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RECTENNA-RELATED ATMOSPHERIC EFFECTS

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1. INTRODUCTION

The primary interest in the assessment of possible environmental effects arising from the existence and operations of the satellite power system (SPS) rectifying antennas (rectennas) is meteorological in nature. The presence of a rectenna covering an area of approximately 100 km^2 would be expected to alter the aerodynamic characteristics of the surface in its immediate vicinity. A change in surface roughness affects the vertical fluxes of momentum and thermal energy, and a change in radiative properties (albedo and emissivity) affects the surface energy budget. The operation of a rectenna would add an additional heat source at the surface. The consequences of these changes would be expected to alter the wind velocity profile and stability of the planetary boundary layer and hence to alter the local cloud population.

The possible influence of microwave transmission through the troposphere would be due to the absorption, especially in clouds, of microwave energy along the beam path, causing local heating. On the other hand, the presence of convective or turbulent air motions and the existence of hydrometers cause refraction, scattering, and absorption of microwave and can lead to beam wandering and spreading. The scope of this discussion is limited to the effect of SPS on tropospheric atmosphere. Many issues of concern regarding the effects of atmospheric conditions on SPS beam propagation can be found in the proceedings of a workshop held in August, 1978,[1] and will not be discussed here.

2. PREVIOUS STUDIES

A preliminary assessment based upon the maximum microwave-beam power density of 230 W/m^2 and an average waste heat release rate of 7.5 W/m^2 from a rectenna covering approximately 100 km^2 was conducted in 1977 by the Johnson Space Center.[2] The findings were that the effects of an SPS rectenna on weather and climate would be small compared to the direct environmental consequences of construction, and that the rectenna's influence would be similar to that of an average suburban development. Microwave heating of the lower atmosphere through gaseous absorption would be negligible. Any actual effects of microwave heating inside a cloud would not be detected in the presence of the natural variance of cloud and storm phenomena. Scattering by particles, even in heavily-polluted atmosphere, would also be negligible.

3. CONSENSUS OF AUGUST 1978 WORKSHOP[1]

The above study was reviewed at the August 1978 workshop and the conclusions were updated. Three main topics were discussed: the effects of waste-heat release on the atmosphere at the rectenna site; microwave interactions with the atmosphere; and the possible effects of the microwave beam on atmospheric electrification processes. The following brief summary highlights the most important issues.

a. Rectenna Waste Heat and Structure. Construction of a rectenna would modify the thermal and radiative properties of the ground on which it is built; operations would introduce a heat source at the surface. Although the magnitude of the perturbation of the average surface heat budget would be on the order of

10%, microwave beam wandering and spreading due to atmospheric refraction may occasionally give rise to larger effects.

It is possible to investigate the effects of the rectenna by studying the effects of land-use changes. Small temperature changes (of the order of 1°C) can be expected under light wind conditions. Changes in cloud populations can also be expected. Somewhat larger man-made dissipation rates over comparable areas have been associated with apparent anomalies in the distribution of rainfall.

In hilly terrain, on scales smaller than the rectenna dimensions, diurnally varying changes occur in the surface energy budget that are larger than the projected rectenna waste heat. It is therefore expected that the meteorological effects of a rectenna would vary from site to site, and the central maximum heat dissipation (approximately 16 W/m^2) might become important in augmenting a naturally occurring topographic effect.

Assessment of possible weather and climate effects over areas larger than the mesoscale should not be confined to the influence of the rectenna alone -- it is necessary to consider the whole satellite power system in the context of the energy demand it is designed to meet. The overriding feature of the system is that the major inefficiency, the rejection of waste heat, is in space. Furthermore, there are no significant emissions of material into the troposphere during operation.

b. Microwave Propagation. The atmospheric absorption of microwave energy at the proposed SPS frequency is negligible in clear air for the projected tropospheric path lengths of about 20 km. However, some absorption by condensed water (clouds and precipitation) would occur when storms entered the beam path.

c. Atmospheric Electricity. Direct interactions with the atmospheric electric fields are not thought to be important at the proposed frequency. However, the mere physical presence of the rectenna might have some modifying influence on the occurrence and electrical behavior of thunderstorms over and around the rectenna.

4. MODEL CALCULATIONS

In order to examine further the rectenna effects on local meteorological variables, a trial simulation using a three-dimensional, turbulence-closure model[3] was made for a daytime, planetary-boundary-layer condition (constant potential temperature up to 650 m in height, then increasing with height at a rate of 3.5°C/km) with logarithmic wind profile up to 4 m/s and remaining constant above that. It was found that the increased roughness over the rectenna would considerable increase the surface heat flux (by a factor of 3.5) and friction velocity (by a factor of 1.9) at the center of the site in comparison with values located at the upstream boundary. The numerical values given in the parentheses are valid for the case of dry convection and little temperature contrast between the rectenna and the surrounding surface. Inclusion of 8 W/m^2 of waste heat would cause a surface temperature perturbation of less than 0.1°C.

A more realistic simulation was performed for a potentially unstable boundary layer with light winds over moist, flat ground.[4] Such a situation is conducive to the natural formation of cumulus clouds without precipitation. The simulation indicated that, excluding the effects of albedo changes, the major cause of the perturbation is again the change in surface roughness rather than the release of waste heat. Air and soil temperature decreased during the daytime and increased only marginally at night. The increased mechanical mixing resulted in increased evaporation and absolute humidity, increased cloud amount, and decreased cloud-base height. The decrease in solar radiation resulting from the increase in cloud amount is greater than the waste heat term. Cloud modification would be expected to be quite different if the roughness had not been changed. The results found in this case (moist convection) are considerably different from those in the dry convection case above. A preliminary analysis of the problem of rectenna albedo and its diurnal variation indicated that differences between the rectenna albedo and that of the surrounding surface may be most significant factor.[4] These effects need to be quantified in future work.

Information regarding the amount of microwave absorption per unit path length as a function of rainfall rate is available.[5] With the most extreme rainfall rate of 254mm/hr as an example, the attenuation at the proposed 2.45-GHz frequency is estimated to be about 0.063 dB/km. At the proposed maximum power density of 230 W/m^2, the absorbed microwave power inside the storm would be approximately 3.2×10^{-3} W/m^3, which is approximately two orders of magnitude smaller than the release rate of the buoyant energy of a typical cumulus cloud. It is reasonable to conclude that the absorption of SPS microwave power by a storm will have no significant influence on cloud dynamics and thermodynamics and the associated precipitation.

5. CONCLUSIONS

Analyses and model simulations in some chosen site situations and meteorological conditions indicate that the meteorological effects of the construction and operation of a rectenna are small, particularly outside the boundary of the structure. From weather and climate points of view, installation of an SPS rectenna seems likely to have effects comparable with those due to other nonindustrial land-use changes covering the same area. The absorption and scattering of microwave radiation in the troposphere would have negligible atmospheric effects.

It seems clear that rectenna-related meteorological effects are not a critical factor in the overall environment impact of the SPS. However, there are some remaining areas of detail that should be investigated; they are concerned with the radiative properties of the rectenna structure, the possible "triggering" of convective instability under certain meteorological conditions, and the nature of the terrain at and near the structure.

6. REFERENCES

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