 Introduction to NATO RTO – LtCol Ron Verkerk**

To begin the meeting, LtCol Verkerk gave an introduction to the NATO (RTO). He first introduced NATO as a whole, then the objective of the RTO, which is to provide military relevant advice to NATO decision-makers and to align the Research and Technology (R&T) efforts with NATO priorities. He described how NATO Military Committee (MC) directed the Allied Command Transformation (ACT) to “identify and prioritize the type and scale of future capability and interoperability requirements”. ACT developed Long-Term Capabilities Requirements (LTCRs) to identifying a mix of capability requirements, technologies and solutions needed so that research, planning and procurement efforts could be focused and harmonized beyond 2010. He stressed the

need to align R&T efforts with the LTCRs and to look for potential collaboration/coordination with other NATO countries. ACT, assisted by NATO Supreme Headquarters Allied Powers Europe (SHAPE) and supported by the widest possible network of stakeholders, has been conducting the Long-Term Requirements Study (LTRS) in order to derive the next set of LTCR through a more structured and analytical process. He then described the organization of the RTO, including the hierarchical network of the Research and Technology Board (RTB) and Research and Technology Groups (RTGs). The RTG is given three years to complete its task and must follow the Technical Activity Proposal (TAP) which, once approved by the RTB, becomes Technical Activity Description (TAD). Minor changes to the TAD can be made by the Executive (in this case, LtCol Verkerk), major changes need to be approved by the RTB. The RTG work consists of two phases – the planning phase and the working phase. During the planning phase, the TAP/TAD is updated, the membership list is defined, and the three-year meeting plan is constructed. The three-year working phase must conclude with a Symposium or a Specialists' Meeting. Additionally, a technical report must be published within 6 months of the final meeting. The RTG will be allowed 2 funded consultants over the lifetime of the group. This is done through the national coordinator and the RTB. The Chair of the group requests the consultant through the Executive of the group. Discussion among the group following the briefing included deciding whether or not it was appropriate to have sub-groups within the RTG and whether or not electronic meetings were feasible.

#### **6.1.1.3 Exposure Standards for RF Pulses – Dr. Michael Murphy**

Dr. Murphy began by restating that the task of this RTG is to provide advice on how safety standards for high-peak-power pulses should be set. He also added that advice on how to set standards for contact currents are an additional task. He went on to describe the current standard setting boards and what metrics are used to measure Electromagnetic Fields (EMF) for standards, i.e. power density, SAR. He compared and contrasted the standards of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronic Engineers (IEEE). When asked to define HEPP, Dr. Murphy stated that HEPP is generally wide-band and that 1000 kV/m is considered high power. He then pointed out that some of the tasks of the RTG may be to provide definitions, dosimetry, modeling, and measurement procedures. When focusing on the differences between ICNIRP and IEEE, he noted the two standards setting groups contrast in how microwave hearing is addressed and pointed out that this group will have to address that issue. The importance of approaching the establishment of safety standards using a scientific basis was stressed. Potential challenges to the use of EMF by the military were ICNIRP's 2 mJ/kg and the 100 kV/m maximum per single pulse. The discussion concluded by stressing the need to scientifically determine the threshold for biological effect, to determine what effects are considered harmful, and to establish a recommendation from these data.

#### **6.1.1.4 Cellular Bioeffects from High-Power Ultra-Short Pulse Electromagnetic Fields – Dr. Jill McQuade**

Dr. McQuade presented work performed at Brooks City-Base by Dr. Bennett Ibey. This work showed how a high-peak-power pulses, applied across a single cell, cause changes in the membrane conductance. This work was performed using the patch clamp method. After voltage was applied to the cell, the resulting current was measured. This was done in a step-wise manner. Once the conductance curve was established, a pulse was delivered to the cell by an electrode. The same step-wise voltage was applied to the cell, the current was measured, and the conductance was compared to the previous curve. The resistance of the cell membrane following exposure to a pulse (60 or 600 ns) was lowered. This effect was recoverable over time. The proposed mechanism was the rearrangement of the lipid bilayer membrane through the creation of nanopores in the cell membrane. This hypothesis is supported by the appearance of Phosphatidylserine (PS), a lipid found on the inner cell membrane, on the outside of the cell. The effects of electric field amplitude and pulse number were examined. The effect of field amplitude and pulse width was combined into a metric termed 'absorbed dose'. The results

showed that multiple pulses lowered the threshold for the effect but not in a purely additive manner. Future work will include focus on the recovery of the cell membrane, exploration of the mechanism, and modeling efforts.

#### **6.1.1.5 Biological Effects of Acute and Chronic HPM – Dr. René de Seze**

Dr. de Seze presented work performed at his laboratory at INERIS using two systems – SR-X and SR-S. The SR-X system is a 10 GHz system with a peak power of 350 MW, *E*-field of 3 MV/m, 1 ns pulse duration, 100 pps, 10-second train duration every 5 minutes for one hour. The SR-S system is 3.8 GHz, 500 MW peak power, 1.7 MV/m, 2.5 ns, 100 pps with 2 eight-minute trains at 10-minute intervals. Experiments performed following exposure included:

- Various behavior studies (rotarod performance, open field behavior, place preference, and radial star maze), blood-brain barrier permeability; and
- Glial Fibrillary Acidic Protein expression (GFAP, a Central Nervous System protein thought to maintain astrocyte function).

The results showed increased place preference for a Faraday protected side of a cage, and decreased rotarod performance following exposure. There was no increased BBB permeability following exposure, but there was increased GFAP expression 7 days post-exposure for the SR-x system and 2 days post-exposure for the SR-S system. Chronic exposure experiments (8 weeks, 5 days/week exposure) showed changes in survival and tumors in exposed rats as compared to sham control rats. However, a 20 mGy ionizing radiation that accompanies the exposure may be a confounding factor in these experiments. Some questions were raised regarding dosimetry within the separate sections of the test cage.

#### **6.1.1.6 Standardization Activities – Dr. B Jon Klauenberg**

Dr. Klauenberg discussed the role of NATO and the placement of the Standardization Agreement 2345 protecting personnel from exposure to Radio Frequency Radiation (RFR) in the NATO Standardization Agency (NSA) Military Medical Standards Working Group to prevent influence of system design and operations and to therefore maintain scientific medical credibility. The current STANAG 2345 is being expanded to include frequencies from 0 Hz to 300 GHz. It is a military unique document. The STANAG is currently updating the safety standards that fall under this overarching document. STANAG 2345 is being transferred to the civil standards developmental organization IEEE. The IEEE International Committee on Electromagnetic Safety (ICES) will write a safety standard, which can include further guidance, including recommendations from this RTG.

#### **6.1.1.7 Review and Adjourn**

The next meeting is planned for 22-23 October at Brooks City-Base in San Antonio, TX, USA. Invited speakers will include Dr. Bennett Ibey, Dr. Pat Roach and Dr. Andrei Pakhomov. Dr. Klauenberg also presented information on a meeting that will be at Umeå University in Sweden on 6-8 October. Information presented at this meeting will include the status of the proposed EMF Directive 2004/40/EC on Worker Safety [33].



**6.1.2 Institut National de l'Environnement Industriel et des Risques (INERIS)**

Parc Technologique Alata-BP2  
F-60550 Verneuil-en-Halatte  
Creil  
FRANCE

27 May 2009

**6.1.2.1 Participants**

FRA: Dr. René de Seze  
HUN: Dr. György Thuroczy  
TUR: Dr. Nesrin Seyhan  
USA: Dr. B. Jon Klauenberg  
USA: Dr. Michael Murphy  
USA: Dr. Jill McQuade

**6.1.2.2 Tour of Facilities**

The tour of the facilities included the animal facilities, exposure systems and behavioral testing equipment.

**6.1.2.3 Introduction to INERIS – General Secretary Christian Tauziède**

The General Secretary gave a brief summary of the history and current status of INERIS. Also present was the Head of Logistics Department, Frédéric Marcel. INERIS has 600 employees. It started in the 1950's in conjunction with the coal mining industry. Its current iteration came about in the 1990's and they currently study toxicology, industrial risks, etc. The research community is about 25 people strong, mostly at the PH.D. level.

**6.1.2.4 Introduction of RTG Group Activities – Dr. B. Jon Klauenberg**

Dr. Klauenberg described the purpose of the RTG to the INERIS General Secretary and Head of the Logistic Department.

**6.1.2.5 Research from Turkey – Dr. Nesrin Seyhan**

Dr. Seyhan is the head of the Biophysics Department at Gazi University. Dr. Seyhan described the 30 years of research that has been accomplished at Gazi University in Turkey. Some of the studies included exposure to both static and 50 Hz fields and measurement of collagen synthesis, markers of oxidative stress and antioxidant activity in brain, liver, lung, kidney, heart, spleen, testes and plasma. Most variables showed a change, with a large number of these changes being statistically significant. Actual numbers and standard errors were not shown. Dosimetry was not performed in any of the experiments. Results from a study with pregnant female rabbits and the offspring were also presented. In this study, DNA base modification, hydroxyproline content, brain zinc and magnesium, and oxidative factors in a number of tissues were among the many dependent variables measured. Numbers and errors were not shown. The weight of the offspring were not different by group. Oxidative damage and DNA base modification were both shown to be increased in the exposure groups.



Finally, a blood-brain barrier study was presented. In this study, rats were exposed to 4.54 V/m for 20 minutes. Dosimetry performed using SEMCAD revealed the 1 g average SAR to be 5.13 mW/kg at 900 MHz and 2.17 mW/kg at 1800 MHz. Evan's Blue was injected into the tail vein and shown to be increased in the brain of both males and females exposed to 900 MHz and just males exposed to 1800 MHz. Analysis methods, values or pictures of brains were not shown.

#### **6.1.2.6 Discussion**

The discussion following the presentations focused on designing, performing and analyzing experiments properly. Some of the points that were made included the importance of the replication of experiments, Dr. de Seze also described an experiment in which two sham groups were mistakenly run and a significant difference was found. Dr. Klauenberg noted another series of experiments he reviewed where experimental treatment groups did not vary while the sham groups compared to each other did resulting in a significant difference that was otherwise meaningless. Other points of discussion were using power analysis to ensure the proper number of subjects is used, using the proper statistics, and what statistical significance means versus biological significance. The importance of proper dosimetry was also discussed. Further points of discussion included how, as RF pulses become shorter, they become more similar to fs laser pulses; the possibility of HPP pulses causing genotoxic effects was proposed by Dr. Thuroczy. Other points discussed included the importance of determining the averaging mass for dosimetry and the possibility of 100 kV/m limiting military equipment in the future.

## **6.2 REPORTS**

### **6.2.1 HFM Panel Report – 5 April 2011**

Dstl Porton Down  
Salisbury  
UNITED KINGDOM

20-21 September 2010

#### **6.2.1.1 Introduction**

- 1) **Meetings:** Dstl Porton Down, Salisbury, GBR; 20-21 September 2010.
- 2) **Changes in team composition:** Dr. McQuade (USA) is no longer a member.
- 3) **Level of Participation by Partner Nations:** None.
- 4) **General Useful Information:** The RTG membership represents the leading scientific research and standardization experts especially with regard to militarily unique electromagnetic systems. The RTG HFM-189 has had three meetings. A kick-off meeting at RTO HQ Neuilly sur-Seine, France (25 May 2009) with a follow-on meeting on 26 May at the laboratory of Dr. René de Seze, Ph.D, l'Unité Toxicologie Expérimentale, INERIS, FRA, Brooks City Base San Antonio, TX, USA (8-9 November 2009) and a meeting at Dstl, Porton Down, Salisbury, GBR.
- 5) **Status:** Currently open, but may become Limited Participation Technical Team (LPTT) as work on direct-energy systems evolves.

### **6.2.1.2 Status of Activities**

#### *6.2.1.2.1 Major Achievements and Assessment of the Work Plan*

Four tasks were addressed and a new task to look into directed-energy emission standardization has been added:

- 1) Information exchange regarding the development and use of national and NATO HEEP experimental instrumentation, measurement tools, and techniques.
- 2) Bioeffects-based risk assessment of modern and emerging HEEP technologies:

The RTG concluded that no risk to health can be found for high-peak-power ultra-short pulsed radiofrequency emissions. This is supported by modeling and in-laboratory and in-field bioeffects research. Consensus was reached on modeling exposure limits using Specific Absorption (SA) based on the Institute of Electrical and Electronics Engineers (IEEE) 28.8 Joules/kg total energy density permitted during continuous time-averaged period. More recent Air Force Research Laboratory Bioeffects Division (711 HPW/RHD) Radio Frequency Bioeffects Branch (711 HPW/RHDR) research that showed no bioeffects from free-field electromagnetic pulses of high electric field ( $> 2$  MV/m) and short duration ( $< 100$  ns) can induce changes in cellular survival, cellular morphology, and/or genetic expression supports the safe deployment of High-Peak-Power Counter Electronic Systems (HPPCES). This “ultra-conservative” peak electric field limit described within the IEEE, DoD, and NATO standards may be unnecessarily limiting deployment of HPPCES. Limitations on ultra-short ( $< \mu$ s) high-peak pulsed electromagnetic fields are unfounded and will be removed from future military-related safety standards. This action will enable deployment of several military unique systems in development.

- 3) Bioeffects of Induced and Contact Currents (40 mA to 100 mA):

Review of the literature revealed that the major international safety standards and guidances failed to take into account the frequency dependence of human bio-response to contact current shock and burn. Existing limits of the IEEE and the International Commission on Non-Ionising Radiation (ICNIRP) were found to be significantly too conservative and based primarily on power line, mains voltages. The exposure limits for contact currents that can be built up on metal surfaces exposed to High Frequency (HF) emissions should be increased from 40 mA to 100 mA to 250 mA. This change would eliminate severe operational impacts that would arise from the unnecessarily restrictive exposure limits. A research proposal has been prepared by RHDR and will be coordinated with the RTG HFM-189.

- 4) Standardization of exposure limits:

The RTG HFM-189 Chair was appointed official NATO Standardization Agency (NSA) stakeholder representative to the European Commission (EC) for Worker Safety with Regard to Electromagnetic Fields. An historic agreement was engineered between the NSA and the EC for Worker Safety with regard to Directive 2004/40/EC [33] on electromagnetic fields. The agreement provides a waiver from the Directive for all military conducting activities in the European Union as long as alternative safety standards are implemented.

The RTG chair as Custodian of NATO Standardization Agreement (STANAG) 2345 – Evaluation and Control of Personnel Exposure to Radio Frequency Fields – 3 KHz To 300 GHz (Edition 3) – engineered a Technical Cooperation Agreement between the Institute of Electrical and Electronics Engineers (IEEE) and the NATO Standardization Agency and a separate Agreement for the Development of a New IEEE Civil Standard to replace the NATO EMF standard adopted under STANAG 2345. This is the first-ever

transition of a standard from NATO to a civil standards body and is serving as a trialing lessons-learned example for future transitions.

NATO STANAG 2345 is categorized as an “Essential STANAG” for co-operation in multi-national operations needed for implementation as a minimum in order to achieve operational interoperability with NATO forces. The Custodian of the STANAG 2345 has participated as a member of the IEEE editorial committee in the development of the new standard. A draft will incorporate changes including deletion of the arbitrary high-peak pulsed limit of 100 KV/m and modification of the contact current limits to reflect research showing frequency dependence. The draft standard be circulated to the DoD Transmitted Electromagnetic Radiation Protection (TERP) Working Group (17-18 May) and to the NATO E3-RADHAZ ad hoc (25-26 May) following an IEEE editorial meeting on 26-27 April. Editorial changes will then be made and the standard will be presented to the full IEEE TC-95 committee for discussion and possible vote at the 10 June meeting in Halifax, NS, Canada. A report to the NATO Standardization Agency Military Medical Standards Working Group will be provided for the 20-21 June meeting in Slovenia.

The 711 HPW/RHDR led a four-year effort to provide public access to all IEEE C95 standards relating to health and occupational safety in the electromagnetic environment. The DoD Components have purchased a five-year sponsorship of seven standards including the latest version thereof during the period of performance thus incorporating any revisions. Several new or in-revision standards including the IEEE/NATO military workplace standard to be covered by STANAG 2345 will also be available on the public website. This action addresses the problem of funding DoD access to non-governmental standards as required by OMB A 119 and the National Technology Transfer and Advancement Act (PL 104-113), DoD memos, and NATO policy. The world electromagnetic safety standards setting community has repeatedly asked for no-cost access. This action provides health and occupational safety guidance to all and furthers harmonization towards a single global standard for electromagnetic fields.

5) Schedule for submission of the deliverable or end product:

An RSM was planned as an end project activity with a proceedings and final report. A tentative plan was to coordinate with the August/September 2011 meeting of the International Congress on Radiation Research to be held in Warsaw, Poland. This has been postponed again due to lack of travel funding.

The RTG HFM-189 Chair is the:

- Custodian of the NATO STANAG 2345 [98];
- Liaison from the NSA MedStd WG to the E3-RADHAZWG and to the World Health Organization Electromagnetic Field Project;
- NSA stakeholder to the EC Worker Safety Directive 2004/40/EC working group; and
- Lead on NSA Civil Standards Management WG transition of the STANAG from NATO to civil standards developmental organization IEEE.

Presentations were made to the NSA MedStd WG (January and June 2010) and to the Civil Standards Management WG and the NSA Representatives groups (September 2010).

### **6.2.1.3 Recommendations to the Panel or RTB**

Issues/Concerns: Funding for this activity which is primarily travel to the twice annual meetings continues to be a major stumbling block for many Nations. HFM-189 meetings have been scheduled adjacent to other meetings to leverage resources.

## MEETING AGENDA, MINUTES AND REPORTS

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Spring 2010 and 2011 meetings were cancelled due to lack of travel funding for several Nations. The funding issue has yet to be resolved. Every effort will be made to coordinate RTG HFM-189 meetings with other international meetings. Electronic VTC and e-mail will be utilized; however, in person discussions are significantly more productive and necessary for developing projects beyond the PowerPoint briefing stage.

### 6.2.1.4 Future Meetings

A proposal was made for the next meeting to occur adjacent to the NATO E3-RADHAZ scheduled at NATO HQ 20-22 September. Sweden, Hungary, and Turkey have previously indicated interest in hosting.

### 6.2.2 Summary Report of Final Meeting

Val-de-Grâce Military Hospital

Paris

FRANCE

23-24 May 2012

#### 6.2.2.1 Itinerary

NATO Research Technology Organization (RTO) Research Technology Group (RTG) HFM-189, “Bioeffects and Standardization of Exposure to Military Relevant High Energetic Electromagnetic Pulses (HEEP).”

#### 6.2.2.2 Members in Attendance

**Meeting Hosts:** Med General Jean-Claude Debouzy, Ph.D, M.D., Professor, David Crouzier, Ph.D., and Vincent Dabouis, Ph.D. (FRA).

**Participants:** René de Seze, Ph.D. (FRA); Mr. Rachid Jaoui (FRA); Mr. Hubert Harivel (FRA); György Thuróczy, Ph.D. (HUN); John Tattersall, Ph.D (GBR); Mr. Iain R. Scott (GBR); Mr. Auke Visser, Senior Consultant (NLD); Mr. Niels Smit (NLD); Mårten Risling MD, PhD, Professor (SWE); Nesrin Seyhan, Professor Ph.D. (TUR); Mehmet T. Zeyrek Professor Ph.D. (TUR); B. Jon Klauenberg, Ph.D. (USA); Michael Murphy Ph.D. (USA) – Appendix 6A1.

#### 6.2.2.3 Travel Purpose/Objective

Dr. Klauenberg served as Chair and led the final meeting of RTG HFM-189. He participated as the NATO Medical Standardization Working Group (MedStd WG) liaison, as the custodian of NATO Standardization Agreement (STANAG) 2345 and as Subject-Matter Expert (SME) for force health protection on Electromagnetic Fields (EMF) personnel Safety and Occupational Health (SOH). The RTG HFM-189 completed the scheduled plan of work and drafted a consensus statement on High-Peak-Power ultra-short Pulsed (HPPP) Electric fields. We provided an update on the transfer of Institute of Electrical and Electronics Engineers (IEEE)/NATO standard to be covered by STANAG 2345, moving responsibility for the standard from the NATO Standardization Agency (NSA) to IEEE, a civil standards developmental organization. In addition, the status of European Commission (EC) on Worker Safety Directive on EMF 2004/40/EC was briefed. The presentation of several technical updates explored the possibility of future collaborative efforts between members.

#### 6.2.2.4 Discussion

Dr. Klauenberg served as Chair and led the group in developing a consensus for establishing that research indicates HPPP are not hazardous to personnel and that exposure limits for HPPP may safely be eliminated.

The drivers for formation of this RTG were military systems exploiting HPPP in development or to be fielded that were impacted by unnecessarily restrictive exposure limits. The RTG HFM-189 was tasked with providing recommendations to MedStd Working Group for either deletion of these limits or incorporation of them into the new IEEE/NATO military workplace standard. Dr. Seyhan provided a review of the multiple research projects completed over the last decade at her facility. Dr. Risling presented a review of research conducted into blast EMP effects related to traumatic brain injury. Dr. de Seze briefly reviewed his behavioral research on HPPP. Dr. Tattersall presented an informative briefing on HPPP work in their laboratories. The GBR group (Dstl Biomedical Services – Dr. Tattersall and Mr. Scott) has for over twenty years investigated new pulsed signals (ultra-wide-band, fast rise times, high pulse repetition frequency, and high-peak-power / low-average power pulses). They are currently:

- a) Investigating the effects of brief heating events on biological responses to extend the thermal basis of standards to short pulses; and
- b) Using gene array approaches to screen the human genome to search for effects of high-peak fields which may not be related to heating.

They suggested that Dr. Ibey's work on nanosecond pulses integrates very well with their studies on heating effects. Med General Debouzy presented an overview of French research programs "Hazards of Electromagnetic Radiations in the Military Settlement in Operations". He indicated "*RF-NIR (radiofrequency non-ionizing radiation, biological effects are now considered as of first interest for the French DoD)*". The French are investigating biological effects of NIR at the fundamental cellular and molecular level as well as applied topics of specific targets – eyes, skin and internal burns. The research includes high-power microwave weapons and less lethal systems with ultra-short (10 ns – 100 ns) pulses. Most interesting was a 30-year study of mortality and radar exposure among French Navy personnel that showed no significant health effects. General Debouzy discussed research on electromagnetic jammers which found no increase in temperature under normal use conditions, but detected induced currents in presence of stomatological implants (stents, stimulation electrodes). Their current goals are investigation of possible deleterious effects of millimeter wave frequencies, protection of personnel working in fast communications and emitters in the W-band, and evaluation of possible medical applications of chronic low-level exposures. Dr. Murphy presented a briefing on the history of the peak pulse limits and the lack of scientific support for any limits for ultra-short *E*-field pulses. Dr. Klauenberg presented discussions on the status of IEEE/NATO military workplace standard to replace STANAG 2345 and the status of the landmark waiver adopted by the EC for all military that have alternative safety standards such as NATO STANAG 2345. The agreement with EC negotiated by Dr. Klauenberg as the NATO stakeholder and NSA Director will facilitate ratification of STANAG 2345. Drs. de Seze, Tattersall, Murphy, and Klauenberg and Mr. Scott, led an editing session which produced a statement on why the limit on peak power pulsed *E*-fields was unnecessary. A consensus was reached. The Chair polled each member around the table and 16 members from the seven attending Nations unanimously supported the document.

#### **6.2.2.5 Conclusion/Recommendations**

The agreed upon text on HPPP Electric fields will be included in the revisions of IEEE C95.1 and the IEEE/NATO military standard. Elimination of this unnecessary exposure limit will facilitate further development and fielding of systems that employ these types of emissions. Dr. Klauenberg has served for five years as the NSA stakeholder representative to the EC on Worker Safety, which is revising a draft Directive that will be law for all European Union nations and will have direct impact on NATO operations. Derogation (waiver) for all militaries engineered by Dr. Klauenberg has been inserted into the draft Directive. The members of the RTG working group were disappointed that their good work was ending and that proposed continuation of the group to further collaboration and staff the two major proposed changes in exposure limits to national and international standards organizations will not be under the NATO RTO.

## MEETING AGENDA, MINUTES AND REPORTS

### 6.2.2.6 Participant List

Name	Country	Organization	Email
Jean Claude Debouzy	FRA	IRBA/CRSSA	<a href="mailto:jcdebouzy@crssa.net">jcdebouzy@crssa.net</a>
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## Chapter 7 – CONCLUSIONS

**B. Jon Klauenberg**  
UNITED STATES

**Marek K. Janiak**  
POLAND

*“It is not prudent to set limits based on individual reports that have not been scrutinized by peer review or replicated, especially if they are potentially flawed...Fear of possible future criticism and events is unacceptable. As scientists interested in providing the best interpretation of data to support safety and health we should all strive to base our reasoning on solid well replicated science.”*

*B. Jon Klauenberg to RTG-189, 3 May 2013*

Currently, the IEEE C95.1<sup>TM</sup>-2005 [48] and STANAG 2345 [98] standards limit pulsed RF exposure using two independent criteria. First, the Specific Absorption (SA) is limited to protect against a cumulative thermal rise within a tissue volume due to repetitive pulse exposures. At the Dosimetric Reference Limit (DRL), a Specific Absorption Rate (SAR) of 0.4 W/kg corresponds to 144 J/kg energy deposition spatially averaged over the entire body mass for any 6-minute period of 144 J/kg. This SA-based restriction of applies to all pulsed exposures. This limit is based on 10% of 4 W/kg, the SAR shown to disrupt animal behavior. The IEEE C95.1<sup>TM</sup>-2005 thermally-based standard was modified to conservatively restrict the SA to 1/5 of 144 J/kg (28.8 J/kg) as the Exposure Reference Level (ERL) for any 100 ms period. Second, although little bioeffects research had been done at the time, the standards were (first) developed, to protect against any theoretical adverse health effects from exposure to high instantaneous power, peak electric field amplitude of any exposure was limited to 100 kV/m for IEEE C95.1<sup>TM</sup>-2005 and later modified to 200 kV/m for STANAG-2345 [98]. These peak electric field limits were termed “ultraconservative” and had no underlying biological mechanism to support their existence, unlike the thermally-based established adverse health effects limit. This approach was first initiated by the U.S. Air Force with a 1971 provisional Electromagnetic Pulse (EMP) “safe-tolerance limit” and established as a standard limit of 100 kV/m in a U.S. Air Force Directive in 1975 [99]. Selective medical surveillance for United States military workers exposed to EMP was discontinued in 1988 due to lack of any health effects [100].

The lack of a published and replicated adverse health effects or biological mechanisms beyond thermal interaction for pulses shorter than 100 ms suggests that peak electric field limit in the IEEE C95.1<sup>TM</sup>-2005 [48] RF pulse safety standard has no scientific basis. Physical laws governing the propagation of electric fields in air already limit the maximum achievable peak electric field to ~3 MV/m (air breakdown). Current research efforts to expose biological organism(s), tissues, and cells to environmental fields up to this magnitude have been unable to elicit an acute biological response [101]. It is therefore recommended that the limitation based on peak *E*-field be eliminated.

This consensus recommendation was developed by the NATO Research Task Group HFM-189 consisting of 17 subject-matter experts from 7 countries. Those affirming consensus following a polling of participants after group drafted document at the 24 May 2012 meeting in Paris, France, are listed in Table 7-1.

**Table 7-1: NATO Research Task Group HFM-189 Consensus Signatory Members.**

Name	Country	Organization
David Crouzier	FRA	IRBA/CRSSA
Vincent Dabouis	FRA	IRBA/CRSSA



## CONCLUSIONS

Name	Country	Organization
Hubert Harivel	FRA	French MOD DGA
Rachid Jaoui	FRA	DGA-TA
Iain Scott	GBR	DSTL
John Tattersall	GBR	DSTL
György Thuróczy	HUN	NRIRR
Niels Smit	NLD	RNL NAVY
Auke Visser	NLD	RNL NAVY
Mårten Risling	SWE	KI/FOI
Michael R. Murphy	USA	AFRL 711 HPW RHD (retired)
B. Jon Klauenberg	USA	AFRL 711 HPW RHDR
Bennett L. Ibey*****	USA	AFRL 711 HPW RHDR

\*J.C. Debouzy reaffirmed agreement on 6/13/2012 and 10/11/2012; entered abstention on 12/21/2012 [23].

\*\* R. de Seze entered withdrawal of approval and entered abstention on 12/25/2015.

\*\*\* N. Seyhan entered withdrawal of approval on 10/5/2012 [82].

\*\*\*\* M. Zeyrek entered withdrawal of approval on 12/25/2012 [93].

\*\*\*\*\* B. Ibey attended earlier meetings but was not present at final meeting; approved *in absentia*. [44].

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