INADVERTENT WEATHER MODIFICATION POTENTIALS DUE TO MICROWAVE TRANSMISSIONS AND THE THERMAL HEATING AT SPS RECTENNA SITES

by

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The anticipated impact on the weather of the heat dissipated by the rectenna, and the heating due to the attenuation of the microwave beam in the atmosphere are considered separately in this report. It is emphasized that our conclusions are preliminary and additional research work on this topic is required.

I. Influence of heat dissipated by the rectenna on the atmosphere

A. Energy impact of the rectenna as compared with other natural and artificial sources

Hanna and Swisher (1971), and Hanna and Gifford (1975) present estimates of energy released per second for various natural and man-made atmospheric phenomena. Some of these values are reproduced below:

<table>
<thead>
<tr>
<th>Event</th>
<th>Energy Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average flux per unit area of solar energy</td>
<td>3400 watts/m²</td>
</tr>
<tr>
<td>Thunderstorm kinetic energy production</td>
<td>1000 watts/m²</td>
</tr>
<tr>
<td>Latent heat release of 1 cm of rain per 30 min</td>
<td>50000 watts/m²</td>
</tr>
<tr>
<td>Evaporation from a lake</td>
<td>100000 watts/m²</td>
</tr>
<tr>
<td>Suburban area assuming 400 persons/km² and a heating rate of 10⁴ watts per capita</td>
<td>4 watts/m²</td>
</tr>
<tr>
<td>Super energy center or city</td>
<td>10000 watts/m²</td>
</tr>
<tr>
<td>Agroindustrial complex</td>
<td>10000 watts/m²</td>
</tr>
<tr>
<td>Large nuclear power park</td>
<td>10000 watts/m²</td>
</tr>
<tr>
<td>Australian bushfire</td>
<td>10000 watts/m²</td>
</tr>
</tbody>
</table>

(1) Our calculations suggest this value should be 10000 watt/m².
The features listed in numbers 2 through 9 are on the same spatial scale as the rectenna ($\sim 10^2 \text{km}^2$). The energy release rate is, of course, variable depending on ambient atmospheric conditions (and in the case of 5-8, on man's activities as well). Some of these cases (such as #8) involve latent as well as sensible heat input. The man-induced phenomena, #5-8, are expected to be the least variable.

Additional estimates of energy release are available from other sources. Rosenbloom (1974) gives a daily average of 145 watts/m$^2$ for the undepleted solar radiation (undepleted by atmospheric attenuation) received on a horizontal surface at 40°N in January. Mahrer and Pielke (1976) obtain values of energy released per second due to turbulent surface heat flux of up to 400 watts/m$^2$ in their numerical simulation of the air flow over Barbados. This magnitude of heating causes a significant alteration of the low level wind and thermal profile, along with the development of convergence downwind from the island. Kaimal, et.al. (1976) obtained energy release rates on the order of 100 watts/m$^2$ over northwest Minnesota during a typical (as they defined it) day.

The total energy release due to these phenomena must also be considered. Using the figures provided in Hanna and Swisher, and Rosenbloom, the following estimates of total energy release per second are given. (The approximate horizontal areas of some of the phenomena are given in parenthesis.)
Table II

1. global solar energy absorbed per second by the atmosphere
   1.16 x 10^{16} watts

2. solar energy input at the top of the atmosphere over the U.S. during January
   8.7 x 10^{14} watts

3. latent heat release of 1 cm of rain per 30 min (∼10^2 km^2)
   1.0 x 10^{11} watts

4. large power park (∼10^2 km^2)
   10^{11} watts

5. Australian bushfire (∼10^2 km^2)
   10^{10} watts

6. agroindustrial complex (∼10^2 km^2)
   10^{10} watts

7. super energy center or city (∼10^2 km^2)
   10^{11} watts

8. thunderstorm kinetic energy production (∼10^2 km^2)
   10^{10} watts

9. evaporation from a lake (∼10^2 km^2)
   2.4 x 10^{11} watts

10. surface sensible heat flux over Barbados (∼600 km^2)
    4 x 10^8 watts

11. suburban area (∼10^2 km^2)

The total energy released per unit time and the energy released per unit time per unit area of the phenomena listed in Tables 1 and 2 can be used to compare with the heat dissipation of the rectenna. The engineering estimates (Work Statement) give a heat dissipation of 750 x 10^6 watts per rectenna or 7.5 watts m^{-2}, assuming an area of each rectenna of 100 km^2. For a total of 224 rectenna, the total rate of heat dissipation is 1.68 x 10^{11} watts.

1. Global solar heating vs total rectenna heat dissipation
   ∼10^{16} watts vs 10^{11} watts

For 224 sites the heat output of the rectenna compared with the global solar energy absorbed per second by the atmosphere is 5 orders of magnitude less. We conclude that, for the number of rectenna proposed (224), there would be no detectable effect on the global weather (where detectable implies "within the constraints of our ability to monitor such a small thermal forcing on a global scale"). On this scale, doubling or even tripling
the heat dissipation for the same number of rectennas would not alter our conclusion.

2. National solar heating in the winter vs total rectenna heating dissipation

The solar energy input (in the absence of atmospheric attenuation and reflection) over the United States in January is $8.7 \times 10^{14}$ watts (Table II), or over three orders of magnitude greater than the heat dissipation of the rectennas. Although the relative contribution of the rectennas to the heating over the United States is greater, there is still over three orders of magnitude difference in the energy input. Therefore we conclude that, on the scale of the United States (synoptic scale atmospheric features), 224 rectennas would produce no detectable atmospheric effects (even if the heat dissipation of each rectenna were doubled or tripled).

3. Mesoscale heat input vs rectenna heating

The features listed as #3-5, 7 and 10 in Table II have roughly the same horizontal scales as one rectenna, but are comparable to the total heat output of all 224 rectennas brought together at one location. Nevertheless, we can infer the response of the atmosphere to heat dissipation from the rectenna based on observations of existing mesoscale features.

a) energy release of 1000 watts m$^{-2}$ over 100 km$^2$

Hanna and Gifford have shown that this rate of energy release can produce a strong and significant influence on local weather including the development of intense vortices such as fire whirlwinds in bush fires.
b) energy release of $100 \text{ watts m}^{-2} \text{ over } 100 \text{ km}^2$

This rate of energy release is on the order of that found over heated land during the summer, as well as over urban areas. The influence of a city (Metromex Update, 1976) has been shown to have a significant effect on thunderstorm activity, as well as on other meteorological parameters, although the relative importance of anthropogenic releases of moisture and pollutants could not be separated from the sensible heating. With a heating rate of this order, Mahrer and Pielke (1976) found the velocity and thermodynamic fields over Barbados are substantially perturbed from the large-scale state, which leads to a suppression of showers over the island and an enhancement downstream. Clearly, heat dissipation by the rectenna at this rate would significantly alter the local weather.

(c) energy release of $10 \text{ watts m}^{-2} \text{ over } 100 \text{ km}^2$

Hanna and Swisher (1971) give an estimate of $4 \text{ watts m}^{-2}$ for the heat dissipation of a suburban area. Although no quantitative studies of the influence of a suburban area on local weather have been performed, heating of this magnitude would have less effect than on urban area, as discussed under b) above.

d) qualitative estimates of the effect of heat dissipation

It can be shown that if

i) the energy input is constant and is available only to heat the atmospheric layer below an inversion,

ii) the ambient atmospheric lapse rate, $\gamma$, is stable and linear with height,

iii) there is no mixing from above the inversion nor
through lateral sides perpendicular to the rectenna, 

iv) the initial height of the mixed layer, \( h \), is zero; then the depth of a mixed layer, after a specified time, can be expressed as 

\[
h^2 = \frac{2E}{\rho C_p \left( \gamma - \gamma_d \right)}.
\]

where \( E \) is the energy input and \( \gamma_d \) is the dry adiabatic lapse rate \((-1^\circ C/100 \text{ m})\). This model, although a gross simplification, is used only to estimate the possible worse impact of a given heating.

If we use the three energy input rates under (a)-(c) above along with an ambient atmospheric lapse rate of \(+5^\circ C/100 \text{ m}\) (temperature inversion) then, under the conditions specified in (i)-(iv), we obtain the following values of \( h \) and surface temperature change, \( \Delta T_o \), after \( 10^5 \) sec \((\sim 1 \text{ day})\).

<table>
<thead>
<tr>
<th>( E ) (watts/m(^2))</th>
<th>( h ) (meters)</th>
<th>( \Delta T_o ) ((^\circ C))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>183</td>
<td>9.5</td>
</tr>
<tr>
<td>100</td>
<td>577</td>
<td>28.9</td>
</tr>
<tr>
<td>1000</td>
<td>1830</td>
<td>91.5</td>
</tr>
</tbody>
</table>

These values of heating would be significant in terms of local weather and appear to contradict the expected negligible effect implied under (c) of this section, for a heating rate of 10 watts/m\(^2\).

It is likely, however, that mixing by horizontal advection the development of dynamic circulations would disperse this heat over an area significantly larger than the rectenna. For the case of 10 watts/m\(^2\), for instance, a constant horizontal velocity of only 1 m/sec without any horizontal mixing would
move $10^3$ km$^2$ of air over the rectenna every $10^5$ seconds (an area equal to 10 times that of an individual rectenna). With air taking $10^4$ seconds to make a transit of the rectenna, the mixed layer (by this simple model) would grow 57 m with a temperature change at the surface of about 2.5°C. Dynamic circulations which would develop as a result of this heating, and lateral and vertical mixing from above the inversion should reduce the magnitude of surface heating even more. Other heat losses such as heat conduction into the ground as well as radiative heat dissipation would further act to reduce the temperature differential.

The simple analytic analysis presented here suggests that even with energy inputs as small as 10 watts/m$^2$, significant effects can result under certain situations. The available observational evidence, however, suggests that heating of this magnitude rarely, if ever, causes a significant meteorological effect.

Our conclusion from the results discussed in (a)-(d) is that simple analytic estimates of the influences of heat dissipation by the rectenna on local weather are not adequate to estimate the range of possible atmospheric effects. We recommend the utilization of non-linear mesoscale and microscale atmospheric models to study the perturbation of ambient atmospheric conditions for specified heat dissipations. An accurate surface heat budget and long-wave radiative flux divergence parameterization must be included. Specific observational case study analysis should also be undertaken to verify the model results. A scientific under-
standing is required to explain the apparent discrepancy between the observations, which show a negligible influence of 4 watts/m² on local weather, and the analytic estimates which suggest a possible significant impact under certain conditions. In particular, it is essential to show that heat dissipation of this order is or is not important under certain specific atmospheric conditions. If the effect is shown to be important the magnitude must be clearly described as well as the atmospheric condition under which the effect is encountered.

Based on these estimates we conclude that the heat dissipation due to the absorption and conversion of the microwave beam to electric power should have about the same influence as a suburban area, and should, therefore, be small compared with other man-made installations. However, our analytical treatment suggests that, under certain atmospheric conditions, the effect on the atmosphere on a local convective scale can be considerable. Because of the non-linear nature of the problem we urge that a careful analysis using both numerical models and observational input be carried out to resolve this question. The direct heating of the rectenna by the sun as well as its capability to radiate and conduct heat during the day and night would, without proper design, amplify the above possibility of serious local impact upon the atmosphere.

The partitioning of the heat energy of the rectenna is important in estimating its effect on the local weather. Only the turbulent heat flux and long-wave radiative heating from the rectenna will be directly involved in the development of local
weather anomalies. Some of this heat will be conducted into the ground, whereas some will be radiated to space. The relative magnitude of these last two effects will depend on the overlying thermal and moisture stratification. A thermally stable and moist environment, for instance, will cause a proportionately greater amount of heat conduction into the ground and a proportionately larger radiation heating of the atmosphere above the rectenna, as compared with a thermally unstable, dry ambient atmosphere.

B. Possible influences of the rectenna on the meso- and microscale

As opposed to several of the other sources of energy input, such as the power park, urban area, etc., the rectenna inputs only sensible heat (except for a small amount of additional water vaporization when wet due to a higher equilibrium temperature than its surroundings). No large amounts of latent heat are involved, nor are particular materials released into the atmosphere during its operation.

Although the heat dissipation due to the absorption of the microwave beam is relatively small under most situations compared with other man-made features, as we have already discussed, an option exists for accentuating or minimizing the sensible heating (or cooling) of the rectenna by adjusting its albedo along with the thermal characteristics of the structure. Significant meso- and microscale meteorological effects could be created or minimized through the deliberate design of the equipment.
The possible influences of these effects on the lower atmosphere above and downwind of the rectenna (hereafter referred to as the vicinity of the rectenna) are given below. Without actually modelling or observing the airflow perturbation by the rectennas, the quantitative evaluation of its effect cannot be determined.

1. The velocity profile in the vicinity of the rectenna will be altered due to changes in surface roughness and surface layer stability relative to the original ground characteristics. At a given level, an aerodynamically rougher surface tends to give slower velocities, whereas greater instability near the surface may produce higher or lower velocities depending upon the sign and magnitude of the vertical shear of the horizontal wind.

2. Heating of the air near the ground by the rectenna will cause localized convergence over itself during light winds, and downwind when the flow is stronger. The intensity of convergence will depend on the differential temperature gradient between the rectenna and its surroundings. With certain velocity fields and thermodynamic stratification, sufficiently intense convergence could produce a preferred area for shower and thunderstorm development.

3. Changes in the thermodynamic and momentum structure near the rectenna will alter the soil characteristics below the rectenna. Evaporation of rain and snow, and the melting of snow will be affected by the changed environment.

4. The change in the albedo of the rectenna to visible radiation will likely produce a more significant effect than the
heat dissipation unless care is taken to mimic the natural reflective characteristic of the terrain. A rectenna which is completely reflective to visible light, for example, could be made cooler than the surrounding terrain during the day despite the heat dissipation from the electrical generation. On the other hand, a non-reflective rectenna could significantly accentuate the local heating up to the level of several hundred watts/m$^2$ of heat dissipation for cloudless skies.

5. The thermal characteristics of the rectenna will determine the rate of long-wave radiative cooling during the night and day. A structure with high heat capacity, for example, would permit more storage of heat in the rectenna, rather than in the ground, possibly facilitating a more rapid loss of this heat to the atmosphere and space if the conduction of heat in the material is high. Alternatively, the absorbed heat could be removed (e.g. in the form of heated water).

It can be concluded from this summary that the changes in the natural terrain by the different thermal characteristics of the rectenna material such as its albedo, heat capacity, conductivity, along with its altered aerodynamic roughness can be up to an order of magnitude more important than the heat dissipation generated by the conversion to electric power. Indeed it is probably desirable to minimize the effect of the rectenna using the properties of its structural materials.

C. Possible positive benefits of the rectenna

As stated above, substantial alterations of the local weather by the rectenna could be derived from its physical pre-
sence and, to a lesser degree, by the microwave heating (providing it is on the order of 4 watts/m² over the area specified for a rectenna). Some of the positive benefits that could be attained by accentuating the sensible heating include:

1. The positioning of the rectenna upwind of an agricultural region to enhance rainfall (see Black, 1963) for a proposal to modify local weather by asphalt coating of a specified ground area.

2. Higher temperatures under the rectenna, and between component units could be used to accelerate composting of organic material for fertilizer.

3. A sufficient heat release could penetrate an overlying thermal inversion and aid in the evacuation of pollutants from a region. Neiberger (1957) estimates that $1.4 \times 10^{10}$ ergs cm⁻² would be needed to eliminate a typical Los Angeles smog inversion.

D. Ways to minimize the influence of the rectenna

1. The albedo of the rectenna for visible light could be adjusted to compensate for the heat gained by the electric power generation.

2. The physical characteristics of the rectenna could be adjusted to mimic, as closely as possible, the natural terrain characteristics in the area.

E. Possible negative effects of the rectenna

Because of the relatively small heat dissipation of the rectenna, undesirable negative effects might occur only through a failure to properly minimize the alteration in the natural terrain caused by the building of the structure (i.e. **
changes in albedo, etc.). The following effects are possible with an improperly designed rectenna.

1. A preferential development of showers and thunderstorms downwind of the rectenna could be undesirable depending on economic use of that area. The tendency of developing this type of precipitation would be greatest in regions (such as the southeast United States) where a conditionally unstable atmosphere occurs most frequently. The preferential development of snow showers downwind from the rectennas along the lee shores of the Great Lakes might cause a problem depending on the use of the land (a negative benefit for a highway, but positive for a ski slope).

2. At certain sun angles, an increased albedo of the rectenna to compensate for the microwave heating, might cause excessive reflection of light.

F. Recommendation for Part I

The heat input due to the microwave appears comparatively negligible on the global and regional scale. The effects of the rectenna structure and, to a lesser extent, of the microwave heat dissipation on the local weather could be substantial however, unless care is taken in the design of the rectenna to minimize its influence. In order to quantitize the effect of replacing natural terrain with the rectenna, it is recommended the following two steps be taken:

1. The mathematical simulation of the airflow over rectenna for a variety of climatological conditions would be an essential step in establishing its influence on local circulations
Computer costs on the order of $10,000 would probably be sufficient to complete this task using existing mesoscale modeling techniques, providing some estimate of the thermal and roughness characteristics of the rectenna could be made.

2. The building of a prototype rectenna or part of a rectenna in regions where its effect is expected to be a maximum, would be a valuable method to verify and to provide inputs to the mathematical model, as well as to observe the atmosphere's response to this deliberate modification. In particular, it would be valuable if not essential, to determine the actual temperature differential \((\text{rectenna surface } T - \text{natural surface } T)\) under varying atmospheric conditions (velocity, temperature and moisture stratification). It would also be important to measure the changes in the horizontal velocity field over the rectenna compared to the surroundings for varying atmospheric conditions.

II. Influence of microwave transmission on the troposphere

The important possible influence of a concentrated microwave transmission through the atmosphere is absorption of the beam along any part of the path length, which will cause localized heating. Since the decibel level, \(n\), is equal to

\[
\begin{align*}
n &= 10 \log_{10} \frac{I_2}{I_1},
\end{align*}
\]

where \(I_1\) is a nominal value of power flux, generally chosen as \(10^{-3}\) watts cm\(^{-2}\) and \(I_2\) is the input power flux, it is possible to compute an expected temperature change rate assuming a known attenuation in the atmosphere. This rate of temperature change
is given as

$$\frac{\delta T}{\delta t} = \frac{\delta I_2}{\delta d}$$

where \( \rho \) is the density of air, \( C_p \) is the heat capacity of air at constant pressure, \( \frac{\delta T}{\delta t} \) is the rate of temperature change and \( \frac{\delta I_2}{\delta d} \) is the attenuation per unit cross section over a path length \( \delta d \). The equivalent attenuation in decibels can be expressed as

$$I_2$$

(3)

Using the maximum allowable power density at the ionosphere of \( 23 \times 10^{-3} \) watts cm\(^{-2} \), as listed in the Summary Report, the required attenuation to produce a certain rate of temperature change are given in Table III.

Rates of temperature changes of \( 10^{-2} \)°C/day or smaller would be expected to have no noticeable effect on the atmosphere (even over long time periods because of the normal atmospheric advection and mixing of air) while a value as large as 1°C/day could have substantial effect on weather if this energy was not dispersed.

Table III

<table>
<thead>
<tr>
<th>( \frac{\delta T}{\delta t} ) (°C/10^9 sec)</th>
<th>( \delta I_2 ) ergs/sec cm^3</th>
<th>( \delta n/\delta d ) decibels/km</th>
<th>total release for 224 microwave beams (watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 10^{-3} )</td>
<td>( 10^{-4} )</td>
<td>.000189</td>
<td>( 2.24 \times 10^9 )</td>
</tr>
<tr>
<td>( 10^{-2} )</td>
<td>( 10^{-3} )</td>
<td>.001888</td>
<td>( 2.24 \times 10^{10} )</td>
</tr>
<tr>
<td>( 10^{-1} )</td>
<td>( 10^{-2} )</td>
<td>.0189</td>
<td>( 2.24 \times 10^{11} )</td>
</tr>
<tr>
<td>1</td>
<td>( 10^{-1} )</td>
<td>.193</td>
<td>( 2.24 \times 10^{12} )</td>
</tr>
</tbody>
</table>
In the following sections we will report on expected attenuation for various states of the troposphere. Particular emphases will be given for a microwave beam of 12 cm, as currently planned; however, some figures will be presented illustrating the attenuation at different frequencies. The path length of the beam through the troposphere will be on the order of 10 km.

A. Attenuation due to gases

Figure 1 (from Blake, 1970) illustrates the expected attenuation of electromagnetic radiation by oxygen and water vapor as a function of frequency for various beam angles and for a two way transit. The proposed geostationary microwave beam would, of course, travel only once through the atmosphere and would have a nearly vertical beam angle (near 90° in the Figure). As seen in the Figure, the chosen frequency of $2.45 \times 10^9$ Hz for this beam angle is not even shown on the graph. Therefore the beam would be expected to attenuate less than 0.005 dB/km (assuming a 10 km path length of the main region of the oxygen-water vapor portion of the atmosphere). As seen in Table I, this would be expected to produce a rate of temperature increase of about $0.5 \times 10^{-1}$°C/day.

Bean, Dutton and Warner (1970) give additional information concerning gaseous attenuation in the atmosphere. Two of their Figures, reproduced here as Figures 2 and 3, illustrate the absorption at Bismarck, North Dakota and Washington, D.C. to heights up to 75,000 feet for representative February and August soundings. As evident in the Figures, there is about a 0.004 dB/km
Fig. 1 Absorption loss for two-way transit of the entire troposphere, at various elevation angles, calculated by using the Van Vleck theory for oxygen and water-vapor absorption. Ray paths are computed for the CRFL exponential reference atmosphere, $N_r = 313$. The pressure-temperature profile is based on ICAO standard atmosphere. Surface water-vapor content is 7.5 g/m². Approximation is employed between 45 and 75 GHz (oxygen-resonance region). (From Ref. 13.)
Fig. 3 Gaseous atmospheric absorption from the surface to 75,000 ft: Bismarck, N.Dak.
to .006 db/km attenuation near sea level decreasing to approximately .00014 db/km at 40,000 feet for a 12 cm microwave.

Bean, et.al. also give gaseous atmospheric absorption for elevations greater than 75,000 feet (Figure 4). For a 12 cm microwave, the values range from about .000015 db/km at 75,000 feet to .0000001 db/km by 130,000 feet.

From these values of attenuation, it appears the maximum rate of temperature change is near the surface and is less than .05°C/day. Therefore, since normal atmospheric mixing and advection would quickly disperse this heat, our conclusion is that microwave heating of the lower atmosphere through gaseous absorption is negligible.

B. Attenuation due to clouds, rain, fog, snow, hail and other particulate material

Bean, et.al. report attenuation of a 10 cm microwave of .02, .004 and .001 db/km at 0°C for visibilities of 30 m, 90 m and 300 m, respectively in liquid fogs and clouds. They report that for the purpose of establishing attenuation, visibility is a good indicator of liquid water content. At temperatures of 15° and 25°C the attenuation should be multiplied by 0.6 and 0.4.

Attenuations as high as .0481 db/km are estimated in rain, for a wavelength of 10 cm, when the precipitation rate is 150 mm/hr and the ambient air temperature is 13°C. Table IV, (after Bean, et.al.), lists attenuations for other precipitation rates and for several wavelengths.
Snow and hail, in the completely frozen state, is reported by Bean, et al. to have a much smaller attenuation than rain of the same amount. (In the case of hail they report the attenuation as $1/100$ that of an equivalent amount of rain. However, when the snow or hail becomes partially wetted, the attenuation can increase markedly. For wavelengths of 1 and they report that when 10 to 20 percent of the ice has melted, the attenuation can be twice as large as completely melted hydrometeors. No information was found to indicate whether or not this effect also occurs at or near the 12 cm wavelength.

Figure 5, also reproduced from Bean, et al., shows the expected attenuation for three different frequencies. Since the planned frequency is less than indicated on the Figure, the expected attenuation must lie to the right of the 4 GHz line. Thus, from this Figure, with the extreme rainfall rate of 10 inches/hr, the attenuation would be less than .4 db/km.

Little material has been found concerning the attenuation of the microwave beam by suspended particulates. Bean, et al. claim that, for conventional radar usage, attenuation by dust, smoke and smog particles can be ignored because their dielectric constants are small relative to water drops. They do not, however, answer the question as to the absorption properties of particulates when they go into solution with the water.

The estimates of attenuation provided here suggest that clouds and fogs could, at most, warm at rates up to several tenths of a degree Celsius per day. The largest warming is for the clouds with the larger liquid water contents. This amount of heating, although larger than due to gaseous
### Table 1: Attenuation in Decibels per Kilometer for Different Rates of Rain Precipitation at Temperature 15°C

<table>
<thead>
<tr>
<th>Precipitation rate, p, mm/hr</th>
<th>Wavelength λ, cm</th>
<th>1.0</th>
<th>1.25</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>3.2</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.180</td>
<td>0.160</td>
<td>0.218</td>
<td>0.239</td>
<td>0.259</td>
<td>0.280</td>
<td>0.297</td>
<td>0.316</td>
</tr>
<tr>
<td>1.0</td>
<td>0.300</td>
<td>0.299</td>
<td>0.299</td>
<td>0.302</td>
<td>0.305</td>
<td>0.309</td>
<td>0.312</td>
<td>0.315</td>
</tr>
<tr>
<td>2.5</td>
<td>0.353</td>
<td>0.353</td>
<td>0.353</td>
<td>0.353</td>
<td>0.353</td>
<td>0.353</td>
<td>0.353</td>
<td>0.353</td>
</tr>
<tr>
<td>5.0</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
</tr>
<tr>
<td>10.0</td>
<td>0.470</td>
<td>0.470</td>
<td>0.470</td>
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<td>0.470</td>
<td>0.470</td>
<td>0.470</td>
</tr>
<tr>
<td>15.0</td>
<td>0.530</td>
<td>0.530</td>
<td>0.530</td>
<td>0.530</td>
<td>0.530</td>
<td>0.530</td>
<td>0.530</td>
<td>0.530</td>
</tr>
</tbody>
</table>

### Diagram 5: Theoretical rain attenuation vs. rainfall rate.
absorption, should be readily mixed and advected away by the atmosphere with no significant effect.

The highest attenuations are in heavy rain, which is always confined to the lowest several kilometers of the troposphere where the water contents are greatest. With the most extreme rainfall rates given of 10 inches/hour (250 mm/hr) an attenuation of several tenths of decibels can be estimated from Figure 5. This could produce temperature changes of a couple of degrees Celsius per day, however, such large values are very unlikely because heavy showers are convective and are generally short lived in one location. The more common but still very heavy, rainfall rate of 150 mm/hr (Table IV) has an attenuation of almost .05 db/km which would produce warming of several tenths of a degree Celsius.

Our conclusion is that under most situations the heating by the microwave will have an insignificant influence on the dynamics and thermodynamics of the clouds and associated hydrometeors. In the extremely rare situation where a heavy shower remained stationary for a long period over the rectenna, it might be possible to cause a noticeable but, compared to the energy being released naturally, minor effect. The influence of the microwave on wetted, suspended particulates, on the other hand needs to be looked at more closely.

C. Global influence of the heating by the microwave

As seen from the right hand column of Table III, attenuations on the order of .02 db/km will produce a heating
from the 224 microwave beams* comparable to the heat dissipated by the 224 rectennas, as given in the first part of this report. As shown in that section, the expected influence of this amount of heat release on the global scale is negligible compared with the solar input, and even with certain of man's activities. Moreover, this heat would be distributed over a larger volume, so that the same amount of energy would be expected to have a proportionate smaller effect.

**D. Possible benefits and potential hazards of the microwave beam**

Because of the extremely small effects of the microwave on the gases and hydrometeors in the troposphere it is difficult to discern any possible positive influence without focusing the beam further - which would have serious repercussions in other areas (i.e. non-linear effects in the ionosphere).

The possible hazards of the microwave which should be considered include:

1. exposure of aircraft moving through its beam.
2. possibility that the microwave beam or a portion of it could be refracted by varying atmospheric stratification, and that it could be accidently focused by horizontally, as well as vertically varying atmospheric structure. If this is a problem, the beam could be misdirected and perhaps focused off the rectenna target. With 10 cm radar's, there is a problem of anomalous propagation when the beam is roughly parallel to thermal inversion (Battan, 1959). The natural average radar

*Assuming a beam volume of 10 km by 10 km by 10 km.
refractive index of the atmosphere is 1.0003 near the earth, decreasing to one higher up (Bean, et al., 1970).

3. reflection of a significant amount of microwave energy off of the rectenna.

E. Recommendation

A definitive analysis of the attenuation properties of a 12 cm radar beam of the proposed intensity needs to be conducted. Such an investigation should not only verify the estimates we have made here, but categorize the climatological expected frequency of attenuation over each rectenna site. In a desert, for example, gaseous absorption would dominate, whereas in a moist, cloudy region such as south Florida the higher absorptions of heavy rain would occur more often.

At least two specific questions also need to be addressed:

1. Is there a possibility of significant refraction of the microwave beam and could this cause a focusing of its energy? Could reflection of a fraction of the beam occur and could this cause problems in mountainous areas, for example, where significant microwave energy could be directed towards populated areas.

2. How does wetted, suspended particulate material absorb and scatter microwave energy of the proposed wavelength?

III. Summary

We conclude that on scales larger than the mesoscale ($\sim 10^3$ km$^2$) the influence of heat dissipation by the rectenna is
small when compared with other inputs of energy provided by

The heating of the atmosphere by the microwave beam on
scales is estimated to be negligible. The heat dissipation
along with the thermal and momentum effects of replacing the
natural terrain with a rectenna, however, could have a substan-
tial influence on local weather. Under certain atmospheric
conditions such as very light winds and a strong inversion in
rough terrain, the heat dissipation of the rectenna due to
microwave beam could be important. These effects need to
be examined quantitatively.
References


