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Tabulation of Calculated RF Power Density
Existing Stations, and Existing *with* DTV Channels

E-W	N-S	Existing	With DTV
2300	1200	0.261%	0.300%
2300	1300	0.259%	0.305%
2300	1400	0.279%	0.338%
2300	1500	0.287%	0.359%
2300	1600	0.289%	0.374%
2300	1700	0.292%	0.390%
2300	1800	0.286%	0.396%
2300	1900	0.275%	0.393%
2300	2000	0.264%	0.385%
2300	2100	0.255%	0.374%
2400	-2400	0.231%	0.295%
2400	-2300	0.232%	0.301%
2400	-2200	0.256%	0.348%
2400	-2100	0.282%	0.392%
2400	-2000	0.302%	0.413%
2400	-1900	0.317%	0.426%
2400	-1800	0.325%	0.429%
2400	-1700	0.331%	0.429%
2400	-1600	0.334%	0.423%
2400	-1500	0.331%	0.410%
2400	-1400	0.322%	0.391%
2400	-1300	0.304%	0.362%
2400	-1200	0.289%	0.339%
2400	-1100	0.279%	0.325%
2400	-1000	0.278%	0.320%
2400	-900	0.279%	0.321%
2400	-800	0.283%	0.324%
2400	-700	0.290%	0.335%
2400	-600	0.298%	0.346%
2400	-500	0.307%	0.360%
2400	-400	0.303%	0.358%
2400	-300	0.280%	0.336%
2400	-200	0.229%	0.283%
2400	-100	0.163%	0.195%
2400	0	0.160%	0.193%
2400	100	0.222%	0.277%
2400	200	0.289%	0.348%
2400	300	0.307%	0.364%
2400	400	0.297%	0.353%
2400	500	0.297%	0.350%
2400	600	0.293%	0.343%
2400	700	0.283%	0.330%
2400	800	0.277%	0.320%
2400	900	0.271%	0.313%
2400	1000	0.266%	0.310%
2400	1100	0.269%	0.316%
2400	1200	0.265%	0.316%
2400	1300	0.265%	0.321%
2400	1400	0.280%	0.346%
2400	1500	0.291%	0.369%
2400	1600	0.296%	0.388%
2400	1700	0.285%	0.385%
2400	1800	0.274%	0.381%
2400	1900	0.264%	0.375%
2400	2000	0.254%	0.367%
2400	2100	0.248%	0.358%
2500	-2400	0.272%	0.346%
2500	-2300	0.286%	0.372%
2500	-2200	0.288%	0.379%
2500	-2100	0.291%	0.388%
2500	-2000	0.296%	0.395%
2500	-1900	0.305%	0.404%
2500	-1800	0.314%	0.412%
2500	-1700	0.323%	0.417%
2500	-1600	0.332%	0.421%
2500	-1500	0.339%	0.421%
2500	-1400	0.340%	0.415%
2500	-1300	0.318%	0.386%
2500	-1200	0.303%	0.365%
2500	-1100	0.298%	0.361%
2500	-1000	0.276%	0.333%
2500	-900	0.266%	0.321%
2500	-800	0.274%	0.329%
2500	-700	0.266%	0.320%
2500	-600	0.268%	0.323%
2500	-500	0.284%	0.343%
2500	-400	0.282%	0.341%
2500	-300	0.273%	0.332%
2500	-200	0.258%	0.317%
2500	-100	0.209%	0.266%
2500	0	0.211%	0.267%
2500	100	0.261%	0.319%
2500	200	0.276%	0.334%
2500	300	0.277%	0.335%
2500	400	0.274%	0.333%
2500	500	0.276%	0.334%
2500	600	0.270%	0.326%
2500	700	0.254%	0.308%
2500	800	0.258%	0.313%
2500	900	0.258%	0.313%
2500	1000	0.255%	0.312%
2500	1100	0.274%	0.336%
2500	1200	0.281%	0.346%
2500	1300	0.282%	0.349%
2500	1400	0.277%	0.349%
2500	1500	0.279%	0.359%
2500	1600	0.284%	0.374%
2500	1700	0.274%	0.370%
2500	1800	0.263%	0.363%
2500	1900	0.254%	0.355%
2500	2000	0.249%	0.350%
2500	2100	0.246%	0.344%
2600	-2400	0.297%	0.367%
2600	-2300	0.298%	0.373%
2600	-2200	0.297%	0.377%
2600	-2100	0.296%	0.380%

East-West and North-South are *meters* from Sutro Tower. Power density is in *% of FCC Standard* for public exposure.

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Tabulation of Calculated RF Power Density
Existing Stations, and Existing *with* DTV Channels

E-W	N-S	Existing	With DTV
2600	-2000	0.294%	0.381%
2600	-1900	0.298%	0.386%
2600	-1800	0.304%	0.392%
2600	-1700	0.312%	0.400%
2600	-1600	0.324%	0.410%
2600	-1500	0.327%	0.409%
2600	-1400	0.317%	0.393%
2600	-1300	0.319%	0.394%
2600	-1200	0.324%	0.399%
2600	-1100	0.325%	0.402%
2600	-1000	0.305%	0.379%
2600	-900	0.295%	0.369%
2600	-800	0.298%	0.376%
2600	-700	0.283%	0.359%
2600	-600	0.270%	0.346%
2600	-500	0.263%	0.340%
2600	-400	0.272%	0.352%
2600	-300	0.277%	0.356%
2600	-200	0.268%	0.345%
2600	-100	0.224%	0.301%
2600	0	0.224%	0.301%
2600	100	0.268%	0.344%
2600	200	0.271%	0.348%
2600	300	0.261%	0.338%
2600	400	0.248%	0.323%
2600	500	0.253%	0.330%
2600	600	0.260%	0.338%
2600	700	0.268%	0.344%
2600	800	0.262%	0.335%
2600	900	0.265%	0.338%
2600	1000	0.276%	0.349%
2600	1100	0.274%	0.347%
2600	1200	0.280%	0.354%
2600	1300	0.286%	0.362%
2600	1400	0.275%	0.351%
2600	1500	0.263%	0.342%
2600	1600	0.255%	0.338%
2600	1700	0.260%	0.349%
2600	1800	0.256%	0.347%
2600	1900	0.250%	0.340%
2600	2000	0.248%	0.336%
2600	2100	0.251%	0.336%
2700	-2400	0.300%	0.364%
2700	-2300	0.300%	0.367%
2700	-2200	0.298%	0.368%
2700	-2100	0.297%	0.369%
2700	-2000	0.295%	0.370%
2700	-1900	0.296%	0.373%
2700	-1800	0.299%	0.378%
2700	-1700	0.305%	0.385%
2700	-1600	0.307%	0.384%
2700	-1500	0.306%	0.381%
2700	-1400	0.304%	0.378%
2700	-1300	0.315%	0.393%
2700	-1200	0.322%	0.405%
2700	-1100	0.320%	0.404%
2700	-1000	0.317%	0.404%
2700	-900	0.313%	0.403%
2700	-800	0.307%	0.399%
2700	-700	0.302%	0.399%
2700	-600	0.292%	0.393%
2700	-500	0.278%	0.381%
2700	-400	0.278%	0.378%
2700	-300	0.277%	0.375%
2700	-200	0.268%	0.363%
2700	-100	0.252%	0.345%
2700	0	0.250%	0.342%
2700	100	0.262%	0.356%
2700	200	0.266%	0.361%
2700	300	0.263%	0.359%
2700	400	0.258%	0.355%
2700	500	0.263%	0.364%
2700	600	0.265%	0.364%
2700	700	0.258%	0.351%
2700	800	0.260%	0.349%
2700	900	0.272%	0.359%
2700	1000	0.283%	0.371%
2700	1100	0.267%	0.350%
2700	1200	0.258%	0.337%
2700	1300	0.253%	0.329%
2700	1400	0.257%	0.333%
2700	1500	0.247%	0.322%
2700	1600	0.235%	0.310%
2700	1700	0.237%	0.314%
2700	1800	0.235%	0.313%
2700	1900	0.237%	0.314%
2700	2000	0.251%	0.327%
2700	2100	0.258%	0.332%
2800	-2400	0.294%	0.353%
2800	-2300	0.298%	0.359%
2800	-2200	0.300%	0.361%
2800	-2100	0.300%	0.363%
2800	-2000	0.300%	0.364%
2800	-1900	0.297%	0.363%
2800	-1800	0.297%	0.364%
2800	-1700	0.299%	0.368%
2800	-1600	0.290%	0.357%
2800	-1500	0.287%	0.355%
2800	-1400	0.296%	0.368%
2800	-1300	0.303%	0.381%
2800	-1200	0.306%	0.389%
2800	-1100	0.299%	0.385%
2800	-1000	0.308%	0.400%
2800	-900	0.310%	0.408%
2800	-800	0.301%	0.404%
2800	-700	0.311%	0.423%

East-West and North-South are *meters* from Sutro Tower. Power density is in *% of FCC Standard* for public exposure.

Sutro Tower, Inc. • Digital Television • San Francisco, California

Tabulation of Calculated RF Power Density
Existing Stations, and Existing *with* DTV Channels

E-W	N-S	Existing	With DTV
2800	-600	0.309%	0.429%
2800	-500	0.299%	0.423%
2800	-400	0.293%	0.415%
2800	-300	0.287%	0.407%
2800	-200	0.282%	0.400%
2800	-100	0.280%	0.397%
2800	0	0.277%	0.394%
2800	100	0.275%	0.392%
2800	200	0.275%	0.393%
2800	300	0.277%	0.398%
2800	400	0.281%	0.404%
2800	500	0.281%	0.402%
2800	600	0.270%	0.385%
2800	700	0.250%	0.354%
2800	800	0.254%	0.355%
2800	900	0.264%	0.361%
2800	1000	0.268%	0.360%
2800	1100	0.252%	0.338%
2800	1200	0.234%	0.314%
2800	1300	0.220%	0.295%
2800	1400	0.234%	0.305%
2800	1500	0.231%	0.300%
2800	1600	0.223%	0.291%
2800	1700	0.217%	0.284%
2800	1800	0.217%	0.283%
2800	1900	0.225%	0.290%
2800	2000	0.250%	0.315%
2800	2100	0.260%	0.324%
2900	-2400	0.283%	0.339%
2900	-2300	0.292%	0.347%
2900	-2200	0.298%	0.353%
2900	-2100	0.302%	0.357%
2900	-2000	0.304%	0.360%
2900	-1900	0.292%	0.347%
2900	-1800	0.285%	0.340%
2900	-1700	0.286%	0.343%
2900	-1600	0.284%	0.343%
2900	-1500	0.284%	0.347%
2900	-1400	0.291%	0.359%
2900	-1300	0.284%	0.357%
2900	-1200	0.283%	0.361%
2900	-1100	0.292%	0.378%
2900	-1000	0.286%	0.377%
2900	-900	0.287%	0.386%
2900	-800	0.297%	0.407%
2900	-700	0.293%	0.411%
2900	-600	0.288%	0.412%
2900	-500	0.283%	0.413%
2900	-400	0.295%	0.431%
2900	-300	0.298%	0.434%
2900	-200	0.294%	0.429%
2900	-100	0.291%	0.427%
2900	0	0.289%	0.424%
2900	100	0.287%	0.422%
2900	200	0.286%	0.421%
2900	300	0.285%	0.422%
2900	400	0.284%	0.422%
2900	500	0.258%	0.388%
2900	600	0.247%	0.369%
2900	700	0.244%	0.358%
2900	800	0.244%	0.352%
2900	900	0.237%	0.337%
2900	1000	0.221%	0.311%
2900	1100	0.228%	0.314%
2900	1200	0.220%	0.300%
2900	1300	0.209%	0.282%
2900	1400	0.205%	0.271%
2900	1500	0.208%	0.271%
2900	1600	0.218%	0.279%
2900	1700	0.214%	0.274%
2900	1800	0.218%	0.276%
2900	1900	0.226%	0.283%
2900	2000	0.232%	0.287%
2900	2100	0.244%	0.299%
3000	-2400	0.271%	0.325%
3000	-2300	0.281%	0.332%
3000	-2200	0.292%	0.342%
3000	-2100	0.299%	0.348%
3000	-2000	0.299%	0.347%
3000	-1900	0.314%	0.361%
3000	-1800	0.323%	0.369%
3000	-1700	0.318%	0.365%
3000	-1600	0.316%	0.366%
3000	-1500	0.306%	0.360%
3000	-1400	0.287%	0.347%
3000	-1300	0.278%	0.345%
3000	-1200	0.273%	0.345%
3000	-1100	0.272%	0.350%
3000	-1000	0.273%	0.360%
3000	-900	0.274%	0.370%
3000	-800	0.274%	0.379%
3000	-700	0.279%	0.396%
3000	-600	0.277%	0.404%
3000	-500	0.272%	0.405%
3000	-400	0.275%	0.410%
3000	-300	0.275%	0.410%
3000	-200	0.272%	0.407%
3000	-100	0.269%	0.404%
3000	0	0.267%	0.402%
3000	100	0.265%	0.400%
3000	200	0.264%	0.399%
3000	300	0.262%	0.397%
3000	400	0.258%	0.393%
3000	500	0.243%	0.375%
3000	600	0.239%	0.366%
3000	700	0.238%	0.356%

East-West and North-South are *meters* from Sutro Tower. Power density is in *% of FCC Standard* for public exposure.

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Tabulation of Calculated RF Power Density
Existing Stations, and Existing *with* DTV Channels

E-W	N-S	Existing	With DTV	E-W	N-S	Existing	With DTV
3000	800	0.228%	0.334%				
3000	900	0.222%	0.319%				
3000	1000	0.218%	0.307%				
3000	1100	0.212%	0.293%				
3000	1200	0.211%	0.287%				
3000	1300	0.213%	0.283%				
3000	1400	0.207%	0.270%				
3000	1500	0.207%	0.264%				
3000	1600	0.213%	0.267%				
3000	1700	0.223%	0.276%				
3000	1800	0.229%	0.281%				
3000	1900	0.233%	0.283%				
3000	2000	0.234%	0.283%				
3000	2100	0.240%	0.289%				

East-West and North-South are *meters* from Sutro Tower. Power density is in *% of FCC Standard* for public exposure.

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Comparison of Measured RF Power Density with Calculated Values

Measurement Location [1]	Measured Power Density [2]	Calculated Power Density [3]	Calculated % FCC Standard [4]
1	0.0229 mW/cm^2	0.0247 mW/cm^2	11.4%
2	0.0234	0.0269	11.5
3	0.0077	0.0171	6.98
4	0.00076	0.00663	2.54
5	0.0014	0.00951	3.88
6	0.0020	0.00350	1.64
7	0.00011	0.00110	0.470
8	0.00038	0.000880	0.407
9	0.00045	0.000700	0.316
10	0.00013	0.00139	0.529

[1] Selected arbitrarily at various distances from Sutro Tower; shown on Figure 2

[2] Measured on December 5, 1996, with Holaday HI-3004 Broadband Exposure Meter

[3] Based on formulas in Appendix B; see also Figure 4

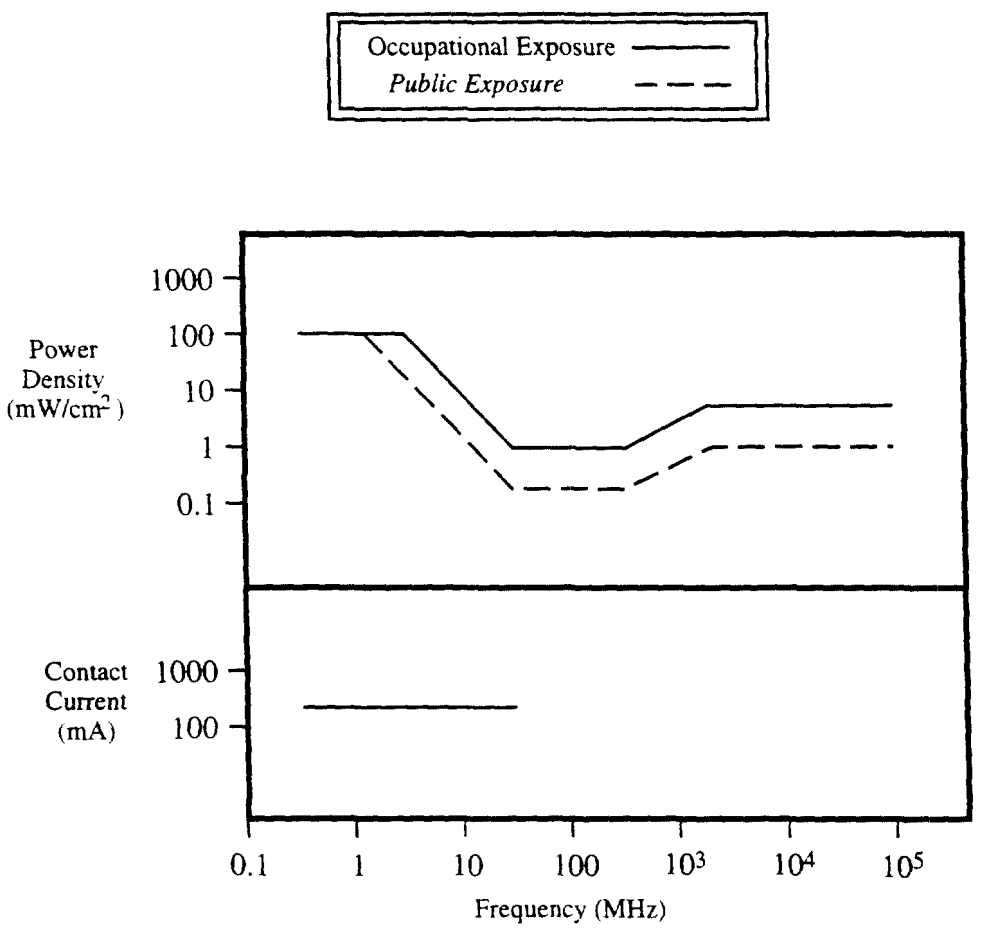
[4] Based on appliable limits for public exposures of unlimited duration

National Council on Radiation Protection and Measurements
Report No. 86 (Published 1986)
"Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields"

Radio Frequency Protection Guide

Frequency	Electromagnetic Fields						Contact Currents
Applicable Range (MHz)	Electric Field Strength (V/m)		Magnetic Field Strength (A/m)		Equivalent Far-Field Power Density (mW/cm^2)		(mA)
0.3 – 1.34	614	*614*	1.63	*1.63*	100	*100*	200
1.34 – 3.0	614	*823.8/f*	1.63	*2.19/f*	100	*180/f²*	200
3.0 – 30	1842/f	*823.8/f*	4.89/f	*2.19/f*	900/f²	*180/f²*	200
30 – 300	61.4	*27.5*	0.163	*0.0729*	1.0	*0.2*	no limit
300 – 1,500	$3.54\sqrt{f}$	*$1.59\sqrt{f}$*	$\sqrt{f}/106$	*$\sqrt{f}/238$*	f/300	*f/1500*	no limit
1,500 – 100,000	137	*61.4*	0.364	*0.163*	5	*1*	no limit

Note: f is frequency of emission, in MHz.



Calculation Methodology

Determination by Computer of Compliance with Human Exposure Limitations

The U.S. Congress has required of the FCC that it evaluate its actions for possible significant impact on the environment. In Docket 79-144, the FCC adopted the radio frequency protection guide of the American National Standards Institute Standard C95.1-1982, "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz." Exposures are to be averaged over a six-minute period. In 1992, ANSI published a revised standard, C95.1-1992, which defined "controlled" and "uncontrolled" environments, setting for the latter limits generally five times more restrictive. The C95.1-1992 controlled (*i.e.*, occupational) limits are approximately the same as in C95.1-1982. In Docket 93-62, the FCC adopted the exposure limits for field strength and power density recommended in Report No. 86, "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," published in 1986 by the National Council on Radiation Protection and Measurements, a standard very similar to C95.1-1992. The effective date for applying this standard to FCC licensees is September 1, 1997.

The FCC Office of Science and Technology Bulletin No. 65 (October 1985) gives the formula for calculating power density from an individual radiation source:

$$\text{power density} \quad S = \frac{2.56 \times 1.64 \times 100 \times RFF^2 \times [0.4 \times VERP + AERP]}{4\pi D^2}, \text{ in } mW/cm^2,$$

where VERP = total peak visual ERP for NTSC TV stations, in kilowatts,
AERP = total aural (or average for DTV stations) ERP, in kilowatts,
RFF = relative field factor at the direction to the actual point of calculation, and
D = distance from the center of radiation to the point of calculation, in meters.

The factor of 2.56 accounts for the increase in power density due to ground reflection. The factor of 1.64 is the gain of a half-wave dipole relative to an isotropic radiator. The factor of 0.4 converts peak visual ERP (for NTSC TV stations) to an average RMS value; for FM stations, of course, and for DTV stations the value of VERP is zero. The factor of 100 in the numerator converts to the desired units of power density. The above formula, by itself, is adequate for calculating the power density from RF sources that have line-of-sight to the calculation point.

The signal levels produced by radio and TV stations are affected by the nature of the terrain between the source (*i.e.*, Sutro Tower) and the reception point. For instance, an intervening hill may considerably attenuate the signal at those points that are blocked by it. Although transmitting sites are generally high to minimize the effects of terrain, there will still be some locations where reception is impaired due to terrain obstruction. For those locations where terrain obstruction is significant, the result of the above "free space" formula must reduced by a loss factor based upon the degree and type of blockage. The Terrain Integrated Rough Earth Model ("TIREM") is used to calculate the amount of attenuation due to terrain effects. This model evaluates the profile between the source and each receive site and, based on the geometry of the profile, selects automatically the most probable propagation model to calculate the loss.

For this project, a custom computer program has been developed to calculate the power density as a fraction of the NCRP Public Limit at some 8,900 points in San Francisco. The operation of the program is as follows: first, the antenna height, relative field factors due to the antenna azimuth and elevation pattern, and effective radiated power are input for each station at Sutro Tower. The program then calculates for each station the vertical terrain profile to each calculation point, and determines the amount of additional loss, if any, to be added. Due to the large height of Sutro Tower, about 85% of the calculation points are within line-of-sight, and the formula above was applied without modification. For the remaining points, a loss factor was added to the result. The calculated power density for each station is then converted to a fraction of the applicable NCRP-86 public limit, which ranges from 0.2 mW/cm^2 for the FM stations and the VHF TV stations to 0.521 mW/cm^2 for UHF Channel 66. Finally, the fractions contributed by each station are summed at each point.

APPENDIX B:

TECHNICAL REPORT

BIOLOGICAL EFFECTS OF RADIOFREQUENCY RADIATION (RFR): POSSIBLE HEALTH EFFECTS OF RFR ON NEARBY HUMANS FROM SUTRO TOWER DIGITAL TELEVISION BROADCASTS

July 9, 1997

Peter Polson, Ph.D
AUSA Research
Cupertino, California

and

Louis N. Heynick, M.S.
Consultant
Palo Alto, California

Prepared for:
S. Maxwell and
Woodward-Clyde Consultants
Oakland, California

Contributions by:
Asher Sheppard

Peer Reviewed by:
C.K. Chou

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1.0 INTRODUCTION

This Technical Report contains analyses of the potential bioeffects of RFR and their relevance to possible health effects of exposure to the RFR from the Sutro Tower Digital TV transmitters on human populations in its vicinity. The analyses are based on reviews of papers selected as being representative of the many thousands published in scientific journals, typically after peer review, through about mid-1997. With a few exceptions, presentations at scientific symposia or abstracts thereof have been excluded on the assumptions that they were not peer-reviewed or that detailed peer-reviewed accounts of such studies may appear subsequently. Some analyses included here were derived from three general reviews: Heynick (1987), and Heynick and Polson (1996a, 1996b). Assessed in the first report were more than 500 detailed reviews and analyses of research papers published through about mid-1986. The report by Heynick and Polson (1996a) includes analyses of papers on RFR teratogenesis derived from Heynick (1987) but also analyses of papers on that topic published subsequently. Similarly, included in Heynick and Polson (1996b) are analyses of epidemiologic studies and studies on RF exposures of human volunteers. Both 1996 reports were completed in 1994.

The first section below summarizes RFR human-exposure guidelines adopted or under consideration by several organizations, and places the RFR levels expected from the Sutro Tower Digital TV transmitters in relation to those guidelines. The proposed ten new Sutro Tower Digital TV transmitters will operate in the frequency band from 500 to 734 MHz (Hammett and Edison, 1997). Electromagnetic energy at such frequencies occupies a portion of the spectrum which is referred to as microwaves. Because there is no possibility that members of the general public would be exposed to RFR levels higher than allowed by the guidelines, this report pays particular attention to scientific information relevant to exposures below the safety guideline limits. Current safety standards are based on scientific data for exposures over a range of intensities, some of which are well above the levels permitted by safety standards. The main value of research conducted at high levels is the formulation of a solid basis for safety guidelines, but such data are sometimes important in assessing biological responses found in research conducted at lower intensities.

1.1 RFR SAFETY GUIDELINES

Terms such as "safety standards" and "exposure standards" generally refer to, and are frequently used interchangeably with, specifications or guidelines on maximum permissible exposure levels to electromagnetic fields. Guidelines differ for exposures to the general public and for exposures occurring in occupations settings where persons are aware of the presence of RFR. In both situations, the safety levels are usually expressed as maximum permissible incident field intensities and/or power densities in specific frequency ranges averaged over specified exposure periods.

In most guidelines for human exposure to RFR, the maximum permissible exposures (MPEs) are stated in terms of the maximum allowable incident power densities, expressed in milliwatts per square centimeter (mW/cm^2) or in watts per square meter (W/m^2, with $1\ W/m^2 = 0.1\ mW/cm^2$). Such MPEs are selected on the basis of the highest values of "specific absorption rate" (SAR) that were found not to be harmful to animals in experimental studies. SAR is defined as the rate at which RFR energy is absorbed in any small volume of a body, and is usually expressed in watts per kilogram (W/kg) of the mass in that volume (or sometimes in milliwatts per gram, with 1 mW/g = 1 W/kg). For any specific value of incident power density, the SAR thus defined varies with location within the body, so it is often called the "local SAR". Guidelines are based primarily on "whole-body" exposure. Spatial averages are obtained from internal SARs when an entire silhouette of a body facing a source is exposed, but separate consideration is given for partial-body exposures to RFR from sources very close to the body.

Modern RFR safety standards reflect a historical process which may be noted in the following summaries of standards developed in recent decades.

In 1982, the American National Standards Institute (ANSI) issued guidelines for human exposure to RFR, prepared by its Subcommittee C95.IV (ANSI, 1982). Those guidelines were frequency-dependent and applicable to both occupational exposure and exposure of the general public. They covered the frequency range from 300 kHz to 100 GHz and were based on a whole-body SAR limit of 4 W/kg. This criterion was based on many RFR-exposure studies on animals published in the scientific literature up to that time which showed hazardous effects for whole-body exposures above 4 W/kg, but no demonstrable hazardous effects below 4 W/kg. A safety factor of 10 was applied, reducing the maximum allowable whole-body SAR to 0.4 W/kg. For frequencies where body dimensions are similar to the wavelength of the RFR, the body absorbs energy resonantly and SAR varies significantly with frequency. As a result, for certain frequencies the limits on incident power density were dependent on frequency. The lowest limit, 1 mW/cm^2, was for the range 30-300 MHz, within which resonant absorption of RFR by the human body is highest. In recognition of the need to set limits for intense exposures of short duration, a 6-minute period was set as the time over which exposures may be averaged. Therefore, an exposure lasting three minutes could be at twice the level of a continuous exposure.

The American Conference of Governmental Industrial Hygienists published threshold limit values (TLVs) also based on 4 W/kg with a safety factor of 10, but intended for occupational exposures only (ACGIH, 1984). Those TLVs were intended for use in the practice of industrial hygiene only by persons trained in that discipline. The 1-mW/cm^2 lowest limit in the 1982 ANSI guidelines was also specified in ACGIH (1984), but extended only from 30 to 100 MHz and rose with a slope f/100 at 100 MHz to 10 mW/cm^2 at 1 GHz. The difference was based on the premise that children, who have higher whole-body resonant frequencies than adults (see Section 2.1), are not likely to be occupationally exposed to RFR. Also, the lower frequency limit for the 100-mW/cm^2 TLV of the ACGIH guidelines was at 10 kHz instead of 300 kHz. As noted above, the 1984 ACGIH guidelines were based on whole-body SAR, but they did not provide limits for the occurrence of RF shocks or burns under some conditions (essentially unrelated to whole-body exposure). Instead, the guidelines suggested procedures for avoiding such potential hazards.

In 1986, Scientific Committee 53 of the National Council on Radiation Protection and Measurements (NCRP) had issued its report (NCRP, 1986), which contained recommendations of specific exposure limits for the frequency range 300 kHz to 100 GHz. Those limits were also based on 4 W/kg, but with a safety factor of 50 for the general population rather than 10. The corresponding lowest incident-power-density limit was 0.2 mW/cm^2 for the frequency range 30-300 MHz. The limits in ANSI (1982) (embodying the safety factor of 10) were recommended for occupational exposure.

The fivefold lower value for the general population relative to 1 mW/cm^2 (the lowest value in the 1982 ANSI guidelines) was based on the assumption that the general public is exposed continuously (168 hours per week) and that the ratio of 40 hours in the work week to 168 hours is approximately 0.2. The implication was that exposure at low levels, such as at the limits prescribed in ANSI (1982), could be cumulative and potentially harmful to the more sensitive subpopulations of the general public, such as infants, the aged, and the infirm. However, the existence of RFR threshold levels appears to have been ignored, and there is no experimental evidence that those subpopulations would be at any greater risk from chronic exposure at or below the limits specified in ANSI (1982). Since 1995, the NCRP has been engaged in reviewing its recommendations on RFR-exposure limits, using findings in papers published in scientific journals after those considered in the preparation of the NCRP (1986) document.

The International Non-Ionizing Radiation Committee of the International Radiation Protection Association (IRPA/INIRC), with representatives from Australia, France, Federal Republic of Germany, Italy, Netherlands, Sweden, the United Kingdom, and the United States, published guidelines (IRPA, 1988) for exposure of the general public and occupationally to RFR in the frequency range 0.1-300 GHz. Environmental health criteria issued by the World Health Organization (WHO, 1981) served as the rationale.

The limits for occupational exposure, averaged over any 6-minute period, are shown in Table 1. In the range 10 MHz upward, they are based on a whole-body SAR of 0.4 W/kg, and are expressed as limits on the RMS electric field (E) and magnetic field (H) and their equivalent plane wave power densities (P_{eq}). For 10 MHz and lower, the limits are stated solely as root-mean-square (RMS) electric and magnetic fields.

TABLE 1: IRPA/INIRC (1988) MAXIMUM PERMISSIBLE LIMITS FOR OCCUPATIONAL EXPOSURE TO RFR

Frequency f (MHz)	E (V/m)	H (A/m)	P_{eq} (W/m^2)	P_{eq} (mW/cm^2)
0.1-1	614	1.6/f	--	--
>1-10	614/f	1.6/f	--	--
>10-400	61	0.16	10	1
>400-2000	3(√f)	0.008(√f)	f/40	f/400
>2000-300,000	137	0.36	50	5

For part-body exposure in the range 10 MHz upward, the maximum SARs are 20 W/kg in the extremities (hands, wrists, feet, and ankles) and 10 W/kg in any other part of the body.

The limits for exposure of the general public, shown in Table 2, are based on a whole-body SAR of 0.08 W/kg (a fifth of the occupational SAR), also averaged over any 6-minute period.

TABLE 2: IRPA/INIRC (1988) MAXIMUM PERMISSIBLE LIMITS FOR GENERAL PUBLIC EXPOSURE TO RFR

Frequency f (MHz)	E (V/m)	H (A/m)	P_{eq} (W/m^2)	P_{eq} (mW/cm^2)
0.1-1	87	0.23/(√f)	--	--
>1-10	87/(√f)	0.23/(√f)	--	--
>10-400	27.5	0.073	2	0.2
>400-2000	1.375(√f)	0.0037(√f)	f/200	f/2000
>2000-300 000	61	0.16	10	1

The IRPA/INIRC guidelines (1988) also specified a maximum body-to-ground current of 200 mA and suggested limits on pulsed RFR per se. About shocks and burns, the guidelines state: "Hazards of RF burns should be eliminated by limiting currents from contact with metal objects. In most situations this

may be achieved by reducing the E values from 614 to 194 V/m in the range from 0.1 to 1 MHz and from 614/f to 194/√f) in the range from >1 to 10 MHz . . . In general, RF burns will not occur from currents on point contact of 50 mA or less." About pulsed RFR, the guidelines suggested that the pulse power density (averaged over the pulse duration) not exceed 1000 times the specified average plane wave power density limits, or that the peak field strengths not exceed 32 times the specified field strengths.

In 1991, Standards Coordinating Committee (SCC) of the Institute of Electrical and Electronic Engineers (IEEE), which had taken over the functions of ANSI Subcommittee C95.IV in 1988, issued a revision of the 1982 ANSI guidelines. Those revised guidelines were adopted by ANSI in 1992 and are cited herein as ANSI/IEEE (1992).

The ANSI/IEEE (1992) guidelines cover the frequency range from 3 kHz to 300 GHz and separately state maximum allowable RF exposure in "uncontrolled environments" (generally accessible by the general public) and "controlled environments" (such as occupational exposure). Both are based on a maximum whole-body SAR of 4 W/kg, above which possibly hazardous RFR-bioeffects have been demonstrated in studies with laboratory animals. Wherever the guidelines for controlled and uncontrolled environments differ, the differences reflect application of more conservative safety factors for uncontrolled environments.

The limits for uncontrolled environments are based on a safety factor of 50 (to 0.08 W/kg). From 100 to 300 MHz, the limit on averaged power density is 0.2 mW/cm^2; the limitrises in accordance with the formula f/1500 from 0.2 mW/cm^2 at 300 MHz to 10 mW/cm^2 at 15 GHz, and is 10 mW/cm^2 in the frequency range 15 to 300 GHz (with the frequency f in MHz).In the frequency range from 3 kHz to 1.34 MHz, the averaging time is 6 minutes, and between 3.0 MHz and 3 GHz, it is 30 minutes. In the transition range 1.34-3.0 MHz, the averaging time is given by f2/0.3 (rising from 6 to 30 minutes with frequency). Between 3 GHz and 15 GHz, however, the averaging time is given by 90,000/f, thus decreasing with frequency to 6 minutes again at 15 GHz. Between 15 GHz and 300 GHz, the formula for averaging time is $(616,000)/f^{1.2}$, thus decreasing to only about 10 seconds at 300 GHz.

The limits for controlled environments are based on a safety factor of 10 (to 0.4 W/kg). For frequencies between 100 MHz and 300 MHz, the limit on average power density is 1.0 mW/cm^2; the limit rises in accordance with f/300 from 1.0 mW/cm^2 at 300 MHz to 10.0 mW/cm^2 at 3 GHz, and is 10.0 mW/cm^2 in the frequency range 3-300 GHz.The values are to be averaged over any 6-minute period, but (unlike for uncontrolled environments) for the entire frequency range up to 15 GHz. On the other hand, the formula for averaging time in the range 15-300 GHz is again given by $(616,600)/f^{1.2}$.

Also included in the ANSI/IEEE (1992) guidelines are maximum allowable values for RF current flow induced within the feet of a person immersed in an RF field or by the person's contact with an inanimate object (e.g., a fence or vehicle) electrically charged by immersion in an RF field.

The ANSI/IEEE (1992) guidelines are currently undergoing the (nominally 5-year cyclic) examination for reaffirmation or revision of its provisions by the IEEE SCC 28, based on critical analyses of the research papers in current databases on RFR-bioeffects published in scientific journals.

For more than a decade, the Environmental Protection Agency (EPA) had been planning to issue RF-exposure guidelines for the general population, but has not done so to date. In 1995, the EPA announced its intention to issue general-population guidelines for exposure to levels of RFR that can cause thermal effects, but shelved that plan shortly afterward. In the absence of an overall mandatory Federal exposure

standard (but not necessarily for that reason), various state, county, and municipal bodies have promulgated ordinances on exposure of the general public to RFR that are usually more stringent than those of ANSI (1982) or ANSI/IEEE (1992).

In 1985, the Federal Communications Commission (FCC) had adopted the ANSI (1982) guidelines as a standard applicable to persons or non-governmental organizations licensed by the FCC to operate RFR transmitters, thus rendering it a mandatory rather than a voluntary federal standard. On 8 April 1993, the FCC issued a "NOTICE OF PROPOSED RULE MAKING" (FCC, 1993) to consider the adoption of the ANSI/IEEE (1992) standard to replace the ANSI (1982) standard. In that notice, the FCC had requested comments and recommendations from various federal, state, and local municipal bodies; industrial organizations, including those in the wireless communications businesses; and committees engaged in preparing or revising exposure guidelines.

In a "REPORT AND ORDER" dated 1 August 1996 (FCC, 1996), the FCC noted receipt of over 100 responses, including recommendations from the EPA that the FCC adopt a mixture of the exposure limits recommended in the NCRP (1986) document and those in the ANSI(1982) standard, to the extent such limits pertain to its jurisdictional areas. The stated basis for use of the exposure limits recommended in NCRP (1986) is that where they differ from those in ANSI/IEEE (1992), they would be more protective of the general public. This point has been questioned because of the lack of supporting evidence. Several opposing responses submitted by various other organizations and individuals (including agencies in the Department of Defense) were cited but not discussed in FCC (1996). A major objection in some of those responses was to the use of the NCRP (1986) recommendations.

Thus, as detailed in FCC (1996), that agency has accepted many (but not all) of the recommendations by the EPA, and has adopted the standards for occupational/controlled and general-population/uncontrolled exposures shown respectively in Tables 3 and 4.

TABLE 3: FCC (1996) MAXIMUM PERMISSIBLE LIMITS FOR OCCUPATIONAL/CONTROLLED EXPOSURE TO RFR

Frequency f (MHz)	E (V/m)	H (A/m)	P_{eq}* (mW/cm^2)	Averaging Time (minutes)
0.3-3.0	614	1.63	100	6
3.0-30	1842/f	4.89/f	900/f2	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100 000	--	--	5	6

*P_{eq} = Free-space equivalent power density

TABLE 4: FCC (1996) MAXIMUM PERMISSIBLE LIMITS FOR GENERAL-POPULATION/UNCONTROLLED EXPOSURE TO RFR

Frequency f (MHz)	E (V/m)	H (A/m)	P_{eq}* (mW/cm^2)	Averaging Time (minutes)
0.3-1.34	614	1.63	100	30
1.34-30	824/f	2.19/f	180/f2	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100 000	--	--	1.0	30

*P_{eq} = Free-space equivalent power density

Among the major similarities and differences between the FCC (1996) and ANSI/IEEE (1992) standards are:

1) Both standards are largely based on a whole-body SAR of 4 W/kg, reduced by specific safety factors.

2) The FCC (1996) standard only covers the frequency range from 300 kHz to 100 GHz, whereas the frequency range of the ANSI/IEEE (1992) standard is from 3 kHz to 300 GHz.

3) In both standards, the lowest maximum permissible incident free-space power density for occupational/controlled exposures is 1 mW/cm2 for the frequency range 100-300 MHz, with an averaging time of 6 minutes.

4) Similarly in both standards, the lowest maximum permissible incident free-space power density for general-public/uncontrolled exposures is 0.2 mW/cm2 (reduction factor of 5) for the same frequency range, with an averaging time of 30 minutes.

5) In both standards, the MPEs for occupational/controlled exposures in the frequency range 300-1500 MHz are the same: f/300. The MPEs for the frequency range 1500-3000 MHz in the ANSI/IEEE (1992) standard are also given by f/300, rising to 10 mW/cm2 at 3.0 GHz, and remaining at that value to 300 GHz. However, the MPEs in FCC (1996) rise to only 5 mW/cm2 at 1.5 GHz and remain at that value to 100 GHz [the upper frequency limit of FCC (1996)].

6) For general-public/uncontrolled exposures in the frequency range 3000-15000 MHz [3-15 GHz], the ANSI/IEEE (1992) standard prescribes the formula f/1500, yielding 10 mW/cm2 at 15 GHz, a value also specified for the range 15-300 GHz. In the FCC (1996) standard, the formula f/1500 is applicable only in the range 300-1500 MHz, rising to 1.0 mW/cm2 at 1.5 GHz and remaining at that value to 100 GHz.

7) Contrary to the point offered in FCC (1996) about providing more protection to the general public (by use of NCRP, 1986), the averaging times in ANSI/IEEE (1992) for general-public/uncontrolled exposures in the frequency range 3.0-100 GHz are progressively shorter than 30 minutes with increasing frequency, thus rendering the MPEs of ANSI/IEEE (1992) more stringent than those

recommended in FCC (1996). At 15 GHz, for example, the total maximum permissible energy density equivalent to 5 mW/cm^2 for 30 minutes is 9 J/cm^2 (FCC, 1996), whereas for 10 mW/cm^2 for 6 minutes it is only 3.6 J/cm^2 (ANSI/IEEE, 1992). Such total-energy calculations are pertinent primarily to incident RFR in the form of very short individual pulses of extremely high peak power density. In such cases, the corresponding average power densities per pulse would be inversely proportional to the averaging time.

Formal protests about adoption of the exposure standard contained in the FCC (1996) document have been filed by various organizations, including the Department of Defense. Those protests have been directed primarily toward the absence of scientific justification for the preference in the use of the 10-year-old NCRP (1986) document over the ANSI/IEEE (1992) standard (where they differ), against the alleged improper procedures used in the adoption of the new FCC standard, and questions of jurisdiction among the federal agencies.

On December 24, 1996, the FCC released a First Memorandum Opinion and Order, FCC 96-487, extending the transition period for determining compliance with their new standard from January 1, 1997, to September 1, 1997.

1.2 DIGITAL TV MODULATION PATTERN

When RFR is used for heating, as in the case of diathermy, microwave ovens, and industrial processes such as glue curing, plastic sealing, and induction heating, modulation is unimportant. RFR used for these purposes is classified as continuous wave (CW) and is unmodulated (although inadvertent amplitude modulation can occur).

Radar systems use pulse-modulated RFR having pulse widths that are typically in the range of one to several microseconds with repetition rates of several hundreds or thousands of pulses per second. Pulse modulation is a particular type of amplitude modulation (AM), but is not often labeled as AM.

Specialized biologic research studies (e.g., calcium efflux studies, see Section 4.4.5, below) have used AM RFR with sinusoidal modulation at single frequencies such as 10, 16, 30, 60, or 120 Hz. A complete specification of this type of AM requires the carrier frequency, modulation frequency, depth of modulation, and peak envelope amplitude.

Commercial radio and television broadcasting involve AM or frequency modulation (FM) in which modulation of the carrier ("station frequency") is created by the speech, music or picture content of the program. Unlike single frequency AM used in some research, broadcast modulation contains a constantly changing assortment of frequencies. As a consequence, AM stations broadcast over a narrow range of frequencies (sidebands) centered on the original carrier frequency. The carrier is the only frequency when there is no modulation, that is, if the station's voice or music program is silent. Frequency modulation is the second form of modulation for commercial broadcasting. In this case the speech and musical frequencies are encoded as shifts in carrier frequency. Like an AM station, an FM station occupies a band of frequencies surrounding the carrier. Television signals occupy a band of frequencies in which both AM and FM modulation are used. The AM part of the signal is used for the picture information and the FM part for the sound.

Digital TV uses a form of modulation which is different from both existing forms of AM and FM because both video and audio signals are represented by a digital code. The code is expressed by eight different amplitude levels of a brief pulse which, unlike the case for radar, is followed by another pulse in a steady stream of pulses of varying amplitude. However, as is true for all other modulation schemes, DTV requires a band of frequencies adjacent to the carrier frequency. The modulation scheme is called 8-level vestigial sideband, where "vestigial sideband" refers to an engineering technique which eliminates an unnecessary sideband in order to make most efficient use of the spectrum. The rapid, nearly random sequence of shifting amplitudes has a noise-like character which is unlike the single-frequency AM used in biological research and is more like the signal generated by conventional TV. However, a prominent feature of conventional TV signals is the regular appearance of relatively strong synchronizing pulses for the raster scanning of the picture at 30 frames per second. These contribute modulations at 60 Hz and 15.75 kHz. In the case of DTV, there is a single pilot tone which occurs at a frequency of 12.9 kHz and it is at a low level compared with the total signal, that is, it adds only 0.3 dB to the total transmitted power of the DTV signal.

Based upon this comparison of modulation characteristics, DTV signals are distinct from all signal types used in health-related research. However, based on spectral and temporal properties, DTV bears resemblance to forms of RFR used in existing research. In order of decreasing degrees of resemblance, DTV resembles standard broadcast TV signals, broadcast FM signals, broadcast AM signals, CW sources, and radar. Because commercial AM radio operates at frequencies several hundred times lower than DTV, exposures near AM towers and near the Sutro DTV tower are not especially similar. It should also be noted that radar systems employ a range of frequencies including frequencies lower and higher than DTV and use a range of power levels. Traffic radar requires relatively low level signals whereas long-range military surveillance needs higher power. The various types of radar use a variety of pulse widths and repetition patterns. These features make biological and epidemiological studies of radar exposure least relevant to DTV.

1.3 DTV SERVICE EFFECTIVE RADIATED POWER

DTV service is expected to use average effective radiated powers that are below the present NTSC analog system peak power. This means that a DTV station would radiate a signal with an average effective radiated power that is about one-eighth (12 percent) of the present average power radiated by the traditional television technology. As a consequence, with introduction of DTV, public exposure to RFR due to the DTV signal alone would actually be only a fraction of the present values associated with the NTSC system. However, in view of the manner in which the FCC has decided that the DTV system shall be implemented in the U.S., an approximate 9 to 15 year period will result in which DTV signals will be broadcast simultaneously with the current NTSC signals. During this period of overlap, the additional DTV service will slightly increase ambient environmental RF fields from the television service. In terms of average RF field exposure levels, this will amount to an anticipated 12 percent increase.

2.0 INTERACTIONS OF RFR WITH BIOLOGICAL ENTITIES

The interactions of RFR incident on a biological body are dependent on the electromagnetic properties of the body's constituents and their distribution within the body. However, except in a number of species with special sensing abilities, most tissues are essentially nonmagnetic, so any effects depend primarily on the interactions of the internal electrical field component of the RFR (generated from both the incident electric and magnetic field components) with the dielectric (resistive and capacitive) properties of the body, as well as on the RFR's characteristics (its frequency, power density, polarization).

The refractive index of any material is related to its dielectric constant. RFR is reflected and refracted at boundaries between regions of differing dielectric properties, such as at the air-surface interface of a body, for the same physical reasons as those that apply to light incident at an air-glass interface. Such transmissions and reflections also occur at internal boundaries between constituents having different dielectric properties, thereby affecting the variation of electric field with internal location.

The fraction of the incident power density that enters a body undergoes progressive attenuation with depth because of energy absorption. The extent of such attenuation is termed the "penetration depth" or "skin depth." For an ideal specimen consisting of a single, uniformly distributed constituent, and with the RFR directed perpendicularly to its surface, the penetration depth is the distance into the specimen at which the power density is diminished, by absorption, to about 14% of its entrance value.

In the RFR-bioeffects literature, the energy absorbed by a body from an incident electromagnetic field is usually quantified by SAR (defined above). The local SAR at any site within a body depends on the characteristics of the incident RFR (carrier frequency, modulation, amplitudes and directions of its components) and on the properties of the body and location of the site. For bodies of complex shape and large internal spatial variations in properties, local SAR values are difficult to determine by experiment or by calculation. Instead, the whole-body SAR, representing the spatial average SAR for the body, is often used because it can be determined without information about internal variations in local SARs.

Researchers have calculated whole-body SARs for models of relatively simple geometry such as spheroids, ellipsoids, and cylinders that have weights and dimensions approximately representative of various species, including humans. Others have experimentally verified such calculations by exposing physical models in various orientations to linearly polarized plane-wave RFR and determining distributions of heat produced therein. Details of such dosimetry investigations are discussed in the Technical Report.

Many important results of theoretical and experimental investigations have been presented in four handbooks issued by the U.S. Air Force. Durney (1986), the last handbook issued, summarizes the data in previous editions and contains other pertinent information as well. Of particular interest are the plots of calculated whole-body SAR versus frequency for prolate-spheroidal models of an "average" man, woman, and 5-year-old child for exposure to 1 mW/cm^2 in three orientations.

2.1 THERMAL INTERACTIONS AND SARS

For exposure of any given model to linearly polarized plane-wave RFR, the largest value of whole-body SAR occurs when the longest dimension of that model is parallel to the electric-field component of the RFR and when the wavelength of the RFR is about 2.5 times the longest dimension of that model (or conversely, the longest dimension is 0.4 of a wavelength). The adjective "resonant" is used for that wavelength or for its corresponding frequency; at resonance, the model absorbs RFR energy much like a lossy half-wave-dipole antenna. That exposure arrangement is called the E-polarizaton. Exposures at other orientations yield lower SARs.

Specifically, the resonant frequency for the average man is about 70 MHz (when insulated from ground). At this frequency, the whole-body SAR is about 0.2 W/kg for an incident plane-wave power density of 1 mW/cm^2. This SAR is about one-sixth of his resting metabolic rate or one-twentieth to one-ninetieth of his metabolic rate when doing exercises ranging from walking to sprinting. By calculation, exposure of a man at this SAR (to 1 mW/cm^2) for, say, 1 hour would produce a mean temperature increase of about 0.2°C if

no heat-removal mechanisms were operating (conduction, convection, radiation). Actual temperature increases would be smaller with such heat-exchange mechanisms present. In addition, the compensation provided by the thermoregulatory systems of live mammals may prevent any rises in body temperature

Similarly, the resonant frequency for a prolate-spheroidal model of an average woman is about 80 MHz, and her mean SAR is about the same as for the average model man. For the model of a 5-year-old child, the resonant frequency is about 110 MHz, and the resonant SAR is about 0.3 W/kg per mW/cm^2.

By contrast, the resonant frequency for a prolate-spheroidal model of a medium rat is about 650 MHz, and the resonant whole-body SAR is about 0.8 W/kg per mW/cm^2. These values and those for other laboratory animals used in RFR-bioeffects studies are important in assessing the results of such animal studies relative to possible effects in humans.

At the Sutro Tower Digital TV transmitters' frequencies, which are above the resonant frequencies of humans, the whole-body SAR of an average adult in the E-polarization is only about 0.02 W/kg per mW/cm^2. Therefore, a 1-hour continuous exposure of an average adult to 500 MHz at, say, 0.1 mW/cm^2 would cause a theoretical temperature rise of only 0.002°C, a completely negligible change. The Sutro Tower Digital TV exposures, in publicly accessible areas, will therefore give rise to negligible temperature changes.

RFR pulses of appropriate characteristics are known to be perceived by some humans as apparent sound (the RFR-auditory effect). Pulsed RFR has also been reported to produce other effects, such as alterations of the blood-brain barrier and behavioral changes in animals. Other researchers were unable to confirm that pulsed RFR at nonthermal time-averaged levels alters the BBB or adversely affects behavior. There is no experimental evidence that the RFR-auditory effect is harmful to humans or animals nor are the Sutro Tower DTV signals capable of producing the RFR-auditory effect. Some researchers who used RFR amplitude-modulated at specific low frequencies--primarily below about 30 Hz but up to about 400 Hz--have reported biological effects from the amplitude modulation *per se*, notably the calcium-efflux effect, and have regarded those reports as evidence of possibly harmful nonthermal RFR bioeffects. It should be noted that speculations about the implications for hazards associated with altered cellular calcium have not yet been demonstrated by experiment and purported mechanisms for the calcium efflux effect remain controversial (Myers and Ross, 1981; Albert et al., 1987; Halle, 1988; Sandweiss, 1990; Adair, 1991; Prasad et al., 1991). See section 4.5.5 for additional discussion of the literature on calcium efflux and section 4.5.6 for other research on the effects of modulated RF.

2.2 NONTHERMAL INTERACTIONS AND SARS

As just shown, it is impossible that there would be a biologically significant change in body temperature as a result of exposures to the public from Sutro Tower Digital TV RFR. In the absence of any hazard from heat, nonthermal interactions remain the main focus of inquiry into potential adverse effects of Sutro Tower RFR. In past RFR research, a relatively important area of study involved modulated RFR signals. Because reported effects depended on specific forms of amplitude modulation and not overall SAR, this research was identified with potential nonthermal mechanisms of interaction. In order to use RFR for communications, the signal must be modulated, but there are many forms of modulation and these can differ greatly. Neither the type of modulation of the proposed Sutro Tower Digital TV signals (8-level vestigial side-band) nor of existing Sutro Tower TV signals (amplitude-modulated for video information

and frequency modulated for audio information) matches or closely resembles the type of modulation used in past biological research with modulated RFR.

In the context of possible nonthermal interactions, the term "local SAR" denotes the rate of energy absorption at any local site within a biological object and does not necessarily indicate that such absorption occurs with a measurable increase in temperature. Rather, it is a useful measure of the local field strength resulting from RF exposure, especially at internal field strengths too low to produce heat at biologically significant rates.

Specific absorption rates are generally unaffected by modulation. Under similar exposure conditions, the whole-body SARs obtained with amplitude-modulated (AM) RFR at any given carrier frequency and average power density are the same as those of continuous-wave (CW) RFR or frequency-modulated (FM) RFR. However, in specific laboratory research studies it may be uncertain if the experimenter assured that SARs under AM conditions were fully equivalent to CW conditions.

Adey (1993) reviewed research and theoretical ideas concerning biological effects of ELF and RF electric and magnetic fields with emphasis on mechanistic models for nonthermal interactions. The author suggested such models will establish nonlinear, nonequilibrium physical and biochemical processes as key features of the transduction of RFR signals at the plasma membranes of cells. Adey presented a model based on the observation that currents in tissues were concentrated in the space surrounding cells and thereby exposed cell membranes to a current flow along the membrane surface. This is in contrast to the transmembrane current flows associated with cell electrical activity and cell membrane ion channels. Adey reviewed previous research concerning biological effects of weak AM RFR. The cited reports from a number of laboratories were in the areas of development, central nervous system function – particularly neuroendocrine function, immune system function, cell growth regulation, tumor promotion, gene expression, and stimulated healing of fractured bone. Several ideas were given as possible mechanisms for cell detection of weak AM RFR. These included resonant interactions with ion binding, magnetically-sensitive free radical chemistry, the biochemistry of iron-containing enzymes, dark solitons, electron transfer reactions on proteins, second messenger systems in cells, and cooperative binding of calcium ions. This paper presented no experimental research data and was almost entirely non-quantitative in nature. Speculative papers of this type can be useful guides to understanding experimental results and for the design of future experiments, but can have only an indirect role in assessing risks from exposures to RFR.

2.3 RFR AND POWERLINE-FREQUENCY FIELDS

Nonionizing fields consist of various forms of electric and magnetic fields. Such fields occur both naturally, among them the earth's magnetic field and the electric fields in the atmosphere (most prominent during storms), and by electric generation for various uses. Some reports claiming deleterious effects on humans from exposure to the electric and magnetic fields present in homes from the power lines supplying electricity to the house, the fields from operating appliances within the home, and those from any nearby high-voltage power lines, have generated some concerns. A recently published report by the U.S. National Research Council (1996), which examined some 500 scientific studies, is reassuring in that it concluded that no clear, convincing evidence exists to show that residential exposures to electric and magnetic fields are a threat to human health.

In this Technical Report, only the RFR emissions from the Sutro Tower Digital TV transmitters antenna are pertinent. Nevertheless, in considering any possible bioeffects of the RFR from the Sutro Tower

Digital TV transmitters, it is important to recognize the distinction between fields at powerline frequencies and RFR at the frequencies such as those from the Sutro Tower Digital TV system.

Specifically, U.S. power sources operate at 60 Hz. The corresponding wavelength (distance from one peak of the electric field to the next peak) is more than 3,100 miles, so people near a powerline are in its induction zone (meaning at distances of only a tiny fraction of a wavelength), within which terms such as "propagation" and "radiation" do not apply. Instead, the electric and magnetic fields from such a source may induce currents in the body, and any possible effects of each field need to be considered separately.

By contrast, the Sutro Tower Digital TV system is planned for operation at frequencies about 8,330,000 - 12,230,000 times higher than 60 Hz, and the corresponding wavelengths are only about 2 - 1.3 feet. Thus, outside the boundary fence of the Sutro Tower site, people would be many wavelengths from the source, and in the region where the fields are propagating at the speed of light. People at such distances and beyond would be in the antenna's "far-field" region, in which the intensity falls off with the square of the distance (inverse-square law). In such radiation, the electric (E) and magnetic (H) vectors are at right angles to each other and to the propagation direction, and their magnitudes have a fixed numerical ratio to one another (E/H=377 ohms, "the impedance of free space"), so the intensity of the RFR can be stated in terms of the intensity of either E or H alone.

3.0 SUMMARY OF CURRENT KNOWLEDGE ABOUT RFR BIOEFFECTS

Most of the evidence for biological effects of RFR is derived from the results of experiments in which various mammals (including human volunteers) and nonmammals (e.g., birds, insects, bacteria, other microorganisms) were exposed to RFR and specific biological effects were sought. Also studied were tissues such as excised organs and neurons, blood, single cells, cultures of cells, and subcellular components kept alive artificially. Evidence is also derived from epidemiologic studies of the general population and studies of those occupationally exposed to RFR. However, such results are indirect or inferential because the RFR-exposure levels and their durations are usually not known with any degree of accuracy. Nonetheless, because of the particular relevance given studies of human beings, the discussion below treats a number of epidemiological studies with a moderate degree of technical detail.

3.1 EPIDEMIOLOGIC/OCCUPATIONAL STUDIES

Among the early epidemiologic studies done in Eastern European countries on possible detrimental effects associated with exposure to RFR were those of Pazderová (1971), Pazderová et al. (1974), Klimkova-Deutschova (1974), Kalyada et al. (1974), Sadchikova (1974), and Siekierzynski (1974). In general, mixed findings were reported, including symptomatology such as "asthenic syndrome" and "microwave sickness" that were not generally recognized or supported by subsequent epidemiologic studies in Western countries.

Robinette and Silverman (1977) examined the decedence records of 19,965 Navy veterans of the Korean War, classified those with specific titles as having had significant occupational exposure to RFR, and compared them with the decedence records of 20,726 Naval men who, by their titles, presumably had little occupational exposure to RFR. The data showed no statistically significant differences between exposed and control groups in the deaths from all disease, respectively 1.6% and 1.5%, both of which were significantly lower than for the age-specific general population.

Lilienfeld et al. (1978) conducted a study of the health of the U.S. personnel assigned to the Moscow embassy during the period from 1953 to 1976 during which time the embassy was irradiated by RFR at varying intensities (5 to 18 $\mu W/cm^2$) and frequencies (0.6 to 9.5 GHz). The study was undertaken in response to questions about possible health effects from prolonged exposures to these low-level emissions. The authors, after expending considerable efforts in tracing employees and dependents, identified 1,827 employees and 1,228 dependents as having been at the Moscow embassy. The control population consisted of 2,561 employees and 2,072 dependents who had been assigned to the embassies and consulates in various Eastern European countries during the same period. Periodic tests for RFR at those control sites showed only background levels of 1 $\mu W/cm^2$.

Based on available medical records and returned health questionnaires, no discernible differences were found between Moscow and control groups in total mortality or mortality from specific causes, nor were there any mortality differences between the Moscow and control groups of adults or dependent children. The mortality rates for the Moscow and control groups were lower than for the U.S. population at large, except for cancer-related deaths, which were fractionally higher among Moscow-female (8 of 11 deaths) than control-female employees (14 of 31 deaths). Regarding the latter, the authors remarked: "It is difficult to attach any significance to the relatively proportion of cancer deaths in females because of the small numbers of deaths involved."

In one of two studies, Lester and Moore (1982a) endeavored to establish an association between mortality from cancer and proximity of the decedents to Air Force bases in the United States. The authors' assumption was that persons living in census tracts closest to the bases were most exposed to RFR from military radar. An accounting was made of shielding from the radar that might have occurred because of variations in terrain. The authors found a correlation between cancer mortality and radar exposure. Polson and Merritt (1985) found this study to be flawed by incorrect assembly of the data base. When they independently assembled the data base correctly and analyzed it, they found that the cancer incidence for either sex in counties that had Air Force bases did not significantly differ from the incidence in counties that did not have Air Force bases.

In the other study, Lester and Moore (1982b) sought to determine whether there was a geographic pattern of cancer incidence in the city of Wichita, Kansas which included a number of Air Force bases with operational radar. The authors sought to determine whether specific sources of RFR could be identified and related to any such pattern. They derived a formula purported to associate RF exposure with cancer incidence, which was based on erroneous assumptions and which yielded levels having no relation to actual exposure levels. Thus, their finding of an association of cancer incidence in Wichita and exposure to the RFR from the two airports was unwarranted.

Hamburger et al. (1983) sought to determine whether physical therapists might have adverse health effects from exposures to emissions from various diathermy units during patient treatments. They analyzed the responses from male members of the American Physical Therapy Association (ACTA) to a mailed questionnaire on their history of treatments of patient with microwave and shortwave diathermy. Also considered were the use of infrared and ultrasound diathermy.

Three mailings of questionnaires yielded a population sample consisting of 3004 respondents. Those respondents were divided into subgroups according to exposure across and within the energies of the modalities above. However, the smallness of several groups necessitated merging them into other groups to ensure more meaningful statistical results, yielding nine subgroups. The reported prevalence rates for the

entire cohort were below the rates for the general population, and no one subgroup showed markedly higher rates relative to the total rates. When the authors recast and analyzed new subgroups based on those who used more than one modality (a method that resulted in double-counting of some subjects), they reported a significant association of heart disease with short-wave exposure. However, that result pertained to only 4 of 90 contingency tables, rendering the finding no better than chance.

Burr and Hoiberg (1988) compared the hospitalization rates of 1063 Naval pilots, who primarily flew "electronically modified aircraft", with an age-matched control group of 2126 pilots who flew other types of aircraft. A major difference between the two groups was that the pilots of the test group were presumed to be subjected to greater potential risks from exposure to ionizing radiation (such as at high altitudes) and nonionizing radiation (e.g., from onboard antennas, electronic equipment) than the control group. Although there were significant differences between the groups in mortality and hospitalization rates, neither group had any hospitalizations for conditions related to ionizing or nonionizing radiation.

Djordjevic et al. (1979) did a clinical study of 322 radar workers who had been occupationally exposed for 5 to 10 years to pulsed microwaves at average power densities less than 5 mW/cm^2 in Yugoslavia, with 220 controls. The numbers and percentages of the exposed and control subjects diagnosed for various ailments were tabulated. The most prevalent diagnosis was for "Neurocirculatory Asthenia" in 15.2% of the exposed subjects and 13.2% of the control subjects, a nonsignificant difference. Nonsignificant differences were also observed in electrocardiograms (EKGs), blood tests, and various subjective complaints. The authors concluded that prolonged occupational exposure to microwaves did not affect the health of the radar workers.

In a later study, Djordjevic et al. (1983) presented the results of a 15-year clinical study of 500 workers occupationally exposed to RFR in the centimeter-wave band from high-power radars for about 2 hours daily at levels usually less than 5 mW/cm^2, with 350 controls for comparison. Most prevalent was the diagnosis "Neurovegetative Dystonia", but the authors noted that none of the differences between the groups was significant. However, the absence of statistical data in the two Djordjevic et al. papers diminishes the credibility of those negative findings. Also, neither "Neurocirculatory Asthenia" nor "Neurovegetative Dystonia," the major diagnoses therein, are disorders recognized in Western medicine.

In a detailed report, Milham (1983) analyzed the information on age and year of death in Washington State of 429,926 male decedents for 1950-1979 and 25,066 female decedents for 1974-1979, and presented cause-of-death analyses (160 causes) for 219 male and 51 female occupational categories. The author used the "proportional mortality ratio" (PMR), for which the sum of the PMRs for all occupations considered must be 100%. Use of the PMR is questionable because it does not directly measure the risk or probability of a person in a population dying from a specific disease as does a cause-specific mortality rate. More commonly used is the "standardized mortality ratio" (SMR), because it represents the percentage of actual deaths for each cause relative to the expected number of deaths from that cause, independent of any other SMR.

Among the mortality patterns, those for the workers in 11 occupations presumed to have been occupationally exposed to magnetic and/or electrical fields were analyzed, and the PMRs for "acute leukemia" and "all leukemia" were calculated, for a total of 22 categories. For those 22 categories, 3 PMRs were high at the 1% significance level and 2 PMRs were high at the 5% level. Of the remaining 17 PMRs, 13 were elevated, 3 were depressed, 1 was unchanged, but none was statistically significant

Because the PMRs must sum to 100%, the 5 significantly high PMRs may reflect abnormally low PMRs in 3 of the 11 occupations, a point explicitly recognized by the author. Thus, little credence can be given to the author's claim that the higher PMRs for acute leukemia and for all leukemia are associated with exposure to electric and magnetic fields.

Szmigielski et al. (1982) presented epidemiological data from workers in the Polish military who had RF exposure in the period 1971-1980 with the finding of about a three-fold enhanced risk especially for cancers of the hematopoietic system. Morbidity rates were found strongly correlated with exposure duration and tumors of the same type occurred earlier among RFR exposed groups. These observations were reported more fully for a cohort of military workers from 1971 to 1985 by Szmigielski (1996) who found an odds ratio of 2.07 (95% CI = 1.12-3.58) for all cancer mortality for workers in all age-groups who were exposed to radiofrequency and microwave energy. Although the number of cases was sometimes small, the odds ratio for various specific tumor types were strongly elevated. The odds ratio for hematopoietic and lymphatic tumors was 6.31 (95% CI = 3.12-14.32), with particularly high ratios for chronic myelocytic leukemia (odds ratio 13.9, 95% CI = 6.72-22.12), myoblastic leukemia (odds ratio 8.62, 95% CI = 3.54-13.67) and non-Hodgkin's lymphoma (odds ratio 5.82, 95% CI = 2.11-9.74). Odds ratios for colorectal cancer and cancer of the esophagus and stomach were elevated to statistically significant levels of 3.19 (95% CI = 1.54-6.18) and 3.24 (95% CI = 1.85-5.06), respectively. The results of this retrospective study of a large occupational cohort are striking for the number of hematopoietic malignancies for which the odds ratios were elevated with strong statistical reliability. Interpretation of the data is limited by the relatively scant information on exposure. It would be difficult, if not impossible, to assess individual exposures from measurements made at several military posts. The author reports that although some military sites had exposures to pulse-modulated RFR at intensities of 0.2 to 0.6 mW/cm^2, and some occasionally exceeded 0.6 mW/cm^2, 80 to 85% of all military posts were exposed to pulsed fields below 0.2 mW/cm^2. There was only "a marginal" exposure to CW fields. It is important to note that Szmigielski reported that brief periods of overexposure were quite frequent and that it was not possible to control for exposures to solvents, a potential confounding cause of hematopoietic cancers.

Milham (1985, 1988a) comprised two studies of the records of deceased amateur radio operators who had been members of the American Radio Relay League (ARRL) in Washington State and California, the "silent keys" compiled in the ARRL publication QST. In the first study, information was obtained for a total of 1,691 decedents in the two states. Statistical analysis yielded a PMR of 281 for acute, chronic, and unspecified myelogenous leukemia (16 deaths found versus 5.7 deaths expected, $p<0.01$); the PMR for monocytotic leukemia was only 77 (well below 100), and was 0 for lymphatic leukemia. Thus, the PMR for all leukemias was 191 (24 deaths versus 12.6 expected, $p<0.01$).

In the second study, Milham extracted the names of 67,829 males in Washington State and California listed as licensed in the 1984 U.S. Federal Communications Commission Amateur Radio Station and/or Operator file. The list was searched for deaths during a 5-year period, which yielded a total of 2,485 decedents. In this study, the author did use the calculated SMRs. Because the total expected deaths in both states from all causes was 3,479, the 2,485 deaths of licensees yielded an SMR of 71, with a 95% confidence interval of 69-74, showing significantly lower death rates for licensees than for the general population. This was also true for the categories "all circulatory diseases" (which yielded the largest number of deaths) and "all malignant neoplasms". The only subcategory of malignant neoplasms that yielded an SMR that significantly exceeded 100 was "other lymphatic tissue", for which there were 43 deaths versus 27 expected; the SMR was 162, with a 95% confidence interval of 117-218. The subcategory "leukemia" had 36 deaths versus 29 expected, for an SMR of 124, but the 95% confidence interval was 87-172, rendering