5-4 Space Weather Forecast in the Future Manned Space Era

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Space weather is the conditions of the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human and animal life or health. In 2050, everyone will be able to enjoy his/her space tour. The space weather research will transform into more and more practical science in that future manned space era.

Keywords
Space weather forecast, Manned space activities, Space radiation environment

1 Introduction

Space weather refers to various physical and chemical phenomena that occur naturally in a region that extends from an altitude of a few tens of kilometers into the solar system, in which the main component is plasma. Therefore, space-weather research is an interdisciplinary and interactive research field ranging from geophysics to astronomy, covering aeronomy, space physics, and solar physics.

However, as is the case in the fields of geophysics, space-weather research holds practical interest in terms of the ways in which the natural environment (in this case extending from the Earth to the Sun) affects human activities. It is in this context that the term space "weather" was coined.

From this viewpoint, the definition of Space weather is as follows: "Conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."

A prime example of space weather activity can be found in forecasting research, in which a wide range of research activities—from the most basic research to complex applications—are applied to forecasting space weather in a practical and useful manner[1].

This paper describes an overview of space-weather applications, addressing issues such as how space-weather research and forecasting will benefit humanity, and possible near-future uses in the context of full operation of the International Space Station (the "ISS") and applications involving manned Mars explorations and space tourism, envisioned for the middle of this century.

2 Sources of space-weather variation

In order to ensure human safety and protect various man-made systems, it is essential to research and understand the sources and global structure of space weather, which has a significant effect on such safety and systems. Since individual research achievements relating to the area from the upper atmosphere to the Sun have been discussed in detail by other authors, this paper will summarize the primary sources of space-weather variation (Fig.1).

The Sun is the greatest energy source in the region from the upper atmosphere into the solar system.

In the surroundings of the geomagneto-

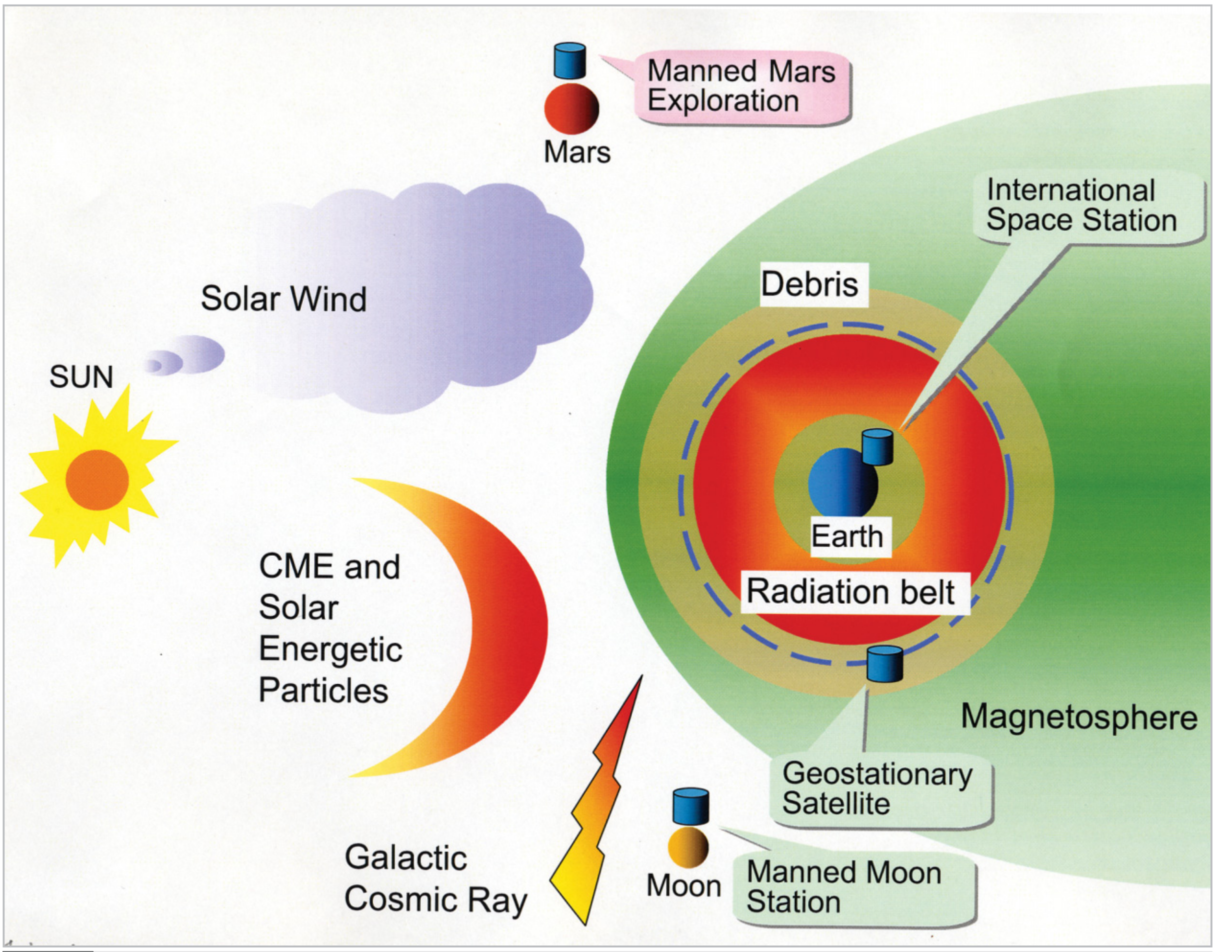

Fig.1 Sources of space-weather variation that affect human activities on Earth and in space

sphere, the "solar wind" constantly blows from the Sun into the solar system, accompanied by a magnetic field. The characteristics of the solar wind vary significantly, temporally and spatially, in the region of its origin near the Sun, creating disturbances in the geomagnetosphere and the upper atmosphere.

Furthermore, sudden eruptions of "plasma clouds" (referred to as coronal mass ejections, or "CMEs") and a "flare" are generated in active regions on the surface of the Sun, often resulting in space-weather variations.

Additional factors other than those originating in the Sun also lead to space-weather variation; these include galactic cosmic rays, meteorites, and debris.

We will describe the ways in which space-weather variation originating from such sources affects human life in Fig.2.

3 Influence on the ground

3.1 Radio communications

All communications using radio waves are influenced by space weather. In particular, short-wave (HF band) radio waves in the polar region are sometimes absorbed by the ionosphere when auroras appear and do not return to the ground.

Frequencies of mobile wireless terminals have already been shifted to the UHF and SHF bands, and it is expected that in the future terrestrial communications will no longer rely strictly on the HF band. Nevertheless, numerous ham radio stations around the world remain active, and since these involve relatively simple transmitter/receiver systems, HF-band radio communications are expected to play a number of continued roles: in international short-wave broadcasting, information communication in regions of low population

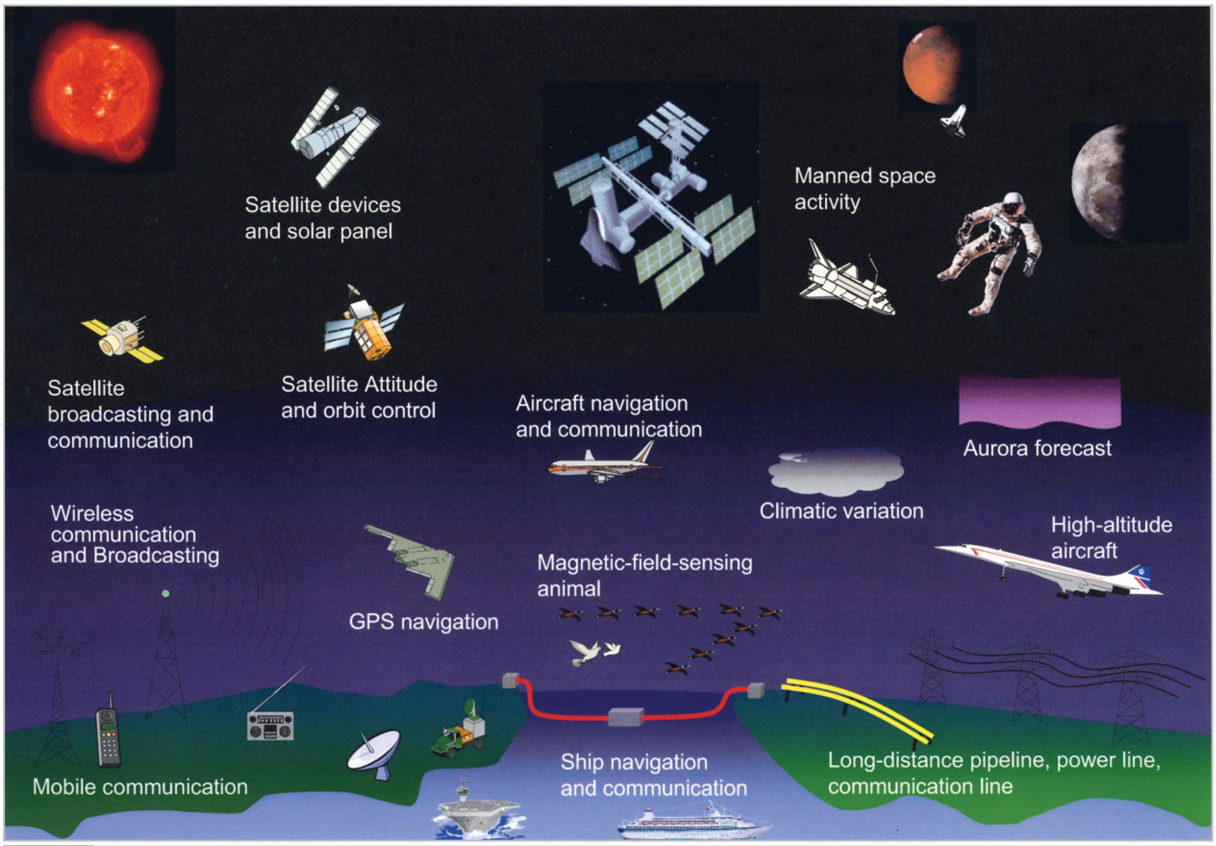

Fig.2 *Space weather factors affecting various human activities Such variation may, in some cases, be life-threatening*

densities, communications at the time of a disaster or emergency, communications for military purposes, and in backup communication systems. Therefore, in order to support safe operations in these and other contexts, an understanding of the nature of ionospheric storms and the prediction thereof will play a necessary role continuously into the future. As a point of note, although mainstream navigation communications for aircraft and ships are gradually moving toward satellite communications, many users today continue to employ VHF-band (short-distance) and HF-band (long-distance) communications with ground/land facilities.

Although satellite broadcasting and communications between satellites and the ground have become an essential part of modern life, ionospheric storms have undesirable effects on satellite-related radio-wave propagation from the VHF band to the SHF band, as the propagation paths of these bands pass through the ionosphere. Specifically, in cases in which the direction of radio-wave propagation is nearly parallel to the direction of the Sun's rays, solar radio bursts are extremely likely to have direct undesirable effects on satellite broadcasting and communications, especially on communications between geostationary satellites and the ground.

Space weather also affects users of cellular (i.e., mobile) phones, whose numbers have increased explosively in recent years. It is predicted that the frequency of failed calls, in which a cellular-phone user cannot reach his or her party due to increased noise level caused by solar radio bursts, is at least once every 3.5 days at the time of solar maximum, and at least once every 18.5 days during solar minimum[2]. Furthermore, cellular phones may become more susceptible to the undesirable effects of space weather variations in the future through reduction in the transmitting/receiving electric power used (for purposes of safety and further miniaturization of telephone sets). Most interference in communication between base stations and cellular phones due to solar radio bursts occurs at sunrise and sunset, when solar altitude is low.

Although the undesirable effect of natural phenomena such as magnetospheric/ionospheric storms on radio communications and broadcasting cannot be avoided even with highly accurate space weather forecasts, damage can be minimized by suspending important communications at the predicted times and, if necessary, by switching to other way of communications, such as satellite circuits, optical fiber lines, or cable.

3.2 Navigation

For ship navigation systems that use the LF and VLF bands for LORAN, OMEGA, and so on, it is important to determine ionospheric height precisely. Variation in the heights of ionospheric layers at the time of magnetospheric/ionospheric storms can result in errors on the order of km in positional calculation.

GPS (Global Positioning System) technology has become an indispensable element of daily life due to the popularization of automobile navigation systems and other applications, while more advanced uses of highly accurate and reliable positional information is envisioned—in aircraft takeoff and landings and in control of distance between automobiles, for example. Since the sudden change in the electron density of the ionosphere accompanying a magnetospheric/ionospheric storm generates a short-period radio-wave variation referred to as scintillation, with an undesirable effect on GPS signals, space weather forecasts will be indispensable in the development of positional measurement systems requiring greater accuracy. It is worth noting that the United States and a number of other countries are already applying space weather forecasts to high-precision military GPS applications.

With an accurate space weather forecast or an awareness of the instantaneous state of communications (positional error information), serious accidents otherwise attributable to reliance on GPS navigation alone can be avoided.

3.3 Terrestrial long-distance wired communication lines, power lines, etc.

In 1849, the influence of space weather on man-made systems was reported; specifically, the electromagnetic induction phenomenon accompanying geomagnetic storms and affecting terrestrial cable communication (telegraph) was noted. Today the roles of medium/long-distance communications have been taken over by satellite communications and fiber-optical communications (after brief experimentation in microwave communications and other technologies); however, the influence of space weather remains strong, in its effects on satellite communications as described above as well as on optical fiber communications, insofar as the latter relies on long-distance power transmission to repeaters (as will be described later).

Modern life relies heavily on electric power, generated primarily through hydraulic, thermal, and nuclear power, with a small but growing contribution from wind power, geothermal energy, and solar power. Consumption of electricity is extremely localized depending on population density, and it is often the case that the sites of power consumption are far from the sites of production, to minimize the pollution from power plant facilities on residential areas. This has resulted in the expansion—both within and between nations—of long-distance power lines carrying vast amounts of electric power.

Long-distance electric power lines are affected by induced currents caused by variations in the geomagnetic field. The effects can be serious, especially in high-latitude regions, where variation in the geomagnetic field is large. For example, a nine-hour power failure occurred in Canada in March, 1989, affecting about 6 million people. Fig.3 shows the interior of a transformer that was burnt out by the same magnetic storm in a power plant in New Jersey, U.S.

The damage was caused by a magnetic storm on March 13, 1989 (Photograph taken by U.S. Electric Power Research Institute).

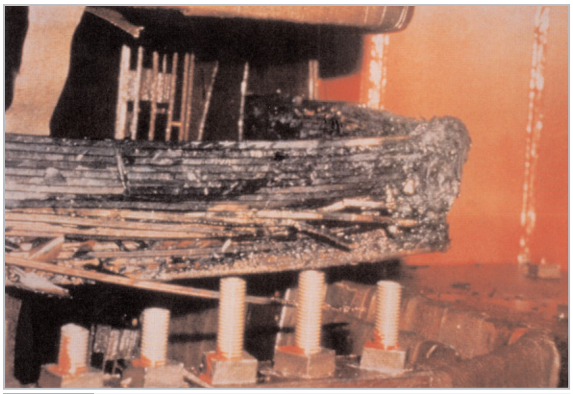

Fig.3 *Coil inside an electric power transformer burnt out by space storm (Photograph courtesy of the United States Electric Power Research Institute)*

In order to minimize the effects of this induced current (referred to as a geomagnetic induced current, or "GIC"), electric power companies and other relevant parties worldwide are carrying out various research and development projects, including those relating to space weather, and at the same time are cooperating to establish multiple route networks and systems to supply electric power via safe routes during high-risk periods. Therefore, it is becoming possible to prepare for the worst, avoiding electric power failure by selecting routes that are less susceptible to geomagnetic disturbances and by establishing backup lines that are always available in the event of magnetic storms. Such preparation, however, depends upon the availability of advance magnetic storm data obtained via space weather forecasts.

Long-distance pipelines from oil fields to power-generation facilities, especially those in high-latitude regions, are similarly affected by geomagnetic storms. Because induced current on the surface of a metallic pipe promotes corrosion of junction or grounding components of the pipe, oil-mining enterprises and transportation enterprises are conducting research and development of effective methods of processing the induced current.

3.4 Magnetic-field-sensing capabilities of animals and human beings

Some fish, birds, and mammals have organs for geomagnetic detection, located near the olfactory organs; it is well known, for example, that carrier pigeons and dolphins alike rely on detection of the Earth's magnetic field.

In one case, numerous pigeons in an international carrier-pigeon race were lost due to a large geomagnetic storm. Today such races are scheduled with reference to space weather forecasts. Moreover, research on the influence of magnetic-field variation on the human body has also begun[3].

3.5 Aurora forecast for sightseeing

Since Gauss first measured the total magnetic force of the Earth at the beginning of the 18th century, the Earth's magnetism has tended to decrease steadily. Estimation show that if this decrease continues at this rate, in about 700 years, auroras will be seen even in Japan, and 500 years after that, the Earth's magnetism will have been reduced to zero. This also means that dangerous high-energy particles will increasingly penetrate to Earth surface from space.

Auroras, natural phenomena occurring in the high-latitude regions, have become objects of sightseeing in Alaska and Northern Europe, etc. In order to view these curtain-like auroras rippling in the skies, and in particular to enable viewing of auroral expansions, it will help to predict the arrival of geomagnetic storms through space weather forecasts, enabling those who wish to view these phenomena to head to high-latitude regions at the ideal times.

3.6 Influence on terrestrial semiconductor devices

Most radiation on the ground originates from the ground, buildings, air, foods, and other materials containing radioactive substances; the proportion of radiation from space represents about 1/3 of the whole at Earth surface. Most of this radiation comes in the form of high-energy particle showers originating in galactic cosmic rays (GCRs); variations in

GCR of 10 % or so cannot be said to exert a significant influence on terrestrial life.

However, technological development is leading to greater miniaturization of semiconductor devices, integrated circuits, and similar devices, resulting each year in greater integration and sophistication (as will be described later in discussion of the influence of high-energy particles on devices aboard aircraft and spacecraft). Furthermore, higher-performance devices are configured to work with smaller currents; as a result, the influence of high-energy particles on semiconductor devices and integrated circuits is becoming increasingly non-negligible even in terrestrial applications.

While the variable component of space weather does not exert a particularly large influence on terrestrial events, care must be taken to mitigate the influence of constant radiation from space. For example, in order to store high-precision semiconductor devices, CCDs, etc., safely for long periods, shielded rooms made of concrete or equivalent materials are required.

3.7 Influence on climatic variation

Space weather includes the upper-atmospheric environment of the Earth, and this upper atmosphere connects continuously with the terrestrial atmosphere. Therefore, it is expected that variations in space weather attributable to galactic cosmic rays and solar activity affect the climate and weather of the Earth. Currently research is underway to look for correlations between various elements of weather data and variations in the galactic cosmic rays and solar energetic particles, while additional research is focusing on the effect of solar activity (e.g., numbers of Sunspots) and geomagnetism on climatic variation[4][5].

However, in order to determine the magnitude of the effects of space-weather variation on weather and climate—in terms of factors such as trace atmospheric components, aerosols, clouds (vapor), oceans, wind systems, the Earth's axis, and in terms of the interaction among these factors—continuous observation and research is required.

4 Influence on aircraft

As mentioned above, space weather affects direct short-wave radio communications and satellite communications between aircraft and base stations, and GPS navigation; in this context this chapter will discuss the influence of high-energy particles on aircraft in the space radiation environment.

As the number of international airline flights continues to grow, with increasing passenger numbers, it has become difficult to ignore the influence of space radiation on the crew and passengers aboard aircrafts, especially in planes that pass over regions of high latitude in a "great-circle track." In these cases, applicable sources of space radiation include GCR, present on a near-constant basis; radiation belt particles, permanently present but in varying intensity; and solar energetic particles (SEP), which arrive suddenly and exert a significant influence for several days. It has been reported that if either a crew member or passenger flies a number of high-latitude flights, his/her annual exposure to radiation may exceed 1 mSv.

Particularly in the case of a crew member subject to continual high-latitude exposure in the course of his/her work, exposures as high as 3 mSv/year have been reported, and in the case of passengers spending in excess of several hundred hours per year on high-latitude routes, radiation exposure rates cannot be ignored[6]. If the aircraft happens to encounter a solar particle event (SPE) while flying at high altitudes over a high-latitude region, there will be a spike in exposure during that flight; therefore, in the case of a high-latitude and high-altitude passenger airplane such as the Concorde, space weather forecasts have led to alteration of course and/or altitude.

Furthermore, in light of the continued enhancement of performance and integration of electronic parts used for aircraft control, research and development in these areas is also focusing on resistance to space radiation, as with the case of space-borne devices, to be described in next chapter.

5 Influence on spacecraft

5.1 Influence of high-energy particle particles on devices aboard spacecraft

High-energy particles damage electronic devices in satellites, generate erroneous signals (as with the "single event effect," or "SEE"), and quickly degrade or disable component functions. Moreover, accumulated exposure (the total dose effect) shortens the lives of devices, especially those installed on satellite surfaces, such as solar panels. In one case a single SPE accelerated the degradation of a solar cell panel by a few years or more.

If the arrival of high-energy particles and the conditions of the plasma environment surrounding a satellite could be predicted in advance, damage could be minimized by turning off high-voltage power supplies, initiating backup calculation modes, or temporarily housing solar-cell panels.

A plasma environment of comparatively low energy in the surroundings of a satellite can trigger erroneous operation due to electrostatic discharge ("ESD"), which is caused by excess charge on the satellite surface, potentially shortening the life of the satellite itself. Today, it has become possible to avoid much of the damage caused by surface charging and abnormal discharge phenomena through the incorporation of conductivity and insulation design into satellite construction (using anti-static coatings, etc.).

On the other hand, in recent years a significant problem has been known in the form of a phenomenon referred to as "deep dielectric charge" or "bulk charge," attributed to a group of high-energy "killer" electrons in the outer radiation belt. With this phenomenon, high-energy electrons (over a few hundreds of keV) enter a satellite in the form of accumulated electric charge inside the dielectrics of cables, semiconductor devices, etc.; when the charge surpasses insulation limits, an abnormal current pulse is generated. To cope with this phenomenon, efforts have been made to conduct careful grounding of devices and cables and to increase effective shield thicknesses; however, no method has been found to cope adequately with more than an occasional increase in electron flux of more than a few MeV.

Continued technical development has led to greater miniaturization and integration of circuits. These high-performance integrated circuits are configured to operate with a smaller current, which means that higher-performance circuits are more susceptible to the single event effect, deep dielectric charge, and so on; therefore continued improvement in the radiation resistance of such circuits will be increasingly important in the future. It is worth noting that the high radiation resistance of such components leads to poor cost-performance due to the restricted range of applications of these items, contributing to the elevation of overall satellite costs. Therefore, establishment of appropriate radiation-environment models and the development of the most accurate technology for prediction of radiation damage (allowing, for example, prediction of a single event effect generation rate) stands as an important target of technological development, that will bring direct benefits to spacecraft design and cost.

5.2 Influence of atmosphere on orbit control of spacecraft

Increased heat (amounting to 10^{13} W at maximum) generated by auroras and solar radiation (mainly ultraviolet light) change atmospheric density (composition and temperature) and wind systems in the upper atmosphere. Therefore, especially in orbiting satellites with perigees at altitudes of a few hundred kilometers, satellite orbits and attitudes will be subject to abnormal conditions, due to variations in atmospheric drag. This influence will appear as excessive thruster injection in orbital maintenance in the short term, and will manifest itself in shortened satellite life in the long term. In the worst case, these phenomena may lead to earlier-than-anticipated failure and descent of the satellite. Moreover, at the time of atmospheric entry of manned spacecraft (such as the space shuttle), if calculations do not take these effects into consideration, the lives of space crews will be at risk.

5.3 Influence of geomagnetism on attitude control of spacecraft

Geomagnetic storms exert undesirable effects on satellites that perform attitude control using geomagnetic sensors. If the influence is deadly strong, various satellite functions that depend on the attitude are temporarily paralyzed; thruster fuel is then required for frequent attitude recovery. Such effects ultimately have an influence on satellite service life.

In such cases, damage can be minimized by temporarily interrupting the geomagnetic-sensor attitude-control mechanism in accordance with space weather forecasts.

5.4 Influence on human activities in space

The high-energy particles that come from space (space radiation) exert not only an undesirable influence on devices aboard satellites and spacecraft but also have serious harmful effects on human activities on the ISS, on the moon's surface, and on Mars. Fatal accidents due to radiation exposure cannot be ruled out.

At an altitude of approximately 400 km, with an orbital inclination of 51.6˚, the ISS has now begun to host long-term manned space operations, introducing a detailed model of radiation-exposure using the data collected onboard various space shuttles and the Mir space station. The results have led to the prediction that when an astronaut stays onboard the ISS under normal environmental conditions (with no SPEs), the effective exposure is about 1 mSv/day, and that during several days of an SPE, the value increases by a factor of approximately ten to one hundred times the above case. Moreover, during extra-vehicular activity ("EVA"), the exposure rises to several times that of onboard activities, and the exposure of skin and organs near the body surface increases accordingly.

As shown in Fig.4, ordinary people on the ground are exposed to radiation of approximately 1 mSv for one X-ray photograph, and a reference value of annual exposure is set to 5 mSv. The reference value for radiation workers in nuclear-power facilities in Japan and

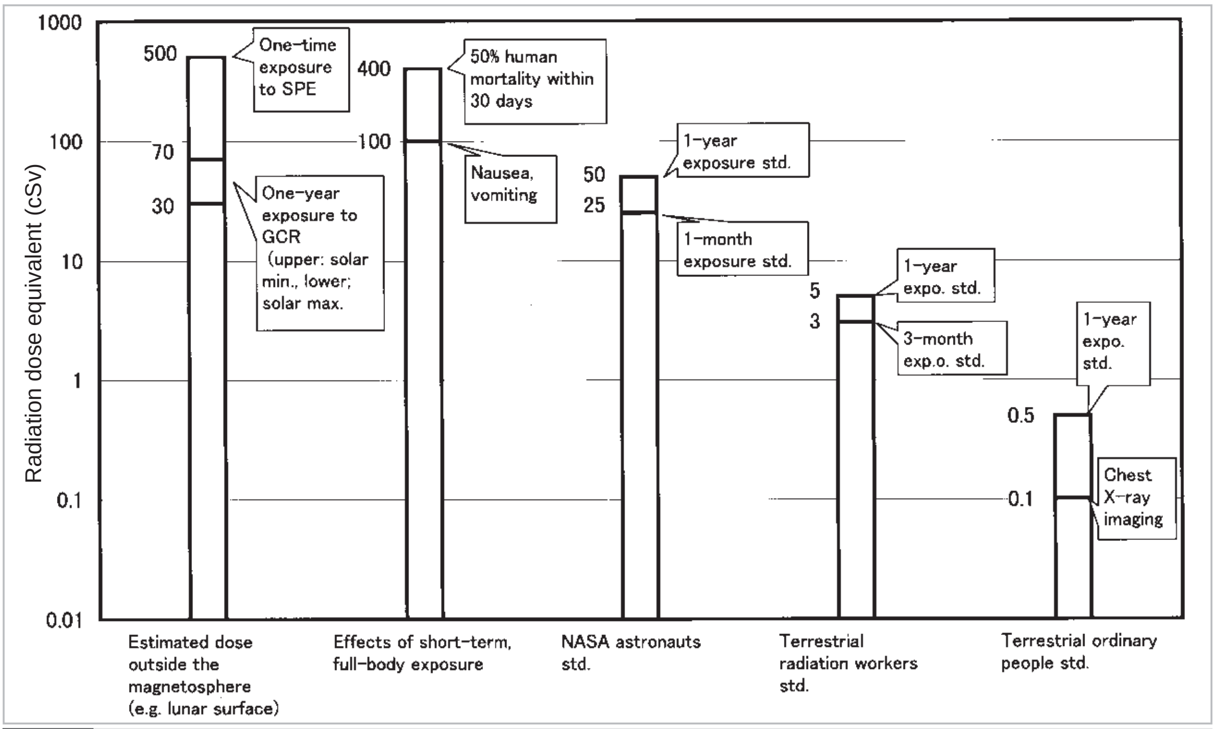

Fig.4 *Comparison between expected values and reference values for radiation exposure in space*

Table 1 *Exposure limit for Japanese astronauts aboard ISS*

Career effective dose limits

Age at first exposure in space	Male (mSv)	Female (mSv)
27〜29	600	600
30〜34	900	800
35〜39	1000	900
40〜	1200	1100

Equivalent dose limits for the critical organs

Time period	Weekly (Sv)	Annual (Sv)	Career (Sv)
Bone marrow	−	0.5	−
Lens of the eye	0.5	2	5
Skin	2	7	20
Testis	−	1	−

similar personnel is set to ten times that of ordinary individuals, in consideration of the risks of the work involved, whereas in the case of astronauts in NASA (U.S. National Aeronautics and Space Administration), the reference value for annual exposure is 500 mSv (0.5 Sv/year) for bone marrow, in light of the special nature of their duties[7][8].

The vertical axis denotes dose equivalent (unit: cSv, centisievert) expressed in logarithmic form.

In the case of an astronaut onboard the ISS, even in the absence of a sudden event (such as an SPE) or any EVA, it is expected that exposure over several months exceeds the reference value for radiation workers in Japan. This leads to the question of where to set the standards for risk in terms of radiation exposure for professionals engaged in special missions, such as manned space experimentation or exploration of the Moon or of Mars.

The NCRP (National Council on Radiation Protection and Measurements) and the NASDA (National Space Development Agency of Japan) have come to the conclusion that it is appropriate to set up an exposure limit for astronauts based on a lifetime excess risk of cancer mortality of 3 % (normally the risk is 15-18 %). The results are shown in Table 1[9].

The upper figure shows career effective dose limits. The lower figure shows equivalent dose limits for the critical organs. Cited from a report of Space Radiation Health Subcommittee of Manned Space Technology Support Committee of National Space Development Agency of Japan.

It is anticipated that from 2020 to 2050 and after, manned spacecraft will travel outside the magnetosphere of the Earth, and that manned Moon operations and exploration of Mars will be carried out. In these cases, although exposure to radiation belt particles may be eliminated, the exposure to GCRs and

SPE will increase, as space travelers will no longer be protected by the magnetospheric barrier. Consequently, the total exposure dose when not encountering SPE will range from 300 mSv to 700 mSv. However, in these cases, unlike the case of the ISS—in which the astronaut can go back to Earth on the space shuttle or the like with comparative ease—the astronaut can encounter significant SPE, depending on the period of solar activity; therefore countermeasures must be established in advance. At the least, space weather forecasts (featuring highly accurate SPE prediction), in-situ radiation measurement, and installation of a shelter for emergency evacuation will be required.

"Space tourism" in the vicinity of the Earth will also likely become reality. Accordingly, it can be imagined that a reference value for radiation exposure will be set for such sightseers, according to length of stay (in days) in space, with the above-mentioned ISS reference value as an upper limit. If the sightseers encountered (or were likely to encounter) SPE, they would be returned to Earth as soon as possible.

6 International space station operation in the near future

A system of protecting astronauts from exposure to space radiation was established by NASA in the U.S. when the Gemini program was first underway, and the system entered full use when the Apollo program began; thus it may be said that space weather information was first applied to manned space activities during this period. Currently, the Space Environment Center (SEC) of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, and the 55th Weather Squadron (55^{th} WX) of the United States Air Force (USAF) are jointly responsible for space weather forecasts. During space-shuttle missions, the SEC and the Space Radiation Analysis Group (SRAG) of the Johnson Space Center (JSC) exchange information on a 24-hour basis. In the system thus established, when a warning of a significant disturbance is issued by the SEC, the warning is transferred immediately to space-shuttle mission control through SRAG (or directly), allowing those in charge to make a prompt decision, such as suspension of EVA. Russia, for its part, has established the Institute for Biomedical Problems, with the influence of the space radiation environment as one of its major research themes, ranking alongside the influence of zero gravity and other such topics[10].

Measures required for safe utilization of the ISS include monitoring of the exposure doses of individual astronauts at all stages—before boarding the ISS, while onboard, and after boarding; these results are then recorded for use in radiobiological research. While astronauts are onboard, not only is individual dose monitoring required, but the energetic-particle environment in several positions inside and outside the ISS must be measured comprehensively and continuously (in terms of types of particles, energy spectra, etc.).

Along with the above, space-weather monitoring is also required; specifically, forecasting and "nowcasting" (determinations of current states) of factors that affect the space radiation environment in the vicinity of the ISS (such as SPEs) must be conducted periodically, with greater frequency as required.

It is conceivable that an ISS operation system will be agreed upon among the participating countries within a few years. An operation system such as the one shown in Fig.5 can be imagined, based on the current system employed by the U.S. The roles of the component system elements indicated in Fig.5 is shown in Table 2.

Space weather is continuously monitored by the ISES (International Space Environment Service), and nowcasting and forecasting information is also issued every few hours. The results are sent to SRAG, an international organization that analyzes and examines the radiation weather specifically in the vicinity of the ISS, and as a result of consultations between the ISES and SRAG, the nowcast and

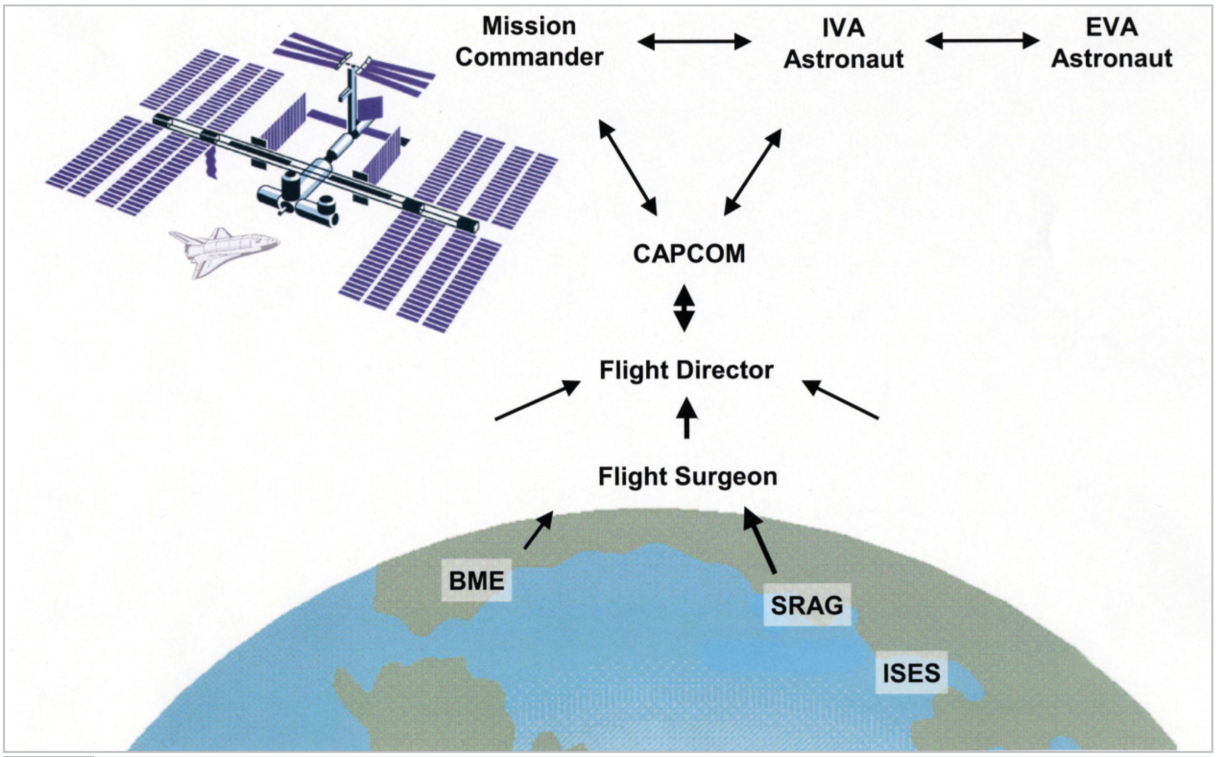

Fig.5 *Anticipated ISS operation support system*

Table 2 *Various component system elements for ISS operations support and their roles*

Components	Roles
Mission Commander	Responsible for safe execution of mission
IVA (Intra-Vehicular Activities) Astronaut	Supports, monitors, and directs EVA crews
EVA (Extra-vehicular Activities) Astronaut	Performance EVA task
CAPCOM (Capsule Communicator)	Communicates with crew, represents crew requirements
Flight Director	Overall responsibility for safe mission execution
Flight Surgeon	Monitors crew health, emergency treatment
BME (Bio-Medical Engineer)	Monitors crew physiological parameters
SRAG (Space Radiation Analysis Group)	Monitors crew radiation exposure
ISES (International Space Environment Services)	Monitors space weather

the forecast for the radiation weather in the vicinity of ISS are recorded. The recorded information is sent to an international group of aerospace medical specialists, and is used to evaluate astronauts' health. The results are then reported to the flight director, the final person in charge of ISS operations. Additionally, since biomedical factors other than the space radiation environment—such as zero gravity and long-term confinement in an enclosed space—have complex effects on the human body in the ISS, analysis of these factors and related predictions are performed by various expert biomedical engineers (BME) to a group of aerospace medical specialists (flight surgeons).

Based on the information, analytical results, and advice provided, the flight director communicates with the ISS crew via CAPCOM and determines a detailed schedule of manned space activities, such as EVA, to be executed by the astronauts.

7 Space weather forecast as part of the infrastructure in 2050

As stated previously, space weather already affects the daily life and health of

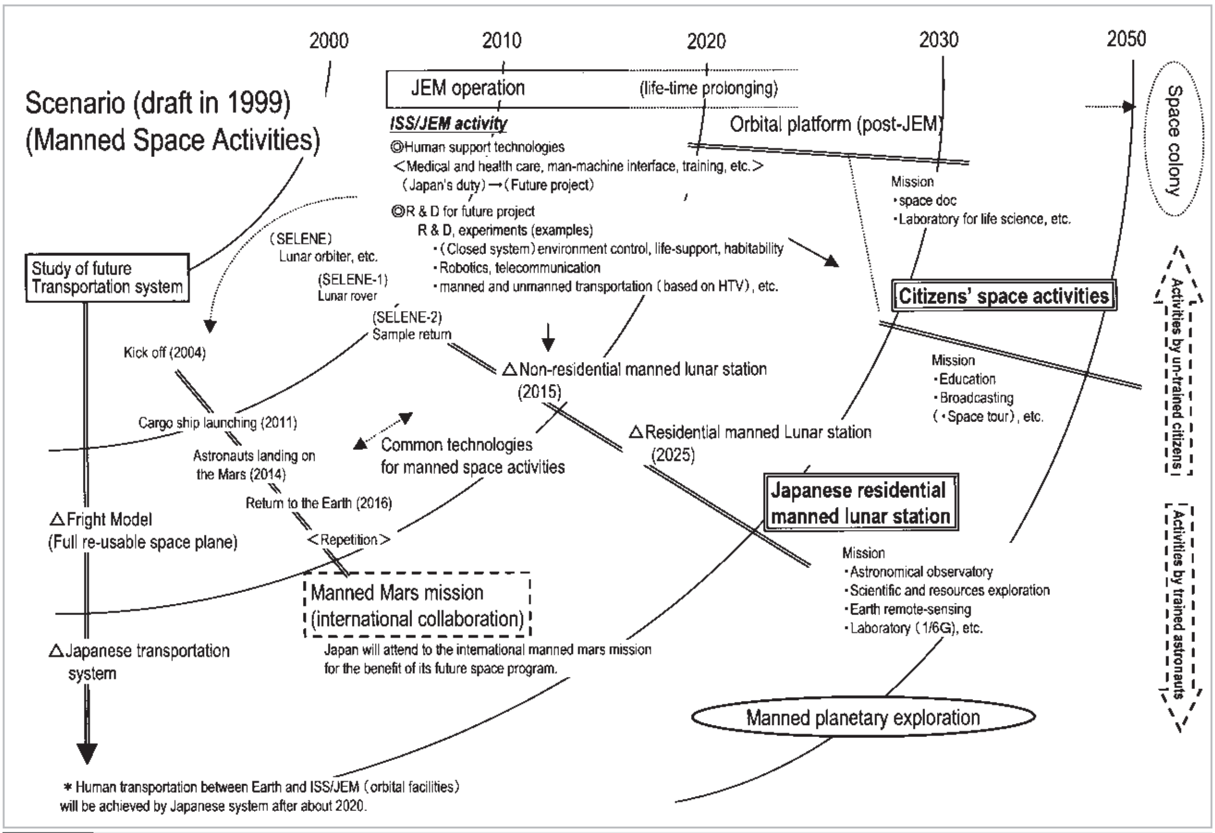

Fig.6 *Overall scenario of manned space activities (draft). Cited from a report of the Space Infrastructure Study Group of Japan*

human beings through its influence on a variety of artificial systems. International shortwave broadcasting, radio communications for aircraft and sea vessels with no alternate means of communication, long-distance power transmission in high-latitude regions, high-precision GPS navigation, and a host of other applications may be strongly affected by space-weather variations. Space-weather nowcasting and forecasting will prove extremely useful in the safe operation of these systems, albeit naturally less important in practice than ground-weather reports.

It is the author's opinion that it will take until between 2020 and 2050 for people to sense a close daily connection with space weather forecasts and consequently view related research as practical and necessary in society.

Today the use of meteorological and broadcasting satellites has become a part of daily life, and more and more people are relying on navigation using satellites. Further, in many regions (particularly in Southeast Asian countries, such as China, and on islands in the Pacific Ocean), the use of communication satellites forms an essential part of the societal infrastructure. The use of a global-scale high-speed space-communication network using inter-satellite communication, in addition to global environmental monitoring using multi satellites, may also be expected to grow in importance and scope. In terms of more sophisticated advanced satellite use, more satellites will be launched into new kinds of orbits (such as quasi-zenith orbits), and a solar power satellite will become reality as well. Moreover, it is predicted that space applications will also be pursued simply to ensure greater global safety. Since space weather may often have serious undesirable effects on satellites in the vicinity of the Earth, space-weather forecasts will become increasingly indispensable in the operation of increasingly diverse satellites.

Furthermore, as can be seen from Fig.6 taken from a report of the Space Infrastructure

Study Group of Japan, and also in light of the prediction that China will become the third nation to achieve manned space flight around 2003, space-environment activity and development may easily be expected to progress dramatically[11].

The mystery of the evolution of life on Earth may be illuminated by manned exploration of Mars, the only other planet in the solar system likely to have traces of life. Such exploration must be accomplished by astronauts, as there is a limit to the discoveries afforded by unmanned exploration alone. In this context, during the slightly more than two years of space flight required for a round trip to Mars, the safety of the crew must be protected through reliance on space-weather forecasts.

Observations of Earth by manned spacecraft may also be carried out to enable us to cope flexibly and effectively with a number of critical situations. Moreover, it is also likely that transportation technologies, such as those related to the space shuttle, will progress further; sightseeing businesses may spring up to cater to civilian space travel, and consequently the number of people traveling into space may increase dramatically. There is also the possibility that mankind may return to the Moon, as a site of resource exploration and to perform various observations and experiments. The safety of these people, orbiting the Earth or working on the Moon, must also be protected through space-weather forecasts.

In light of the above, it can be concluded that space-weather forecasting, a field currently in the phase of basic research and development of necessary technologies, will eventually form an indispensable element of the societal infrastructure.

8 Concluding remarks

Long ago—4.55 billion years before the current era—our solar system was created as a planetary system following several generations of such system development throughout the universe following the Big Bang; at this time a planet was formed of such convenient dimensions and location as to produce Earth-type life—Earth. Less than one billion years after Earth's formation, life first appeared; sea plants began to emit oxygen into the atmosphere, and an ozone layer was formed; then the flora appeared on land, followed by the fauna. Then, approximately one million years ago, one creature came to evolve a relatively large brain, allowing it to consider and imagine its future. If the time from the Earth's birth to the present were viewed in terms of a single year, man's emergence at this time would have taken place at 10:53 pm on December 31. Evolution to date has developed gradually in most cases, although occasionally significant events have led to rapid changes, affecting the history of the entire Earth. Humans, with their large brains, have come to create a small history of their own against the backdrop of the vast expanse of Earth's history, and in very little time have managed to have an impact on the entire Earth, affecting even the atmospheric environment, resulting in the world we are faced with today.

In the flow of history, human beings came to learn that their planet is round; Vasco da Gama, Magellan, Columbus, and others thus set off to navigate the vast oceans, acquiring new knowledge through their explorations, at the same time expanding the sphere of human habitation.

Reflecting on this history, I would argue that Gagarin's manned space flight in April, 1961 and the landing of Apollo 11 on the Moon in July, 1969 are more significant events for mankind than the discovery of the American continent by Columbus in October, 1492. We are lucky to have lived in the 20th century and to have had the opportunity to witness such historical events, and I feel compelled to say that we must make strenuous efforts to conduct further space development, to pass such good fortune on to the next generation. Space is waiting for mankind, promising ever-increasing knowledge and further evolution.

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