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An Evaluation of the Radiofrequency Environment at the World Trade Center North Tower

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by

Richard A. Tell
Richard Tell Associates, Inc.

[illegible] Canyon Lane Las Vegas, NV 89129

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Summary

During June 6-9, 1997, a comprehensive survey of radiofrequency (RF) fields was accomplished on the north tower of the World Trade Center (WTC) to evaluate the magnitude and distribution of RF fields resulting from the many broadcast and wireless telecommunications transmitting facilities located at the WTC. A total of nine television (TV) stations and four FM radio broadcast stations operate from the WTC antenna facility on the north tower. In addition, some 83 wireless telecommunications antennas are located on the roof of the WTC for paging and specialized mobile radio services. Recent action by the Federal Communications Commission (FCC) to adopt new, more stringent rules related to Maximum Permissible Exposure (MPE) limits for RF fields has heightened interest by most FCC licensees in re-evaluating their facilities for compliance with the new rules which are proposed to become effective later in 1997. In light of the new federal regulations, and because of the large number of wireless telecommunications antennas located at a major broadcast transmitter site, it was deemed necessary to perform an in-depth evaluation of the existing RF environment at the WTC.

The study was designed to incorporate both direct measurements of the ambient broadcast fields and theoretical analysis of fields that could be produced by the many wireless telecommunications antennas. Theoretical modeling of wireless antenna fields permitted an evaluation that included the maximum possible RF field levels that might exist on the WTC roof since direct measurements of the wireless communications fields are fraught with uncertainty associated with their intermittent activity.

Coordination for the study was accomplished by interaction between Motorola, the broadcast community at the WTC represented by Mr. Jim Baker, Chairman of the TV Broadcasters All Industry Committee, and Mr. Jules Cohen, P.E., consultant to the All Industry Committee. Arrangements were made by Motorola to shut down operation of all of the roof-mounted wireless communications antennas except for 17 antennas used as 72 MHz paging links. The transmitters used with these paging link systems were, however, arranged to be operating continuously during the entire roof survey period to avoid variability in measured field values due to intermittent operation. Measurements were performed for three different conditions: (1) normal broadcasting operations, (2) the tower maintenance mode of operation normally used when access to the antenna mast on the roof is required from time-to-time and (3) an emergency, backup mode of operation, in which all stations operated in such a manner with auxiliary antennas that the maximum possible RF field levels would be found on the roof. While the emergency, backup mode of operation was acknowledged as an extremely rare and very unlikely scenario, it was included in this study for reference purposes and in the interest of completeness.

Field measurements were performed using broadband, isotropic field probes designed to provide an output that is weighted according to the frequency variation of the FCC rules for human exposure. By making use of a built in capability of the digital meters used with the probes, direct measures of the spatially averaged RF field levels, obtained over a height ranging from the roof surface to six feet above the roof, were possible, thereby allowing direct comparison with the FCC limits. An initial evaluation period in the afternoon of June 6 was followed by two nights of detailed measurements on the roof during June 7 and 8. Measurements at night were necessary to accommodate the concerns of the many wireless communications companies about disruption of service during periods of maximum message traffic.

While five measurement teams, consisting of Motorola and broadcast facilities personnel, collected data under the three defined conditions above, measurement data were entered into a software package designed for computing RF fields produced by wireless communications antennas. The program was modified to allow for display of the data in the form of colorized roof maps that portrayed the distribution and intensity of the measured fields. Subsequently, detailed analysis of RF fields that would be expected from the wireless antennas was performed to obtain estimates of the composite RF fields that would result with all antennas active. These results are summarized in Table 8 and show the maximum percentage of the MPE determined on the roof for each condition evaluated and the percentage of the roof area subject to fields less than 20% of the controlled exposure MPE, in the range of 21-50% of the MPE, 51-100% of the MPE and greater than 100% of the MPE. Several alternative scenarios were evaluated through the use of the RF analysis software including the effect of activating all of the present wireless antennas and raising the antenna mounting heights.

As can be seen from Table 8, the maximum RF fields expected on the north tower WTC roof range from about 57% of the controlled exposure MPE to 373% of the MPE, depending on the operational scenario. The contribution by the broadcast stations was found to be nominally 57% to 135% of the MPE without any contribution from the wireless antennas, although under normal broadcast conditions, no areas were found that exceeded the MPE for controlled exposures. Strong fields in the close vicinity of many of the wireless communications antennas mounted close to the roof surface are responsible for increasing the likelihood that the composite fields on the roof might exceed the FCC limits.

Based on the results of this study, it is clearly apparent that RF fields on the WTC north tower roof exceed the more stringent general public, or uncontrolled exposure, MPE contained in the new FCC rules, even under the best of the several scenarios studied. Under the combined action of both the broadcast stations and the wireless communications facilities, it is expected that RF fields will also exceed the more permissive controlled exposure MPEs set for workers with up to 27% of the roof being subject to such fields for the emergency backup condition. These results demonstrate that the roof should be designated as a controlled exposure area and that appropriate signage be installed at the site to inform individuals accessing the roof of the presence of strong

RF fields that could exceed general public, and worker limits, in some cases. It is my opinion that without the installation of appropriate signs, the roof area cannot be declared as complying with the new FCC rules for RF exposures. The present situation of no signage relative to RF fields must be corrected.

Beyond posting of the site, the development and implementation of an RF safety program should be considered for workers who have access to the roof. The safety program should contain site specific procedures related to work on the roof to insure compliance with the FCC rules. For example, areas that should be avoided could be identified on the roof and declared in the written program materials that would be provided to roof workers. All individuals who have access to the roof should be required to be presented with the RF safety program materials so that there is no question about them being informed of the presence of RF fields on the roof and appropriate procedures for reducing their exposure to help maintain compliance with FCC rules at the site.

Alternative methods for complying with the FCC rules include engineering changes such as increasing the mounting elevation of the wireless communications antennas and the use of RF protective clothing. The relatively dramatic effect of raising antennas on the composite RF fields on the roof is seen in Table 8 and associated roof maps in this report. In lieu of engineering modifications, the roof could represent an excellent site for the use of protective garments for controlling worker exposure.

Background

All FCC licensees are required to comply with rules related to Maximum Permissible Exposure (MPE) to RF fields. This requirement has existed since January of 1986, when the FCC first adopted RF exposure rules. In August of 1996, the FCC once again adopted updated rules on RF exposures that were more stringent than those previously used. These new rules, in contrast to the earlier ones, placed new requirements on most of the wireless telecommunications industry by requiring engineering evaluations of transmitting systems meeting certain criteria such as effective radiated power and antenna mounting height. After October 15, 1997, affected licensees will be required to evaluate and bring their antenna sites into compliance with the new rules. Motorola, in its role as site manager for telecommunications (non-broadcast) facilities at the north tower at the WTC, is presently responsible for the operation of 83 antennas located on or near the roof level of the north tower. These antennas, in some cases, have the potential for producing strong RF fields in their vicinity and, hence, particular care must be used during work activities near the antennas to insure compliance with the applicable MPE limits imposed by the FCC. The RF fields produced by the telecommunications antennas are additive, of course, and, hence, any ambient RF fields produced by the broadcasting facilities on the WTC north tower will increase the background level of RF energy to which personnel working on the roof may be exposed. Motorola is committed to evaluating the roof RF environment in sufficient detail to permit an accurate assessment of compliance with the FCC rules and to implement any necessary engineering, work practices or personal protective equipment (PPE) controls to insure compliance. It is in this context that the subject study was performed.

A number of past studies performed at the WTC have investigated the magnitude of RF fields on the north tower roof. However, in the interest of creating a relatively high resolution map of ambient RF fields, and to insure that sufficient data were obtained on the RF fields associated with the many wireless antennas, the study documented here was performed.

Introduction and Study Objectives

This report documents the design, execution, results and conclusions of a major study of RF fields atop the roof of the north tower of the WTC. Several objectives of the study were envisioned:

Because of the high concentration of RF transmitting facilities located at the WTC, it has been of interest to Motorola to perform a current assessment of the existing RF field environment from the perspective of evaluating compliance with applicable rules on RF exposure adopted by the Federal Communications Commission (FCC). One objective of this study was, then, to perform a detailed survey of the existing RF fields produced by the broadcast facilities at the WTC so that additional work to assess RF fields produced by the many telecommunications antennas could be put in perspective relative to FCC rules.

A second objective was to analyze the RF fields that would be associated with full-time operation of the telecommunications antennas, exclusive of the contribution to RF fields from the broadcast facilities as well as in combination with the broadcast fields. Again, the results would be scrutinized from the point of view of compliance with FCC RF rules.

A third objective was to examine the results of the measurements and analyses to identify practical engineering approaches to mitigating excessive RF fields, if they should exist, and appropriate site specific work practices for minimizing personnel exposure.

This study was not directed to the issue of RF fields that exist on the structure of the antenna mast or inside the mast. The outer surface of the antenna mast can be accessed by various platforms and ladders near the bottom of the mast. At the upper level of the climbing structure, personnel can come into very close proxmity of some of the auxiliary antennas mounted on the mast. While the exposure that individuals might encounter when working on this structure during tower maintenance mode was not evaluated in this study, care should be used in examining this area to avoid RF exposure in excess of the standard.

Description of the World Trade Center Transmitting Facilities

The north WTC tower is home to nine TV stations and four FM radio stations. Antennas are supported by a central antenna support structure that extends 351.5 feet above the roof. Figure 1 illustrates the configuration of the antenna mast showing the location of the main antennas as well as various auxiliary antennas that are used during tower work or as emergency backup antennas during temporary failures associated with the main antennas for some stations. Table 1 lists the various stations and indicates their licensed effective radiated power (ERP) levels and the approximate height of each antenna to the center of radiation above the roof. These broadcast stations normally operate 24 hours per day, seven days per week, except for maintenance periods when personnel must access the antenna mast, for example to replace beacon lamps. During those periods, WCBS (channel 2) normally switches to transmission from its auxiliary antenna located at the Empire State Building, the UHF TV stations cease operation and the remaining VHF TV stations assume operation from their lower mounted auxiliary antennas. Because of the lower mounting height of the auxiliary antennas, elevated RF fields at roof level will be expected.

Some 83 wireless telecommunications antennas are also situated on the roof of the north WTC tower. These facilities, typically consisting of vertical, collinear type antennas, usually omnidirectional in their radiation characteristics, are scattered over most of the roof area. In some cases, the antennas are mounted very close to the roof surface while with others the bottom of the radiating aperture of the antenna is at least eight feet above the roof deck. While none of these antennas operate with power levels comparable to any of the broadcast antennas, their close proximity to the roof surface and the fact that the area near the antennas is unrestricted in terms of access lead to the possibility that these antennás can also play a significant role in RF exposure of roof workers who may have reason be near them. Figure 2 shows an example of the disposition of various telecommunications antennas on the roof.

Technical Approach to Study

A two-pronged approach was taken to investigating the RF environment at the WTC. First, because of the intermittent nature of the various telecommunications transmissions, it was reasoned that attempting to measure these RF fields would be problematic. Without continuous operation of the stations, it would be difficult to confirm that field measurements made at any given point on the roof and at any given time would reflect the maximum possible RF field levels that might be achievable under maximum operating conditions. Hence, it was decided that a more appropriate way to assess the telecommunications fields would be via theoretical analysis. In this way, the maximum possible output from each antenna could be assessed. This would require, of course, detailed information on the precise location of each antenna, their physical sizes (radiating aperture heights), antenna input power levels, frequencies and mounting heights. This information was readily available from Motorola who manages the wireless telecommunications aspects of the WTC antenna site.

Secondly, direct measurements were proposed as the most expedient and accurate method for assessing the contribution of the broadcast transmitting facilities to the aggregate roof-top fields. Such measurements would, however, require that any contribution made by the many wireless telecommunications service antennas be controlled and, preferably, eliminated. Arrangements were made by Motorola to shut down the operation of all telecommunications antennas on the roof, during the field measurement exercise, except for several antennas used as paging links to important paging services. These antennas represented 72 MHz paging links and arrangements were made to insure that each of these transmitters were locked on during the measurement periods. In this fashion, while these 17 antennas would introduce some contribution to the ambient RF fields, their contribution would be constant with time without the attendant problems of dealing with intermittent sources as discussed above.

The measurement plan was for shutting down the remaining telecommunications antennas beginning at 10:00 p.m. for as long as the measurements took to accomplish. To facilitate obtaining the required data in the shortest reasonable time, arrangements were made to field five measurement teams. In this way, the entire roof area, consisting of approximately 900 measurement points, could be measured in about a 90 minute period of time. Immediately following a measurement period, the telecommunications facilities were activated to minimize their down-time.

During an early planning meeting between Motorola and the WTC broadcast community, it was decided that such a study should examine three alternative modes of operation of the WTC broadcast stations: the normal operating mode with all stations operating from their main antennas, the tower maintenance mode of operation, as described above and a worst case (emergency backup) mode of operation in which the VHF TV stations would switch to their lower auxiliary antennas, WCBS (channel 2) would remain operating from its main antenna rather than switching to its auxiliary antenna at the Empire State Building, the UHF stations would remain operating, and WQCD-FM would operate into the master antenna at the WTC (normally, WQCD-FM operates from the Empire State Building). Although the tower maintenance mode of operation is the most likely scenario for operation other than the normal mode, it was felt that the absolute worst case possibility of strong RF fields on the roof should be investigated. The results of such a measurement would reveal the greatest possible RF fields that could occur with the present stations and provided a degree of completeness to the study.

A test-run was scheduled during the afternoon of June 6, to familiarize individuals participating during the measurements with the roof and to practice the special measurement procedures that would be used during the evening tests. During that afternoon, the measurement teams were assembled and lead through a series of evaluation measurements to assess measurement repeatability and inherent artifacts introduced by reflections from the presence of the observer. Each measurement team consisted of three individuals, a person performing the measurement, one for recording the resulting data and another person to assist in identifying the many measurement points assigned to the various teams. The presence of the third team member was extremely valuable since all of the test measurements were performed at night with very limited lighting on the roof; spotting each sequential measurement point at many areas of the roof was challenging and to maintain a consistent rate of covering all the required measurement points required minimal time spent making sure of a particular point. Motorola provided the individuals for performing the measurements, since these personnel had past experience with the equipment and the techniques, and the WTC broadcast community provided personnel to fill out each measurement team.

The actual test measurements were performed during late Saturday night, beginning about 10:00 p.m. and early Sunday morning, beginning about 2:00 a.m., during which time both the normal and emergency, worst-case backup modes of operation were studied. During early Monday morning, the tower maintenance mode of operation was tested. Due to a temporary problem with operation of a coaxial switch at WNET (channel 13), the early Monday morning test protocol had to be delayed to approximately 4:00 a.m. whereupon the measurements started and were completed by approximately 5:30 a.m.

Processing of the measurement data included analysis of the projected RF fields that are produced by the 72 MHz paging link transmitters that were active during the measurements. In this way, the contribution of the paging links could be removed from the measured ambient fields. By knowing the location of each 72 MHz antenna, the RF fields in the vicinity of each such antenna, computed on the basis of antenna input powers and other technical parameters, could be subtracted from the total field consisting of both the broadcast and paging link transmitters.

The theoretical analysis of RF fields from telecommunications antennas was accomplished with the use of the RoofView™ software package originally developed for application at roof-top antenna sites. RoofView is a sophisticated Microsoft Excel™ spreadsheet that performs a near-field computation of the RF fields associated with vertical collinear telecommunications antennas of the type commonly used on the WTC roof.[1] RoofView performs calculations of RF fields for every square foot of roof area defined by the user and expresses the computed fields as a percentage of a selected human exposure limit. Each roof pixel is then colored in accordance with user selected values for field thresholds and colors for the composite RF field from all selected antennas on the roof. This analytical tool was believed to be the best approach to analyzing the complex antenna configuration on the WTC roof top. Since RoofView allows for convenient solution of what-if scenarios for antenna locations and antenna mounting heights, it would permit easy examination of various alternatives for mitigating excessive RF field levels, should such be found during the study. A customized version of RoofView was developed specifically for application to the WTC project that permitted inputting of measurement values obtained on the roof and presentation of colorized roof maps showing

[1] RoofView™ is a development and product of Richard Tell Associates, Inc., Las Vegas, Nevada.

the distribution of the measured field values. Details of the software are given in the section below on RoofView RF Analysis Software.

Instrumentation and Measurement Methodology

RF fields were measured via the use of broadband, isotropic electric field probes (Narda Model 8742) connected to a digital survey meter (Narda Model 8718). The use of broadband instrumentation was considered the only viable alternative for accurately assessing the ambient RF fields in terms of spatially averaged values. Since the Maximum Permissible Exposure (MPE) limits in the FCC rules are specified in terms of spatially averaged values of the squares of the fields or plane wave equivalent power densities, no other method capable of measuring the individual contributions of the many different frequencies present on the WTC roof was deemed suitable for acquiring the massive amount of data needed for this study. For example, commonly applied narrow-band measurement methods, involving tuned receivers or spectrum analyzers connected to calibrated reception antennas, are simply not practical for performing spatially averaged values of electromagnetic fields. However, using broadband measurement probes permitted the direct assessment of the spatially averaged field magnitudes by slowly moving the probe along a vertical axis from the roof surface to a height of six feet. Using the Narda Model 8718 meter, readings were acquired at a rate of 10 per second from the probe during the measurement period. At the termination of this process, lasting between approximately 12 and 15 seconds for each measurement, the meter automatically presented the spatially averaged value of the readings taken at that point.

The Model 8742 probe has a shaped frequency response that is designed to match the frequency dependency of the new FCC MPEs over the frequency range of 300 kHz to 2,000 MHz. This shaped frequency response provides for measurements in complicated field environments, similar to the WTC antenna site, in which numerous RF fields, each at different frequencies over a wide range, are appropriately summed but weighted according to the exposure limits at each frequency. In this way, the readings on the Model 8718 meter are in terms of a percentage of the MPE, not the equivalent plane wave power density. Hence, through use of this probe and meter combination, the measurement task was considerably simplified and permitted all of the measurements to be made in a timely fashion. This would not have been possible using a flat response probe since the relative contribution of the many different frequency fields would not have been known and, therefore, it would have been impossible to determine whether a given power density reading was actually in compliance with the frequency dependent MPE. In practice, all measurements made during the project included recording the spatially averaged value and maximum value of the percentage of the measured MPE even though it was the spatially averaged value that was of most importance. Figure 3 shows the Narda Model 8742 probe and Model 8718 meter that were used during a measurement. The back lit screen of the meter was used to advantage during the night-time measurements allowing the field measurements to proceed without interruption.

The Model 8742 probe is specified to permit measurements over the range of 0.6% to 600% of the MPE for controlled or occupational exposures. The detection elements within the probe are compensated diodes that are used in the square law response range so that the readings are properly related to the sum of squares of the electric field components and, hence, will correctly represent the magnitude of the composite RF field from multiple frequency fields that are simultaneously present at the probe. The Model 8742 probe has a specified isotropic response of ±0.75 dB between 1.5 MHz and 2,700 MHz. This specification is related to the possible variation in reading due to orientation of the probe in the field being measured and corresponds to a maximum variation of +18.9% and -15.9% as the probe is rotated or reoriented within the field.

Each probe was individually calibrated by the manufacturer at 13 frequencies across its detection range of 300 kHz to 2,700 MHz with RF fields having an uncertainty not exceeding ±0.5 dB. Correction factors were determined for each of these frequencies such that, if measurements are being performed at a single frequency (not the case in the WTC study), these calibration data can be used to correct the meter reading for the response of the individual probe. Narda warrants that the frequency sensitivity of the Model 8742 probe will not exceed 2 dB from the standard for exposure.[2] Table 2 lists the manufacturer's determined correction factors for each of six Model 8742 probes that were available for use during the WTC project. Table 2, and Figure 4, show that each of the six probes conform to the specification of ±2 dB deviation from the standard, the greatest deviation being at the lowest calibration frequency of 300 kHz. The probe having serial number 1004, however, was observed to exhibit the greatest correction factors in what was presumed to be the most important frequency range of nominally 50 MHz to 1000 MHz when compared to the other five probes. Based on this observation, and in the interest of reducing unnecessary uncertainty in the survey results, it was decided that the roof measurements should be performed with the remaining five probes which exhibited a much tighter grouping of correction factors.

For the five probes used in the general RF survey, Table 3 summarizes the correction factors over the important frequency range for which data were available, that being 27 MHz to 915 MHz. The data were analyzed from the point of view of determining the overall average value by which the probes, as a group, might read low or high compared to the true field magnitude. The results indicate a possible overall average low reading of 21.6% (-1.06 dB) and a possible overall average high reading of 39.5% (1.44 dB). This analysis suggests that, on average, the probes used in the survey might under-estimate the true field by 21.6% (range of 16.7% - 30.0%).

Since a high resolution mapping of the roof RF fields was desired, a relatively fine five foot by five foot measurement grid was defined for the accessible roof area following

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[2] While the Narda Model 8742 probe was designed to conform to the frequency dependency of the ANSI/IEEE C95.1-1992 standard for controlled environments over its entire frequency range of 300 kHz to 2,700 MHz, within ±2 dB, the manufacturer has determined that this probe also conforms, within the ±2 dB specification, to the recent FCC rules which adopted the recommendations of the National Council on Radiation Protection and Measurements (NCRP, 1986) for frequencies up to 2,000 MHz.

the general guidance on measurement procedures recommended by the National Council on Radiation Protection and Measurements (NCRP, 1993). The roof of the WTC, not including the window washer track along the outer perimeter of the roof, is a square approximately 173 feet on a side. Hence, a square consisting of 1,225 potential measurement points (35x35) was defined prior to the study (overall area of 170 by 170 feet equivalent to 28,900 ft^2). Measurement points were laid out by starting in the southwest corner of the roof and measuring in five foot increments relative to that corner of the roof using an x-y coordinate system. Three regions within the defined area used for the stairwell to reach the roof, the central broadcast antenna mast area and the window washing machine docking area could not be measured, reducing somewhat the actual area to be measured. These three areas amounted to 1,695 ft^2 making the valid measurement area a total of 27,205 ft^2.

The measurement plan called for excluding measurements in the very close vicinity (within 2.5 feet) of metallic structures including antennas, cable trays, lights or any other features that could materially perturb the local field strengths. This practice reduced the total number of roof-top measurement points from a potential of 1,225 down to 889. Figure 5 illustrates these 889 measurement points and shows the areas allocated to the stairwell, antenna mast and window washer unit.

During the night-time measurements, a single spatial scan was performed at each valid measurement point (i.e., those more than 2.5 feet from any antennas or metallic structures). The measurements were accomplished with the individual performing the measurements standing so that the arm holding the probe was perpendicular to a radial line from the measurement point to the central antenna mast. In this way (a) the body was never between the field probe and the antenna mast and (b) the probe was never between the mast and the body. This approach was taken to minimize both shielding and reflections that would interfere with measurement of the desired field values.

A total of 3,267 measurements were performed during the project which includes the initial evaluation measurements (600) (see Special Measurement Evaluation) as well as the area roof measurements during the two nights of the project (2,667).

Special Measurement Evaluation

Each of the five measurement teams was equipped with the same model meters and probes. Initially, during the afternoon evaluation phase of the project, these five meters were used by the respective teams to characterize the variability in the measurement process that was subsequently used at night. The measurement evaluation phase of the study consisted of having each measurement team measure the spatially averaged RF fields at a total of ten randomly selected points distributed across the roof that had been defined earlier. At each of the ten points, the individual performing the measurements faced the marked spot on the roof from each of four directions, 90 degrees with respect to one another, for each measurement. Once the four measurements of spatially averaged fields was completed, the team proceeded to another measurement point until the entire set of ten points was completed. This same process was then repeated a total of three times such that each team performed 120 measurements at the ten points. Through this process, data were generated that revealed something about the repeatability of the measurement process. Variation among the four measures of field at a point are influenced by the perturbations that can be caused by the body of the observer. Such perturbations may include both shielding of the measurement point from some of the fields or reflections of fields from the body back to the measurement point.

Table 4 summarizes the observed variation in measured percentages of spatially averaged fields over all orientations and three repetitions for all ten measurement evaluation points on the WTC roof for each of the measurement teams. The results reported in Table 4 indicate that each measurement team demonstrated quite consistent technique since the range of deviation in the many measurements is quite small (9.9% to 14.4%) over all five teams with an average standard deviation in the measured values of 12.6%. This represented a positive deviation of +0.51 dB and a negative deviation of 0.59 dB. Thus, these data indicate that the measurement process itself was reasonably stable and within the inherent accuracy and uncertainties of the measurement probes.

RoofView RF Analysis Software

While the many measurements conducted at the WTC formed a substantial basis for this study, the theoretical analysis of RF fields was equally important since the contribution of the many wireless communications antennas to the overall aggregate field levels had to be determined as a part of the compliance evaluation objective. Fields produced by the wireless antennas were analyzed through the use of the RoofView™ software package which was designed specifically to address vertical collinear types of wireless communications antennas.[3] This program is a sophisticated Excel™ spreadsheet that can model the RF fields in the vicinity of multiple antennas located on a roof-top antenna site, using a near-field model, taking into account the frequency of each field source and producing colorized roof maps that express the composite fields from all selected antennas in terms of a percentage of a selected exposure limit <u>based on a spatial averaging of the fields</u>. In this sense, the output is directly comparable to the frequency shaped probes used in the measurement phase of this study and, hence, can be amalgamated with the measurement data. This feature strongly influenced the use of the RoofView software since it would allow for convenient summation of the ambient broadcast fields with projected fields from the various wireless antennas, allowing for a very fine-grain analysis in the near-vicinity of each antenna.

RoofView carries out calculations at every selected one-square-foot pixel of roof surface for every selected antenna contained in its underlying data table. Detailed information obtained from Motorola was entered in this data table which specified each antenna's exact location on the roof in x-y coordinates, the mounting height to the base of the radiating aperture from the roof surface, the aperture height (important for near-field

[3] RoofView™ is an analysis tool developed and marketed by Richard Tell Associates, Inc.

analysis), antenna input power levels, frequencies associated with each antenna, and pointing directions and azimuthal beamwidths for directional antennas. Human RF exposure limits may be selected from an array of 14 different standards and guidelines. Since the Narda broadband probes are designed to read out in terms of a percentage of the controlled environment MPE of the IEEE (300 kHz to 2,700 MHz) and the new FCC limits for controlled exposure (300 kHz to 2,000 MHz), all analyses accomplished with RoofView for this study were referenced to the FCC controlled exposure MPEs.[4]

User defined thresholds are used to control the way in which RoofView displays analysis results. In this case, four ranges corresponding to <20%, 20-50%, 50-100% and >100% of the FCC worker MPE were used to determine the thresholds and, hence, coloration of the roof maps that are generated in the computation process. These four thresholds were set to produce map colors of green, yellow, red and blue respectively. Hence, all pixels having composite fields in the range of 50 to 100% of the MPE were displayed as red and so forth. Using this approach, colorized roof maps were generated for the WTC roof that could provide meaningful graphic feedback on the magnitude and distribution of RF fields.

The RoofView software computes fields of vertical collinear antennas using a cylindrical model in which the radiated power from the antenna is assumed to be distributed over the surface of an imaginary cylinder that surrounds the aperture. Appendix A provides details of the use of this model in RoofView. A user set factor, in terms of the antenna aperture height, is entered to inform RoofView as to when it should begin using a far-field, inverse square law for power density as compared to the inverse distance law in the near field. For the analyses prepared in this study, a factor of 1.5 times the aperture height was applied; as the many calculations are being performed within RoofView, the program makes decisions 'on the fly' as to how it should compute the field at each specific pixel.

RoofView version 3.0 was modified specifically for this project to permit the inclusion of the measurement data so that it could be plotted in a fashion similar to how the computed model results are normally plotted and so that computed fields of the many wireless telecommunications antennas could be combined with the measurement data to assess the combination effects of both the ambient broadcast fields and wireless antenna fields. Also, by performing a reverse calculation of the fields associated with the 72 MHz paging link antennas, which were not turned off during the measurements, an estimate of the field produced by only the broadcasting facilities could be made.

Although the colorized roof maps represent a powerful visual approach to examining the combined effects of multiple antennas at a roof-top antenna site, the RoofView software also provides a statistical summary of the results that can be highly

[4] The FCC RF exposure limits specify a more stringent MPE for uncontrolled or public exposures that are one-fifth the MPEs for controlled or worker exposure limits. This means that fields measured or calculated to be 20% of the controlled (worker) MPE are equivalent to 100% of the uncontrolled (public) MPE.

informative of the extent of the roof area exhibiting RF fields within the various ranges selected by the user. For all of the measurement and analysis results reported here, the square footage and percentage of the roof area subject to fields in the four defined ranges (percentages of the FCC RF MPEs) were determined and are presented along with the corresponding roof maps.

While RoofView normally computes the estimated field at each roof pixel, each comprising a square foot of the roof, the field measurements were only obtained at a nominal spatial resolution of five feet. To allow the measurement data to be presented in a compatible manner, modifications were made to the software to perform an interpolation of the measurement data on the basis of a one-foot spacing using a straight line method of interpolation. Alternative, more sophisticated interpolation methods were initially evaluated for displaying the measurements but in the final analysis, it was decided that a straight line method was satisfactory considering the boundary conditions present at the WTC site.

This interpolation method was evaluated by collecting detailed field measurements of the spatially averaged fields in a five by ten foot grid located in the southwest part of the roof, near one corner of a helipad. A total of 66 measurement points, each one foot adjacent to the next point, covered the overall area including the points along each edge of the area. In this case a single spatial average scan with the probe was made at each point, following the same protocol used for the entire roof measurements. These particular measurements were accomplished at approximately midnight during the second evening of measurements with all broadcast stations operating in their normal mode on their main antennas.

Table 5 presents the individual measured values of spatially averaged fields expressed as a percentage of the MPE. These data indicate a general increase in field level toward the northern edge of the test area compared to the southern edge ranging from approximately 28% MPE to about 45% MPE. An evaluation of the interpolation scheme was performed by using only the measured values obtained on five foot centers. This represented a total of six measurement values from which all of the other values, at one foot intervals, were determined as shown in Table 6. The differences between the interpolated values and the corresponding actual measurement values were computed and are given Table 7 as percentages. These differences ranged from as much as 12.8% below a measured value to as much as 12.0% higher than the real value, the average difference being approximately +0.97% with the distribution of low and high values being very close to the same proportion. Of the 56 interpolated values, 28 were less than the measured value and 32 were greater indicating, in this test, that the interpolation scheme did not seem to introduce any significant bias in the resulting values.

RF Measurement and Analysis Results

The numerous results of both measurements and analyses at the WTC are presented in this section beginning with the normal operation scenario for broadcast facilities with the inclusion of the 72 MHz paging links and progressing through the tower maintenance mode of operation and ultimately to the worst case, backup scenario. For these various conditions, several alternative RF conditions were examined.

Normal Broadcasting Operation

Figure 6 shows the measurement results for normal broadcasting operation with the 72 MHz paging links included. In this case, it is apparent from the roof map that a substantial area of the roof, approximately 63%, exhibited RF field values less than the continuous exposure MPE for uncontrolled exposures, or for unaware public access. Conversely, about 37% of the roof area (about 17,000 square feet) had fields above the uncontrolled exposure MPE, corresponding to 20% of the controlled, or worker, MPE. However, there were no areas that exceeded the controlled exposure MPE for workers under this operating scenario. The maximum field level found for this condition was 70.2% of the controlled exposure MPE. It must be remembered, however, that the many wireless communications antennas on the roof will increase the ambient levels of RF, especially in the near vicinity of these antennas.

The impact of continuous operation of all of the wireless telecommunications antennas at the same time in combination with the normal broadcast operation is shown in Figure 7. Under this condition, the maximum MPE is observed to increase substantially to 314.1% although this occurs on only 286 square feet of the roof corresponding to only slightly over 1% of the total roof area. About 83.5% of the roof area has fields exceeding the uncontrolled exposure MPE. This substantially greater roof area of higher RF fields is directly related to the additional fields produced by the many wireless communications antennas. This is evident from the numerous spots in the figure that are represented by red or blue colors.

The contribution of the 72 MHz paging link antennas was examined by removing the theoretically calculated fields from those antennas using the RoofView software. This was accomplished by making custom modifications to RoofView which permitted the computation of those fields, as would be performed during a conventional roof analysis, but then subtracting those results for each pixel on the roof. When this process was accomplished, the maximum RF field on the roof was found to decrease from 70.2% (with the 72 MHz pagers included) to 56.6% of the MPE, thereby increasing the amount of roof area subject to fields less than 20% of the MPE. Under this condition, only 15% of the roof area (3,943 square feet) was found to exceed 20% of the MPE. Figure 8 illustrates the resulting colorized roof map of this hypothetical mode of operation.

RoofView was then exercised by examining the effect of raising all of the 72 MHz paging antennas to six feet above the roof deck. Those antennas already above six feet were left as is. The results are shown in Figure 9 and indicate that the maximum RF field level would decrease from 70.2% of the MPE (with the paging links at their present mounting heights) to 57.2% of the MPE. RoofView was first used to subtract the calculated fields from each paging link antenna at each roof pixel, and then to add their contribution back into the ambient, measured broadcast field levels for the condition of being raised to six feet above the roof where applicable.

Finally, the result of raising all wireless antennas on the WTC roof to at least six feet was evaluated using RoofView. All antenna mounting heights that were indicated as less than six feet above the roof deck were increased to six feet. Those already mounted greater than six feet above the roof were left as is, similar to the treatment of the 72 MHz paging links discussed above. As expected, this process resulted in significantly lower fields, bringing the projected maximum RF field, found at any place on the roof, down from 314% of the MPE to only 67.2%. Figure 10 illustrates the colorized roof map for this condition. In this case, no area on the roof exceeded 100% of the MPE and the roof area subject to fields greater than the uncontrolled exposure MPE (83.5% before raising the wireless antennas) was reduced to only 32.6%. This substantial reduction in RF field levels supports the common contention that antenna mounting height can play a very significant role in controlling RF fields at roof-top antenna sites.

Tower Maintenance Mode

Figure 11 shows the measurement results obtained during the tower maintenance mode of operation of broadcast facilities with the inclusion of the 72 MHz paging links. In this instance, ambient fields are seen to increase, as would be expected because of RF emissions from the lower mounted auxiliary antennas. The maximum field level observed via measurements for this condition was 147% of the MPE (up from 70.2% of the MPE for the normal broadcast operation with inclusion of the 72 MHz paging links) with almost the entire roof area (96.17%) subject to fields exceeding 20% of the controlled exposure MPE (or 100% of the general public exposure MPE).

With the added RF fields produced by all of the wireless telecommunications antennas operating, the maximum field on the roof is projected to be 352% of the MPE with almost the entire roof (99.52%) exhibiting fields greater than the MPE for general public exposures. Again, localized areas shown in blue on the roof map in Figure 12 illustrate the fact that many of the wireless communications antennas tend to dominate the composite fields in the immediate region about the antennas. Of particular relevance is that observation that 16.5% of the roof area (4,489 square feet) is projected to be subject to fields exceeding 100% of the controlled exposure MPE.

If the contribution of the 72 MHz paging links is removed, in a fashion like that described above, the resulting roof map, shown in Figure 13, shows that the maximum RF field level has been reduced from 147% of the MPE to 138% and the extent of the roof area that is subject to fields exceeding the lower, general public MPE is slightly decreased to 94.3% of the roof surface. This condition projects the expected ambient RF field levels on the roof top that would be due solely to the operation of the various broadcast stations during the tower maintenance mode.

The RF field mitigation effects of elevating the many wireless antennas to at least six feet above the roof surface is illustrated in Figure 14. In this case, wireless antennas not already mounted at least six feet above the roof were elevated in mounting height through use of the RoofView software. When this was done, the maximum RF field on the roof was found to be 144% of the MPE compared to 352% before raising the antennas and the amount of roof area subject to fields exceeding 100% of the MPE now represents only 2.55% of the roof area. However, 96.4% of the roof area is still at RF levels exceeding the general public MPE.

Emergency Backup Operation Scenario

The greatest RF field levels were observed during the hypothetical emergency backup mode of operation wherein the UHF TV stations continued to operate from their main antennas, the VHF TV stations operated from their lower mounted auxiliary antennas, WCBS (channel 2) remained broadcasting from their main antenna at the WTC and WQCD-FM operated from the master FM antenna at the WTC rather than from their main antenna at the Empire State Building. Under this scenario, which, again, included the operation of the 72 MHz paging links, RF fields as high as 156.3% of the controlled exposure MPE were observed on the roof. Figure 15 illustrates the observed results. Almost 10% of the roof area (2,581 ft^2) is subject to fields exceeding the controlled exposure MPE.

The absolute, worst case scenario is when the contributions of the wireless antennas are included with the composite RF fields produced by the broadcast operations in the emergency backup mode. The computed results from RoofView are seen in Figure 16. The maximum field level is seen to be 373% of the MPE with 99.99% of the roof exceeding the general public MPE. Almost 27% of the roof surface (7,276 square feet) is projected to exceed the controlled exposure MPE.

If the contributions of the 72 MHz paging links or any other wireless antennas are removed from the measured ambient fields, the maximum RF field is projected to reduce to 135% of the MPE with a resulting roof map as illustrated in Figure 17. When this is done, the amount of roof area with fields less than the general public MPE is increased from less than 1% previously to more than 4%. However, there is still 3.25% of the roof (corresponding to 888 ft^2) that is subject to fields exceeding 100% of the MPE.

Should all wireless antennas be mounted at least six feet above the roof deck, a substantial reduction in RF field levels is found to result as seen in Figure 18. Even with this change, however, still, greater than 99% of the roof area is subject to field exceeding the general public MPE and more than 6% of the roof area still exceeds the worker MPE (down from 27% of roof area before raising the antennas).

Other Scenarios

Two additional scenarios were investigated. The projected fields that would result from operation of just the wireless communications antennas, without the influence of the 72 MHz paging link antennas or from any broadcast operations, were evaluated through the normal use of RoofView and these results are shown in Figure 19. Under this scenario, a maximum field of 273% of the MPE was found and 36.3% of the roof area was found to exceed the public MPE limits. Only 0.32% of the roof was projected to exhibit fields greater than the controlled exposure MPE. Figure 19 illustrates the localized impact of the wireless antennas on ambient fields.

Finally, the potential for strong, localized RF fields in the 800-900 MHz frequency range was evaluated by invoking the cylindrical spatial peak mode of operation for RoofView. In this instance, the cylindrical spatial peak model produces RF fields that are 3.0 times greater than the spatial average model; this is based on evaluation of the ratio of spatial peak and average fields near vertical collinear antennas (see Tell, 1996). Actual ratios of the spatial peak and average fields can range, generally, between two and four times but in many practical applications, a figure of three times represents a good average value. The spatial peak model finds application in instances where it is of interest to estimate the absolute maximum field values that could be found during an RF field survey near wireless antennas. Alternatively, evaluating RF exposure situations relative to the use of protective clothing where peak power density values have been specified by the manufacturer could be another practical application. For example, in some working conditions, it may be acceptable for workers to not wear head protection for RF fields. The issue of partial body exposure to RF fields is importantly related the spatial peak value of RF fields rather than that value as averaged over the whole body

Figure 20 illustrates the roof map found when calculating fields based on the spatial peak values for just those antennas operating at greater than 800 MHz. Of special note is that none of the resulting projected fields exceed 276% of the controlled exposure MPE, and these occur only in the immediate vicinity of several of the wireless antennas.

Overall Observations, Insights and Conclusions

Performing any study of RF fields of this magnitude represents a serious challenge. Simply the required coordination among so many stations, personnel and transmitter shut-downs can lead to complications in carrying out the project. Nonetheless, this study included measurements at 889 different points on the roof of the WTC at three different times. In this context, this study is believed to represent the most comprehensive set of measurements performed to date at the WTC north tower. It also provides considerably more spatial resolution detail of the RF field distributions on the roof than in any other study heretofore performed at the WTC. The extensive analytical approach used to assess the contribution of RF fields from the many wireless telecommunications antennas also formed a major part of the overall study and allowed insight to the way in which wireless antennas can influence the ambient fields at a major broadcast site.

The three different measurement conditions used in this study clearly demonstrated progressively stronger RF fields on the roof. Table 8 summarizes all of the various measurements and analyses included in this study. For example, the measurement data, without any computed input from the wireless communications antennas, other than the 72 MHz paging links that could not be turned off during the bulk of the measurement periods, show maximum field levels ranging from 70.2% of the controlled exposure MPE to 147% MPE for the tower maintenance mode to 156% MPE for the emergency backup mode of operation. This increase in maximum field level makes sense due to the use of lower mounted auxiliary antennas. With only broadcast stations and the 72 MHz paging links active, the extent of roof area exceeding the controlled exposure MPE changed from zero to as much as 9.5% under the emergency backup mode of operation.

When the additional contributions from the many wireless communications antennas are added to the already existing background of RF fields produced by the broadcast facilities, maximum field levels are found to rise substantially being in the range of 314% to 373% of the MPE, depending on conditions. Using the methodology described above for estimating the RF field levels that would exist on the roof if no wireless antennas were to be operative, the maximum field levels were projected to range from 56.6% MPE to as much as 135.2% MPE with the extent of the roof subject to fields exceeding the general public MPE ranging from as low as 14.5% to 99.07% of the roof area. Obviously, however, the presence of the many wireless communications antennas on the roof leads to the possibility of substantially greater fields, near these antennas, and the extent of roof area exhibiting higher fields.

An immediate observation from this study is that large areas of the roof exhibit RF fields that can substantially exceed the MPE for uncontrolled exposure or the general public. Presently, there exist no signs to indicate the presence of strong RF fields that exceed the general public MPE. The new RF rules adopted last year by the FCC specify that transmitter sites which present the potential for human exposure to RF fields that exceed the more stringent public, or uncontrolled exposure, MPEs must also make such individuals "fully aware" of this potential. The FCC has indicated that the use of appropriate signs at the site can be one way of providing this awareness. To comply with the new FCC rules, the roof must be posted to indicate the presence of RF fields that exceed the general public MPE set by the FCC. This conclusion is irrespective of the operation of any of the wireless communications equipment at the WTC; even without any contribution from the wireless antennas, almost 15% of the roof exceeds the more stringent public MPEs.

A related observation is that the RF fields on the roof of the north tower, in many instances, not only exceed the general public MPE but also the controlled exposure, occupational MPE set by the FCC. Because of this, the roof should be designated a controlled environment and be so posted. Beyond posting of the site, the development and implementation of an RF safety program should be considered for workers who have access to the roof. The safety program should contain site specific procedures related to work on the roof to insure compliance with the FCC rules. For example, areas that should be avoided could be identified on the roof and declared in the written program materials that would be provided to roof workers. All individuals who have access to the roof should be required to be presented with the RF safety program materials so that there is no question about them being informed of the presence of RF fields on the roof and appropriate procedures for reducing their exposure to help maintain compliance with FCC rules at the site.

The maximum RF field levels determined in this study are generally consistent with those found during an earlier study conducted by Jules Cohen & Associates, P.C.[5] During a study conducted in 1986, which included both broadband and narrowband measurements of RF fields, during the normal broadcasting condition, no areas on the roof were found that exceeded the RF rules then adopted by the FCC. Those rules, for the frequency range applicable to the WTC roof antennas, were identical to the new rules adopted last year by the FCC for controlled exposure or occupational situations. During the tower maintenance mode of operation, Cohen found one area in the northeastern part of the roof that exceeded the FCC rules. In personal communications with Mr. Cohen, it was disclosed that he did notice elevated fields in the near vicinity of some of the roof-mounted wireless communications antennas.

The strong effect of raising wireless antennas on the resulting roof level RF fields was observed through the study. Perhaps the most important finding of the study, relative to bringing the site into compliance with FCC rules on human exposure, is that associated with operating the wireless communications antennas with a minimum elevation of six feet above the roof. By assuming that all of the wireless antennas are mounted at least six feet above the roof, the projected RF fields on the north tower roof during normal broadcasting operations are all less than the controlled exposure, occupational MPE set by the FCC. This one mitigation measure would be expected to result in maximum fields no greater than about 57% of the occupational MPE and would leave only 14% of the roof area exceeding the general public MPE. Selective mounting height increases could also prove effective in reducing roof-top fields; those antennas operating in the 30-300 MHz frequency band, wherein the FCC limits are most restrictive, could provide substantial improvement in the ambient RF field situation without having to modify all antennas.

In areas where RF fields may exceed the general public MPEs, it would be deemed appropriate to post a Notice sign to indicate the presence of such fields. A Caution sign would be appropriate, however, to indicate areas with fields that may exceed the occupational MPEs. With the present antenna configuration at the WTC north tower for wireless antennas in conjunction with the ambient broadcast fields, the Caution sign would be required since it is possible, under this scenario, to find areas that do exceed the occupational MPE. In the event that that the various wireless antennas were to be raised to a minimum height of six feet, the measurement and analysis results suggest that while the maximum spatially averaged RF fields on the roof would, then, not exceed the higher

[5] Now, Denny and Associates, P.C., Washington, DC, Jules Cohen is a consultant to the firm. Field Strength Measurments World Trade Center, New York, New York.

occupational MPE, a substantial amount of the roof area would still be subject to fields that exceed the uncontrolled exposure MPE. Hence, even with raising the antennas, the roof needs to be appropriately posted but, under this specific condition, should be able to accomplished with Notice signs as opposed to Caution signs.

In the event that the antennas are not raised, or that not all of the wireless antennas are raised, areas on the roof subject to RF fields that may, from time to time and depending on wireless communications transmitter activity, exceed the controlled exposure MPEs of the FCC, should be identified and marked. Part of the work procedures for roof workers should, then, include awareness of those areas to avoid. Depending on the degree of detail desired in a safety program, limits on access time could be assigned to specific areas of the roof. To accurately implement such an approach, however, it is recommended that additional measurements be taken on the roof to more clearly define those specific areas. In no circumstance, when theoretically projected fields approach applicable human exposure limits, should complete reliance be placed on just analysis results. Direct measurements will provide the added degree of confidence in assessing potential exposure in those cases. Also, it must be recognized that wireless antenna sites are often very dynamic in terms of equipment changes. Hence, results obtained at one time may not accurately portray RF field conditions at a later time when additional antennas or other operating parameters have changed.

The analysis results provided in this report are based on the conservative assumption that all wireless communications transmitters connected to roof-top antennas are active. This approach has been taken in the interest of erring on the side of caution and since attempting to determine, in any rigorous and defensible way, the transmitter up-time profiles for each transmitter active at the site would be a very major task. Nonetheless, it should be recognized that under normal operating conditions, the RF field levels on the roof of the WTC will vary throughout the day due to changes in transmitter activity, or up-time. Such normal communications operations lead, generally, to the observation that the likelihood of simultaneous operation of all transmitters is rare and, hence, the field projections arrived at in this report will generally overstate both the magnitude of RF fields at various points and the roof area subject to such fields. However, without direct measurements of typical transmitter up-times for the many wireless communications transmitters at the WTC, using appropriate computer controlled scanning receivers, assigning values for transmitter up-times inherently contains considerable uncertainty with a corresponding uncertainty in the projected field levels. In view of such uncertainties and the additional time and effort that it would take to fully assess the up-time characteristics of all of the antennas, it was decided that this evaluation should explore the maximum possible RF field levels to which individuals might be exposed. Clearly, informed judgment on times of day during which most transmitters will be operating at a high duty cycle may be useful in guessing when fields may be at higher or lower levels. But such 'guestimates' should not be used for declaring compliance with the FCC rules on RF exposures unless supported by some kind of on-site measurement data.

Another reason for using a 100% up-time assumption in these analyses is that any on-site data collection related to transmitter up-times must be collected for a sufficiently long time to provide acceptable statistical confidence for projecting the up-time of any specific transmitter at any particular time of the day. In practical terms, this means that, contrary to the situation with broadcast transmitters in which signal levels remain constant throughout the day, repetitive measures of the wireless communications transmitter up-times, perhaps for multiple days, must be acquired to provide the required measure of statistical confidence for assigning up-time profiles. Application of these transmitter up-time profiles for the many antennas would then mean that each roof map that depicts the projected RF field levels for a particular condition, such as normal broadcasting or the tower maintenance mode, would carry with it some statement of confidence that the estimated field levels are actually at that level at some particular time of the day. All of these technical and practical considerations led to the worst case approach used in this study. By applying the results obtained in this study, while acknowledged to generally overstate the composite RF field levels on the roof, the extent of the roof area subject to specific field levels and the projected field levels themselves should provide a margin of safety when defining site specific work procedures.

A final observation is that related to maximum expected field levels on the roof for frequencies in the 800 MHz to 1000 MHz range. The standards against which these analyses are to be compared are based, generally, on whole-body averaged specific absorption rate (SAR), the rate at which the energy contained within the electromagnetic field is absorbed within the tissues of the body. The whole-body averaged SAR is limited to a value of 0.4 watts per kilogram (W/kg) of body mass for controlled exposures and to a value of 0.08 W/kg for uncontrolled exposures. For this reason, field measurements are normally performed by determining the spatially averaged value of plane-wave equivalent power density as performed in this study. Besides the whole-body averaged SAR, the limits are also based on preventing spatial peak SARs from exceeding 8 W/kg in any one gram of tissue in the body for controlled exposure environments.[6] The local, peak SAR in the body is usually, for near-field exposures, related to the local value of equivalent power density to which the body is exposed rather than the spatially averaged value.

A maximum value of the RF fields associated with transmitters operating in the 800 and 900 MHz bands was explored by invoking the spatial peak mode of calculation within RoofView. In this case, an upper value of 276% of the controlled exposure MPE was found near some of the wireless antennas. This finding has relevance relative to the potential use of RF protective clothing as one possible exposure mitigation at the WTC.

In an earlier investigation of the effectiveness of a particular RF protective suit, Tell (1997) found that, for near field exposure conditions used in the study at 835 MHz, exposure of the unprotected head did not result in peak SARs exceeding the underlying basis of 8 W/kg until the incident RF field exceeded 325% of the controlled exposure MPE. This suggests that, should RF protective clothing be used as a possible exposure mitigation method at the WTC, wearing of a protective hood assembly by workers would not necessarily be required. The coverall type of suit, without the hood, would, of course,

[6] Higher peak SARs are permitted in the extremities where 20 W/kg is acceptable for the hands, wrists, ankles and feet for controlled exposure situations.

have to be worn to insure that worker body exposures did not exceed limits prescribed by the FCC.

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