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AN OVERVIEW OF CHARGING ENVIRONMENTS

S. B. Gabriel and H. B. Garrett
Jet Propulsion Laboratory
California Institute Of Technology
Pasadena, California

This paper presents a brief synopsis of the natural environments that play a role in spacecraft charging. Environments that cause both surface and internal charging are discussed along with the mechanisms involved. The geosynchronous and low altitude (< 1000 km) regions of the Earth's magnetosphere/ionosphere are considered and simple descriptions of each environment presented. As material properties are critical to the charging process, definition of material properties important to charging, which can be affected by the environment, will also be described. Finally, several space experiments are proposed that would help fill the gaps in our knowledge of the performance of materials in a charging environment.

Figure 1 lists the major natural environments that contribute to charging. This list is not comprehensive and has been selected on the basis of those environments that interact directly with surfaces (surface charging) or through surfaces (internal charging) to cause the production of high electric fields. Because of this rather restricted definition, environments such as contaminant molecules, x-rays, electron/ion beams, and cosmic rays have not been included.

Surface:

- Thermal Plasma
- High Energy Electrons (1-100 keV)
- UV/EUV Radiation
- Magnetic Field
- Neutral Particles

- Internal:
  - High Energy Electrons ($\geqslant$100 keV)

FIGURE 1

Figures 2 a) and b) show schematically the interactions between the environments and the surface that cause surface and internal charging, respectively. In surface charging, the process is governed by current balance (1) (i.e. in the steady-state, the net sum of all the currents to the surface must be zero and the equilibrium potential will satisfy this condition). To first order these currents comprise the currents from the thermal or low energy plasma (including any ram ions), the high energy electrons and ions, the secondary electrons emitted by impacting high energy electrons and ions and photo-electrons released due to the incident UV/EUV radiation. The presence of a magnetic field and space charge can affect the escape of low energy secondary/photoelectrons.

For internal charging, the primary process is the build up of negative charge (electrons) in or on isolated surfaces inside the spacecraft body caused by penetration of the external surfaces by high energy (> 100 keV) electrons (2). As shown in the figure, charge can accumulate on/in ungrounded conductors or insulators and cables as well. This charge can produce high electric fields and induce breakdown.

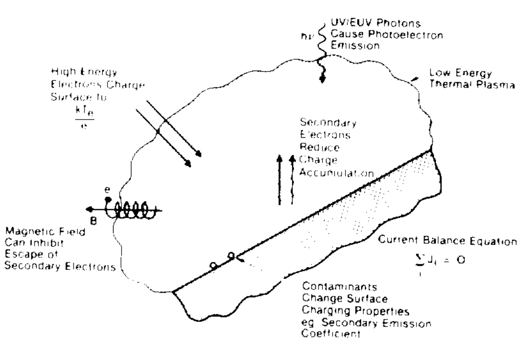

FIGURE 2a

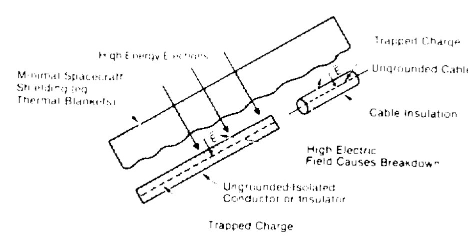

FIGURE 2b

The presence of a high density, low energy plasma can significantly affect surface charging. Qualitatively, this can be understood by thinking of this plasma as a good conductor which "drains off" any charge accumulation thus preventing high surface potentials. Figures 3a) and b) (3) are presented to illustrate that the thermal plasma electron density varies by many orders of magnitude in the magnetosphere/ionosphere regions. At one extreme, in the geosynchronous region, densities are as low as 1 cm^{-3} while at 300 km in the F region they can be as high as $10^6 cm^{-3}$. These large differences in density have 2 major implications:

1) *At low altitudes (< 1000 km), even in the presence of high energy electron population, (~ 10 keV) such as the precipitating electrons in the high latitude auroral oval regions, high spacecraft potentials are unlikely to occur.*

2) *Charging calculations are quite different in the two regions. At geosynchronous altitudes the ratio of characteristic dimension of the spacecraft to the Debye length (R) is << 1 whereas at 300 km the reverse is true (i.e. R ≥1), leading to the so-called thick and thin sheath approximations. In the former, space-charge effects can be neglected (ie. the charge density in the sheath region can be set to 0) while the latter necessitates the inclusion of space-charge effects.*

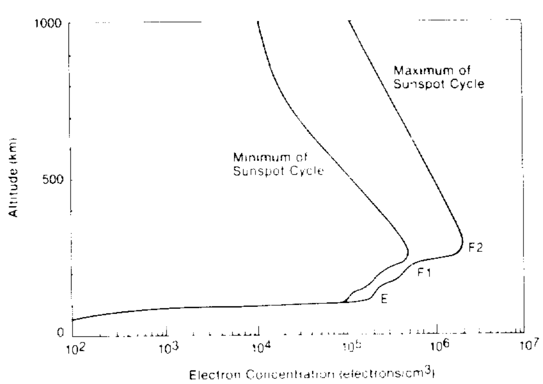

FIGURE 3a

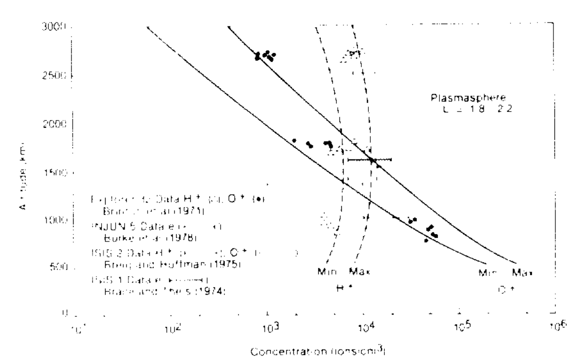

FIGURE 3b

Figures 4a) and b) show representative spectra for the high energy electron population at geosynchronous (4) orbit and for a discrete auroral arc (5), respectively. With respect to surface charging, the most notable feature is the presence in both cases of electrons with energies of 10 keV and greater; typically one can describe these populations in terms of a Maxwellian distribution function with a characterstic temperature, T_e. *Simple charging analysis demonstrates that, in the absence of significant thermal plasma and a photoelectron current, the spacecraft potential is directly proportional to the mean temperature of the electrons. As electron temperatures can vary from 1-20 keV, potentials of 1-20 kV are possible and indeed, have been observed.*

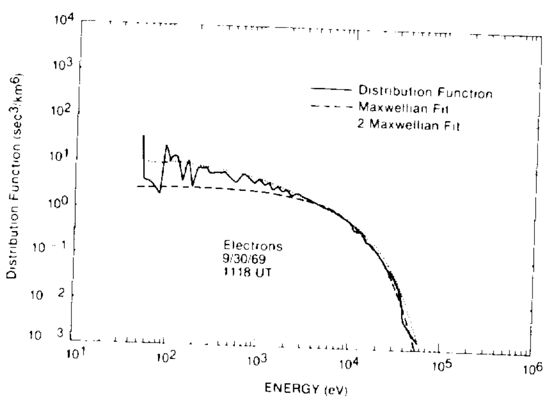

FIGURE 4a

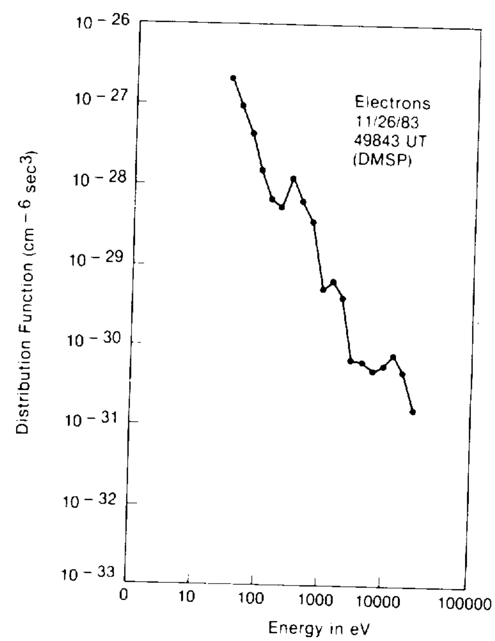

FIGURE 4b

The photoelectron current, emitted from the surface by the impact of the incident high energy photons, can make an important contribution to the overall current balance. This is particularly true at higher altitudes, where, for example, at geosynchronous altitude in the absence of a significant thermal plasma, the photoelectron current plays a dominant role. The photoelectron current is a function of satellite material, solar flux, solar incidence angle and satellite potential (6). In figure 5, adapted from reference 7, is a composite plot of: W(E), the electron yield per photon; S(E), the solar flux; and their product, H(E), the total photoelectron yield, as a function of energy, E, for aluminum oxide.

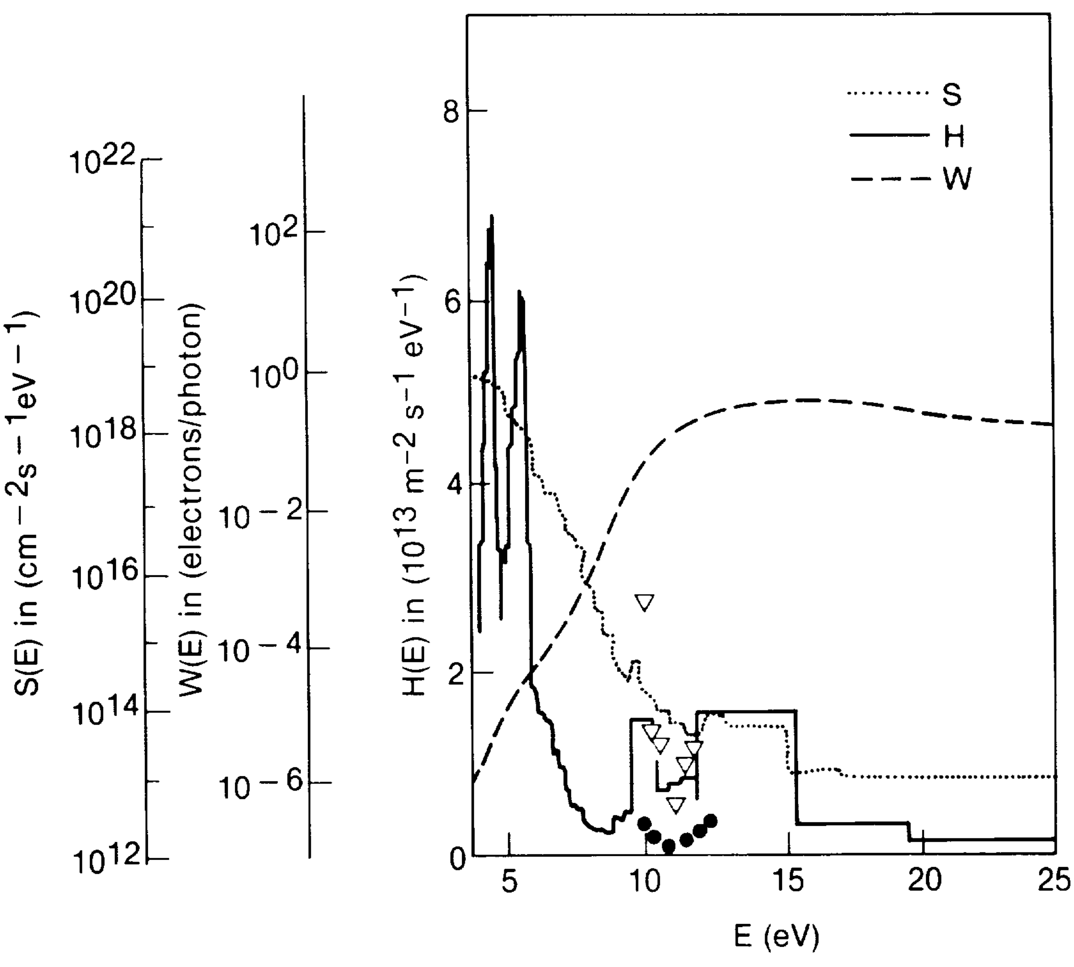

FIGURE 5

The Earth's magnetic field can be approximated by a magnetic dipole located near the centre of the Earth. The dipole moment is $M = 0.312\ G\ R_E{}^3$, where R_E is the radius of the Earth, and the dipole is directed so that the magnetic south pole on the Earth's surface is located in northern Greenland (geographic coordinates: 78.5° N, 291° E). The spatial distribution of the dipolar magnetic field strength beyond the surface of the Earth is given by (8):

$$B = B_E \left(\frac{R}{R_E}\right)^{-3} \frac{[\ 4\text{-}3\ \cos^2\lambda\ ]^{1/2}}{\cos^6\lambda}$$

where R is the radial distance measured from the center of the Earth, B_E = 0.312G is the equatorial field at $R = R_E$, and λ is the magnetic latitude.

Figure 6 shows a schematic of the Earth's magneto/ionosphere indicating the various domains. The solid lines represent the magnetic field lines which can be seen to be distorted from a purely dipolar pattern due to the interaction with the solar wind. In terms of charging environments, the magnetic field can be viewed as playing essentially three roles: 1) it is a major factor in determining the shape and location of the charging regions (i.e. the domains shown in figure 6); 2) it can affect the escape of photoelectrons or secondary electrons emitted from the surface (9) 3) it can introduce anisotropy in particle fluxes.

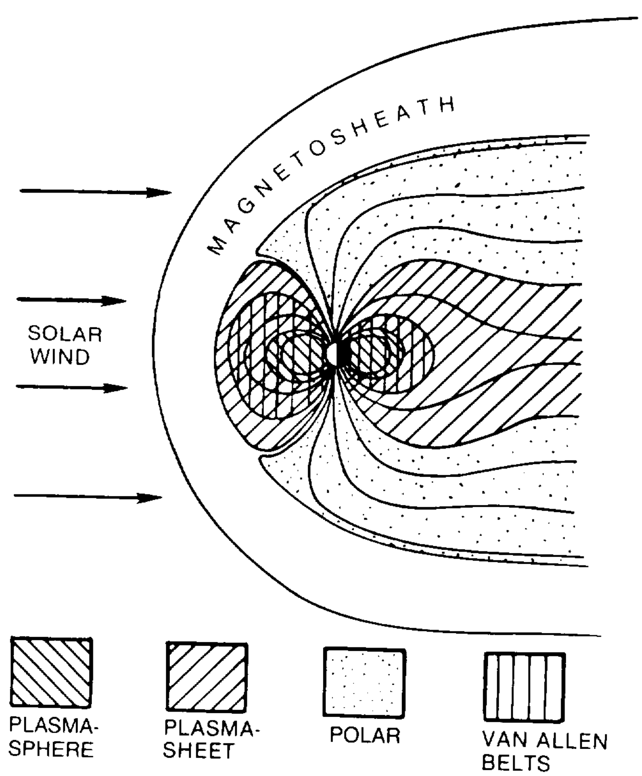

FIGURE 6

Figure 7 shows the neutral atmosphere environment up to an altitude of 1000 km. The important feature of this environment is that the neutral density is approximately two to three orders of magnitude higher than the electron/ion density (i.e. the atmosphere is weakly ionized). At higher altitudes where the mean free path for collisions between neutrals and electrons is very large, collisionless probe theory can be applied to surface charging calculations, while at lower altitudes, collisional theory is probably needed and ionization may be of importance. Little attention has been paid to charging calculations at altitudes between 100-200 km where the thermal plasma density is low but where auroral precipitations of high energy electrons are still found. This may because it has been assumed that the simultaneous increase in the local thermal plasma density caused by the precipitating auroral electrons is of sufficient magnitude to prevent significant charging. In addition, at these altitudes, satellites cannot orbit for long periods due to aerodynamic drag. However, with the advent of the proposed tethered satellite systems (e.g. TSS2) which will be able to trail a downward - deployed platform to altitudes of about 100 km, this problem warrants more detailed study.

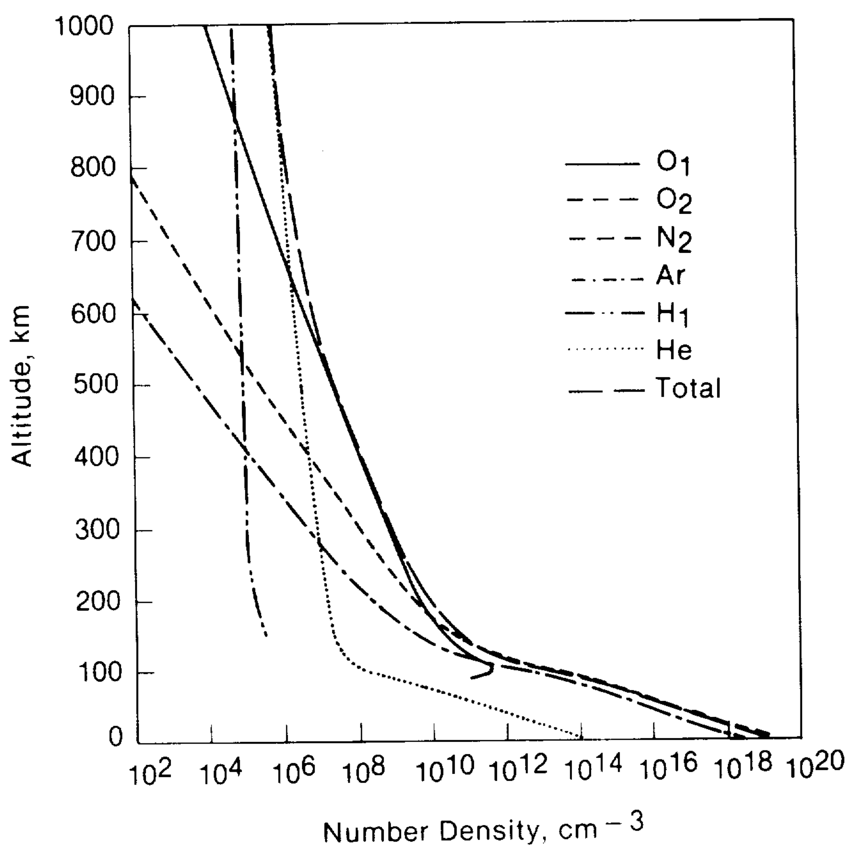

FIGURE 7

Figure 8 (10) shows empirical radiation belt electron fluxes at L = 1.4. The important feature to note here, as far as internal charging is concerned, is the presence of significant fluxes at energies between 0.1 and 1.0 MeV. These energetic electrons can penetrate lightly shielded parts of the spacecraft and accumulate on ungrounded cables, conductors or insulators, located inside the spacecraft. If the resultant electric field rises to a high enough value, breakdown can occur. The ranges of 0.1 and 1.0 MeV electrons in aluminum are about 3 and 70 mils, respectively.

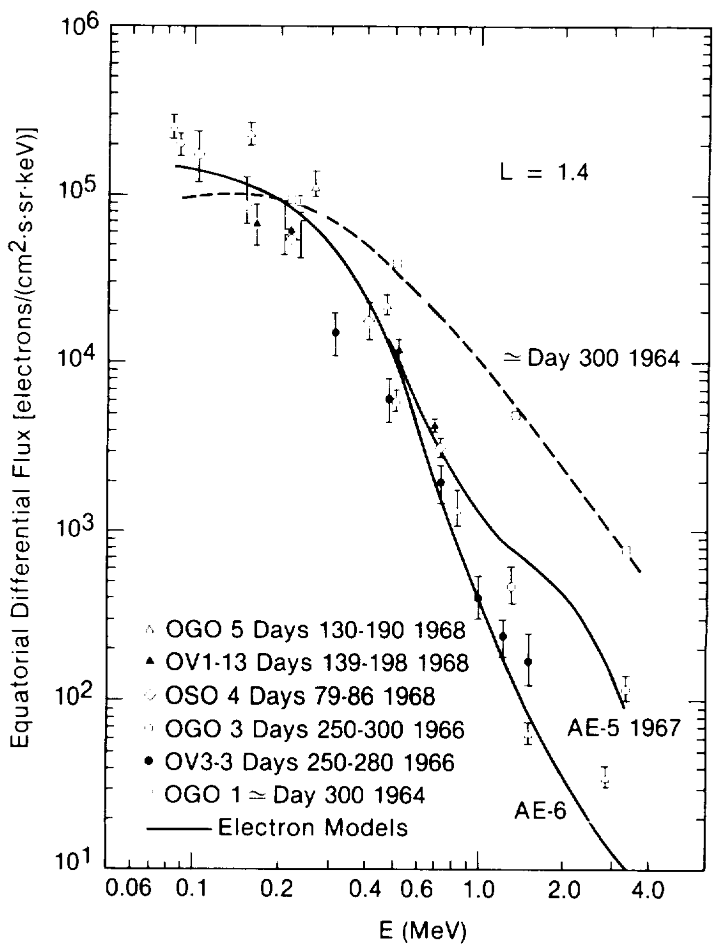

FIGURE 8

TIME VARIATIONS OF GEOPHYSICAL PHENOMENA

Nearly all of the charging environments described previously show dynamic variations both temporally and spatially. Consequently, in many cases, modelling of an environment has to be done statistically with average and worst case environments being defined. Further, the environments are not independent but form a coupled and highly-complex interacting system. Figure 9 shows order of magnitude time variations for some of the phenomena associated with charging environments.

Geophysical Event	Time Period
1. Solar Cycle	11 Years
2. Geomagnetic Storms	1-10 Days
3. Substorms	1-3 Hours
4. Magnetic Pulsations	Sec-Min
5. Plasma Boundary Crossings	Sec-Min
6. Plasma Waves	mS - μS

FIGURE 9

POTENTIAL IN SITU MATERIAL CHARGING EXPERIMENTS

For many of the adverse interactions between the space environments and spacecraft materials described here, the critical parameters required to accurately model the physical response are currently lacking or poorly known. In particular, for spacecraft charging, 6 key parameters are required as a function of material and, as some of the interactions result in long term variations in properties, time. These are

1) *Bulk and surface electrical properties*
2) *Secondary emission coefficients for electrons and ions*
3) *Backscatter properties for electrons*
4) *Photoemission properties*
5) *Sputtering characteristics*
6) *Arc breakdown properties*

To date, these properties are known only through ground tests or, in situ, by indirect methods--primarily through variations in parameters to fit charging observations. Given the hypothesized variations over time of these parameters due to radiation damage, contamination, etc., in situ measurements are vital to a proper understanding of how materials behave over the long term in a charging environment.

POTENTIAL IN SITU MATERIAL CHARGING EXPERIMENTS

Three experiments are presented in Figure 10 that would make possible measurements of the in situ material properties relevant to spacecraft charging. First, for surface charging it is necessary to study the in situ secondary, backscatter, and photoemission properties. Although ground experiments are useful for this purpose, it is not likely that the in situ surfaces will actually retain their ground values following long term exposure to space. This experiment (referred to here as the Electrical Properties Degradation experiment) would alternately expose samples to the ambient environment and then to a probe capable of directly measuring the secondary emitted electrons and ions--one potential configuration would be a carousel tray for the samples with a commercially available secondary emission probe. The second experiment would measure natural and, if necessary, simulated surface arcs with the objective of locating them on the test surface and estimating the conducted and radiated emissions (referred to here as the ElectroStatic Discharge experiment). Such instruments have been flown in the past on SCATHA but, for various reasons, did not return sufficient information on the arc discharges to unambiguously define their characteristics or their locations.

- Electrical Properties Degradation Experiment
    - Secondary Emission Properties
    - Photoemission Rate
    - Surface Electrical Properties
- Electrostatic Discharge Experiment
    - Arc Properties
    - Surface Location
    - Surface Conditions at Time of Arc
    - Surface Damage
- Internal Discharge Monitor
    - Internal Arc Characteristics
    - Material Bulk Property Changes

FIGURE 10

POTENTIAL IN SITU MATERIAL CHARGING EXPERIMENTS

The third experiment, the Internal Dischrge Monitor, is planned to fly on the CRRES spacecraft in 1990 in a simplified form to monitor arc discharges on samples inside a protected tray assembly. As in the case of CRRES, more advanced forms of this instrument will also need to be flown through the radiation belts to obtain useful information in a short time period. All 3 instruments would need supporting environmental sensors to monitor the natural environment--particularly the relevant particle and EUV fluxes. Finally, while the EPD and ESD instruments might be suitable for low-altitude, short duration missions (although the longer the exposure, the better), the IDM will clearly require multi-year missions.

CONCLUSIONS

In this paper we have identified and provided brief descriptions of the major natural environments that contribute to charging. The intent has been to provide an overall picture of the charging environment but in a very short space. The result is a necessarily oversimplified and idealized view of a highly complex interdependent physical system; in essence, only allusions have been made to some of the realistic features such as temporal variability and particle flux anisotropies.

The importance of surface properties in determining charging levels makes it essential to measure these properties in the real environment. However, to correlate charging levels with the environment and surface characteristics, simultaneous monitoring of the environment will also be required.

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