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The ARPANSA ELF Standard – Update on progress

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Australian Radiation Protection and Nuclear Safety Agency

Excerpts from DDP for ELF Standard (2002)

- Action proposed: withdraw NHMRC 50/60 Hz Guidelines, replace with EMF Standard for 0 - 3 kHz
- Aim: to develop a scientific limits-based approach to restricting human ELF exposure; to ensure protection against established adverse health effects
- Affected parties: mainly industries producing/using high power/current electrical apparatus - not just 50 Hz.
- Consideration of both occupational and general public exposure categories
- Originally: Public comment draft by Sept/Oct 2004: Publication 2005

Synopsis

- What's happened since the Public Consultation draft was issued in Dec 06
- Common themes of the submissions
- How the submissions are dealt with
- Main changes to Standard and the limits in response to submissions
- What has still to be done
- When will the job be finished?



Submissions during Public Comment period

- 64 in all, some quite substantial in length
- Main issues raised:
 - 15 argued for substantial lowering of limits (to $< 1 \mu\text{T}$); in recognition of childhood leukaemia association
 - 7 saw no need for further conservatism compared to 1989 NHMRC guidelines; in recognition of lack of evidence of harm in the workplace (25 mT limb limit in particular)
 - 22 (highest proportion) argued that static field guidelines would make operation of MRI units impossible
- Cost-Benefit Analysis in Regulatory Impact Statement was judged deficient by many submitters.

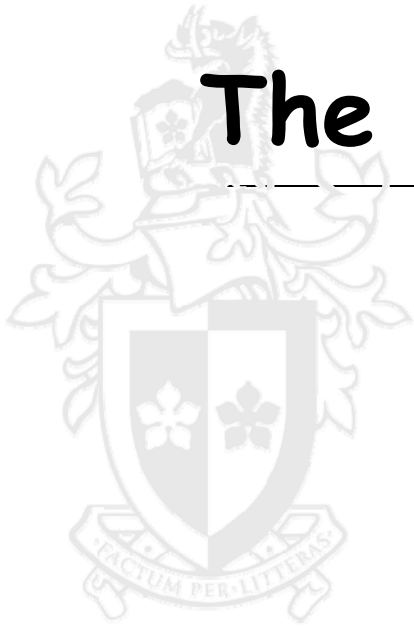
What has the Working Group done?

- **Met 6 times:** 8/07; 9/07; 10/07; 12/07; 1/08; 10/08. Also ELF Forum with Consultative Group & Industry Reps

■ **Tasks**

- Issues raised by several of the submissions have been identified and responses have been discussed
- For each submission, issues raised have been tabulated and responses inserted
- Some changes have already been made to the Consultation Draft and these have been approved by the RHC

The big issues



Changes made by Working Group

- In response to Public Comment: the precautionary approach needs to be emphasised more - particularly since the health benefits (if the leukaemia link is found to be causal in the future) would flow from precaution, and not from limits.

■ Title

- Original: Exposure Limits for Electric & Magnetic Fields — 0 Hz to 3 kHz
- Amended: Limits and Precautionary Measures for Reducing Exposure to Electric & Magnetic Fields — 0 Hz to 3 kHz

Changes: 'Controlled Activity' gone

■ Magnetic Field limits

- Original: Had a 'Controlled Activity' category and 'Normal' category which was harmonised to ICNIRP at 50 Hz for General Public
- Amended:
 - No 'Controlled Activity' category
 - No harmonisation with ICNIRP: 50 Hz General Public limit now 300 μ T (determined by advanced modelling from Basic Restrictions)
 - For Occupational exposure, addition of 50 Hz limb limit of 9 mT (5 x 'torso' limit) under consideration, with more detailed analysis for e.g. exposures with high harmonic content

More on the 300 μT limit

■ Basic Restrictions (BRs)

- No changes to Cons. Draft: but detailed rationale now published (Wood, Bioelectromagnetics 29: 414-428, 2008)

■ Reference Levels

- Recall: detailed voxel models (Dimbylow, UK; Caputa et al., Canada) used to derive RLs (new approach)
 - According to models, an external 1 mT magnetic field (@ 50 Hz) generates 13.5 mV/m in the retina, so to keep this below the (Gen Public) BR of 5 mV/m, the external field should be < 0.3 mT (this was the old 'Controlled Activity' Limit)
 - At higher frequencies, RLs are to keep fields within excitable tissue below 40 mV/m for GP (no change)

Changes:

■ Electric Field limits

- Original: had a rather artificial reduction in 'Normal' limits to give approximate harmonisation with RF standard at 3 kHz
- Amended:
 - 'Controlled Activity' now 'Controlled Circumstance'
 - Controlled Circumstance now has no reference to time; it is now linked to management measures
 - Now a discontinuity between ELF/RF standards at 3 kHz: Occupational 1100/614 V/m; General Public 220/86.8 V/m
 - Margin of 5 consistent with derivation from direct, rather than indirect effects (where 2 is used)

Side-by-side:

REFERENCE LEVELS FOR EXPOSURE TO RMS ELECTRIC FIELDS (UNPERTURBED FIELDS)

Exposure category	Frequency range	E field strength (V/mrms)	Controlled Activity E field strength (V/mrms)
Occupational	0.1 – 25 Hz	20,000	20,000
	25 – 165 Hz	$5 \times 10^5/f$	20,000
	165 – 825 Hz	$5 \times 10^5/f$	$3.3 \times 10^6/f$
	820 – 3,000 Hz	614	$3.3 \times 10^6/f$
	50 Hz	10,000	20,000
General Public	0.1 – 25 Hz	10,000	10,000
	25 – 66 Hz	$2.5 \times 10^5/f$	10,000
	66 – 3,000 Hz	$2.5 \times 10^5/f$	$6.6 \times 10^5/f$
	50 Hz	5,000	10,000

Exposure category	Frequency range	E field strength (V/m rms)	Controlled Circumstance ^{a,b} E field strength (V/m rms)
Occupational	0.1 – 165 Hz	10,000	20,000
	165 – 330 Hz	10,000	$3.3 \times 10^6/f$
	330 – 3,000 Hz	$3.3 \times 10^6/f$	$3.3 \times 10^6/f$
	50 Hz	10,000	20,000
General Public	0.1 – 66 Hz	5,000	10,000
	66 – 132 Hz	5,000	$6.6 \times 10^5/f$
	132 – 3,000 Hz	$6.6 \times 10^5/f$	$6.6 \times 10^5/f$
	50 Hz	5,000	10,000

NOTES: *f* is the frequency in Hz.

For explanation of Controlled Activity see Glossary/Schedule 1.

For explanation of frequency ranges, see Schedule 1.

Definition of Controlled Circumstance

a. Controlled Circumstance (occupational) means the following circumstances:

- training & information (including field levels) are provided to employees;
- suitable screening for implants is undertaken;
- the possibility of indirect hazard is removed; and
- advisory signage is placed in appropriate locations.

b. Controlled Circumstance (general public) means the following circumstances:

- the possibility of indirect hazard is removed and advisory signage is placed in appropriate locations. [It is likely that in practice this will only occur on easements under transmission lines].

What's driving Controlled Circumstance?

■ For Occupational Exposures

- If microshock hazard can be minimised by control measures, then E-field limits can be increased, by 2-fold at 50/60 Hz
- But why cap at 20 kV/m? Could continue $3.3 \times 10^6/f$ line. However, dc limit around 28 kV/m, $(20\sqrt{2})$: this based on corona effects on hair perception threshold (N.B. 40 kV/m intolerable)
- Signage is probably pre-existing

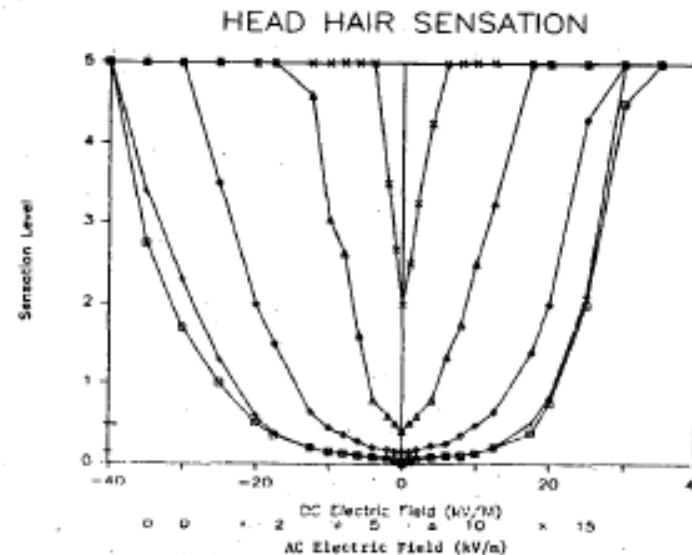
■ For General Public

- As above, but 10 kV/m actually involves exceeding both phosphene and PNS BRs, which are conservative

E-field Limits at ULF & dc

■ Data from Clairmont et al. 1989

- 5 = 'intolerable'
- 1 = 'just perceptible'



■ Blondin et al. 1996

- 28 kV/m detected by 33% of population

Controlled Circumstance E-fields cf BRs

Tissue Type	Excitable?	Tissue E-field induced by 10 kV/m external field (Vertical)		Tissue E-field induced by 0.3 mT external field (Side-to-side)	
		99 th percentile mV.m ⁻¹	Limit exceeded?	99 th percentile mV.m ⁻¹	Limit exceeded?
Bone		494.00	* &	15.27	**
Tendon		379.00	* &	2.81	
Skin	?	331.00	* &	10.80	**
Fat		252.00	* &	10.05	**
Trabecular bone		151.00	* &	7.29	*
Muscle	√	81.40	* &	6.90	*
Bladder	?	64.90	* &	13.74	**
Heart muscle	√	39.80	*	8.40	*
Spinal	√	29.20	*	8.10	*
Liver		28.80	*	11.46	**
Pancreas		27.60	*	4.08	
Lung		25.40	*	7.32	*
Spleen		24.90	*	5.52	*
Vagina	?	23.40	*	3.60	
Uterus	?	21.30	*	2.83	
Thyroid		20.30	*	6.54	*
White matter	√	20.20	*	9.42	*
Kidney		18.60	*	6.75	
Stomach	?	18.60	*	4.50	
Adrenals		18.30	*	5.76	*
Ovaries		16.90	*	1.59	
Blood		16.60	*	5.25	*
Grey matter	√	16.20	*	9.06	*
Oesophagus		16.10	*	3.00	
Duodenum	?	16.00	*	4.23	
Lower LI	?	15.30	*	3.66	
Breast		14.60	*	9.30	*
Gall bladder		13.60	*	2.89	
Small intestine	?	12.00	*	3.12	
csf		11.50	*	4.44	
Thymus		10.90	*	5.88	*
Cartilage nose		10.30	*	9.45	*
Upper LI	?	9.89	*	3.81	
Bile		8.05	*	1.99	
Urine		7.00	*	1.41	
Lunch		6.21	*	1.94	
Sclera		5.67	*	4.89	
Retina	√	5.52	*	4.05	
Humour		2.76		2.22	
Lens		2.68		2.01	

Data from Dimbylow 05

5 mV/m in *eye* tissue (GP); if exceeded in particular tissue shown thus (*)

40 mV/m in *excitable tissue* (GP); if exceeded in particular tissue shown thus (&)

Note BRs exceeded for CC E-fields

More on 'signage'

■ Different signs for different hazards

- Controlled Circumstance signs are to warn against possibility of microshock (but also of exceeding BRs)
- Refer to *immediate* E-field related hazards

■ For magnetic fields (precautionary)

- Concern is for *long-term* 'unusually high' exposure due to 'concealed equipment' (examples: substation in shopping centre; buried cables under pavement)
- People expected to *remain* rather than transit
- When are levels 'unusually high'?

More on precaution: new section

■ Section 6 now where precautionary measures are discussed (separate section)

- Maybe also mandated here (currently section 5.7). Still Annex on precaution
- Main emphasis is on protecting children

■ For Occupational Exposures

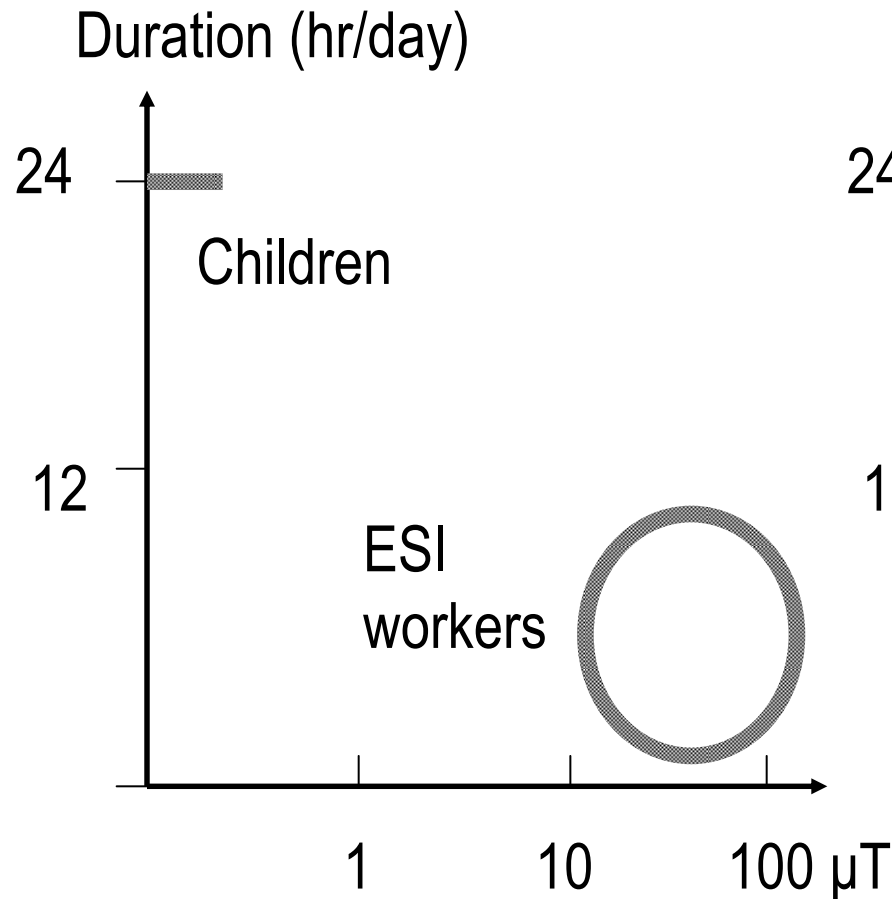
- 'Adult prior to conception or during pregnancy'

■ For General Public

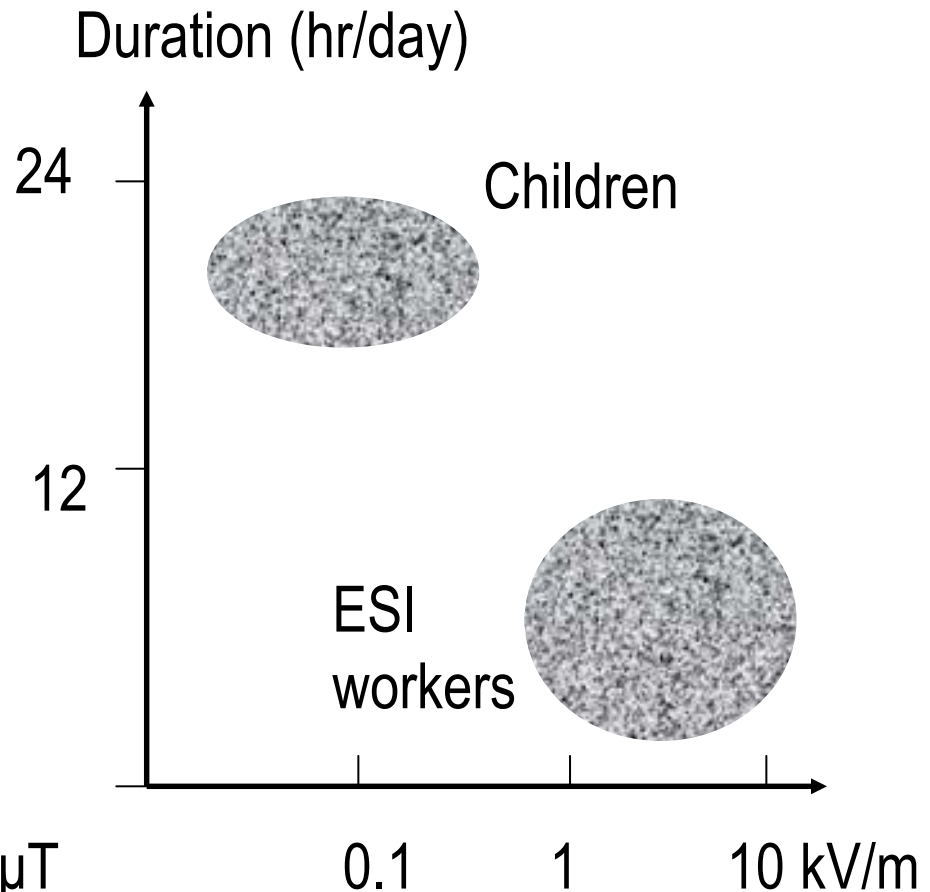
- Decision on what to do 'should take into account the full range of risks.....'

Exposures: GP & Occ quite different

■ Magnetic Fields

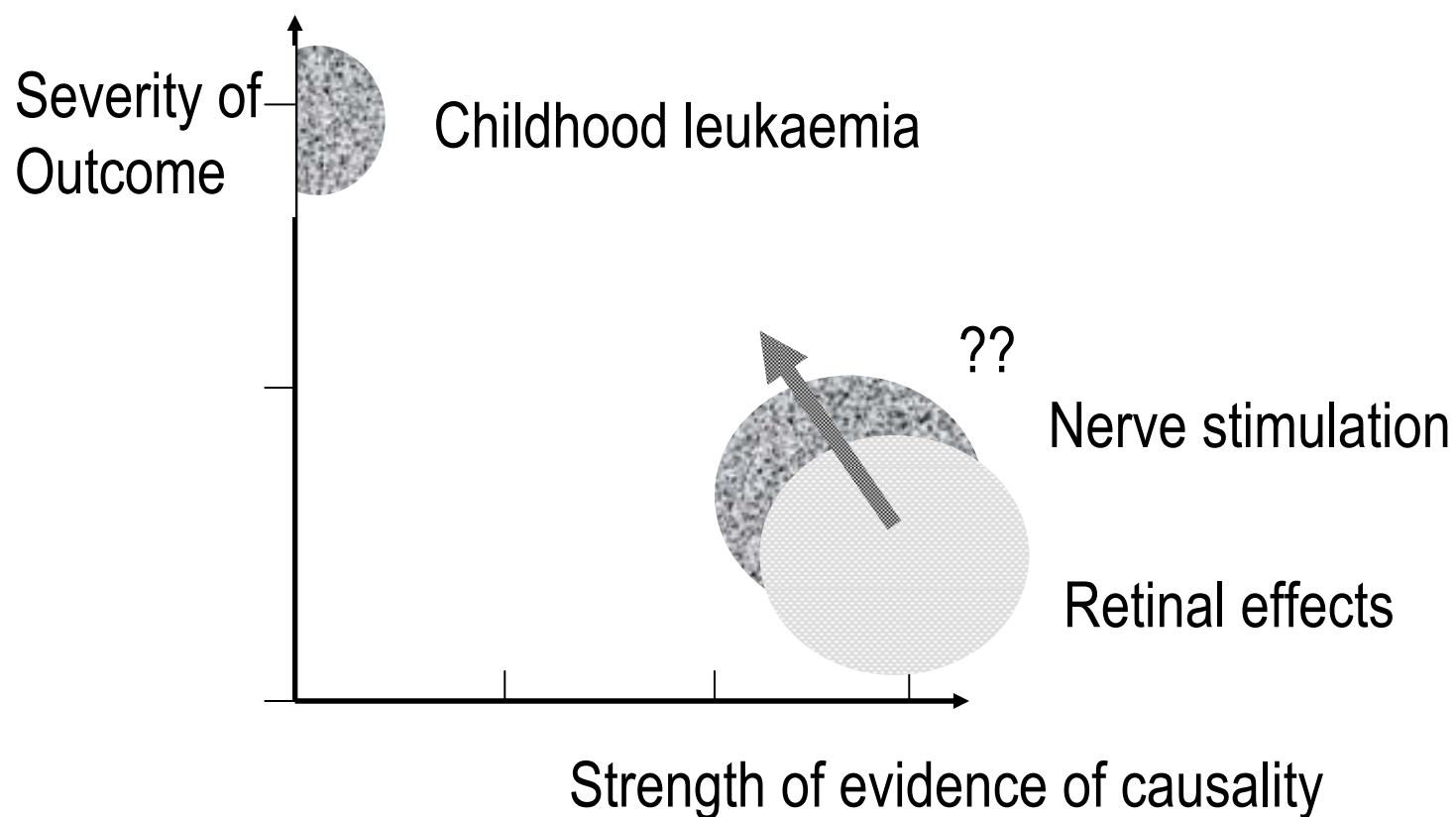


Electric Fields



Health Risks of EMFs

- Concerns for children & workers quite different



Role of limits vs. precaution

- Sets boundaries on hazards where there is some degree of understanding: ELF: at high enough fields muscle spasm will result



What do we do about suspected, but unproven, hazards?: Role of precaution - take care!

Be Safe - Take care

- Do not venture near cliff edges - they can fall at any time
- Keep to the tracks and lookouts
- Closely supervise children - at all times
- Stay on designated walking tracks
- Wear a hat and sensible shoes
- Lock your car and carry valuable items with you
- Please do not feed or handle wildlife
- Report sick or injured wildlife - Call 0500 540 000 24 hours

EMERGENCY CONTACT Call 000

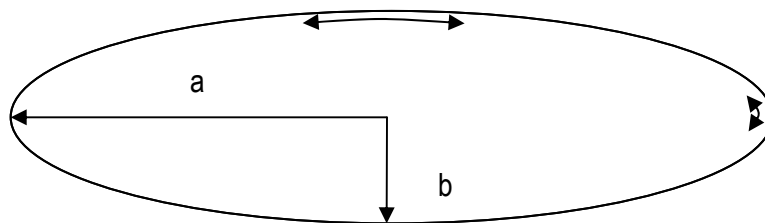
- Fire
- Police
- Ambulance

Parks
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Limb limits: working with cables

■ Magnetic Field limits

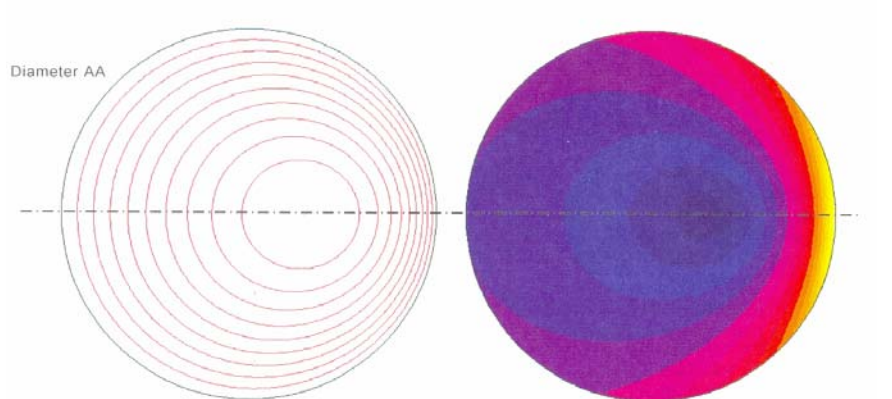
- The arm and fingers can be considered as prolate spheroids: maximum induced E-field determined by minor axis, so will be less than for a sphere
- $E_{(\text{ellipse})}/E_{(\text{circle, radius } a)} = 2b/(a(1 + (b/a)^2)) \rightarrow 2b/a$
- For arm $a = .35$ $2b = .1$; for torso $a = .9$ m, so reduction of $3 \times 3 = 9$ on torso limit is reasonable. Err on conservatism: use 5.



Limb limits: non-uniform fields

■ Magnetic Field due to current in wire

- IEC 62226-2-1: Table of K values, which give reduction in max. induced E-field in a disk compared to value with uniform field of same value is the max. value in the non-uniform case.
- E.G. for 100 mm radius disk 10 mm from a wire, K value is 0.23. For 1000 A get $B = 20$ mT at edge: expect max $E_{\text{int}} = \pi r f B = 30$ mV/m for uniform field, but for non-uniform case get $30 \times .23 = 7$ mV/m.



Spreadsheet method (Hart) for induced current density from non-uniform fields

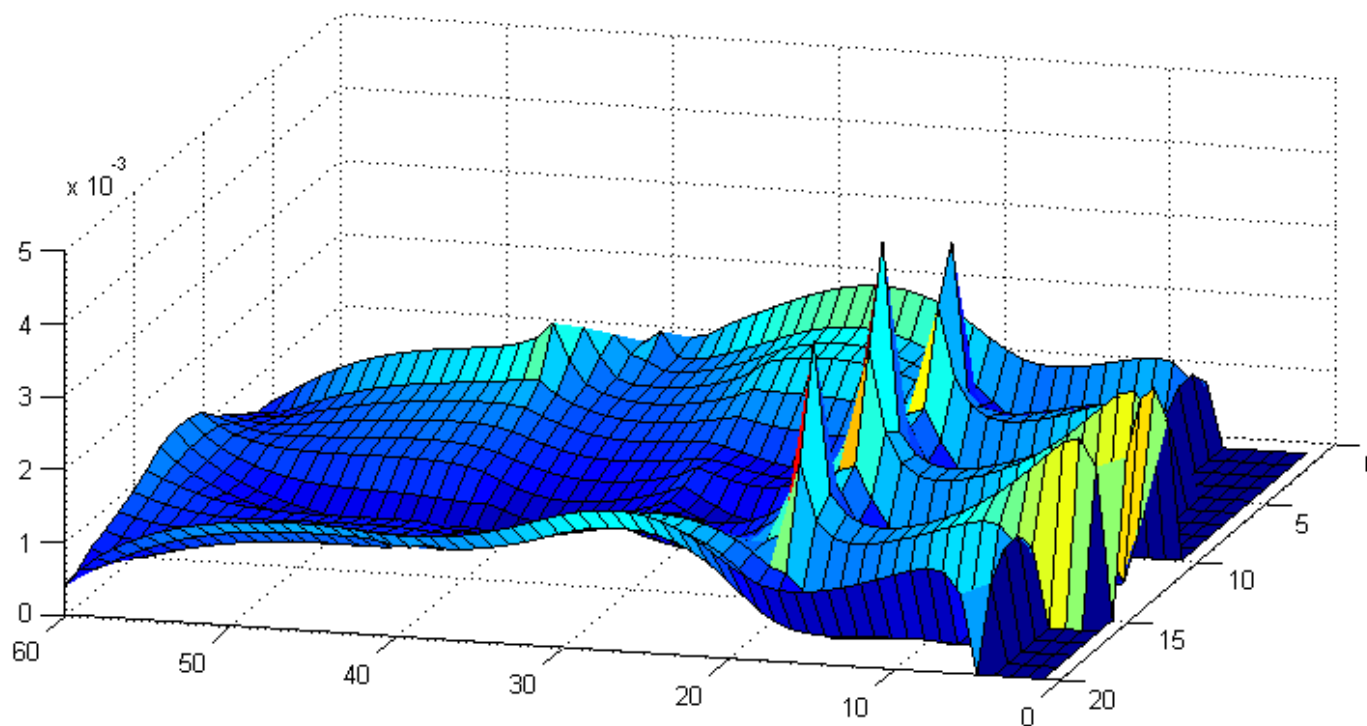
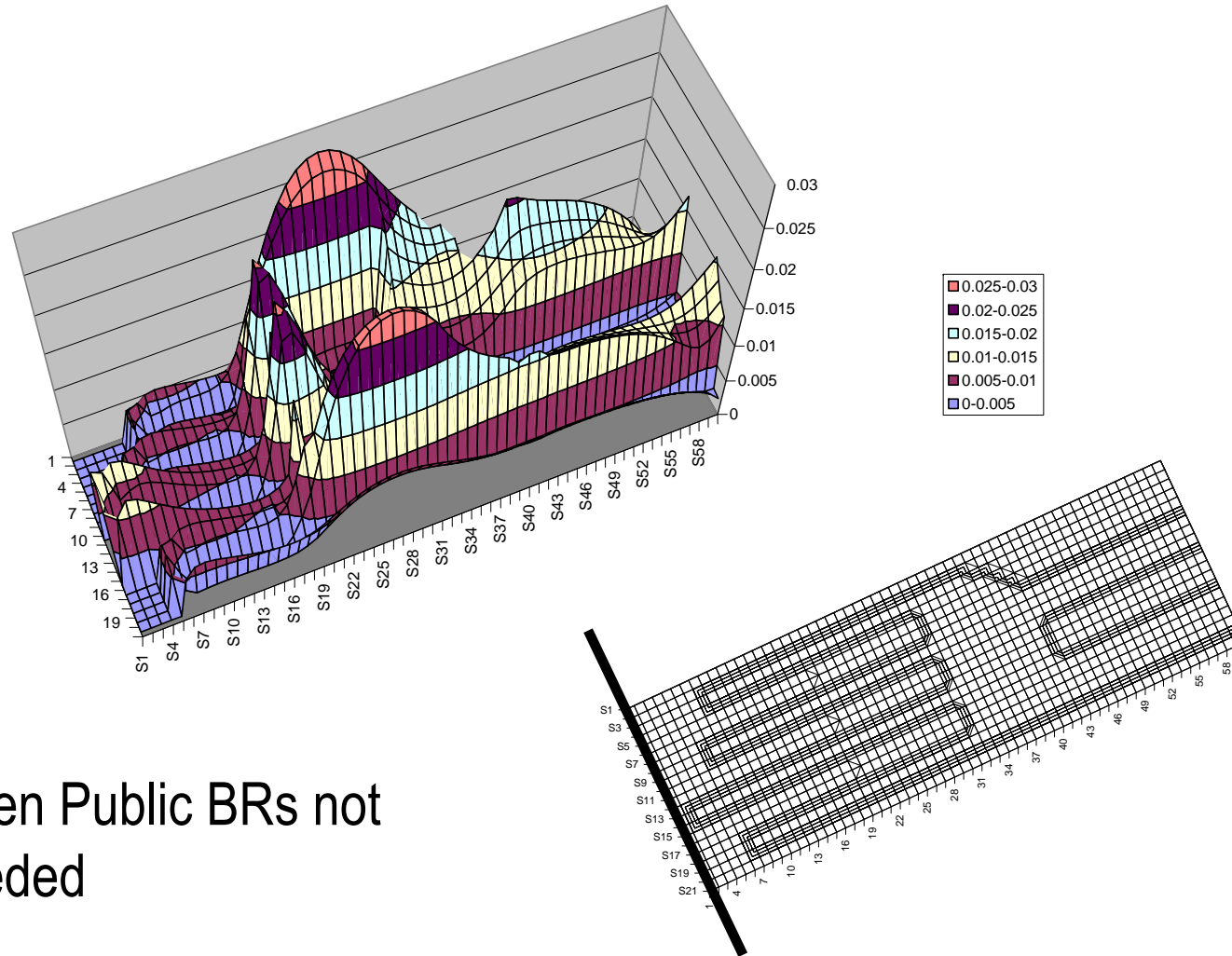


Figure 5. Induced current density in the fingers, hand and forearm, middle finger 1 cm from a cable carrying 1000 A

Spreadsheet method (Hart) for induced Electric field from non-uniform fields



i.e. Gen Public BRs not exceeded

MRI Issues

■ Static Field Guidance Level

- Currently .283 mT TWA or 2 T maximum
- Already 4 T MRIs in Australia and 7 T o/s
- ICNIRP are revising figures: could be published in Health Physics soon.
- Vertigo: determined by field x spatial field gradient product Needs to be $< 1 \text{ T}^2\text{m}^{-1}$

■ Movement in Static Fields

- Equivalent to dB/dt. Changing 2 T in 1 sec via moving towards magnet is 2 T/s (our limit)
- E_{int} in retina over 500 mV/m in modelling studies (Wang et al., 2008), but at $f = .16 \text{ Hz}$

MRI Issues

■ Switching Field Gradients

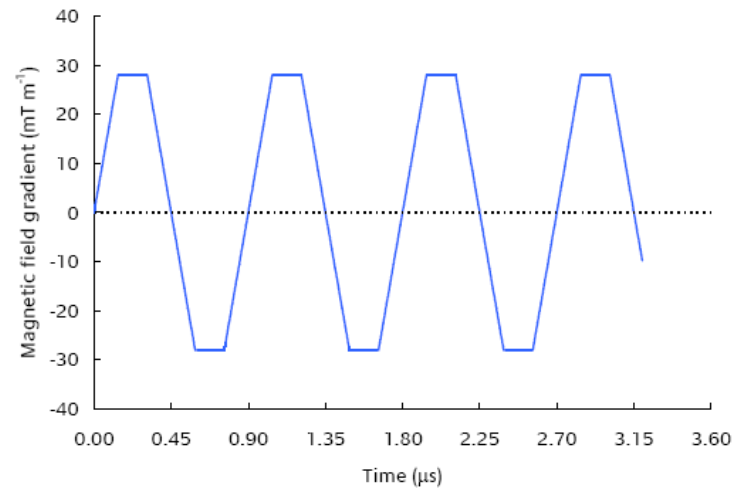
- Fields switched in a trapezoidal manner with ~ 0.25 ms rise time (corresponds roughly to ~ 1 kHz)
- This corresponds to E_{int} values of 500 mV/m for practical situations
- Occ BR is 200 mV/m, so safety margin reduced from 10 to 4.

■ Combined Field Gradient + Movement

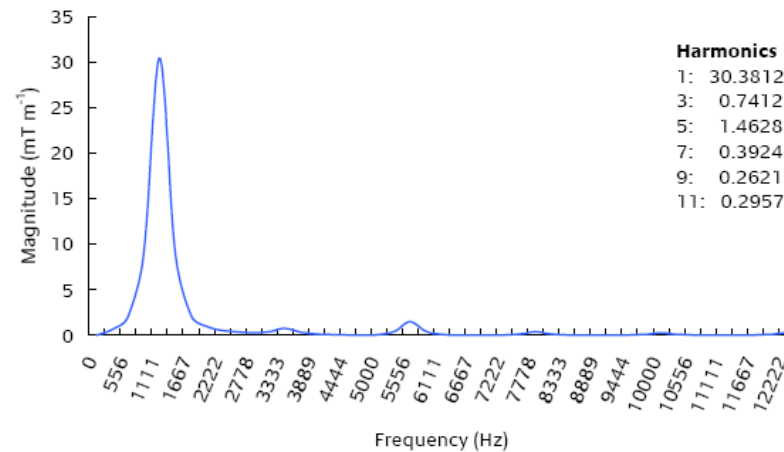
- E_{int} values > 1000 mV/m, but different bioeffects with different frequency sensitivity

Switching Field Gradients

- Max slew rate $200 \text{ T m}^{-1}\text{s}^{-1}$
- Induced fields in patients could be up to 10 V/m
- (BR is 0.2 V/m)



(a)



MRI Issues

■ Regulatory options

- **Exclude MRI from scope:** some other document to provide guidance. Problem: other groups could also claim they want to use some other document

- **Global Risk Minimisation (Escape clause).** Argument to be made (?to regulator) on grounds of minimising overall risk to worker and/or community. Need not be limited to MRI workers

Procedural Issues:

- How the submissions have been dealt with

- Submissions on Standard
- Submissions on Regulatory Impact Statement (RIS)
- Appendices to submissions

Summary of issues & responses:

1. Each submission analysed for the particular section of the docs. referred to
2. Submitters referred to by number, to provide some anonymity
3. Issues colour coded (more on next slide)
4. Various sections assigned to pairs of members of WG for independent preparation of responses
5. Draft responses considered by whole WG
6. Possible to re-format so that original submissions + responses re-constituted

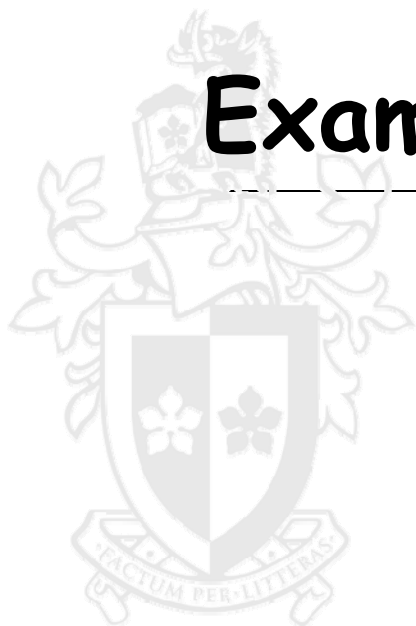
Further stages:

7. Responses analysed for statements made regarding changes to be made to the Standard/RIS
8. Changes to text considered and agreed to by WG
9. Intended: near final version to be reviewed by someone not involved in ELF, for clarity
10. Consultative Group informed of changes (in more than 1 stage)

Then:

11. Final version of docs. forwarded to RHC (between sessions) and to OBPR
12. OBPR response, responses to submissions and final Standard + RIS (plus any other web-based information material) considered by RHC at March meeting
13. If cleared by RHC, then considered by RHSAC
14. ARPANSA CEO (or acting CEO) to then sign off for publication

Example:



Submissions – colour coding

- Pink** Comments that will require a substantive change to the Standard
- Grey** Comments that require further explanation or clarification to the wording in the Standard
- Yellow** Comments that will not require a change to the Standard, or are disagreed - but will require a response to the comment
- Green** WG will need to decide what category
- Light blue** MRI

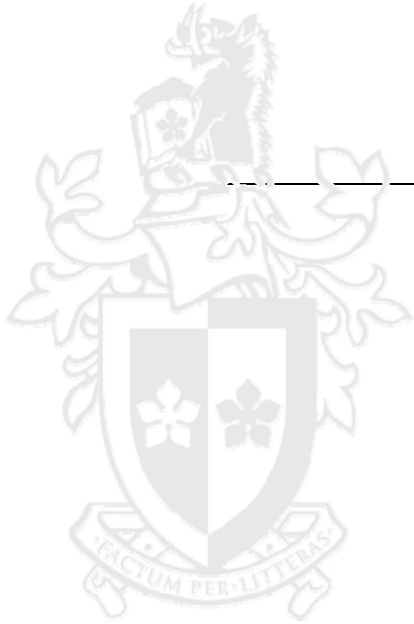
DRAFT ELF STANDARD COMMENT	RESPONSE
REWORD	
<p>Submitter 10</p> <p>The core of this draft standard, which are the human exposure limits cannot be supported. The statement “the standard has been specifically devised to protect everybody including children” is in our view simply not true. It is not sustainable given that the draft standard proposes a continuous level of exposure for the general population of 1000 mG, far in excess of that assessed “as possibly carcinogenic to humans at 4mG and above” by the International Agency for Research on Cancer in 2001.</p> <p>It proposes 8 hour levels of exposure for workers that are never reached in the real world. It bases its safety rationale on preventing a extremely rare event, the formation of magetophosphenes in vision and avoids dealing with the far more common exposures that carry with them the serious if not deadly risks of cancers that afflict both children and workers.</p>	<p>Limits are based on short-term phenomena for which the link between over-exposure and hazard has been adequately established. The Standard has mandatory precautionary measures to mitigate against long-term effects, where association but not causation has been established. It is the intent of the Standard that the reduction of exposure brought about by precautionary measures would reduce risk, if there is indeed a direct or indirect link between ELF and cancer incidence.</p>

Regulatory Impact

- **Introducing a standard (even if non-regulated)** has resource implications
- **Cost-Benefit Analysis (done for ARPANSA)**
 - Costs: Industry compliance & governmnt. admin.
 - Benefits: 'Willingness to pay' to avoid possibility of some lives lost AND/OR less than perfect health
- **Regulatory Impact Statement (original)**
 - Modest benefit from **non-regulatory** option (\$4M)
 - Educational material on leukaemia issue for ARPANSA website was developed

RIS revised

- **Cost of regulation probably over-stated**
originally: \$740M, mostly procedural, related to fencing, restriction of access or shielding
- **With the changes indicated, does much need to change wrt procedures**
 - Probably not, but signage remains an issue
 - 'Precautionary' (B-field) signs probably quite rare, but 'microshock' (E-field) signs more widespread. Possible solution: educational material to indicate that existing warning signs warn of possible microshock in addition to 'high voltage'



Thank you