1. Call to Order
The meeting was called to order by Co-chairman Ziskin at 0845 h.

2. Introduction of those Present
Each of the attendees introduced her/himself. (See Attachment 1 for list of attendees.)

3. Approval of Agenda
Following a motion by Meltz that was seconded by D’Andrea, the agenda was approved with the following changes: Technical presentations moved up to follow Chairman’s Report; update by Weller on the GLORE Meetings added under New Business. (See Attachment 2 for approved agenda.)

4. Approval of the Minutes (15 June 2012 Meeting)
Woolery pointed out that Attachment 4 of the June 2012 minutes (GAO Report), which was not vetted by IEEE, has the appearance of an IEEE position and not that of individuals who happen to be members of ICES. Since the statement was not vetted, she recommended removing Attachment 4 from the June 2012 meeting minutes. Ziskin explained that the working group strove to ensure that it would be understood by GAO that the response was from individuals and was not an IEEE position. Woolery agreed that it is important that questions such as those from GAO should be addressed but the response has to go through the IEEE process before release. Should a similar circumstance arise in the future, IEEE can provide a detailed statement describing the process. In response to a question from Tell, Woolery noted that she was not clear if COMAR is also susceptible to the same requirements. Weller moved to remove Attachment 4 from the June 2012 SC3/SC4 Meeting Minutes – the motion was seconded by Elder. Following a brief discussion, Weller amended the motion to instead defer the decision to the AdCom, Elder agreed. The amended motion passed. Following a motion by Elder that was seconded by Bodemann, the minutes of the June meeting were approved with the understanding that Attachment 4 may be removed at the discretion of the AdCom.

5. Secretary's Report
The secretary’s report will be presented the following day at the TC95 Meeting.

6. Chairmen’s Reports
Ziskin discussed that the results of the SC1/SC3 ballot on PC95.1-2345 Draft 6.3. He noted that 44 members of SC3 and SC4 joined the ballot group and 40 returned ballots. Of the 40, 9 approved
Ziskin then reviewed some of the statements that were submitted with their ballots by Bergeron, Croft, DeFrank, Gledhill, Klauenberg, Sheppard and Tell. (See Attachment 3) He noted that Bergeron’s concern is that by combining C95.1 and C95.6, a logical inconsistency in rationale is generated (the rationale of C95.6 is based on log-normal distributions of the effect considered adverse while C95.1 is based on adding a safety factor to the no observable adverse effects level). Bergeron pointed out that there are three obvious choices: ignore the problem, provide a statistical basis for the RF microwave range, or make the safety factors in at the lower frequencies an arbitrary lowering below the mean NOEL for the effect being protected against.

Ziskin noted that Croft commented on the dissenting opinion documents that were included with the ballot, one by Klauenberg and one by Reilly, both of which apply to the rationale for the induced and contact current ERLs and the values in Table 7 (see Attachments 4 and 5). Croft pointed out that given the uncertainty suggested by Reilly’s comments regarding Roger’s results, it is very difficult to justify the use of any adjustment factors beyond 3MHz, and thus supports Reilly’s Option 1 (define limits only up to 3 MHz, with a statement that thresholds are undefined above 3 MHz but would not be less than at 3 MHz). Ziskin noted that Sheppard supports making Table 7 consistent with the fact that insufficient research has been conducted above 3 MHz to determine thresholds for perception or pain appropriate for developing exposure limits based on established adverse health effects; Tell supports a fixed value for induced and contact current across the RF frequency range. Kavet was optimistic that consensus will be reached – discussion today will attempt reaching that end.

7. Technical Presentations
   a) Klauenberg Presentation

Klauenberg briefly discussed the status of the NATO standard, PC95.1-2345 (See Attachment 6). He reviewed the NATO decision process to transition from standards developed by NATO to civil consensus standards, which began in 2006. He pointed out that consideration for adopting the ICNIRP guidelines would be problematic because of the induced current limits. Although several standards and standards developing organizations, e.g., IEC, were considered, eventually the consensus was that rather than adopting an existing standard, a new standard should be drafted to specifically address NATO operations with the understanding that any such standard must not only protect personnel from overexposure, but must address alternative risks that may develop due to loss of electromagnetic-based operations. Practical induced and contact current limits are key, especially in the RF range on shipboard where values well above 100 mA are found routinely during assessment programs.

Klauenberg discussed contact current studies at 2-20 MHz carried out at AFRL by Rogers during the early 1980’s and similar work carried out by Chatterjee et al. He noted that data from the two studies differ, especially at frequencies greater than 2 MHz, and suggested that resolution could only be achieved by repeating/investigating Roger’s study. He said the issue of the appropriate numbers for Table 7 is still evolving but seem to becoming more stable. He questioned the origin of 16.7 mA in Table 7 (shown in slide 27 of his presentation) – Reilly explained that it was a projected value from frequencies below 100 kHz, i.e., 16.7 mA derives from the 50 mA value estimated for less than the 1% percentile and includes a safety factor of ______.

b) Reilly Presentation

Reilly also discussed the induced and contact current values in Table 7 in the draft PC95.1-2345 standard (see Attachment 7). He noted that the exponent, 0.12, in the table on slide 3 was arrived at after discussions with Kavet – the resulting values are a compromise. He pointed out that the word “pain” associated with Chatterjee’s work shown on slide 4 should be called “tolerance

without comments, 19 approved with comments, 10 disapproved and 2 abstained. The response rate (91%) rendered the ballot valid but the approval rate (74%) is below the 75% requirement for approval of TC95 subcommittee draft standards.
limit,” since the accompanying value is always well above the threshold for sensation. The same thing holds for Roger’s “let go” values. Kavet pointed out that with regard to the standard deviation values of 0.22 and 0.36 for medium touch and grasping contact currents, respectively, shown on slide 7, the important factor, time, is missing. Since the pain threshold follows sensation after time, more information on time is needed. Reilly pointed out other issues with the data, e.g., Roger’s “let-go” thresholds and Chatterjee’s “touch pain/let-go” thresholds do not track (slide 13). He noted that there were few female subjects and in response to a question he noted that gender does matter – the thresholds for females are generally lower. Differences in age, occupation (e.g., laborer versus office-worker) also matters as does body size, e.g., the differences in threshold between males of the same stature are small. Results for Chatterjee and Rogers for “tap contact” showed similar results.

Reilly explained that he tends to agree with Klauenberg on the values in Table 7 (slide 15) for Zone 1, but the values should be consistent for both PC95.1 and PC95.1-2345. Also, the values for Zone 2 could be higher, but scientifically defensible. He offered three options for contact currents (slide 16) – the choice would be based on how conservative the standard should be. He noted that the second alternative \( I = k f^a \) where \( a = 0.15 \) matches Chatterjee at 3 MHz. Shkolnikov pointed out that the electrical properties of skin could vary considerably. This would suggest using the most conservative data when reporting extrapolated results if the skin characteristics are known. Reilly explained that the real issue is the lack of reliable data. The key question is where to begin the curve above 2 MHz. Bodemann summarized both presentations with 1) more research is needed and 2) a comparative graph of all of the proposals would be useful.

c) Tell Presentation

Tell explained a simple experiment that he set up to examine the variation in pain thresholds with frequency (see Attachment 8). The experimental setup consisted of the output of an HF radio transceiver coupled through a current transformer and an RF voltmeter. He examined the Dewhirst data shown in at the lower left of the figure in Slide 2. He found that for wet skin, and a surface contact area of \(~1 \text{ cm}^2\), the results for a CW sine wave were very stable and repeatable. He also examined the effects of contact area and the associated edge effects, and RF burn thresholds associated with arcing. Tell responded to a question from Klauenberg regarding the frequency dependence of the burn threshold explaining that it has more to do with source length versus wavelength, e.g., for a given length conductor, a higher frequency will produce a lower current than a lower frequency. In answer to a question from Chou regarding which of the three options discussed by Reilly would he choose, Tell responded that he would like to see constant values across the HF band and explained that what is really needed is current density information. Meltz pointed out that, obviously, more research is needed and suggested establishing a group to examine the available data and bring forth recommendations regarding needed research. Klauenberg agreed that it would be important for moving forward, but time is of the essence – NATO is looking for a document in the June timeframe.

Harmon pointed out two critical issues when assessing exposure shipboard; field strength and contact current. He noted that protocol is to carry out daily assessments at approximately 16 frequencies in the 4-8 MHz band. He noted that based on his experience, contact current appeared to increase with increasing frequency.

Bailey pointed out two issues. The first, as discussed by Klauenberg, is that NATO has specific requirements, some for atypical exposure situations. The second is that similar induced and contact current issues have to be developed or reaffirmed for the revision of C95.1. It’s not clear that the ERLs in both standards will be in harmony, or whether that is necessary. DeFrank noted that the 100 mA limit has been used by the US Navy for years without untoward effects and suggested moving forward with the NATO limits and addressing the limits for C95.1 more
deliberately. Klauenberg recommended using Roger’s data capped at 100 mA, or use 100 mA across the frequency band. Kavet supported different limits for the military if required. Before breaking for lunch, Chou explained that the Editorial Working Group will be working on this issue while addressing the several hundred comments received with the ballots.

8. Issues on Merging of C95.1 and C95.6

Following the lunch break, Co-chairman Ziskin called the meeting to order at 1515 h. He briefly summarized the activities of the Editorial Working Group (EWG), pointing out that the EWG will meet within the next month to begin addressing the comments received with the ballot on PC95.1-2345-D6.3. Petersen announced that the intent is to begin sponsor (IEEE) ballot sometime in May or June. He pointed out that only SA members can vote during sponsor ballot – not only ICES SA members, but any IEEE SA members. He noted that in the past, TC95 members who provided major input to the development of C95 standards who were not SA members, and had no reason for being IEEE members, could participate in sponsor ballot as “invited experts.” This is no longer an option. There was considerable discussion about this change – many attendees felt it was unfortunate and would probably result in lower interest and input from many talented members of the subcommittees.

a) Literature surveillance and review/evaluation

Elder provided an update on the status of the literature review/surveillance process (see Attachment 9). He explained that the Mobile Manufacturers Forum is expected to provide funding for maintaining the database updates and noted that he relies on many sources for relevant papers, including the BEMS Journal and the abstracts on PubMed. Bailey raised the issue of potential bias in many papers and offered to help in the review process. Tell recommended examining all relevant studies, especially those cited in BioInitiative Report II since they seem to be well-publicized by activists. In response to a question from Klauenberg regarding copyright issues associated with the pdf files of selected papers, e.g., who has access to the papers, Elder explained that the papers are accessible to only a select few who are directly involved in the evaluation process. Although all the papers are listed in the searchable TC95 online database, only the abstracts are available to the general membership and the public.

b) Report from Editorial Working Group – status of the merging work

Chou provided an update on the efforts of the EWG on merging C95.1-2005 with C95.6-2002 and progress on the NATO standard, PC95.1-2345. He expressed concern about the low number of SC3/SC4 members that joined the ballot group for PC95.1-2345 and the number who earlier sent comments on the draft of PC95.1. For example, out of approximately 150 members of SC3 and SC4 combined, only 44 chose to join the ballot group for the NATO standard. He encouraged the subcommittee members, especially the younger members, to become more interested and active. He announced that the next face-to-face EWG meeting will take place in February (the date has not yet been set), to begin the process of resolving the several hundred comments that were submitted with the PC95.1-2345 ballot, and will probably meet several times after that via teleconference. The intent is to move the recirculation ballot forward to try to increase the number of affirmative votes to well-above the ~73% approval rate of the first ballot.

c) Update on NATO standard

In addition to what was said in his earlier presentation, Klauenberg provided a brief update on the status of the NATO process pointing out the importance of having available an “almost final draft” of PC95.1-2345 available at the June 2013 meeting of the NATO Military Medical Standardization Working Group. He encouraged the EWG try to have a subcommittee-approved draft by then.
9. Other New Business

Update on GLORE Meeting
Weller provided a brief review of the Global Coordination of Research on Electromagnetic Fields Health (GLORE) meeting held November 15th in Tokyo (see Attachment 10). One of the items discussed was a two-tier rating for cellphones that is being considered for adoption by Korea. Specifically, phones will be either green or red. The maximum peak spatial-average SAR value for green phones will < 0.8 W/kg; the corresponding value for red phones will be between 0.8 and 1.6 W/kg. He noted that the next GLORE meeting is scheduled to be held in Washington DC. It will be a two-day meeting; the first day will be open, the second day will be open only to government delegates and invitees. Based on previous meetings, attendance is usually about 75 the first day and about 25 the second day.

10. Date and Place of Next Meeting
The next series of TC95 meetings will be held in conjunction with BIOEM 2013 in Thessaloniki, Greece. The intent is to hold the TC95 meetings 6, 7 and 8 June 2013 – immediately before the BIOEM Meeting.

11. Adjourn
There being no further business, the meeting adjourned at 1645 h.
### Sign-in Sheet

**TC95 SC3/4 Meeting, 17 January, 2013**  
**Ft Sam Houston, TSRL**  
**San Antonio, TX**

<table>
<thead>
<tr>
<th>Last Name</th>
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<td>Leeor</td>
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<td>2. Bailey</td>
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<td>5. Bushberg</td>
<td>Jerrold</td>
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<td>6. Cho</td>
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<td>15. Elder</td>
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<td>Independent Consultant</td>
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<td>Paul</td>
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Approved Meeting Agenda

IEEE/ICES TC95 Subcommittee 3
IEEE/ICES TC95 Subcommittee 3 and Subcommittee 4
Tri-Service Research Laboratory, Bldg 3260, 4141 Petroleum Rd
Fort Sam Houston, San Antonio, Texas, USA
January 17, 2013: 0800 – 1700h

1. Call to Order
2. Introduction of those Present
3. Approval of Agenda
4. Approval of the Minutes (15 June 2012 Meeting) Ziskin
5. Secretary's Report Petersen
6. Chairmen’s Reports SC3/SC4
7. Technical Presentations Co-chairs
   a) Klauenberg Presentation
   b) Reilly Presentation
   c) Tell Presentation
8. Issues on Merging of C95.1 and C95.6 Ziskin
   a) Literature surveillance and review/evaluation Elder
   b) Report from Editorial Working Group – status of the merging work Chou
   c) Update on NATO standard Klauenberg
   d) SC3/4 Ballot Results Chou
9. Other New Business Ziskin
    Update on GLORE Meeting Weller
10. Date and Place of Next Meeting
11. Adjourn
Comments Accompanying Ballots

Bergeron

We all go back to the microwave guide of 1982 or earlier. Allow me to recap a few key points. Thanks to Guy, we were able to incorporate dosimetry as SAR. We also incorporated whole body resonance absorption using worst case E-polarization for the range of body sizes from infant to adult. Many contributed to developing the envelope over these sizes.

The studies of several species including primates (DeLorge in particular) led to the view that adverse effects due to heating were observed for SARs at or above 5 W/Kg. The mean of 4 W/Kg was selected as the value for which some decrement in performance was observable (behavioral studies). Though the term was not used then, one could call 4W/Kg a NOAEL (no observed adverse effect level).

I wrote a draft rationale arguing against a statistical approach to safety. The accepted rationale did not allude to statistics. We took an arbitrary factor of 10 lowering the guide to the exposure of 0.4W/Kg.

Over time the concept of controlled and uncontrolled (a.k.a. Occupational and General Population) environments was introduced and an additional factor of five lowering was added for the uncontrolled to 0.08 W/Kg. Hence, 4W/Kg/0.4 W/kg and 0.08 W/kg became entrenched for frequencies where thermal effects are the sole or predominant effect.

SC3 was struggling with an exposure guide where nerve stimulation is predominant but thermal effects can mix in. The literature on stimulation from shock sensation to electrocution (ventricular fibrillation) had both the physiological concept of threshold as well as a population distribution response literature. Over time, the latter has become the controlling approach to defining safe exposures. Of particular interest is the emphasis on lognormal distributions (by definition no zero effect)

The effort to meld the two ranges generates a logical inconsistency as we all recognize.

What to do? There are three obvious choices: ignore the problem, provide statistical basis to the RF-Microwave range, or make the safety factors in the lower end an arbitrary lowering below the mean NOEL for the effect being protected against, consistency with SC4 would be the observed mean for the effect, a factor of 10 reduction for controlled and an additional factor of five for uncontrolled environments. These could just be picked off the plots favored by Reilly and SC3

I realize that all of this is probably too late to affect the current draft but if the arguments seem to have value (make sense) to you perhaps you might try to nudge SC3 to agree that such values would be safe.
Croft

I have not read the original research pertaining to the induced and contact current views that B. Jon and Pat refer to in their very useful documents. However, based the dissenting opinion documents, I would make the following comments.

1/ Given the uncertainty suggested by Pat’s comments regarding Roger’s results, it is very difficult to justify the use of any adjustment factors beyond 3MHz, and thus Pat’s option 1 would appear the only tenable solution. This would mean that there is no point accepting the new standard at present as it would not be adopted by NATO.

2/ To use Roger’s results to make our numbers suit NATO’s purposes would not appear appropriate to me, and so we should not do this (unless we are able to convince ourselves that Roger’s data is in fact the most reliable).

3/ There is thus a difficulty (particularly as we are creating this Standard for NATO), but I think that perhaps we are looking in the wrong place to resolve the impasse. That is, if the data (no matter how premature it is) suggests that above a particular level there is a reasonable chance of harm, and that that level results in degraded operability, then the only option (should we want to assist with operability, which I do), would seem to me to be to take a step back and ask what the purpose of the Standard is. At present we seem to be saying that ‘you must follow our standard to protect your staff, and that if you don’t you are potentially harming them’. That is, there is no room for flexibility. However, to me this is counter-productive, as, as described by B. Jon, this may result in more harm than we save (e.g. the rescue boat not being able to be deployed), and to me such flexibility is the only way to avoid the impasse.

4/ So how would flexibility resolve the issue? At present we seem to be saying that the STANAG will differ from the normal standard in that we are happy that the extra rigor of the military will make it easier for staff to stop going in harm’s way (i.e. they don’t need as big a safety factor as for the general community). However, rather than this, I think that what we need to do is acknowledge that the military have other important factors to consider, and allow them to make informed choices (given that they have the expertise and training to allow this), based on the facts, rather than giving strict limits. For example, we could have Zone 0 as the generic zone where no special knowledge is required, and reserve Zone 1 rather as a zone that requires an informed decision to enter. The relevant information, to me, would seem to be the type of harm that would be expected to be encountered, such that the informed worker can decide that ‘relative to a reasonable possibility of a brief pain’, for instance, ‘I value the life of the sailor overboard as more important’, and so enter Zone 1. This could get rid of Zones 2 and 3, or perhaps they could usefully be used as a way of clarifying the different levels of health severity that could be expected, so as to enable informed decisions. I think the problem that we have really boils down to having to make a decision as to what is harmful, as this will always be a relative issue. It is fine for the general public, as we are comfortable to assume that all things being equal, there will not be any reason to invoke the slight possibility of small harm (this is what OH&S practices seem to want), but where there are clear and substantial competing health consequences, I do not think that we are in a position to decide what is ‘the’ level of harm that should be avoided.
5/ I appreciate that another option is to have the military decide when to follow the standards and when to ignore them (with our Standard a statement of the levels where harm can occur), but from my time with the Australian Defense Force looking at RF safety, it is clear that that is the guidance that they are looking for in the STANAG. The problem is that the average officer will not know how dangerous it is to allow someone to exceed the proposed Zone 0 or 1 limits, for instance, and so will not be able to make an informed decision as to whether or not it is now OK to ignore the STANAG. In the ADF at least, the default view has been to treat the limits as gospel and not deviate at all. Thus a clear statement of the level/type of harm that is to be expected within a certain zone would make it much easier for informed decisions to be made within unique situations that I doubt we can delineate in advance.

I appreciate that it is very late in the day to be considering this, but as it seems that we are at an impasse, I don’t think that we’ve any option but to consider any ways that may allow us to move forward.

DeFrank

Use of 'restricted no access' suggests that no one is permitted to occupy Zone 3. This is unnecessarily restrictive. Since limits are time averaged we should be permitted to allow brief excursions into Zone 3 without risk or harm. Use of 'restricted expert-only' is excessively restrictive for a region where trained personnel are allowed.

Refer to these zones numerically and allow the definition to explain what is required for each zone. (Zone 0; Zone 1; Zone 2; Zone 3)

The use of phrases (unrestricted; restricted; REO; restricted no access) are unnecessary and misleading. There is no reason to deny access to a region/zone where radiation is below the lowest observable adverse effect level.

It's unreasonable to require someone to be an E3 expert before they can be permitted into an area where Zone 2 levels may be present.

Suggested change: 
"ZONE 2: A zone where exposures would exceed Zone 2 ERLs and may exceed the established adverse health effects level. This zone provides a margin of safety buffer for those permitted into Zone 2. NOTE—The Zone 2 ERLs are below the established adverse health effects level; personnel protection procedures are enhanced. Zone 2 requires Caution signs."

Suggested wording: "ZONE 3: An environment that is restricted to all but trained personnel experienced with the specific equipment or systems mission essential access to areas where EMF levels exceed the ERLs for Zone 1 but are below the ERLs for Zone 2. NOTE—Zone 3 requires Warning or Danger signs and possibly barriers to prevent access. "

Approved Minutes – 17 January 2013 TC95 SC3/SC4 Meeting
Gledhill

Explanation for negative ballot by M Gledhill and specific actions/words which would resolve my objections.

My reason for a negative ballot is the use of the term “social policy factor” in this draft, as detailed in the accompanying comment matrix. I see no reason to introduce this term here, when it has not been used in previous IEEE/ICES Standards which use exactly the same safety factors. My objection would be resolved by removing this term.

Klauenberg

Table 7—Induced and contact current exposure reference limits (ERLs) for continuous sinusoidal waveforms at frequencies between 100 kHz and 110 MHz

<table>
<thead>
<tr>
<th>Condition</th>
<th>Unrestricted Zone 0 100 kHz – 3 MHz (mA)</th>
<th>Restricted Zone 1 100 kHz – 3 MHz (mA)</th>
<th>Unrestricted Zone 0 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 1 3 MHz – 30 MHz (mA)</th>
<th>Restricted expert only (REO) Zone 2 100 kHz – 30 MHz (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced, each foot</td>
<td>45</td>
<td>100</td>
<td>45</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp(^a)</td>
<td>--</td>
<td>100</td>
<td>NA</td>
<td>100(f/3)(^{0.40}) mA</td>
<td>250</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>61.4</td>
<td>12.025(f)(^{0.2989}) mA</td>
<td>44.2(f)(^{0.2989}) mA</td>
<td>61.4 mA (3 MHz) capped at 100 mA (15.4 -110 MHz)(^9)</td>
</tr>
</tbody>
</table>

\(^a\) Contact, grasp
NOTE 1—Tabulated values are given as rms quantities.
NOTE 2—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.
NOTE 3—For frequencies between 30 MHz and 110 MHz the numerical limit at 30 MHz shall apply.
NOTE 4—There are no values for grasp in unrestricted environment since the population will not have training.
NOTE 5—The averaging time for determination of compliance for induced current is 6 minutes (Restricted) and 30 minutes (Unrestricted). The averaging time for contact is 1.0 second.
NOTE 6—The ceiling values for induced (temporal peak values) are 500 mA for no more than 14.4 seconds per six minute period and 200 mA for no more than 10.4 seconds per 30 minute period for the upper tier Zone 1 (restricted) and the lower tier Zone 0 (unrestricted), respectively.
NOTE 7—Exclusion zones may be established using REO values only when mission essential and only when all personnel who may inadvertently contact parasitically charged surfaces are informed that such contact may produce discomfort including shock or heating which could become painful after 15-20 seconds with fingertip contacts. Grasp is the appropriate method of contact.
NOTE 8—Light “brush” contact may result in arcs and shock, burn even at 40 mA, and should be avoided especially with long objects such as cranes or cables.
NOTE 9—Touch contact current is capped at 100 mA as in STANAG 2345 (Ed 3); (100 mA from 15.4 to 110 MHz)

Sheppard

Table 7 is inadequately supported, particularly the exponent 0.12 for frequency dependence. Moreover, the problematic matter of contact current limits above 3 MHz is not dealt with satisfactorily, essentially because the data do not allow a definitive standard.

NOTE 6, indicating an interim standard because of lack of peer review, is not a satisfactory resolution of the underlying problems. Better to allow discretion (up to some limiting current) by those responsible for personnel safety and health than endorse flimsy numbers through a labored process.

I favor no entries in the table for contact current limits above 3 MHz, but an asterisk supported by text derived from JPR and BJK’s ideas, Appendix C material, plus my suggestion of indicating managerial discretion up to a maximum level. The latter might be derived from experience (per BJK) and could mention Rogers data, but would be clearly flagged as outside the otherwise conservative tone of the standard because of absent data.
As I did not find BJK’s arguments for higher exponents for contact currents in Table 7 persuasive (due to inadequate experimental data and problematic inferences), and also find Table 7 as it stands inadequately explained and motivated, I suggest another go-round to get satisfactory justification for a revised Table 7 and supporting text. I think JPR’s exposition is on the right track and, with some revision and negotiation, could be lined up with BJK’s approach that aims to avoid an overly conservative military standard in restricted areas, but without needing to adopt Rogers’ data as the basis and without specific levels in Table 7 for >3 MHz.

Or in other words, make Table 7 consistent with lines 2052-2056, and pull in some of Appendix C.3.1 into the body text near Table 7. It might seem my suggestion puts all contact currents >3 MHz into the REO Zone 2 category, but that’s not true because there’d be no Zone 1 for comparison.

**Tell**

My negative vote is because of the way the proposed standard addresses contact and induced currents. Table 7 in the D6.3 draft document needs to be revamped through discussion and input from the committee. For example, I think that the concept of having formulas to calculate the permitted touch and grasp contact currents is unnecessary. As they exist in the draft, there is relatively little difference in the magnitude of currents that would be allowed. I think that a fixed value of current would be sufficient across the HF band without any frequency variation.

**Umbdenstock**

Please note that I have voted against the draft. Although I have made a number of minor comments, the only one that affected this decision was the issue of induced and contact currents, with the reason for rejection being what I consider to be an impasse (the convincing argument from Pat Reilly that the Rogers evidence is not strong, and B. Jon’s view that the STANAG will not be accepted by NATO unless it follows something closely consistent with Roger’s results. Thus it seems to me that we need to relook at the draft in order to arrive at something that we will be able to move forward with. I have discussed this in more detail and suggested one such option in the matrix for your consideration.
Dissenting Opinion to Contact Current Limits

B. Jon Klauenberg,
Air Force Research Laboratory
Radio Frequency Bioeffect Branch

This dissenting opinion statement with regard to the P95.1-2345/D6.0, “Draft Standard for the Evaluation and Control of Personnel Exposure to Electric, Magnetic and Electromagnetic Fields, 0 Hz to 300 GHz: Force Protection and Occupational Safety and Health for Military Operations” presents a rationale for higher contact current exposure limits in the High Frequency (HF) range (3 MHz - 30 MHz) based on a review of the limited number of studies on perception of contact currents, reanalysis of data from the only study relevant to the HF range, and experiential evidence. Reports on the frequency dependence of electrical properties of radiofrequency (RF) charged surfaces that provide physical explanation for increased perceptual thresholds as frequency is increased are discussed. A discussion of the impacts of extraordinary low contact current limits on military operations is provided.

I have been privileged, as the NATO Custodian for the Standardization Agreement (STANAG) 2345, to work with the IEEE/ICES Editorial Working Group (EdWG) in development of the draft document. However, neither the operations field technical experts of the NATO Electromagnetic Environmental Effects Radiation Hazards Working Group (E3-RADHAZ WG) nor I support the document as it stands for ballot. I present this dissenting comment to the EdWG with the request that it be included with the ballot draft.

**Contact current limits in the draft are set too low in the high frequency range.**

The conclusion that contact current limits are set too low in the high frequency range is based on five main points: (1) Data, albeit scarce, do not support a need for the proposed 50 mA limit. (2) Based on their physical properties, HF fields do not present the same potential for RF shock and burns as do lower frequency fields. (3) It is important to maintain ultimate safety in the work environment and ultra-conservative standards often generate new, more severe risks to the worker. (4) Field operators have not found the 100 mA touch contact current limit to have adverse health effects. (5) Importantly, especially for militaries, the reduced contact current limits severely impact operations and interoperability.

**History/Background:**

**Reduced contact current limits impact military operations:**

**Degraded operability and interoperability.**

The leading international standard IEEE C95.1 2005 (7) and the major international guideline (6) by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the proposed ICNIRP-based European Union (EU) Directive (4) that may become law for all EU nations in October 2013 each have adopted lowered limits for contact currents without any attention to frequency. The Netherlands (NLD) lead technical expert on electromagnetic field (EMF) operational environmental safety as NLD Head of Delegation (HOD) alerted the NATO Radio and Radar Radiation Hazards Working Group (RADHAZ WG) predecessor of the E3-RADHAZ WG) in 2006 to the major impact on safe operations and to resulting multinational
interoperability breakdown. A subsequent survey of NATO RF experts showed contact current limits in the IEEE C95.1 (2005) (7) were creating unavoidable (unmitigatible) impacts on safe operations. The Canadian delegation to the NATO RADHAZ WG identified several operational impacts that could not be mitigated leading to degraded interoperability. Interoperability is the standardization keystone.

The Director, Electrical Engineering Program Canadian National Defence, in a letter to the Custodian of NATO STANAG 2345 dated 17 October 2006 stated:

“Of greatest concern is the impact on naval surface ship operations during HF radio communication transmissions at powers in excess of 600 Watts. Naval Link-11 and Link-16 transmission can last 5 to 6 hours without interruption. Contact current limits in the 40 to 50 mA range would cause activities involving cranes and hoists on one or more decks to be suspended during this period.

For example, all vertical replenishment (i.e. Helicopter VERTRERP) operations would have to cease, as well as the deployments of boats (i.e. RHIBs and Zodias) for man-overboard and search-and-rescue drills or operations, and ship-to-ship supply replenishments or fuel transfer operations.”

New safety risks.
Given the NATO requirement for a safe environment for all personnel, it is important to consider the potential impact to overall safety from narrowly crafted overly restrictive exposure limits. Reduction of allowable rms contact current limits from 100 mA for touch to 50 mA (IEEE) and 40 mA (ICNIRP) in the restricted (controlled) environment has been shown by way of measurements and calculations by the NLD HOD to result in loss of access to necessary workspaces. The NLD and other nations demonstrated that loss of necessary workspaces led to increased safety risks with no observable gain in personnel safety with regard to contact current thermal effects in the HF frequency range. Thus, present contact current limits impact safe operations and generate new safety hazards.

The reduction in allowable limits in the higher frequency ranges is not deemed necessary by the radiation safety officers and field operators who have years of experience with RF, especially with regard to high frequency fields. The conclusion that there is no observable gain in personnel safety with the reduced limits is based on repeated questioning of operational “real world” technical experts. There have been no reports of adverse health effects when operating under the 100 mA limit that has been in force for decades. Military operational experts, including DoD components including members of the Transmitted Electromagnetic Radiation Protection Working Group (TERP), have indicated that given the working environments in which they operate, a 100 mA exposure limit for contact current is appropriate and necessary. Additionally troubling is the lack of explanation in the C95.1 (2005) (7) for how these limits were derived. Therefore, there is a depth of experiential evidence that should be considered in establishing safe exposure limits.

NATO Standardization includes experience and lessons learned.
NATO recognizes the ISO/IEC concept of a standard as follows: “A standard is a document, established by consensus and approved by a recognized Body that provides, for common and
repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context” and “a standard should be based on the consolidated results of science, technology, experience and lessons learned” (emphasis added) (1). Experiential insights are invaluable to establishing safety limits especially when laboratory data are limited or non-existent.

As Custodian of the Standardization Agreement (STANAG) (8), I sought NATO assistance in finding a suitable mechanism to provide safe operational environment for all militaries involved in NATO missions, including training, combat readiness exercises, and combat environments. Given the NATO adoption of the ISO/IEC definition that experience and lessons learned are parts of the consolidated basis for establishing a consensus-based standard these factors must be taken into consideration. This is not a novel concept with regard to IEEE standardization. The IEEE C95.1(8) has included experiential evidence when there was a need for guidance in the absence of thorough laboratory or other scientific data. Just one example is the 140 V limit on contact voltage. This value, established by the US Navy, was derived from experiential evidence and has been included as an interim guide (9, 10).

Data do not support a need for the draft proposed limit.

Laboratory studies: perception of contact currents:

Only one report of research on contact currents above 3 MHz has been published (12). That study, by Rogers, which examined perception and discomfort from 2 MHz to 20 MHz was published as a US Air Force technical report. It has been criticized for not being peer reviewed (peer review is not a NATO requirement) and for lack of clarity on how some of the data were characterized and reported. However, the methodology is similar to other published reports (2) (See Figure 1) and data for the perception threshold are sound and easily reanalyzed (See below).

A second report on human body impedance and threshold currents for perception and pain for the frequency range of 10 kHz to 3 MHz by Chatterjee, Wu, and Gandhi (2) used a methodology similar to that of Rogers (9) (See Figure 1). Chatterjee et al. defined the threshold current for pain as “the lowest current at which the subject reports very uncomfortable sensations (similar to but more intense than that for perception) for which he/she will indefinitely not continue to touch the electrode anymore.” It is not entirely clear how Rogers interpreted his discomfort threshold. He defines two conditions – one in which barely perceptible sensation is experienced (perception current) and one in which “discomfort” was felt which he termed let-go current. The term let-go has a different definition in the United Kingdom (UK), where Rogers (12) conducted his research. The UK HOD to the E3-RADHAZ WG explained “let-go” to mean “it’s now hurting and I am going to remove my hand or body part from the source of pain.” Additionally, touching the back of the finger could not result in lock-on preventing release. There is no grip. It is therefore a protective response and not the alternative definition used by the IEEE for let-go current: “The current level above which involuntary muscular contraction prevents release of a grip on an energized conductor.” Therefore, Rogers’ definition of discomfort was most likely intended to follow the UK definition and is similar to the withdrawal from uncomfortable sensation that Chatterjee et al. (2) report. As a result of the lack of clarity, the discomfort level data values cannot be reliably incorporated into a standard. On the other hand, Rogers’
description of the sensory threshold as “barely perceptible sensation” is unmistakably clear. It is the lowest observed effect level (LOEL).

**Reanalysis of Rogers’ perception data:**
Rogers looked at both back of finger and finger-tip perceptual thresholds. He only presented data for the back of the finger while stating that threshold currents for the finger-tip were twice those for back-of-the-finger. Since no individual or group fingertip values are presented, only the back-of-the-finger data can be reanalyzed with confidence. Chatterjee et al. (2) and Dalziel and Mansfield (3) report data as rms. Rogers does not state whether his data are rms or peak. The reported values for perceptual threshold were reanalyzed assuming rms and then again assuming the values were peak. They were recalculated to rms by dividing by $\sqrt{2}$.

The number of subjects reporting perception was calculated from the histograms in 10 mA steps at each of the five frequencies (See Figure 2). The RF “burn hazard meter” (Figure 3) appears to be designed to measure rms based on assessment from ICES members Ric Tell, John Osepchuk and William Hurt, however, it remains possible that the meter only reported peak values or that the data were subsequently converted from peak to rms. Most of the reports do not clearly specify whether values shown are derived-calculated rms or meter output rms. Chatterjee, Wu, and Gandhi (2) made measurements with a Fluke that reported values in rms. Figure 2 below shows the reanalyzed Rogers’ (12) values assuming they were either measured rms or peak converted to rms. The lower line represents the most conservative scenario where the values reported are assumed to be peak and are converted to rms. These data are the first observed effects of perception or a warming LOEL and not adverse responses *per se*.

---

**Figure 1.** Experimental arrangement for the measurement of human body impedance.

**Figure 2.** Reanalyzed Rogers’ values assuming they were either measured rms or peak converted to rms. The lower line represents the most conservative scenario where the values reported are assumed to be peak and are converted to rms. These data are the first observed effects of perception or a warming LOEL and not adverse responses *per se*.

Chatterjee, Wu, and Gandhi

Rogers
Figure 1. Experimental set-up for Chatterjee, Wu and Gandhi (2) and Rogers (12).

Figure 2. Comparison of Rogers perception threshold rms vs. peak to Chatterjee et al. and Dalziel and Mansfield rms contact current measurements and Rogers pain to Chatterjee pain threshold.

NOTE: Rogers’ data are presented as means ± standard error of the mean (± SEM). Dalziel and Mansfield’s data are the 50 percentile for perception.
Table 1. Contact current values (mA) for perception and pain from three laboratories.

<table>
<thead>
<tr>
<th>MHz</th>
<th>Mean</th>
<th>SEM</th>
<th>Median</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rogers perception rms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>59.00</td>
<td>2.96</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>72.60</td>
<td>3.37</td>
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<td>20</td>
<td>115.40</td>
<td>4.50</td>
<td>110</td>
<td>100</td>
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<td>Rogers perception peak to rms</td>
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<tr>
<td>2</td>
<td>41.73</td>
<td>2.09</td>
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<td>5</td>
<td>51.34</td>
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<td>15</td>
<td>71.15</td>
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<tr>
<td>20</td>
<td>81.61</td>
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<td>Dalziel-Mansfield perception rms 50%ile</td>
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<tr>
<td>0.01</td>
<td>3.57</td>
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<td>0.04</td>
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<td>0.07</td>
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<td>Chatterjee, Wu, Gandhi perception</td>
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<tr>
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<td>3</td>
<td>40</td>
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<td>Rogers rms pain</td>
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<tr>
<td>2</td>
<td>151.40</td>
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<td>203.60</td>
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<td>20</td>
<td>217.55</td>
<td>3.6</td>
<td>220</td>
<td>200</td>
</tr>
</tbody>
</table>

Dalziel and Mansfield (3) provide detailed tabulated data (rms) for their assessment of frequency dependence of perception of contact current. They note that as the frequency increased, the
sensation was less intense in the 30,000 to 90,000 Hz range. They also reported a phenomenon of accommodation at the higher frequencies when the protocol involved adjusting the current back and forth across the perceptual threshold and that “when the energized plate was touched and contact was maintained many subjects reported an initial sensation that faded away in several seconds. (3)”. They further reported that for above 30,000 Hz, the rate of current increase had an appreciable effect on the threshold for perception. Clearly, numerous physiological factors come into play when the current applied changes from frequencies producing electrostimulation to frequencies that produce thermal changes: accommodation, adaptation, sensitivity to rate of temperature change, dispersion of the thermal gradient, convection, blood flow and environmental temperature.

Figure 3. Rogers RF current meter schematic.

Chatterjee, Wu, and Gandhi (2) show data at six frequencies (10 kHz, 20 kHz, 100 kHz, 120 kHz, 1 MHz and 3 MHz) using a Fluke 8060A (discontinued) “true rms” digital multimeter with a maximum frequency range of 200 kHz. They report measuring 1 MHz and 3 MHz, which are beyond the range of the meter. They extended meter capacity with an 85RF high frequency probe designed to convert the voltmeter into a high frequency (100 kHz to 500 MHz) RF voltmeter. It may be of interest to find out the reliability of use of the probe to extend the meter capabilities to determine if the asymptote at 40 mA was reliably accurate or a reflection of measurement limitations.

Physical properties of contact currents related to adverse effects:
Olsen, Schneider, and Tell (11) investigated why the probability of an RF burn during contact with a conducting object apparently is reduced at higher frequencies and questioned whether there was an upper frequency beyond which contact current limits should not or need not be set. They presented a model for calculating currents that lead to RF burns due to contact with parasitically-excited conductors at frequencies higher than those allowed for quasi-static models such as that used by Gandhi and Chatterjee (4). Finite Difference Time Domain (FDTD) and Method of Moments (MoM) modeling showed that the contact current injected into a person diminishes as frequency increases (See their Figure 4 below).
They stated that the most significant insight from this type of analysis is that very long, or tall, conductors exposed to higher frequency fields, such as VHF transmissions, do not present the same maximum contact current values as with lower frequencies. "This is dramatically illustrated in Fig. 6 where the contact current is plotted vs. conductor height for 1, 10, and 100 MHz. These data show why long conductors exposed to VHF RF fields do not present the same degree of potential for an RF burn as similar length conductors at lower (medium wave) frequencies." (11)

Fig. 4. Contact current injected into a person with $R_p = 1500\Omega$ ($E_0 = 1$ V/m, $h = 25$ m, $r_o = 12.5$ cm). (From Olsen, Schneider, and Tell (2011))

Fig. 6. Calculated contact current vs. height of conductor exposed to an electric field strength of 1 V/m for frequencies of 1, 10, and 100 MHz. Note the similar behavior of the oscillation in contact currents but, importantly, the diminished value of the peak currents at higher frequencies. (emphasis added) (From Olsen, Schneider, and Tell (2011))
They noted

“As the frequency goes up the maximum contact current available at higher order resonances is decreased because the electric field is “collected” from a smaller length of mast because the contributions from different parts of the mast destructively interfere with each other due to phase shifts as they travel along the mast. Given (2) and the fact that the contact current at higher order resonances is smaller than (2), it is clear that as the frequency is increased the largest possible contact current (i.e., that which occurs when a human touches a half-wavelength mast) is reduced. It follows that the electric field exposure required to cause an RF burn at the point of contact is increased as well. At some frequency the FCC MPE limit is large enough that it may be protective against RF burns as well as against exposure of isolated bodies. Hence, at higher frequencies than this, it may not be necessary to limit contact current from passively excited wires separately.” (11)

They concluded that “for a given electric field exposure level, the probability of an RF burn decreases with frequency at a rate of approximately 1/f (MHz).” (11)

Stuchly et al.(13) reported that measurements of foot current vs. finger current showed that stray capacitance of the body reduces the current significantly at high frequencies in the tens of megahertz range. They note that the current limits at frequencies above 100 kHz provide an exceptionally high safety margin because they prevent perception of warmth for the general population and pain due to heat for workers and that these limits occur only after the contact is maintained for a few minutes.

Stuchly et al. (13) below show current through the body is frequency dependent

While the data from Olsen, Schneider, and Tell (11) and Stuchly et al. (13) are not perception or pain _per se_ they do provide support for frequency dependence for contact currents collected and drawn from passive reflectors.

With regard to the use of a power function of 0.36 for perception or 0.12 for pain derived from Rogers (12) it is contradictory to first refuse to acknowledge Rogers’ data but to then adopt it for purposes of extrapolation using a power function based on the very same data. The actual data should be used. Close examination of Rogers’ data showed that the power function for perception sensation was 0.3581.

Based on the data discussed above, curve fitting, and the many years of operational experience working in the MF, HF, and VHF environment, the following chart is presented as an alternative to the contact current limits in the present P95.1-2345/D6.0, draft for ballot.

### Table 7 - Induced and contact current limits for continuous sinusoidal waveforms at frequencies between 100 kHz and 110 MHz

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<td>45</td>
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</tr>
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<td>--</td>
<td>100</td>
<td>NA</td>
<td>100(f/3)^0.40 mA</td>
<td>250</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
<td>16.7(f/3)^0.16 mA</td>
<td>50(f/3)^0.16 capped at 100 mA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**NOTE 1**—Tabulated values are given as rms quantities.

**NOTE 2**—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

**NOTE 3**—For frequencies between 30 MHz and 110 MHz the numerical limit at 30 MHz shall apply.

**NOTE 4**—There are no values for grasp in unrestricted environment since the population will not have training.

**NOTE 5**—The averaging time for determination of compliance for induced current is 6 minutes (Restricted) and 30 minutes (Unrestricted). The averaging time for contact is 1.0 second.

**NOTE 6**—The ceiling values for induced (temporal peak values) are 500 mA for no more than 14.4 seconds per six minute period and 200 mA for no more than 10.4 seconds per 30 minute period for the upper tier Zone 1 (restricted) and the lower tier Zone 0 (unrestricted), respectively.

**NOTE 7**—Exclusion zones may be established using REO values only when mission essential and only when all personnel who may inadvertently contact parasitically charged surfaces are informed that such contact may produce discomfort including shock or heating which could become painful after 15-20 seconds with fingertip contacts. Grasp is the appropriate method of contact.

**NOTE 8**—Light “brush” contact may result in arcs and shock, burn even at 40 mA, and should be avoided especially with long objects such as cranes or cables.

**NOTE 9**—Touch contact current is capped at 100 mA as in STANAG 2345 (Ed 3); (100 mA from 20.6 to 30 MHz)
The grasping contact limit pertains to restricted environments where personnel are trained to make rapid grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.

Conclusion:

In summary, Rogers’ technical report (12) is the only scientific study in the HF region that has looked at perception and discomfort (pain). The data have been reanalyzed and graphically presented showing the resultant rms curve fitting to earlier work by Dalziel and Mansfield (3) up to 2 MHz and do not support a need for the proposed draft limit of 50 mA. The report by Olsen, Schneider, and Tell indicates that based on physical properties, HF fields do not present the same potential for RF shock and burns as similar length conductors at lower (medium wave) frequencies. To maintain overall safety in the work environment ultra-conservative standards should be avoided since they often generate new, more severe risks to the worker. Reduced contact currents needlessly severely impact military operations and interoperability as demonstrated by NLD and CAN measurements and assessments. (See above: Degraded operability and interoperability.)

The contact current exposure limit change was the impetus for establishing the NATO-IEEE Technical Cooperation Agreement under which this standard is being drafted. It should be noted that NATO has final approval authority on whether to adopt the IEEE standard. At this time, as Custodian of STANAG 2345 that will cover the standard, I cannot recommend the document to the NATO Military Medical Standardization Working Group. Based on feedback from the NATO Electromagnetic Environmental Effects Radiation Hazards Working Group, they are reluctant to adopt the standard as it stands in current draft form.

References:


1.0 Introduction
This document reviews available information regarding contact current limits proposed for the revision of IEEE Standard C95.1 and its extension to a military version, with emphasis on the frequency domain above 100 kHz. Some changes to contact current limits have been incorporated into the current balloting document relative to the previous IEEE Standard C95.1-2005. Discussion is also provided concerning an alternative proposal of B. J. Klauenberg (2012).

2.0 Mechanisms of interaction
The mechanism of human reaction to contact current at frequencies below 100 kHz is electro-stimulation, i.e., the direct excitation of sensory and motor neurons from an applied electric field within the biological medium. For stimulation above 100 kHz, the principal mechanism for human reaction is thermal, i.e., stimulation of heat-sensitive receptors due to tissue heating. For pulsed currents between 100 kHz to 3 MHz, both electrostimulation and thermal stimulation are possible, and the dominant mechanism will depend on the duty factor of the applied current (Reilly, 1998b). For sinusoidal current of a continuous nature, the thermal mechanism is dominant. Unless otherwise noted in this report, the available stimulating current is considered continuous, although it may be interrupted by an intermittent contact on the part of the subject.

Our stated goal is to avoid adverse reactions, not just perceptual ones. We have defined an adverse reaction as a painful or aversive response. To this definition we could reasonably add potentially hazardous reflex (startle) reactions. The Underwriters Laboratories, in testing 240 human subjects, reported potentially hazardous startle reactions typically at current levels that were judged to be painful in other experiments (see Reilly, 1998a, pp. 290-291). We consider pain thresholds to be relevant end points in contact current exposure standards.

3.0 Contact current tables in existing and proposed IEEE standards

3.1 Existing standards. Table 1 below expresses contact current limits as they appear in Table 7 of the latest published version of C95.1-2005 (IEEE, 2005). Table 1 differs from an earlier standard by the addition of a touch limit of 50 mA in the “Controlled Environment.” The earlier version only specified a limit based on grasping contact in the controlled environment. Table 2 below illustrates the limits as they appear in the draft Military Standard (IEEE, 2012). A consequence of the specifications is that if personnel are properly trained, the touch limit does not apply in the controlled environment (now called restricted environment). This needs to be explicitly stated.
Table 1. RMS induced and contact current limits for continuous sinusoidal waveforms; 
f = 100 kHz to 110 MHz. Table reproduced from IEEE C95.1-2005

<table>
<thead>
<tr>
<th>Condition</th>
<th>Action level(a) (mA)</th>
<th>Persons in controlled environments (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both feet</td>
<td>90</td>
<td>200</td>
</tr>
<tr>
<td>Each foot</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp(b)</td>
<td>—</td>
<td>100</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
</tr>
</tbody>
</table>

NOTE 1 — Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

NOTE 2 — The averaging time for determination of compliance is 6 minutes.

\(a\) MPE for the general public in absence of an RF safety program.

\(b\) The grasping contact limit pertains to controlled environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.

3.2 Proposed standards. Table 2 expresses the induced and contact current limits presently circulated as a balloting document for a Military Standard (IEEE, 2011). The changes in Table 2 with respect to Table 1 are: (a) the limits for “Both Feet” has been eliminated because it is redundant with the “each foot” specification; b) Contact current limits in Table 2 above 3 MHz for touch and grasp increase as a power law \(I = (f/3)^{0.12}\) but are flat in Table 1.

4.0 Experimental studies.
Experimental data on human reactions to contact current above 100 kHz have been published by Chatterjee et al. (1986), Rogers (1981), and Dalziel and Mansfield (1959). These are succinctly described as:

Chatterjee et al., (1986). Thresholds of perception and pain measured separately for men and women in the frequency range 10 kHz to 3 MHz. Contacts: finger touch of plate; grasp of 1.5 cm diameter rod. The measurements from 10 kHz to 100 kHz nearly overlay the data of Dalziel and Mansfield for both touch and grasp contacts. 367 Subjects (197 M, 107 F). Peer reviewed.

Dalziel and Mansfield (1959). Thresholds of perception determined for DC and oscillating currents from 60 Hz to 200 kHz. 147 subjects (143 M, 4 F). Contacts: fingertip touch on plate; fingertip tapping of plate; grasp #8 wire (3.3 mm diameter). Measurements nearly overlay the touch perception thresholds of Chatterjee from 10 kHz to 100 kHz. Peer reviewed.
Table 2: Proposed Military Standard (Table 7), titled: Induced and contact current limits for continuous sinusoidal waveforms at frequencies between 100 kHz and 110 MHz.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Unrestricted Zone 0 100 kHz – 3 MHz (mA)</th>
<th>Restricted Zone 1 100 kHz – 3 MHz (mA)</th>
<th>Unrestricted Zone 0 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 1 3 MHz – 30 MHz (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced, each foot</td>
<td>45</td>
<td>100</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp</td>
<td>--</td>
<td>100</td>
<td>--</td>
<td>100 (f/3)$^{0.12}$</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
<td>16.7(f/3)$^{0.12}$</td>
<td>50(f/3)$^{0.12}$</td>
</tr>
</tbody>
</table>

NOTE 1—Tabulated values are rms values; f = frequency in MHz.
NOTE 2—For frequencies between 30 MHz and 110 MHz the numerical limit at 30 MHz shall apply.
NOTE 3—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.
NOTE 4—The averaging time for determination of compliance is 6 minutes (restricted environments – Zone 1 and REO Zone 1) and 30 minutes (unrestricted environments – Zone 0) for induced currents, and 1 s for contact current.
NOTE 5—Calculated values for the personnel in unrestricted environments (Zone 0) and for restricted environments (Zone 1) are capped at the 30 MHz values since there is insufficient data to extrapolate above 30 MHz
NOTE 6—Values for touch current above 3 MHz are based on a published technical report (Rogers [B35]) that is not peer reviewed and therefore these values are interim recommendations.
NOTE 7—Light “brush” contact may result in arcs and shock and burn even at 50 mA and should be avoided especially with long objects such as cranes or cables.
NOTE 8—The ceiling values for induced (temporal peak values) are 500 mA for no more than 14.4 seconds per six minute period and 200 mA for no more than 10.4 seconds per 30 minute period for the upper tier Zone 1 (restricted) and the lower tier Zone 0 (unrestricted), respectively.

Rogers (1981). Determined thresholds of perception and a higher threshold he called discomfort and also let-go, but functionally equivalent to the so-called pain thresholds of Chatterjee. The thresholds of discomfort/let-go/pain at 2 MHz are highly disjoint from thresholds of Chatterjee at 3 MHz. Contrary to theoretical expectations, thresholds of perception and pain rise with increasing frequency at very different rates. 50 subjects. Not peer reviewed.

4.1 Chatterjee et al. study. Chatterjee et al. (1986) reported thresholds of perception and pain for men and women (n = 197 M, 170 F) in the frequency region 10 kHz – 3 MHz. Figure 1 is adapted from the original publication. The reaction curves labeled “pain” deserve some explanation.

Chatterjee and colleagues defined their thresholds as follows:

The subject was asked to inform the experimenter when he/she felt a sensation (for the measurement of perception current) and when the sensation was so uncomfortable that they would definitely not want to hold on to or touch the electrode (for the measurement of pain current. (p. 488)
In our study of human reactions to electrical stimulation, we treated this end point as a \textit{tolerance limit} (Reilly, 1998a, pp. 259-260). We also determined a \textit{pain threshold} as the lowest value at which the subject reported a stimulus of random magnitude as painful (from a list of adjectives). In every case tested, a subject’s tolerance limit always exceeded his/her threshold of pain. Consequently, the thresholds of pain reported in Chatterjee’s study may actually have been lower than that which she reported as pain thresholds.

Figure 2 is a plot of Chatterjee’s mean perception thresholds for subjects making a grasping contact with a metal rod. As in Fig. 1, separate thresholds are shown for males and females. The dashed curve labeled “children” does not apply to actual measurements, but was calculated by the authors based on a body size scaling factor applied to the measured adult thresholds. Body size scaling of electrostimulation thresholds has also been demonstrated in other experiments involving human electrostimulation (Reilly, 1998a, pp. 282-290).

![Figure 1. Perception and tolerance/pain thresholds (mean & standard deviation) for AC stimulation, finger touch contact. Adapted from Chatterjee (1986). Mean and standard deviation values shown. Figure reproduced from Reilly (1998a, p. 267).](image)
4.1.1 Determination of pain thresholds for grip contact. Our standards are based on thresholds of pain, rather than perception. Although Chatterjee and colleagues directly measured pain thresholds for touch contact (as seen in Fig. 1 above), they only tested perception thresholds for grip contact. We can convert their data to putative pain thresholds as explained here. From Fig. 2, the average of male and female mean thresholds at 1 and 3 MHz is 240 mA. Based on the touch data (Fig. 1), the ratio of pain to perception is taken as \( r = 1.25 \). By applying this ratio to the mean of M & F perception thresholds, we calculate the mean pain threshold for grasp contact as \( (240)(1.25) = 300 \text{ mA} \).

4.1.2 Statistical distribution of pain thresholds. Although Chatterjee and colleagues did not tabulate individual thresholds, one can reasonably construct a statistical distribution based on their data. Numerous published studies exist that provide individual thresholds of reaction to electrostimulation (Reilly & Diamant, 2011, pp. 111-114). These involve as many as hundreds of individual measurements of human thresholds of perception and pain in response to contact currents and magnetic fields applied to various body locations. Other
electrostimulation studies examined for statistical distributions of reaction thresholds involve human electroconvulsive therapy, bovine electrical perception, and canine thresholds of ventricular fibrillation. In all cases, electrical thresholds were well fit by the log-normal statistical model over a wide range of statistical ranks – typically from the first to 99th percentiles – although it was sometimes necessary to replot published data on a log-normal format to demonstrate this. The slopes of the cumulative distribution functions fit into a fairly narrow range, typically in which the ratio \( r_s = x_{50}/x_1 \) was a factor between 2 and 3, where \( r_s \) is a statistical slope factor, and \( x_n \) is the value of the statistical variate at the \( n \)th percentile (for \( r_s, \ n = 50 \) and 1).

Figures 3 plots statistical thresholds of touch contact pain on a log-normal format, in which the medians and slope factors have been taken from Chatterjee’s data*, and the slope has been inferred from the coefficient of variation, \( \sigma_x/x_{av} \), where \( \sigma_x \) is a typical standard deviation value, and \( x_{av} \) is a typical average value of the data points in the frequency range 100 kHz to 3 MHz. Figure 4 applies to grip contact, in which case the average pain value has been inferred as described in 4.1.1.

4.1.3 Statistical inferences regarding exposure standards, 100 kHz – 3 MHz.
Table 3 uses the statistical models of Figs. 3 and 4 to express probabilities of adverse reaction that would result from exposure to the limits shown in Tables 1 and 2. With grasp contact in Zone 1, the adverse reaction percentiles expressed in Table 3 are similar to those at low frequencies where electrostimulation is dominant. As in the low frequency standard, the percentiles of adverse reaction for the general public are significantly less than 1%

I make no attempt to be specific about the numerical value of that small percentile, since the adequacy of the log-normal model much below 1% has not been rigorously tested against experimental electrical reaction thresholds. However, note that extrapolation of the curves in Figs. 3 & 4 to smaller current levels leads to very rapidly vanishing percentiles of painful reactions.

4.2 Dalziel & Mansfield’s study. Dalziel and Mansfield (1959) tested perception thresholds with three types of contact: (1) finger touching a plate; (b) finger tapping a plate; (c) hand grasping a #8 wire (3.3 mm diameter). The touch and grasp data are plotted in Figs. 5 and 6, along with additional data from Roger (see 4.3 below). The touch data nearly overlay those of Chatterjee over the common tested frequencies. Dalziel also presented data in which the subject tapped a plate once or twice per second. Tapping and touching thresholds were nearly identical.

* Figures 3 and 4 use the assumption the median values equal Chatterjee’s means. In reality, the median of a log normal distribution is necessarily less than the mean. However, for the slope factors used in Figs. 3 & 4, the discrepancy is most likely too small to fuss about.
Figure 3. Statistical distribution of touch pain thresholds based on log-normal assumption; Mean and coefficient of variation based on data of Chatterjee et al., (1986).
Figure 4. Statistical distribution of grasp pain thresholds based on log-normal assumption; Mean and coefficient of variation of grasp perception based on data of Chatterjee et al., (1986), converted to pain thresholds. Conversion factor taken from Pain/Perception ratio for touch.
Table 3. Expected reaction percentiles using exposure limits from Figs. 3 & 4 (Based on Chatterjee’s data).

<table>
<thead>
<tr>
<th>Zone</th>
<th>Contact</th>
<th>Limit (mA)</th>
<th>Pain response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Unrestricted zone)</td>
<td>Touch</td>
<td>16.7</td>
<td>&lt;&lt; 1</td>
</tr>
<tr>
<td></td>
<td>Grasp</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1 (Restricted zone)</td>
<td>Touch</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Grasp</td>
<td>100</td>
<td>0.5</td>
</tr>
</tbody>
</table>

4.3 Rogers’ study. Rogers (1981), measured human thermal perception thresholds in 50 subjects at the frequencies: 2, 5, 10, 15, and 20 MHz. He presented histograms of current thresholds at each frequency. I previously derived median and average thresholds from his histograms (Reilly, 1998a, pp. 267-268). As expected from a log-normal distribution (demonstrated for other electrostimulation thresholds), mean thresholds exceeded the median (by 18% in the Rogers perception data).

4.3.1 Terminology. Rogers explained that he measured for each subject the threshold of perception, as well as another end-point which he called discomfort in one paragraph, and let-go in another. In most literature on electric shock, the “let-go” threshold refers to grip tetanus of a grasped conduction – a very painful condition. Equating “discomfort” with “let-go” at first seemed contradictory. With further reflection, it seems likely that Rogers’ subjects were responding to a condition in which they could not tolerate the stimulus, and consequently felt compelled to cease contact, i.e., let go of the energized conductor. Such terminology is said to have been common in the UK at the time of Rogers’ study (Klauenberg, 2012).

4.3.2 Variations due to contact location. Rogers noted (p. 79) that the median thresholds of perception and “leg-go” currents for finger-tip contact were about twice those for back-of-finger contact. Perhaps the effect may be related to a dielectric breakdown in the drier and thinner corneal layer on the back of the finger as compared with the fingertip. This might result in micro-channels of high current density that would result in increased temperature in highly localized regions as compared with a more even distribution of current from an electrode in contact with the skins.

It is likely that Rogers’ let-go thresholds have the same interpretation as do the “pain” thresholds of Chatterjee and colleagues. However, we must bear in mind that these might more properly be called “tolerance” thresholds. In any case, the condition should be regarded as an adverse reaction.
Figure 5. Mean perception thresholds of Chatterjee, Dalziel, and Rogers vs. frequency. Upper: finger touching plate; Lower: hand grasping conductor. Note change of vertical scale between upper & lower figures. Rogers’ touch data apply to back of finger. According to Rogers, his data should be multiplied by a factor of 2 for fingertip contact. Plots courtesy of Rob Kavet.
4.3.3 Power law curve fit. Rogers’ data fit well to a straight line when plotted on coordinates of log-frequency against log-current. This represents a power law of the form

\[ I = k f^a \]

(1)

where \( I \) is threshold current, \( a \) is the power law exponent, and \( k \) is a constant that depends on experimental factors. Our focus is on the power law, rather than \( k \). For Rogers’ data \( a = 0.37 \) for the perception threshold, and \( a = 0.12 \) for the discomfort/let-go threshold*. The large difference in power laws for Rogers’ perception and let-go data is contrary to theoretical expectations, which suggest that the two ought to have the same slope.

Also problematic is the huge disconnect between the mean pain threshold of Rogers at 2 MHz, and that of Chatterjee at 3 MHz (Fig. 6). Note that Rogers stated that these thresholds apply to the back of the finger, and that thresholds for the fingertip were two times greater. If we adjust Rogers’ data for fingertip application, the discontinuity between Chatterjee and Rogers at 2-3 MHz is a multiplicative factor of 7.

* The quoted power laws were determined from the means of Rogers’ thresholds vs. frequency. Rob Kavet calculated a power-law regression of Rogers’ individual thresholds (derived from his published histograms) to arrive at \( a = 0.290 \) for perception, and \( a = 0.147 \) for discomfort/let-go (Kavet, 2012).
4.3.4 Inferences from Rogers’ study regarding exposure standards. The two above-mentioned problems taken together – different power laws for perception and pain, and lack of correspondence with other studies at 2-3 MHz – suggest that one ought to be cautious about accepting Rogers’ thresholds at face value without further experimental corroboration. Further discussion on this point appears in Section 6.0.

5.0 Averaging time for contact current exposure limits.
An important element of the standard is the time over which a compliance measurement should be averaged. The appropriate averaging time should be a function of the response time of the biophysical mechanism responsible for the reaction. In the current version of Standard C95.1-2005, the averaging time for induced and contact current at frequencies from 100 kHz to 110 MHz is specified as 6 and 30 minutes for the upper and lower tier, respectively. In the revised version considered here, an averaging time of 1 second is specified, as explained below.

5.1 Experimental information. The issue of averaging time was not directly addressed in the studies considered here. However, some relevant information was provided by Chatterjee and colleagues (1986). In their discussion of experimental results, the investigators noted (p. 491):

d) “The threshold current for perception in the case of a tapping contact was measured to be of the order of 90 percent of the value for continuous contact. This is in qualitative agreement with Dalziel and Mansfield’s results”

e) “For frequencies greater than 100 kHz, for which the sensation was warmth, when the current was adjusted to a value equal to the perception threshold, pain was reported typically within 10-20 s. This phenomenon was not observed for frequencies less than 100 kHz.”

Relative to statement (d), no distinction was made between thresholds below 100 kHz (where electrostimulation mechanisms dominate) and above (where thermal mechanisms dominate). In statement (e), however, the observation was said to be applicable only above 100 kHz. Furthermore, this statement implies that the pain thresholds provided by Chatterjee (Fig. 1 in this report) would apply to brief contacts, probably not more than 1 second in duration.

Relevant to this discussion is the fact that Dalziel and Mansfield found little difference in perception thresholds for touch vs. tapping at a rate of 1-2 per second. Such consistency was apparent at the 0.5, 50, and 99.5 percentile ranks at all tested frequencies.

The fact that thresholds for a held touch contact and contact lightly tapped at 1-2 per second differed but little in both Chatterjee and Dalziel studies points to a brief response time for these reported reactions – probably on the order of 1 second, and that value has been specified in Table 2 for the averaging time for testing contact current compliance.
The importance of the averaging time specification can be illustrated by the following hypothetical example. Consider a pulsed RF waveform with an on time of one second, followed by a quiescent period of 9 seconds (duty factor = 10%). The existing averaging time specification of 6 minutes would permit the RMS value of the exposure during the “on” time to be 10 times the values specified in Tables 2. In fact, one could easily postulate scenarios involving even lower duty factors where the on-time exposures could be thousands of times the values in Table 2.

5.2 Possible mechanisms regarding averaging time. Averaging time in Table 2 is specified as 1 s for contact current, and as 6 and 30 minutes for induced current in the unrestricted and restricted zones, respectively. How can we explain the gross differences the averaging time conditioned only on whether current is conducted through skin contact, or is induced via the electromagnetic field? I offer the following conjecture as a possible explanation.

In our applications, current is conducted through electrodes contacting the skin. The impedance of the epidermis of dry skin greatly exceeds that of underlying tissues. Consequently, the greatest temperature rise would occur in the epidermis. Painful electrostimulation may be due to the excitation of heat-sensitive nociceptors that lie just below the epidermis. On the other hand, electromagnetically induced current would be more likely to travel in deeper tissues having greater conductivity. Thermovascular regulation on short time scales (1 s) may be more efficient within deeper tissues than immediately below the epidermis, and this may result in longer thermal time constants in deep tissue than in the epidermis.

6.0 Rationale for limits on contact current above 100 kHz.
The study of Chatterjee conforms well to other theoretical and experimental studies of human reactions to electrostimulation by sinusoidal current. Her study confirms that thresholds rise approximately in proportion to frequency from several kHz to 100 kHz, and then reach a maximum plateau at about 100 kHz, at which point thermal mechanisms become dominant. Her measured mean thresholds nearly overlay those of Dalziel and Mansfield for both touch and grip contacts up to 200 kHz (the maximum frequency tested by Dalziel).

A limitation of the Chatterjee study is that the maximum frequency is 3 MHz. What happens beyond that frequency? Based on the theoretical considerations in Appendix A, it seems likely that thermal thresholds will rise as frequency is increased into the megahertz region. But at what frequency do thresholds start to rise? At what rate? How far in frequency does this rate continue?

At the present time, we lack reliable peer-reviewed measurements beyond 3 MHz (the upper frequency limit of the Chatterjee study). Additional data is available from the Rogers study up to 20 MHz, however, inconsistencies pointed out in Sects. 4.3.2 and 4.3.3 and the lack of corroborating evidence preclude reliance on these data. Given this state of affairs, we should consider the following options:
(1) Define limits only up to 3 MHz, with statement that above that frequency, thresholds are undefined, but would not be less than those at 3 MHz.

(2) Accept Chatterjee’s findings up to 3 MHz, and specify a further increase based on the power law \( I = k f^a \), where \( a = 0.12 \) (as in Roger’s discomfort/let-go data).

(3) Accept Chatterjee’s findings up to 3 MHz, and then specify a further increase based on the power law \( I = k f^{a_2} \), where \( a = 0.37 \) (as in Roger’s perception data).

Option (1) is the most conservative approach, and it was favored by the ICES Editorial Committee in its latest unreleased draft that combines C95.1 and C95.6. Options (2) and (3) are increasingly less conservative (more speculative). They both disregard Rogers’ absolute thresholds, and use only the slopes indicated in his data.

The choice among these options will be governed by the degree of speculation that ICES is willing to accept. The current consensus of the Editorial Committee is to choose option (2) for the military standard, which is the basis of Table 7 in the balloting document (reproduced as Table 2 in this report).

7.0 Alternative proposals.
Limits in Table 2 up to 3 MHz are based on data from peer-reviewed studies reviewed in Section 4.0. Limits above 3 MHz are somewhat speculative. A power law with an exponent \( a = 0.12 \) is specified above 3 MHz as derived from a power law fit to the perception thresholds of Rogers (1981). However, as noted in Section 4.3, that study was not peer-reviewed and is of doubtful reliability. Based on theoretical considerations noted in Appendix A, we expect a rise in thresholds somewhere in the megahertz region. However the frequency at which the rise would begin, and the rate of rise are not presently known.

7.1 Editorial Committee approach. At the ICES meeting in Ft. Lauderdale in December of 2011 I suggested that the members consider using a power law with an exponent \( a = 0.37 \) for frequency above 3 MHz. That value was determined from a power law fit to Rogers’ perception thresholds. Considering the lack of corroborating data for that specification, the consensus at the Ft. Lauderdale meeting was not to accept it.

Following that meeting, the ICES Editorial Committee considered an alternative that specified limits only up to 3 MHz as in Table 2 of this report, along with the note: *Limits above 3 MHz are not specified due to lack of supporting data, but would not be any greater than those at 3 MHz.* Note that this is equivalent to option (1) of Section 6.0.

A slightly more speculative option for limits at frequencies above 3 MHz has been used for military applications in Table 7 of the Balloting Draft (Table 2 of this report) using a more conservative power law exponent \( a = 0.12 \), which applies to Rogers’ let-go/discomfort thresholds. This is equivalent to option (2) of Section 6.0.
7.2 Dissenting opinion. Table 3 limits recently suggested by B.J. Klauenberg (2012)∗. The limits proposed in the balloting document of December, 2012 are shown in Black face; those proposed by BJK are shown in red where they differ from those of the balloting document. Note that the major differences between the two proposals indicated

Table 3- Comparison of current limits proposed by ICES Balloting document and those proposed by B.J. Klauenberg (2012).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Unrestricted Zone 0 100 kHz – 3 MHz (mA)</th>
<th>Restricted Zone 1 100 kHz – 3 MHz (mA)</th>
<th>Unrestricted Zone 0 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 1 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 2 100 kHz – 30 MHz (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced, each foot</td>
<td>45</td>
<td>100</td>
<td>45</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp</td>
<td>NA</td>
<td>100</td>
<td>NA</td>
<td>100 (f/3)^0.12</td>
<td>132*</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
<td>16.7(f/3)^0.12</td>
<td>50(f/3)^0.12</td>
<td>NA</td>
</tr>
</tbody>
</table>

Limits proposed in the balloting document of December, 2012 are shown in Black font. Limits of BJK are shown in Red where they differ from those of the balloting document, ∗ Limits in Restricted Zone 2 are not specified in Table 2. However, the black font entries in this column are based on an extension to 30 MHz using a power law with \( a = 0.12 \).

in Table 3 are the power laws above 3 MHz, and the inclusion of specifications for “Restricted Zone 2”.

The power laws of BJK use \( a = 0.30, 0.38, \) and 0.40. Although no justification was given for these diverse values, they do not differ greatly from the power law \( a = 0.37 \), which applies to Rogers’ let-go/discomfort thresholds, i.e., option (3) of Section 6.0.

The limits suggested by BJK are nearly identical to those which I proffered at the Dec, 2011 ICES meeting (Reilly, 2011), and which were not accepted by the members at the time – the members opined that additional research was needed to confidently make such adjustments to the contact current limits already in use.

7.3 Averaging time for contact current. Notes associated with Table 7 of the balloting document are shown below Table 2 of this report. Notes given in BJK’s table are similar, except for differences in specific language and numbering. A major difference is in the specification of averaging time. For induced current, the averaging time is 6 and 30 minutes, for the restricted and unrestricted environments, respectively.

* Comments apply to BJK document circulated to Editorial Committee on Nov. 28, 2012. BJK announced his intention to modify that document based on an earlier draft of this report.
For contact current the averaging time is 1 s in the balloting document, but is specified in the BJK proposal as simply:

*The averaging time for determination of compliance is 6 minutes (Restricted) and 30 minutes (Unrestricted),*

i.e., the specification deletes the provision of a 1 s averaging time for contact current. As developed in Section 5.0, the shorter averaging time of 1 s is justified for contact current.

**Appendix A. Thermal mechanisms for perception of current above 100 kHz**

Thermal perception results from the temperature rise in the tissue containing the activated thermal receptors. Assuming there are no thermal losses such as conduction to blood or adjacent tissue, the temperature rise in the biological tissue is expressed by (Chilbert, 1998a):

\[ \Delta T = \frac{J^2 \rho t}{\rho c} = \frac{J^2 t}{\sigma c} \]  

(2)

where \( \Delta T \) is the temperature rise (K), \( J \) is current density (A/cm\(^2\)), \( \rho \) is resistivity of the tissue (\( \Omega \) cm), \( t \) is the duration of current, \( \rho \) is tissue density (g/cm\(^3\)), and \( c \) is the specific heat of the tissue (J/g K). Tissue resistivity (\( \rho \)) and conductivity (\( \sigma \)) are related by \( \rho = 1/\sigma \).

If we assume that \( \sigma \) is independent of frequency, it would follow that heating effects would be independent of frequency, and hence perception thresholds would cease to rise with frequency in the region where thermal effects are dominant. However, this assumption is not strictly true, especially as the frequency of stimulation is raised to megahertz values.

![Figure 7. Frequency variation of complex permittivity typical of soft tissue. \( \varepsilon_r \) = relative dielectric permittivity; \( \sigma \) = conductivity. (Source: Figure 2.4 of Reilly, 1998a).](image-url)
Figure 7 illustrates the variation of $\sigma$ with frequency typical of soft tissue (Reilly, 1998a). Note that as the frequency of current is raised from the ELF region, the conductivity remains relatively constant until the frequency enters the megahertz region. At that point $\sigma$ increases significantly. From Equation (1), it can be seen that this increase in $\sigma$ (decrease in $\rho$) would require an increase in current density ($J$) to achieve a given temperature rise. This phenomenon could explain the rise in thermal thresholds beyond a few MHz.

While Fig. 7 presents a general guide to the variation of $\sigma$ with frequency, it is intended only as an example typical of soft tissue. The specific tissue type for contact current applications is unclear. Would skin be the relevant tissue type? And if so, which layer of skin? Complicating this question are the complexities of skin impedance, which exhibits marked nonlinearities with respect to applied voltage, and great sensitivity to the degree of hydration. It will require additional experimental studies to resolve these questions.

References


STATUS OF IEEE-NATO MILITARY WORKPLACE STANDARD-2345

IEEE International Committee on Electromagnetic Safety

ICES TC-95

17 January 2013

Tri-Service Research Laboratory

Ft. Sam Houston, TX

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Human Effectiveness Directorate

Air Force Research Laboratory
Acknowledgements

• Capt. Andrew J. Lukshis, AFRL-711 HPW/RHDR
• William (Brent) Voorhees, AFRL-711 HPW/RHDR
  – Multiple assists in data analyses

### Outline

1. NATO Standardization Agreement 2345
2. The transition from NATO to civil standards process
3. The impact of overly restrictive contact current limits
4. Assessment of contact current studies
5. Novel military restricted expert only (REO) access zone
6. Solutions toward EC Directive and NATO compatibility
7. Way ahead
NATO Standardization Agreement (STANAG) 2345 (2003)

• Standardization Agreement (STANAG) 2345: “Evaluation and Control of Personnel Exposure to Radio Frequency Fields – 3 kHz to 300 GHz”

• Guidance to protect personnel from potential electromagnetic health and safety hazards in the military operational environment

• Based on internationally recognized IEEE standard

• NATO designated “Essential STANAG”

• Two major revisions; Last 13 Feb 2003
“New IEEE Military Workplace Standard” signed 30 July 2009

“IEEE shall develop, maintain, revise, and update a new IEEE military workplace standard that will address normative military occupational/workplace-specific exposure limits to electric, magnetic and electromagnetic fields.”

Not simply adopting a non-governmental standard *in lieu* of a military drafted standard, but having civil SDO draft a military standard. This is precedent setter.

Agreement between the Institute of Electrical and Electronics Engineers, Incorporated (IEEE) and the NATO Standardization Agency (NSA) for the Development of a New IEEE Civil Standard to Replace the NATO EMF Standard, Adopted Under STANAG 2345
Interoperability Threatened by Lower Limits on Contact Current

• Survey of NATO nations showed operational impact on safety from new EU Worker Safety Directive 2004/40/EC lower limits on contact current

• Operations impacted (non-mitigatable)
  – High Frequency communications often last 6 – 8 hrs
  – Vertical replenishment operations
  – Man-Overboard & Search-And-Rescue
  – Ship to ship supply transfers
  – Fuel transfer
  – Armaments test and transfer

• Entire deck of ship “off limits”

• A new safety problem
Exclusion Zones at 100mA

HNLMS Oblong

Representation of Measurements on Netherlands frigate
Exclusion Zones at 40mA

HNLMS Oblong

Representation of Measurements on Netherlands frigate

No space on deck is open to workers! A new risk to safety
Risks Of Overly Restrictive Standards

- Electromagnetic spectrum supports many military mission essential systems that **enable safe operations**
  - Communications, navigation, detection and tracking, weapons, flight, search and rescue

- Must consider system degradation impact on mission
  - What risks will be reintroduced if emitters are shutdown?
  - Effect of reducing system optimization:
    - Degraded approach radars would lead to unsafe landings
    - Degraded communications systems impact on command and control

- Must protect personnel from electromagnetic (EM) energy overexposure **AND** from alternative risks that may develop due to loss of EM-based operations

DISTRIBUTION A. APPROVED FOR PUBLIC RELEASE.AFRL-RH-FS-OP-20-13-0003
(1) Data, albeit scarce, do not support a need for the proposed 50 mA limit.

(2) Based on their physical properties, HF fields do not present the same potential for RF shock and burns as do lower frequency fields.

(3) It is important to maintain ultimate safety in the work environment and ultra-conservative standards often generate new, more severe risks to the worker.

(4) Field operators have not found the 100 mA touch contact current limit to have adverse health effects.

(5) Importantly, especially for militaries, the reduced contact current limits severely impact safe operations and interoperability.
Contact Current Frequency Dependence (S. J. Rogers, 1981)
Frequency Dependence for Perception of Contact Current

2 MHz – 20 MHz

PERCEPTION CURRENT LEVELS vs. FREQUENCY
CONTACT: BACK OF FOREFINGER ON 18 mm DIAMETER BRASS TUBE
50 PERSONS

NUMBER OF PERSONS

BODY CURRENT (mA)

2 MHz

10 MHz

15 MHz

20 MHz

LET-GO CURRENT LEVELS vs. FREQUENCY
CONTACT: BACK OF FOREFINGER ON 18 mm DIAMETER BRASS TUBE
50 PERSONS

NUMBER OF PERSONS

BODY CURRENT (mA)

2 MHz

5 MHz

10 MHz

15 MHz

20 MHz
Similar Experimental Setup

Chatterjee, Wu, and Gandhi

Rogers
Chatterjee et al. used Fluke 8060A and extended capacity with an 85RF high frequency probe designed to convert the voltmeter into a high frequency (100 kHz to 500 MHz) RF voltmeter.

Is this a valid tool?

Could it be the basis for the asymptotic 40 mA they reported from 0.1 to 3.0 MHz?

Dalziel and Mansfield did not find asymptote: They reported:
- 43.80 mA at 0.1 MHz
- 55.40 mA at 0.15 MHz
- 63.63 mA at 0.2 MHz
Confusing Definitions for Pain

- Rogers defines pain as discomfort which he called “let-go”
- Present day United Kingdom military definition for “let-go”
  “it’s now hurting and I am going to remove my hand or body part from the source of pain. We would use the term 'no let-go' if your muscles had contracted and you are unable to release your grip as can occur in an electric shock from a domestic mains supply.”

  Lee J Alderson Electromagnetic Integration E3A Policy, Head of Delegation to NATO E3-RADHAZ

- Back of finger could not be muscle tetanus since there is no grip
- IEEE for let-go current: “The current level above which involuntary muscular contraction prevents release of a grip on an energized conductor.”
Conceptual Perspective

- Limits are set to protect personnel from exposure to adverse health effects levels

- Sensory perception thresholds are conservative
  - Sensory perception precedes pain
  - Pain threshold is approximately 20% higher (Gandhi, 1987)

- Pain perception is less well defined and more variable
Conceptual Perspective

• RF contact currents above 3 MHz are thermal
  – Electrostimulatory electrophysiological data is irrelevant unless measuring thermal receptor thermal nociceptor activity

• Method of determining sensory threshold is critical
  – Staircase method shown to result in great variability
  – Subthreshold method problems: cumulative and dispersive factors
  – Method of Levels or Forced Choice is preferred; Bayesian updates

• Rate of current increase and size of contact area factors
Conceptual Perspective

- Pain/tolerance limit as the end-point
  - May confound pain measures
  - Neither Chatterjee or Rogers used Tolerance
  - Participants were not instructed to hold-on as long as they could

- Sensory perception
  - Avoids problems of defining discomfort, pain, and tolerance
Contact Current Values (mA) For Perception And Pain Thresholds: Three Laboratories

<table>
<thead>
<tr>
<th>MHz</th>
<th>Mean</th>
<th>SEM</th>
<th>Median</th>
<th>Mode</th>
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</tr>
<tr>
<td>2</td>
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<td>2.96</td>
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<td>5</td>
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<td>3</td>
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<td>176.8</td>
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<td>200</td>
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<tr>
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<td>217.55</td>
<td>3.6</td>
<td>220</td>
<td>200</td>
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<th>SEM</th>
<th>Median</th>
<th>Mode</th>
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<td></td>
<td></td>
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<tr>
<td>0.2</td>
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<tr>
<td>1</td>
<td>50</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Comparison of Studies

Comparison of Rogers perception threshold rms vs. peak to Chatterjee et al. and Dalziel and Mansfield rms contact current measurements and Rogers pain to Chatterjee pain threshold

NOTE: Rogers’ data are presented as means ± standard error of the mean (± SEM). Dalziel and Mansfield's data are the 50 percentile for perception.
Rogers’ Contact Current Perception Threshold (N=50)

Power function: Rogers perception threshold rms contact current measurements (points may represent up to 20 persons)

\[ y = 44.223x^{0.2989} \]
Rogers’ Contact Current Perception Threshold (N=50)

Power function: Rogers perception threshold rms contact current measurements: Extrapolated by 3 MHz steps with power adjusted to fit 50 mA at 3 MHz
Rogers’ Contact Current Perception Threshold (N=50)

Power function: Rogers perception threshold rms contact current measurements: Extrapolated by 3 MHz steps with power adjusted to fit 50 mA at 3 MHz
Rogers’ Contact Current Perception Threshold (N=50)

Power function: Rogers perception threshold rms contact current measurements: Extrapolated by 3 MHz steps with power adjusted to fit 50 mA at 3 MHz
 Restricted Expert Only Zone

- **New concept**: opens new zone of access within protected region
- Provides command flexibility with safety
- Restricted to highly trained EMF workers to carry out necessary activities under strict and explicit guidelines.
- Safety procedures are enhanced and expert is closely monitored.
- System specific expertise required
- **Unique to military; has rigorous safety programs**
- Developed by a civilian SDO
“...take appropriate steps to ensure that only workers who have received adequate instructions may have access to areas where there is serious and specific danger.”

NATO proposed “Restricted Expert Only (REO)” zone

- Supports the provision for a restricted zone for aware expert-trained workers, if a heightened safety program is initiated.

- Supports a zone of higher exposure levels
  - Increased safety procedures
  - Increased restrictions
    - Only highly trained workers with need for access to maintain operational integrity

### RMS induced and contact current limits for continuous sinusoidal waveforms: \( f = 100 \text{ kHz to 110 MHz} \)

*(Developed from Chatterjee et al., Dalziel and Mansfield, and Rogers)*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Unrestricted Zone 0 100 kHz – 3 MHz (mA)</th>
<th>Restricted Zone 0 3 MHz – 30 MHz (mA)</th>
<th>Unrestricted Zone 0 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 1 3 MHz – 30 MHz (mA)</th>
<th>Restricted expert only (REO) Zone 2 100 kHz – 30 MHz (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced, each foot</td>
<td>45</td>
<td>100</td>
<td>45</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp*</td>
<td>--</td>
<td>100</td>
<td>NA</td>
<td>100(f/3) 0.40 mA</td>
<td>250</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
<td>16.7(f/3) 0.36 mA</td>
<td>50(f/3) 0.36 capped at 100 mA§</td>
<td>NA</td>
</tr>
</tbody>
</table>

**NOTE 1**—Tabulated values are given as rms quantities.

**NOTE 2**—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

**NOTE 3**—For frequencies between 30 MHz and 110 MHz the numerical limit at 30 MHz shall apply.

**NOTE 4**—There are no values for grasp in unrestricted environment since the population will not have training.

**NOTE 5**—The averaging time for determination of compliance for induced current is 6 minutes (Restricted) and 30 minutes (Unrestricted). The averaging time for contact is 1.0 second.

**NOTE 6**—The ceiling values for induced (temporal peak values) are 500 mA for no more than 14.4 seconds per six minute period and 200 mA for no more than 10.4 seconds per 30 minute period for the upper tier Zone 1 (restricted) and the lower tier Zone 0 (unrestricted), respectively.

**NOTE 7**—Exclusion zones may be established using REO values only when mission essential and only when all personnel who may inadvertently contact parasitically charged surfaces are informed that such contact may produce discomfort including shock or heating which could become painful after 15-20 seconds with fingertip contacts. Grasp is the appropriate method of contact.

**NOTE 8**—Light “brush” contact may result in arcs and shock, burn even at 40 mA, and should be avoided especially with long objects such as cranes or cables.

**NOTE 9**—Touch contact current is capped at 100 mA as in STANAG 2345 (Ed 3); (100 mA from 20.6 to 30 MHz)

*a The grasping contact limit pertains to restricted environments where personnel are trained to make rapid grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.*
Thank you for your attention!

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Bioeffects Division
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210-539-8058
Rationale for Contact Current Limits at frequencies above 100 kHz

J. Patrick Reilly

Metatec Associates
12516 Davan Drive
Silver Spring, MD 20904

January 17, 2013
Table A: C95.1 Contact limits
(latest unpublished draft)

\[ f = 100 \text{ kHz to } 3 \text{ MHz} \]

<table>
<thead>
<tr>
<th>Condition</th>
<th>General public in unrestricted environs.\textsuperscript{a} (mA)</th>
<th>Persons permitted in restricted environs (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both feet</td>
<td>90</td>
<td>200</td>
</tr>
<tr>
<td>Each foot</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp\textsuperscript{b}</td>
<td>—</td>
<td>100</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
</tr>
</tbody>
</table>

Avg. time induced: 6 minutes restricted environ; 30 minutes unrestricted; 1 s contact current. Limits for \( f > 3 \text{ MHz} \) not defined, but are not less than value at 30 MHz.
### Proposed Military Standard, *Induced and contact current*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Unrestricted Zone 0 100 kHz – 3 MHz (mA)</th>
<th>Restricted Zone 1 100 kHz – 3 MHz (mA)</th>
<th>Unrestricted Zone 0 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 1 3 MHz – 30 MHz (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced, each foot</td>
<td>45</td>
<td>100</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp</td>
<td>--</td>
<td>100</td>
<td>--</td>
<td>100 $(f/3)^{0.12}$</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
<td>16.7$(f/3)^{0.12}$</td>
<td>50$(f/3)^{0.12}$</td>
</tr>
</tbody>
</table>

Averaging time: 6 min. induced current in restrict. environ.
30 min. induced current in unrestricted environ.
1 s for contact current (both restrict. & unrestricted.)
Contact Current, $f \geq 100 \text{ kHz}$

Experimental Studies

- **Chatterjee et al (1986)**
  - $f = 10 \text{ kHz} - 3 \text{ MHz}$
  - $n = 367$
  - Peer reviewed
  - * Perception & “pain”
  - * Touch & grasp

- **Dalziel & Mansfield (1959)**
  - $f = 60 \text{ Hz} - 200 \text{ kHz}$
  - $n = 147$
  - Peer reviewed
  - * Perception
  - * Touch & grasp

- **Rogers (1981)**
  - $f = 2 - 20 \text{ MHz}$
  - $n = 50$
  - Not peer reviewed
  - * Perception & “let-go”
  - * Touch (back of finger)
Perception and tolerance thresholds.

Finger contact on 25-mm\(^2\) plate

Adapted from Chatterjee et al., (1986);
Perception thresholds, Grasp Contact
[from Chatterjee et al., (1986)]
Statistical Distribution parameters

\( f = 100 \text{ kHz} - 3 \text{ MHz} \)

- Determine grasp pain mean, \( f = 200 \text{ kHz} - 3 \text{ MHz} \)
  - Touch pain/percept ratio = 1.25
  - Mean grasp perception \( I = 240 \text{ mA} \)
  - Mean grasp pain \( I = (1.25) (240) = 300 \text{ mA} \)
- Determine statistical distr., grasp & touch pain
  - Median \( \approx \) Mean
  - Med. touch pain = 45 mA; s.d./mean \( \approx 0.22 \)
  - Med. grasp pain = 300 mA; s.d./mean \( \approx 0.36 \)
  - Log-normal form (many experiments electrostim.)

(Data from Chatterjee)
Statistical distribution (Log Normal), touch pain thresholds, 100 kHz – 3 MHz
(data from Chatterjee, 1986)
Statistical distribution (Log Normal), Grasp pain thresholds, 100 kHz – 3 MHz
(data after Chatterjee, 1986)
Expected reaction percentiles using exposure limits in C95.1 and statistical distribution derived from Chatterjee’s data.

Using Contact limits $f = 100$ kHz – 3 MHz

<table>
<thead>
<tr>
<th>Zone</th>
<th>Contact</th>
<th>Limit (mA)</th>
<th>Pain response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Unrestricted zone)</td>
<td>Touch</td>
<td>16.7</td>
<td>&lt;&lt; 1</td>
</tr>
<tr>
<td></td>
<td>Grasp</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1 (Restricted zone)</td>
<td>Touch</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Grasp</td>
<td>100</td>
<td>0.5</td>
</tr>
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</table>
Touch perception vs. frequency:
Chatterjee, Dalziel, Rogers

![Graph showing touch perception vs. frequency.](https://via.placeholder.com/150)

```
<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Threshold Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>10.0</td>
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<tr>
<td>100.0</td>
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</tr>
</tbody>
</table>
```

Courtesy Rob Kavet
Grasp perception vs. frequency: Chatterjee, Dalziel

![Graph showing the relationship between threshold current (mA) and frequency (MHz).](image)

Threshold Current (mA) vs. Frequency (MHz)

- **Chat Grasp/M&F**
- **D&M grasp**

Grasp perception

Courtesy Rob Kavet
**Touch pain/let-go vs. frequency:**

Chatterjee, Rogers

![Graph showing the relationship between threshold current and frequency for touch pain/let-go.

- **Red line:** Chat Pain/M&F
- **Turquoise line:** Rogers "Let-Go"

**Axes:**
- **Y-axis:** Threshold current (mA)
- **X-axis:** Frequency (MHz)

**Legend:**
- **Touch pain/let-go**

*Courtesy Rob Kavet*
Power law fit to Rogers’ Data
\[ f = 2 \text{ – } 20 \text{ MHz} \]

- Power law fit to Rogers data
  \[ I = k f^a \]

- Least squares fit \((I = mA; f = MHz)\)
  \[ a = 0.29, \ k = 44 \] (perception)
  \[ a = 0.15, \ k = 135 \] (let-go)
  previously: \( a = 0.37 \) (perception)
  \[ a = 0.12 \] (let-go)

- Theory: Expect threshold increase in MHz regime
  - Unknown slope and freq. where slope starts
  - Perception & pain ought to track (constant multiple)
# BJK Proposed Limits

<table>
<thead>
<tr>
<th>Condition</th>
<th>Unrestricted Zone 0 100 kHz – 3 MHz (mA)</th>
<th>Restricted Zone 1 100 kHz – 3 MHz (mA)</th>
<th>Unrestricted Zone 0 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 1 3 MHz – 30 MHz (mA)</th>
<th>Restricted Zone 2 100 kHz– 30 MHz (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced, each foot</td>
<td>45</td>
<td>100</td>
<td>45</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Contact, grasp</td>
<td>NA</td>
<td>100</td>
<td>NA</td>
<td>100 $(f/3)^{0.12}$ 100 $(f/3)^{0.40}$</td>
<td>250</td>
</tr>
<tr>
<td>Contact, touch</td>
<td>16.7</td>
<td>50</td>
<td>16.7$(f/3)^{0.12}$ 16.7$(f/3)^{0.36}$</td>
<td>50$(f/3)^{0.12}$ 50$(f/3)^{0.36}$</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Red font**: Proposed by BJK, Dec. 4, 2012
Alternatives to Contact
Current Limits

Use Chatterjee up to 3 MHz; for $f > 3$ MHz state (In order of most to least conservative):

- “Thresholds are not less than those at 3 MHz, but are otherwise undefined.”
- “Above 3 MHz use power law $I = k f^a$ with $a = 0.15$.” (equivalent to Rogers’ “let-go” results)
- “Above 3 MHz use power law $I = k f^a$ with $a = 0.29$.” (equivalent to Rogers’ “perception” results)
Contact current @ 30 MHz by scaling 3 MHz value using \( I = k f^a \)

<table>
<thead>
<tr>
<th>Exponent (a)</th>
<th>Zone 0 (Unrestricted)</th>
<th>Zone 1 (Restricted)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Touch limit (mA)</td>
<td>Grasp limit (mA)</td>
</tr>
<tr>
<td>0</td>
<td>16.7</td>
<td>NA</td>
</tr>
<tr>
<td>0.12</td>
<td>22.0</td>
<td>NA</td>
</tr>
<tr>
<td>0.15</td>
<td>23.6</td>
<td>NA</td>
</tr>
<tr>
<td>0.29</td>
<td>32.6</td>
<td>NA</td>
</tr>
<tr>
<td>0.37</td>
<td>39.1</td>
<td>NA</td>
</tr>
</tbody>
</table>
Averaging time

- C95.1: $t_a = 6$ min upper tier; 30 min. lower
  - Allowed for induced current.
  - Would allow 10x spec. values for 10% duty fact.
    or 100x spec. values for 1% duty fact., etc.
- Shorter avg. time (1 s) is justified for contact current
Rationale for shorter avg. time for contact current

- Chatterjee:
  - Tapping threshold ≈ 90% of continuous contact threshold.
  - @ f > 100 kHz, perception threshold → pain if contact time ~ 10 – 20 s

- Dalziel::
  - Tapping threshold ≈ touch @ 1 – 2 per sec.
    (apparent @ 0.5, 50, and 99.5 percentiles)
Avg. time for induced vs. touch current:

Heat dissipation mechanisms

Cutaneous: low conductivity corneum; heat dissipation via sweating.

Deeper tissue: higher conductivity, heat dissipation via thermo-vascular mechanisms.
Theoretical basis for temperature increase

\[ \Delta T = \frac{J^2 \rho t}{\rho c} = \frac{J^2 t}{\sigma \rho c} \]

\( \Delta T \) = temp. rise (K),
\( J \) = current density (A/cm²),
\( \rho \) = tissue resistivity (Ω cm)
\( \sigma \) = tissue conductivity (S/m)
\( t \) = duration of current,
\( \rho \) = tissue density (g/cm³)
\( c \) = specific heat of tissue (J/g K)
Frequency variation of complex permittivity typical of soft tissue

\[ \varepsilon_r = \text{relative dielectric permittivity}; \]
\[ \sigma = \text{conductivity} \]
Ric’s One-Evening RF Burn Experiment
A Measure of Pain Temperatures

Figure taken from (Dewhirst et al., 2003, Figure 3a).

R Tell (1-7-2013)
The Burn Electrode Made from a Copper Conduit Strap

Transfer impedance was determined for each frequency prior to experiment.

1 cm² surface area
RF Drive from the Transceiver was Increased Quickly to Reach the Pain Level
Some Observations and Insights from My One Evening Experiment

- For such a crude set up, the only practical measure was the current that I could not stand to touch, super hot. I raised the current fairly quickly to reach this point.
- I tested on 1.9, 3.51, 7.05, 14.01, 18.096, 21.05 and 24.906 MHz
- Very roughly, my results indicated that at 1.9 MHz, about 140 mA was my quick-time pain threshold.
- This quick-time pain threshold stayed roughly the same as frequency was increased but was about 180 mA at the highest frequency, about a 30% increase.
- 50 mA through 1 cm² does nothing, no problem, for any duration.
- Contact resistance seems to be critical to obtaining more stable and higher current thresholds. Dry contact with the electrode hurt more for a given current. I used salt water to wet the skin and this made a significant difference.
- The physical nature of the electrode may play an important role in determining these heating thresholds.

R Tell (1-7-2013)
The Edge Effect of Electrodes
AKA: The “perimetrelical” burn problem in electrosurgery

For circular disc electrodes, the effect manifests as a higher current density around the perimeter of the disc with a relatively low current density in the center.

For a square-shaped electrode there is typically a high current density around the entire perimeter, and an even higher current density at the corners.

R Tell (1-7-2013)
Analysis and Control of the Current Distribution under Circular Dispersive Electrodes

J. D. WILEY AND J. G. WEBSTER

Fig. 3. Normalized current density as a function of radius for the electrode shown in Fig. 1 [see (15) and associated discussion].

IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. BME-29, NO. 5, MAY 1982

R Tell (1-7-2013)
Estimation of current density distribution under electrodes for external defibrillation
Vessela Tz Krasteva and Sava P Papazov

Consider for use of electrodes that are smaller in area than the tissue surface upon which they are being placed.

R Tell (1-7-2013)
A Microwave Irradiation Chamber for Scientific Studies on Agricultural Products


Fig. 1. Geometry of the waveguide and post.

Fig. 8. Comparison of center and off-center temperature rise of plaster of Paris post due to microwave irradiation.

Heating of a dielectric post in the center of a waveguide – equivalent to an electrode that is larger than the tissue contact area.

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, MAY 1977

R Tell (1-7-2013)
The Rogers Electrode for Measuring Perception and Pain Thresholds.

When viewed in terms of the raw currents, ~50 vs 300 mA (Rogers corrected for back to front of finger), the values appear to be gigantically different!

Hypothetical assumption:
To elicit same pain response, local current density is the same.

\[ J_c = \sim 50 \text{ mA/25 mm}^2 = 2 \text{ mA/mm}^2 \ (3 \text{ MHz}) \]
\[ J_r = \sim 300 \text{ mA/113 mm}^2 = 2.65 \text{ mA/mm}^2 \ (2 \text{ MHz}) \]

Hence, “average” J is “about” the same. Different spatial distribution of current density in the skin could account for differences.
Average human fingertip size is about 64 – 100 square millimeters (8 – 10 mm wide); the pad of the finger, which most people touch with, is 100 – 196 square millimeters ([Ubuntu Designing for Finger UIs](https://ubuntu.com)).
Food for Thought

Chatterjee:
Local current density, not average, for pain to front of finger around perimeter of a 25 mm² electrode could be closer to 25 mA/3.75 mm² = 6.7 mA/mm². [50% of current through 15% of contact area]

Rogers:
Local current density at 2 MHz for threshold for pain to front of finger (2X back of finger) could be order of 300 mA/113 mm² = 2.65 mA/mm². This could suggest that Rogers’ thresholds are actually lower than Chatterjee after adjustment for concentrating effect of current density at perimeter of electrode.

On the other hand, I can’t explain the Chatterjee observation of only a 50% increase in current required for pain with a 5.76 fold increase in electrode area.

R Tell (1-7-2013)
Some Preliminary Insights to Contact Currents Based Largely on the One Evening RF Burn Experiment

- Threshold pain current increases slightly with increasing frequency from 1.9 to 24.9 MHz, by about 30%

- Rogers data indicates about a 40% increase over this range.

- Contact area and, possibly, electrode type play an important role in determining the current threshold for pain...and perception.

- Further insight is needed to examine the differences in tissue current densities for the two different electrode configurations. Simple average current densities for electrode areas may not be the relevant factor for sensation of heating. Just taking raw currents from different papers as thresholds may not be appropriate.

R Tell (1-7-2013)
The More Important Form of RF Burns: Arcs

Finger Ridges are the First Target of Mild Arcing

R Tell (1-7-2013)
Experimental Setup to Investigate RF Arcs
Initial Work to Examine Arcing Voltages

Arcing to stillborn piglet skin

Varying degrees of RF burns based on duration of current and whether an arc was produced. EPRI report.

Contact RF burn made by cylindrical electrode

SKIN BURNS: NUMERICAL MODEL STUDY OF RADIO FREQUENCY CURRENT SOURCES, John A. Pearce and Jonathan W. Valvano, Proceedings of the ASME 2009 Summer Bioengineering Conference (SBC2009) June 17-21, Resort at Squaw Creek, Lake Tahoe, CA, USA
Some Marks of an RF Burn

A: 10 sec, no arc
B: 10 sec with arc
C: 1 sec with arc

D: 10 sec, no arc
E: 10 sec with arc
F: 1 sec with arc

G: 10 sec, no arc
H: 10 sec with arc
I: 1 sec with arc

J, K, L, M, N
Produced by multiple contacts with skin (no visible marks at 1 W)

R Tell (1-7-2013)
Evaluation of Potential Current Measurement Error in Chatterjee Paper

RF Current Measurement Error for the Fluke 85RF Probe at Low Currents

- Minimal error for currents > 40 mA
- Probe reads low for currents << 40 mA
An Unsolicited Advertisement

Warning: Too heavy to carry on my trip!

R Tell (1-7-2013)
The primary purpose of the IEEE (Institute of Electrical and Electronics Engineers) database (ieee-emf.com/) is to provide a comprehensive database of the world’s English language literature on radiofrequency (RF) energy to support the review and revision, if needed, of RF safety standards published by IEEE. The goal is to identify all peer-reviewed research papers and other relevant reports such as peer-reviewed review articles and letters to journal editors. In March 2011, the database had over 5000 references of which over 3200 are research papers. Each entry has a brief description of the experimental approach/model and results; in addition, many of the research papers have a link to abstracts in PubMed. The database can be searched by a number of ways (author, study type, key word, year, frequency range, etc.). The core of the database is available without charge to the public; however, members of IEEE ICES (International Committee on Electromagnetic Safety) who are writing reviews of specific research areas have access to a password-protected area to support their work.”
In 2011:

New citations: 142

PDF files added: 529

In 2012 (Jan 1 – May 30):

New citations: 50

PDF files added: 213
REGULATION OF RF EXPOSURE IN THE U.S.A.

ROBERT D. WELLER

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF ENGINEERING & TECHNOLOGY
WASHINGTON, DC USA
Agenda

• RF Exposure Regulation in the U.S.A.
• Status of FCC Docket ET-03-137
• Precaution and individual choice
• Summary
RFR Regulation in the U.S.A.

- FCC establishes and enforces RF exposure limits from regulated facilities and equipment, but FCC is not a health agency.

- U.S. Health and Safety agencies are responsible for monitoring research and advising FCC on appropriate safety limits. FCC has regular meetings with experts from:
  - EPA
  - FDA
  - NIH
  - NIOSH
  - OSHA

Radiofrequency Interagency Work Group

Environmental Protection Agency
Federal Communications Commission
Food and Drug Administration
National Telecommunications and Information Administration
National Institutes of Health
National Institute of Occupational Safety and Health
Occupational Safety and Health Administration

Charter

The Radiofrequency Interagency Work Group (RFIAWG) is composed of Federal agencies which have regulatory or public health responsibility to evaluate or control the risk to public health from the use of specific devices or exposure to radiofrequency energy, or have responsibility for regulation and management of the use of the radiofrequency spectrum.

The purpose of the Radiofrequency Interagency Work Group is to provide a forum to discuss public health and regulatory issues pertaining to radiofrequency radiation, and to provide a basis for technical and policy coordination among member agencies in their approach to human exposure to radiofrequency energy. The RFIAWG may address the development of non-ionizing electromagnetic radiation exposure standards, guidance or guidelines to better understand the implications of exposure on human health and the environment, and prudent use of specific devices or technologies. The RFIAWG provides a forum for discussion of specific RF radiation-related activities and policies of the member Agencies that could affect other federal agencies represented in the Group. The Work Group also provides a forum to discuss developing issues, research, and to address the need for long-range federal strategy. It is intended that such coordination and discussion will lead to a more coordinated federal approach to potential health issues associated with existing and proposed technologies which use and produce human exposure to RF energy.

The RFIAWG was originally established by formal invitation to executives of the...
URLs Regarding EMF/Health

- U.S. National Regulatory Agencies
  - (FCC) http://transition.fcc.gov/oet/ea/presentations/files/apr12/5.-Apr-12-RF-Exposure-KC.pdf
  - (FCC) http://www.fcc.gov/oet/rfsafety
  - (EPA) http://radiation.supportportal.com/link/portal/23002/23013/ArticleFolder/1518/Non-Ionizing-Radiation
URLs Regarding EMF/Health

- U.S. National Institutes
  - (NIOSH) http://www.cdc.gov/niosh/topics/emf
  - (NIEHS) http://www.niehs.nih.gov/health/topics/agents/emf/
  - (NCI) http://www.cancer.gov/cancertopics/factsheet/Risk/cellphones
  - (NTP) http://ntp.niehs.nih.gov/?objectid=B8993D85-EC1C-2703-B87EFB95AB26F099
History of RFR at FCC

- First exposure limits adopted 1985 (IEEE C95.1-1982, a one-tier standard)

- Current exposure limits adopted 1996
  - IEEE C95.1-1991 for SAR
  - NCRP Report #86 for MPE / fixed stations
  - both two-tier standards

- Standards adopted primarily on advice of U.S. FDA, EPA, and other Federal health and safety agencies.
ICNIRP vs. NCRP

NCRP Limits similar, but not identical, to ICNIRP.

Power Density, W/m²

Occurred 0

Public

FCC/NCRP

Occupational

Public

10^7

10^6

10^5

10^4

10^3

10^2

10^1

0.1 1 10 100 10^4 10^5 10^6

Frequency, MHz

Approved Minutes – 17 January 2013 TC95 SC3/SC4 Meeting

ATTACHMENT 10
ICNIRP / IEEE C95.1-1991

- FCC/IEEE-1991 SAR limits similar, but not identical to, ICNIRP.

- 1.6 W/kg SAR, 1-gram averaging mass (cube shape)

- 2.0 W/kg SAR, 10-gram averaging mass (contiguous)

- Differences represent a difference in power of about 2 at 900 MHz and 2.4 at 1,900 MHz.

[Source: IEEE Std 1528-2003, Table 7]
Current Issues: Precautionary Measures

• Most public concern is associated with exposures from base stations, where exposures are typically a small fraction of MPE limit.

• Present limits are science-based consensus standards; there are no such precautionary limits

• FCC must “provide a proper balance between the need to protect the public and workers from exposure to potentially harmful RF electromagnetic fields and the requirement that industry be allowed to provide telecommunications services to the public in the most efficient and practical manner possible”

Current Issues: Precautionary Measures

• Present standard recognizes that “…a response to RF radiation may have a ‘thermal basis, an athermal basis, or a combined basis,’ and that a ‘determination of which of these three classes of causation is operative in a given context rests upon appropriate experimentation and inference, not presumption.’”

• “…there is ample evidence that athermal interactions in biological material are not only possible but have been demonstrated for fields both strong and weak.”

• Part of the rationale for establishing more restrictive limits for exposure of the public is to provide protection from mechanisms for which there is inadequate knowledge about vulnerabilities in the population at-large.

Source: NCRP Report No. 86 (1986)
Current Issues: Precautionary Measures

- **Individual Choice**
  For users who are concerned with the adequacy of the FCC's RF exposure standard or who otherwise wish to further reduce their exposure, the most effective means to reduce exposure are to hold the cell phone away from the head or body and to use a speakerphone or hands-free accessory. These measures will generally have much more impact on RF energy absorption than the small difference in SAR between individual cell phones, which, in any event, is an unreliable comparison of RF exposure to consumers, given the variables of individual use.
Global Coordination of RF Communications on Research and Health Policy
RESEARCH NEEDS AND ACTIVITIES FOR COMPLIANCE ASSESSMENT

ROBERT D. WELLER

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF ENGINEERING & TECHNOLOGY
WASHINGTON, DC USA
AGENDA

• Status of NTP Studies
• Status of Inquiry on RF Exposure Limits
• Research needs for compliance procedures
NTP Overall Study Design

- Exposure to RFR in reverberation chambers
  - Intermittent exposure (10 min on / 10 min off) for 18.3 hours/day
- Frequencies and modulations
  - 900 MHz, GSM & CDMA modulated signals – Rats
  - 1900 MHz, GSM & CDMA modulated signals – Mice
- Three phases of study:
  - Thermal pilot, subchronic, and chronic studies
- Power levels
  - Thermal pilot studies at SAR of 4–12 W/kg
  - Subchronic studies at 3, 6, 9 W/kg in rats, and 5, 10, 15 W/kg in mice
  - Chronic studies based on results from subchronic studies
**Chronic Toxicology and Carcinogenicity Studies**

- Male and female Sprague-Dawley rats and B6C3F1 mice
  - Perinatal exposure in rats (from GD-6) with litters reduced to 4 males and 4 females at weaning
  - Exposures in mice beginning at 5 weeks of age
  - 18.3 hours intermittent (10 min on/off) exposure/day, 7 days/week
  - SARs selected after evaluation of subchronic data
  - Maximum SAR for mice limited by power output of system
  - Interim time point at 19 weeks (n = 15) and study termination at 110 weeks of age (n = 90)
NTP Update

2-yr studies underway. Evaluating subchronic data in pathology review.
Inquiry on RF Exposure Limits

“Reassessment of Federal Communications Commission Radiofrequency Exposure Limits and Policies” may seek comment on whether:

- FCC exposure limits are too restrictive or not restrictive enough
- information provided to consumers is adequate
- measurement protocols adequately reflect actual use conditions
RESEARCH NEEDS FOR COMPLIANCE

• Current FCC test procedures and policies in KDB
  - See e.g.:

• Interim test guidance generally case-by-case through KDB inquiries, usually with TCB/Test Lab coordination

• New guidance documents added frequently
Research Needs for Compliance (Devices)

- Wireless Power Transfer
  - Qi/WPC (Wireless Power Consortium)
  - CEA (Consumer Electronics Association)
  - A4WP (Association for Wireless Power)
  - Various automobile manufacturers
- MIMO
RESEARCH NEEDS FOR COMPLIANCE

- SAR evaluation of base station antennas
- Broadband liquids / Thermally stable liquids
- Validation of computational EM software
  - Use and parameter guidelines
Update on RF Regulatory Policies in the U.S.A.

Robert D. Weller
Federal Communications Commission
Office of Engineering & Technology
Washington, DC  USA
AGENDA

• GAO Report

• Status of Docket ET-03-137
TELECOMMUNICATIONS

Exposure and Testing Requirements for Mobile Phones Should Be Reassessed

United States Government Accountability Office

Report to Congressional Requesters

July 2012
“Scientific research to date has not demonstrated adverse human health effects from RF energy exposure from mobile phone use, but additional research may increase understanding of possible effects.”
GAO Report: Science

• Reviewed Epidemiological and Laboratory studies:
  - “...epidemiological research has not demonstrated adverse health effects from RF energy exposure from mobile phone use, but the research is not conclusive. ... Limitations associated with epidemiological studies can make it difficult to draw definitive conclusions about whether adverse health effects are linked to RF energy exposure from mobile phone use.”
  - “Studies we reviewed suggested and experts we interviewed stated that laboratory research has not demonstrated adverse human health effects from RF energy exposure from mobile phone use, but the research is not conclusive because findings from some studies have observed effects on test subjects. ... Limitations associated with laboratory studies can make it difficult to draw conclusions about adverse human health effects from RF energy exposure from mobile phone use.”
### Table 1: Ongoing NIH-Funded Studies on Health Effects of RF Energy Exposure from Mobile Phone Use

<table>
<thead>
<tr>
<th>Description</th>
<th>NIH institute funding the study</th>
<th>Total NIH funding</th>
<th>Estimated year of completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examining environmental and genetic factors for meningioma, a type of brain tumor, at research sites in five states</td>
<td>National Cancer Institute</td>
<td>$8,779,998</td>
<td>2012</td>
</tr>
<tr>
<td>Evaluating brain cancer incidence trends in the United States using cancer registry data to determine if trends are consistent with reported epidemiological associations of mobile phone use and certain types of cancer</td>
<td>National Cancer Institute</td>
<td>Not applicable a</td>
<td>Not applicable a</td>
</tr>
<tr>
<td>Examining effects of mobile phones on brain glucose</td>
<td>National Institute on Alcohol Abuse and Alcoholism</td>
<td>$595,700</td>
<td>2012</td>
</tr>
<tr>
<td>Examining effects of exposure to mobile phones in childhood on the central nervous system using children in the Danish National Birth Cohort</td>
<td>National Institute of Environmental Health Sciences</td>
<td>$423,500</td>
<td>2012</td>
</tr>
<tr>
<td>Examining toxicity and carcinogenic effects of RF energy in laboratory animals as part of the National Toxicology Program</td>
<td>National Institute of Environmental Health Sciences</td>
<td>$25,600,000</td>
<td>2015</td>
</tr>
</tbody>
</table>
GAO: FUTURE RESEARCH

• Additional research needs to increase understanding:
  - long-term prospective cohort (epi) studies
  - case-control (epi) studies on children
  - non-thermal cell (lab) studies
  - human volunteer studies “examining the effect of changes in the neurological system, which could help determine if these possible observed changes in neurological functioning from RF energy are adverse effects.”
  - re-evaluation of existing studies to determine whether additional research in certain areas is warranted.
GAO: Exposure Limits

- "FCC’s RF Energy Exposure Limit May Not Reflect Latest Evidence on Thermal Effects, and Mobile Phone Testing Requirements May Not Identify Maximum Exposure"
  - IEEE/ICES advocated adopting its standard [or INCIRP] as incorporating “improved RF energy research and a better understanding of the thermal effects"
  - Consumer groups advocating not adopting ICES or ICNIRP “because of the relative uncertainty of scientific research on adverse health effects from mobile phone use.”

- Reassessment of exposure limits underway
  - Notice of Inquiry pending before FCC
• “... testing procedures may not identify the maximum SAR for the body, since some consumers use mobile phones with only a slight distance, or no distance, between the device and the body, such as placing the phone in a pocket while using an ear piece. Using a mobile phone in this manner could result in RF energy exposure above the maximum body-worn SAR determined during testing, although that may not necessarily be in excess of the FCC’s limit.”

• Reassessment of body-worn procedures underway
  - FCC already reducing permissible spacing (to 5 mm in some cases) for some equipment classes
  - Notice of Inquiry pending before FCC
**STATUS OF 03-137**

- Awaiting vote by FCC Commissioners
- Three-part document
  - Order, adopting final rules
  - Further Notice, proposing new rules
  - Inquiry, asking questions
- Timing unrelated to GAO Report or IARC Monograph
- Concludes, in part, work begun in 2003
- Reviews and updates some material from 2003
- Considers whether FCC should update its exposure limits
  - Open-minded; no predetermined ideas on what limits should be
  - Explores all exposure metrics in existing standards.
### Current Issues:
**Consistent Exclusions from Routine Evaluation**

<table>
<thead>
<tr>
<th>Transmitter Frequency, MHz</th>
<th>Threshold ERP, Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 – 1.34</td>
<td>ERP ≥ 1,920 R²</td>
</tr>
<tr>
<td>1.34 – 30</td>
<td>ERP ≥ 3,450 R²/f²</td>
</tr>
<tr>
<td>30 – 300</td>
<td>ERP ≥ 3.83 R²</td>
</tr>
<tr>
<td>300 – 1,500</td>
<td>ERP ≥ 0.0128 R²f</td>
</tr>
<tr>
<td>1,500 – 100,000</td>
<td>ERP ≥ 19.2 R²</td>
</tr>
</tbody>
</table>

Regardless of ERP, evaluation is required if the separation distance, R, is less than $\lambda/2\pi$, where $\lambda$ is the free-space operating wavelength, unless the maximum available time-averaged power is less than one milliwatt. Evaluation is required if the ERP in watts is greater than the value given by the formula below for the appropriate frequency, f, in MHz at the separation distance, R, in meters.

Based on general population maximum permissible exposure limits with a single perfect reflection, outside of the reactive near-field, and in the main beam of the radiator, to be compared with the maximum time-averaged effective radiated power.
Current Issues:
Low-Frequency Exclusions from Routine Evaluation

Approximate SAR test exclusion power thresholds at selected frequencies and test separation distances are illustrated in the following table.

<table>
<thead>
<tr>
<th>MHz</th>
<th>&lt; 50</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
<th>160</th>
<th>170</th>
<th>180</th>
<th>190</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>237</td>
<td>474</td>
<td>481</td>
<td>487</td>
<td>494</td>
<td>501</td>
<td>507</td>
<td>514</td>
<td>521</td>
<td>527</td>
<td>534</td>
<td>541</td>
<td>547</td>
<td>554</td>
<td>561</td>
<td>567</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>308</td>
<td>617</td>
<td>625</td>
<td>634</td>
<td>643</td>
<td>651</td>
<td>660</td>
<td>669</td>
<td>677</td>
<td>686</td>
<td>695</td>
<td>703</td>
<td>712</td>
<td>721</td>
<td>729</td>
<td>738</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>474</td>
<td>948</td>
<td>961</td>
<td>975</td>
<td>988</td>
<td>1001</td>
<td>1015</td>
<td>1028</td>
<td>1041</td>
<td>1055</td>
<td>1068</td>
<td>1081</td>
<td>1095</td>
<td>1108</td>
<td>1121</td>
<td>1135</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>711</td>
<td>1422</td>
<td>1442</td>
<td>1462</td>
<td>1482</td>
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<td>1522</td>
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"Devices that are designed to operate on the body of users using lanyards and straps, or without requiring additional body-worn accessories, must be tested for SAR compliance using a conservative minimum test separation distance $\leq 5$ mm to support compliance."

Source: FCC/KDB 447498 27 D01 General RF Exposure Guidance
Global Coordination of RF Communications on Research and Health Policy