Listening for Cosmic Rays!
The Inuvik Neutron Monitor

Introduction

The earth is continuously showered with cosmic rays from the sun and outer space. These are tiny particles that enter the earth's atmosphere at nearly the speed of light (the fastest speed possible in the universe). Cosmic rays affect many aspects of our lives, and sometimes these tiny particles can create significant problems.

The Inuvik Research Center is home to a cosmic ray monitor: it is one of many around the world that detect cosmic rays from outer space. It has been in operation for thirty years, and to many it is a mystery as to why it is here, and what is does. The cosmic ray monitor in Inuvik is a neutron monitor. There are currently three neutron monitors operating in Canada. Bartol Research Institute, from the University of Delaware, operates the Inuvik, and Goose Bay, Newfoundland stations. The third station is located in Calgary, Alberta and operated by the University of Calgary. This report includes data from the Deep River, Ontario neutron monitor, which closed down in 1995. Each location records cosmic rays from a different part of space.

History of the Inuvik Monitor

Construction of the Inuvik monitor was funded by Atomic Energy of Canada Ltd. in 1962-63. The building was built by the National Research Council (NRC), next to the Department of Indian and Northern Affairs research center (Figure 1), Twenty tons (about 20,000 kg) of lead and electrical equipment, which make up the monitor, were shipped from Ottawa and barged to Inuvik during the summer of 1963. Before assembly in December of 1963, a drum dance was held in the circular building, as it seemed to be the perfect design and atmosphere for this community event. The monitor began operating in February 1964. When the Territorial Government took over the buildings in 1988, the Inuvik Research Center became part of the Science Institute of the NWT. In 1995 the Herzberg Institute of Astrophysics (HIA) section of the NRC, ceased its support of the cosmic ray monitor. Bartol Research Institute then contracted the Inuvik Research Centre to continue operating the monitor.

Data collected by the cosmic ray monitor provides information about the strength of solar and galactic cosmic rays, and disturbances in the solar terrestrial environment. The data is sent nightly to the Solar-Terrestrial Physics, HIA, in Ottawa for review and distribution.

Who is Interested in Cosmic Rays?

Scientists have been studying cosmic rays since the early 1900's. They have made many discoveries about matter and energy. Organizations involved in very high altitude flying are interested in their pilots' exposure to radiation. A single cosmic ray particle can change a computer memory cell, or change a chromosome in a reproductive cell. The can also effect radio communication and corrosion in northern pipelines. Cosmic rays indirectly help geologists and archaeologists determine the age of certain items. Residents of high latitude areas enjoy spectacular Northern Lights due in part to cosmic radiation.

What Are Cosmic Rays?

Everything in the universe, including cosmic rays, are made from subatomic particles like electrons, protons, and neutrons. A proton and an electron make up a hydrogen atom. Hydrogen is the most common atom in space. The nuclei of hydrogen (the proton) make up about 90 percent of cosmic rays. The remaining 10 percent is made up of the nuclei of heavier elements such as helium (two neutrons and two protons). Unlike other particles, cosmic rays have extremely high energies and travel at extremely high speeds through space, nearly at the speed of light.

The Earth's magnetic field acts as a protective barrier against cosmic rays. Since they are mostly charged particles, their direction of travel is strongly influenced by magnetic fields. The higher the energy acquired by cosmic ray particles, the less affected they are by magnetic fields.

Cosmic rays do not get far into the atmosphere before they collide with nitrogen or oxygen molecules in the air. The collision destroys the cosmic ray particle and the air molecule, and several new particles emerge. Cosmic rays from space are termed "primary", and any particles created in the atmosphere from collisions are termed "secondary". A bit of energy is transformed to each new secondary particle. Secondary cosmic rays spread out and continue to hit other particles and air molecules, creating a cascade of particles showering towards the ground. Figure 2 shows how the particles shower to the ground. The number of cosmic rays in the atmosphere increases to a maximum, and then diminishes as the energy fades closer to the ground. Because of atmospheric absorption, low energy particles are plentiful and high-energy particles are rare. Scientists studying the neutron monitor data are more interested in the energy of primary cosmic rays, before they affected by the atmosphere. A typical energy level for galactic cosmic ray detected by the neutron monitor is 17 billion electron volts. Solar cosmic rays are more concentrated towards lower energies. The ones reaching ground level started out with an average energy of about 3 billion electron volts before meeting the atmosphere.

Cosmic Rays in the Atmosphere

A variety of neutral and charged particles are produced in a cosmic ray shower (Figure2). During a collision between an air molecule and a high-energy cosmic ray, protons and neutrons and other secondary particles are released. Mesons are particles smaller than protons but larger than electrons. Mesons produced from primary cosmic ray collisions are called Pions. These quickly decay in two ways. Charged Pions decay into Muons, and neutral Pions decay into photons. Muons, produced by the charged Pions are then also charged. The decay occurs so quickly that it often occurs before any other process can take place. At the point of decay the new Muon jets off in another direction. Muons decay into an electron or positron (the antiparticle of the electron), and a neutrino. A neutral pion, as mentioned above, decays into two photons. Photons move with very high energies. Photons decay into the elementary units, electron and positron. If a positron or an electron meets a nucleus in its path then another photon is created.

The stronger the primary cosmic ray, the deeper into the atmosphere the cosmic ray penetrates. Since cosmic ray particles lose energy in the atmosphere, not all secondary cosmic rays make it to the ground.

Why Inuvik?

The magnetic field protects the Earth from most cosmic rays. The magnetic field lines follow a curved path from one magnetic pole to the other (Figure 3). Only the highest energy cosmic rays will penetrate the magnetic field and the atmosphere to hit the ground at the equator. Many cosmic rays penetrate the magnetic field, but are guided along the Earth's magnetic field lines towards the Polar Regions. Since there is no resistance from the magnetic field, friction in the atmosphere is the only force that slows them down.

A cosmic ray destined to be detected by the Inuvik neutron monitor starts out heading for a point over the Pacific Ocean, west of Mexico. About 60,000 km away from Earth, the particle begins to experience effects of the Earth's magnetic field, which deflects the particle towards Inuvik. The first interaction with an air molecule happens about 20 km above Inuvik.

It has been proposed that cosmic ray monitors be equally spaced around the poles to achieve the best view into outer space. Inuvik is geographically well located to record cosmic rays and has the services needed to maintain a monitor.

The Source of Cosmic Rays

Most cosmic rays are protons, which are abundant in the universe. How protons obtain the energy required to become cosmic rays is still a mystery.

Supernova explosions are one source of galactic cosmic rays. In a matter of seconds, the core of an old star collapses, releases a large amount of energy and particles into space, becomes a supernova remnants are identified in space by a nebula (cloud) of gas, which remains in the region of the explosion.

Solar flares are a source of solar cosmic rays. Solar flares are strong eruptions from the sun's surface, which expel solar particles into space. Solar flares, like supernovas, eject cosmic ray particles at such a force that they travel at nearly the speed of light. A neutron monitor on earth records a solar flare approximately 9 minutes after the event.

How does the Neutron Monitor Detect Cosmic Rays?

The neutron monitor in Inuvik has 18 cosmic ray counters. This consists of three units, each with six tube-shaped counters (Figure 4). A unit is covered with polyethylene slabs, and holds six lead tubes covered by polyethylene sleeves. The tubes are 2 m long and 25 cm in diameter. Inside the lead tubes are stainless steel tubes filled with a thin gas called boron trifluoride. A fine wire runs through the gas down the center of the tube and connects to an amplifier. A computer records the data and sends it to Ottawa for analysis.

When a cosmic ray hits the atmosphere it produces secondary particles, for example neutrons. The neutrons pass through the atmosphere, through the building, and penetrate the polyethylene and lead casing. The high energy of the cosmic ray particle is reduced by the polyethylene and leads to about 1/40 of an electron volt-about the same energy as a regular air molecule. At this energy level, a boron atom in the counter absorbs the neutron, and splits into a fast helium and a fast lithium ion. These energetic ions strip electrons from neutral atoms in the tube, producing a charge in the tube of gas. The amplifier as one count detects the charge. Not all neutron monitors are constructed with the lead casing, as the polyethylene is enough to slow the neutron down. The lead increases the neutron count by producing more neutrons as it is bombarded by cosmic rays. Neutron monitors constructed with lead casing count one neutron for every one primary cosmic ray entering the atmosphere through the area in space observed by the monitor.

What Does the Neutron Monitor Tell Us?

The neutron monitor records the number of cosmic rays hitting the monitor over time. Figure 5 is a graph showing both cosmic ray intensity recorded by the Inuvik neutron monitor and the solar cycle over a 30 year period. The sun continually expels matter (in the form of solar wind plasma) and magnetic fields. The expulsion occurs at a higher rate during high solar activity. On average, every eleven years solar activity is high. Plasma and magnetic fields spread out from the sun and create a barrier, which galactic cosmic rays must struggle through. Thus, when the sun is active, fewer galactic cosmic rays reach Earth.

Cosmic ray monitors as well as long-term cycles record short-term events. One of these events is termed a Forbush decrease. A Forbush decrease occurs when the sun releases an exceptionally large burst of matter and magnetic disturbance. The disturbance sweeps away some of the cosmic rays in its path. When the disturbance passes earth a Forbush decrease is seen on the neutron monitor. These disturbances typically travel at a speed of 400-1000 km/s, and take 2-4 days to travel from the sun to the earth. Cosmic ray intensity dips within a few hours, and then slowly recovers over the next few days. Figure 6 shows the large Forbush decrease on March 24, 1991 recorded by the Inuvik neutron monitor.

Another event recorded by neutron monitors is caused by solar flares. Solar flares erupt form the surface of the sun during high solar activity. Occasionally solar particles accelerate to such a high energy (greater than 400 million electron volts) that the neutron monitor sees them. Thus, while galactic cosmic rays are less common during high solar activity, solar cosmic rays are more common. The flare is recorded as sharp spike, and then decreases, usually within 24 hours, to previous values. Figure 7 illustrates how Inuvik, Deep River, and Goose Bay locations responded to a flare on May 24th, 1990.

Cosmic Rays in our Lives!

By monitoring cosmic rays we notice increases and decreases of cosmic ray strength at ground level. The changes occur for various reasons, and depending on the intensity, they have various effects on the Earth's system, our technology, and lives.

The following section describes the different effects of cosmic rays. One must remember that cosmic rays are just one aspect of the complex relationship between the Earth and the cosmos.

Weather

Weather is affected by the Sun, not by cosmic rays. However, cosmic rays are an indication of the sun's activity, and consequently weather patterns have been correlated to cosmic ray behavior. There was a period between the years 1645 and 1715, called the Maunder Minimum, when there was little solar activity and few sun spots (Figure 8). Coincidently, during the same time was a period called the Little Ice Age when temperatures became cooler in North America and Europe.

Computers

Computer companies must take cosmic rays into consideration when designing computers. As components become smaller and more powerful, strikes from high-energy cosmic ray particles can do more damage. One result of a cosmic ray strike is called a "single event" upset, which occurs when a computer memory cell is hit. This can change the basic units of memory, which is made up of a pattern of 0's and 1's. Computers must be designed to run constant checks to correct for any changes made; such as an '1' suddenly changed to an '0'. Another possible result is called a "latch-up".

Latch-ups happen when a cosmic ray burns out a component. By shutting down computers every now and then, glitches caused by the latch-up may be repaired. This problem is especially acute for computers aboard satellites, since they are exposed to a higher intensity of cosmic rays then computers on the ground.

Health Risks

Living organisms exposed to very high levels of any radiation are at risk of cellular damage that may cause cancer. Astronauts and pilots who fly at extremely high levels in the atmosphere are most at risk from cosmic rays. If a high-energy cosmic ray hit, for example, a reproductive cell, it could alter the genetic material possibly causing mutations. For this reason, aviation organizations that send people to these altitudes are interested in the data acquired by cosmic ray monitors. Genetic mutations are not always harmful, as they may allow organisms to adapt to a changing environment.

Astronomy Research

Satellites and spacecraft are exposed to very high energy levels of cosmic rays. Computer equipment and people in space must be highly protected from cosmic rays. A scheduled space walk or even a rocket launch may be delayed during periods of intense radiation.

The most persistent problem for astronomers who point cameras into space are cosmic rays. Cosmic rays hitting the cameras leave a lot of streaks and spots in the photographs. When taking a picture of an object in space, a long exposure is preferable to capture the most light. However, astronomers are limited to about one hour because too many cosmic ray streaks cloud the picture. Figure 9 is a photograph taken from the Hubble Space Telescope, which shows the effect of cosmic rays. It is a 23 minute exposure of a cluster of stars. The round objects are stars. The narrow streaks are cosmic rays that hit the detector on an angle during the 23 minutes. Many of the smaller bright spots are cosmic rays that hit the telescope at 90 degrees (straight on). In order to determine if a point of light is a star, or a cosmic ray, astronomers take three or more pictures of the same area, then filter out the cosmic rays. This is photograph was taken from space, but the effect is the same from Earth.

Radio Communications

Radio wave communication on Earth is disturbed by solar activity that increases the number of ions in the ionosphere. Transmitters send radio waves, which travel outward, reflecting off the Earth's surface and the bottom of the ionosphere. When the number of ions are temporarily increased, the radio waves are absorbed and radio transmissions fade. Cosmic ray monitors measure the amount of solar disturbance, which interferes with radio communication.

Pipeline Corrosion

North-south running pipelines in high latitudes are prone to corrosion from large electrical currents running deep through the Earth. The electrical currents are enhanced by magnetic field changes from the solar wind. Cosmic ray monitors detect the changes in the magnetic field. These currents are a major cause of corrosion in the Trans Alaska pipelines, which runs south from Prudhoe Bay, Alaska.

Power Outage

On March 13th, 1989, six million people were affected when Quebec Hydro, a power company that services much of eastern Canada, experienced a massive blackout. Some areas were out of power for nine hours; other areas had no power for days. More than 10 million dollars were lost by the company, and 10's to 100's of millions were lost by customers. The power outage occurred during a period of very intense solar and magnetic activity observed by cosmic ray monitors. Some researchers believe that cosmic rays can be used to predict potentially damaging solar activity. If this is the case, utility companies could take precautions to minimize damage.

Carbon Dating

Geologists and archeologists use a method called "carbon dating" to obtain the date of carbon based items such as plants and animals. To date times by this method the carbon-14 to carbon-12 ratio is calculated. Carbon 12 (C-12) is the stable carbon atom found in the carbon dioxide we breath out and plants breath in. C-14 atoms is radioactive, and produced from the collisions between cosmic rays and nitrogen atoms. C-14 atoms produced in the atmosphere become a part of living organisms. A similar percentage of radioactive C-14 is found in the tissue of all living organisms. After the last breath is taken and C-14 is no longer consumed, the C-14 present in the tissue begins to decay (stops being radioactive). Radioactive elements have a half life, which means half the amount of the radioactivity decays after a particular length of time. The half-life of C-14 is 5,500 years. By knowing the C-14:C-12 ratio in a sample its age can be calculated. This method of dating is good for archeological items, fossils, and geological units.

The Northern Lights

The charged particles of the Northern Lights, or Aurora Borealis, and cosmic rays are both affected by solar activity. Charged particles (electrons) from the solar wind are directed by the magnetic field towards the northern and southern polar regions of the ionosphere. The interaction between the charged particles and the atmospheric ions of nitrogen and oxygen produces a colorful light (Figure 10). The shifting patterns in the sky are due to changes in the magnetic and electric fields along the paths of the particles streaming toward Earth.

The aurora occur in an oval band around both the south and north magnetic poles. This oval band spreads into lower latitudes during high solar activity, and huge flows of incoming particles. The Activity of the auroras mirror the eleven-year solar cycle. During the Maunder Minimum few auroras occurred at mid latitudes. Also, when Quebec Hydro experiences a massive blackout in March of 1989, the Aurora Borealis were reported seen over the Caribbean Sea.

Conclusion

Monitoring cosmic rays is one way to gain a better understanding of the very complex relationship between Earth and the rest of the universe. In a time when people tamper with practices that alter our atmosphere, we have to be aware of the risks. The atmosphere is naturally balanced to protect life on earth from such dangers as cosmic rays. Ozone, the stratosphere, and ionosphere are all fragile components of the atmosphere which man in many ways has invaded.

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