Listening for Cosmic Rays!

The Inuvik Neutron Monitor

by Jan Houseman
and Alan Fehr

Aurora College

INUVIK RESEARCH CENTRE

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FOREWARD

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Inuvik Research Centre
Box 1430
Inuvik, Northwest Territories
X0E 0T0
Tel: (403) 979-3838
Fax: (403) 979-3570

e-mail: maad@inukshuk.gov.nt.ca
lkutny@inukshuk.gov.nt.ca
invklab@internorth.com

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GLOSSARY

(important words to know)

Antiparticles have the same mass (weight) as an elementary particle (protons, neutrons and electrons) but with the opposite sign. For example, an electron and positron have the same mass but opposite electrical charge of the same magnitude.

Archaeologists study human antiquities.

Astronomers study heavenly bodies, such as planets, stars and comets.

The atmosphere refers to the thin blanket of gases surrounding the Earth.

Atoms are the smallest units of an element. They consist of neutrons and equal numbers of protons and electrons.

Aurora borealis (see Northern Lights)

Aviation refers to the operation of aircraft.

Chromosomes carry the genetic material in animal and plant cells.

Cosmic refers to the cosmos, the entire universe.

Cosmic rays are subatomic particles which travel at nearly the speed of light through space and produce secondary cosmic ray particles in the atmosphere.

Data is the information collected during a research project.

Decay means to divide or break down into two or more parts.

Electrons are an elementary part of all atoms and carry a negative charge.

Energy refers to the ability to do work.

The equator is a line separating the Earth into north and south halves.

A **Forbush** decrease is a decrease in the amount of cosmic rays at ground level due to increased protection by the Earth's magnetic field from high solar activity.

Friction is the resistance to rubbing of one substance over another.

Galactic refers to a galaxy. Our galaxy (The Milky Way) is a large disk shape grouping of stars, nebulae, and interstellar gas and dust.

Genetic material contains the material of inheritance, or DNA.

Geologists study rocks and minerals.

Half life refers to the time required for one half of a radioactive nucleus to disintegrate into a non-radioactive form.

The ionosphere is a layer in the atmosphere 80 to 900 km high where there is a high concentration of ions.

Ions are atoms that have become charged due to the addition or loss of an electron.

The magnetic field is the region influenced by a magnetic body, such as Earth. The Earth's magnetic field is caused by electric currents and magnetic material within the Earth.

The magnetic poles of the Earth are points where magnetic field lines are perpendicular to the Earth's surface. These north and south poles are approximately 11° away from the Earth's geographic poles.

The magnetosphere is the region around a planet occupied by its magnetic field.

Matter is anything that has mass and takes up space.

Mesons are particles with a mass larger than an electron and smaller than a proton. One type of meson is a pion.

A molecule is the smallest amount of a chemical element or a combination of atoms that can exist while retaining the properties of the substance. For example, a water molecule is H_2O.

Muons are subatomic particles that behave like electrons, but have a larger mass.

A mutation is a change in hereditary material.

A **nebula** is a cloud of gas and dust between stars.

Neutrinos are particles with no charge, possibly no mass, which travel at or near the speed of light, similar to photons.

Neutrons are subatomic particles about the size of a proton with no electrical charge, found in the nuclei of all atoms except hydrogen.

Northern lights, or Aurora borealis, are caused by gases high in the atmosphere around the north pole. Aurora also occur around the south pole and are called Southern Lights.

Nuclei refers to more than one nucleus. A nucleus is the part of an atom composed of protons and neutrons. Surrounding the nucleus of atoms are a cloud of revolving electrons.

Ozone (O_3) is a form of oxygen within the Earth's stratosphere that filters out potentially dangerous levels of ultraviolet radiation.

Particles include any type of matter found in the atmosphere or space, including ions, atoms, and molecules.

A photon is a quantity of light energy, with particle and wave characteristics. It has momentum, a specific wavelength, but no mass.

Pions are a type of meson which decay rapidly into other particles.

Polar refers to the areas near the extremities, or poles, of the Earth's axis.

Polyethylene is a type of plastic.

Positrons are particles with a positive charge rather than a negative charge, and the antiparticle of an electron.

Protons are subatomic particles with a positive charge found in the nuclei of all atoms.

Radioactivity refers to a substance exhibiting spontaneous break down of atomic nuclei.

Reproductive cells contain genetic material which enable plants, animals and other organisms to reproduce.

Satellites are man-made objects which orbit the Earth, such as Canada's Anik satellite.

Solar refers to the sun.

Solar activity includes events on the sun including sun spots and flares.

The solar cycle averages 11 years, during which the number of sun spots fluctuates.

Solar flares are sudden, temporary outbursts of light and high energy particles from the surface of the sun.

The solar wind refers to the flow of solar particles, mostly protons and electrons, from the sun into space.

The stratosphere is a layer of the atmosphere between 10 and 50 km high. It is is ideal for flying because of excellent visibility, and smooth flying conditions.

Subatomic refers to any particle smaller than an atom.

Sun spots are temporary, cooler and darker areas on the sun.

A supernova is a star that explodes with enormous energy. The energy released by a supernova in one second is equivalent to the energy released by the sun in 60 years.

Terrestrial refers to the Earth.

The Universe, or cosmos, refers to all things and phenomena observed or believed to exist

INTRODUCTION

(Words shown in italics are explained in the glossary)

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 Centre 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 it 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 centre (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 Centre 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 Section, HIA, in Ottawa for review and distribution.

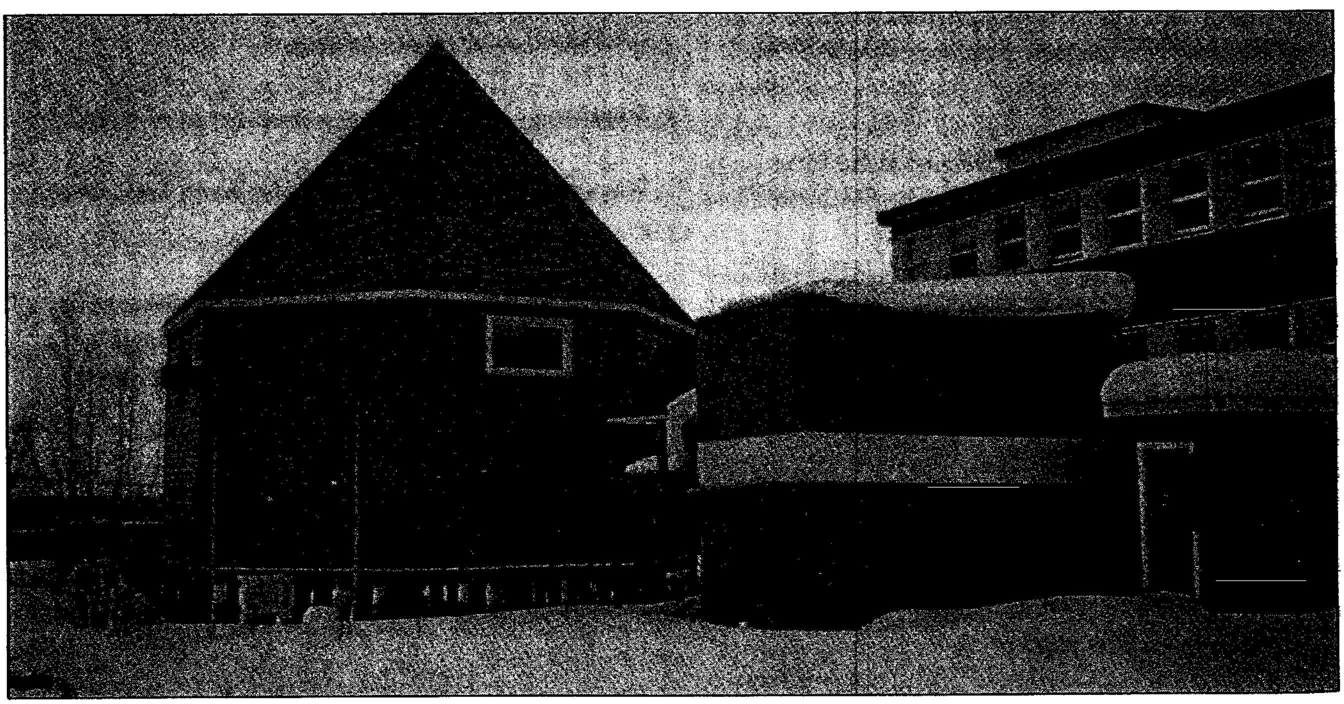


Figure 1. A separate building was built for the cosmic ray monitor. The cone shaped roof prevents snow from accumulating over the monitor. It is attached to the Inuvik Research Centre.

WHO IS INTERESTED IN COSMIC RAYS?

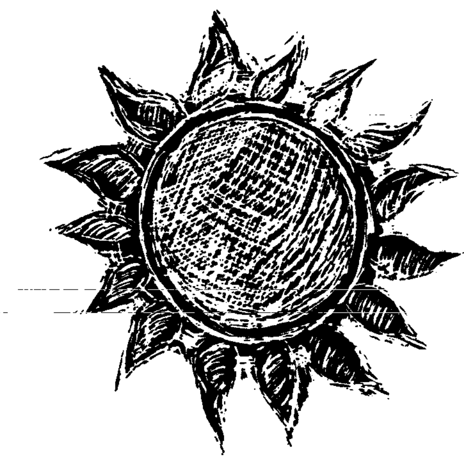
Scientists have been studying cosmic rays since the early 1900's. They have made many discoveries about *matter* and *energy*. Organizations involved in very high altitude flying are interested in their pilots' exposure to radiation. A single cosmic ray particle can change a computer memory cell, or change a *chromosome* in a *reproductive cell*. They 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 precent 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 then 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 transferred 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 are affected by the atmosphere. A typical energy level for a 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.



*The **Speed of Light** is almost 300,000 kilometres per second. It is the speed of all electromagnetic radiation through a perfect vacuum. It is the fastest speed possible. Space, as we read in this paper, contains particles and is not a pure vacuum. Light takes about 8 minutes to travel from the sun to the Earth. So if the sun burnt out we wouldn't know until 8 minutes later.*

N Neutron
P Proton
• Air molecule
π Pion
μ Muon
e-, e+ Electron, Positron
Υ Photon

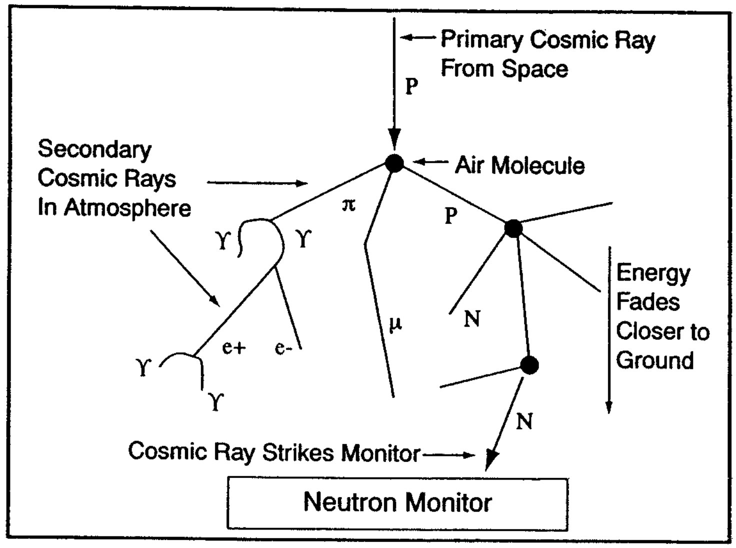


Figure 2. Primary cosmic rays enter the atmosphere and strike air molecules. This collision produces an array of new secondary cosmic ray particles. Each new secondary cosmic ray carries with it a part of the energy and then collides with other air and cosmic ray particles. The cosmic ray shower fades as energy becomes widely dispersed.

COSMIC RAYS IN THE ATMOSPHERE

A variety of neutral and charged particles are produced in a cosmic ray shower (Figure 2). 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.

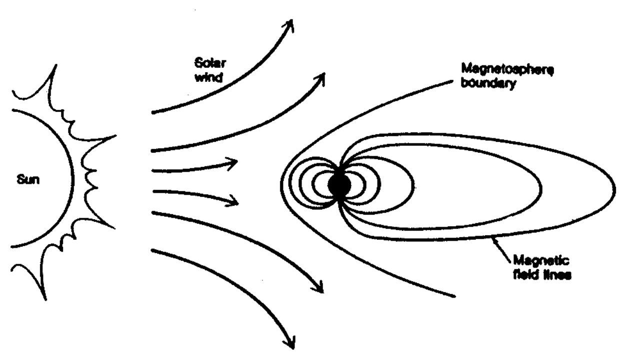


Figure 3. The magnetosphere is the region in space and in the upper atmosphere encompassed by the Earth's magnetic field. The Earth's magnetic field is deflected into teardrop shape under the influence of the solar wind. (Figure from Morgan and Morgan 1991)

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, and becomes a supernova remnant. 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 solar flare is recorded by a neutron monitor on earth 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 centre of the tube and connects to an amplifier. A computer records the data and sends it to Ottawa for analysis.

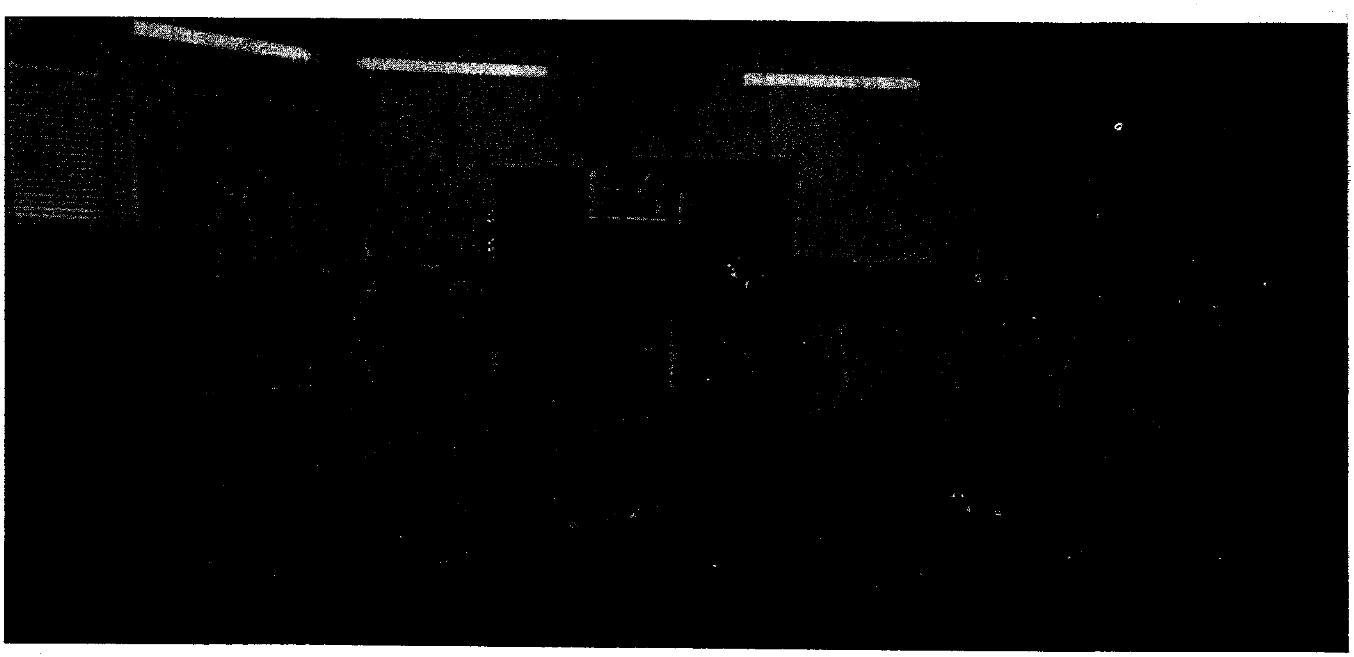


Figure 4. The neutron monitor is in three units. Within each unit are six counters covered by lead casing and polyethylene slabs.

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 lead 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 charge is detected by the amplifier as one count. 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.

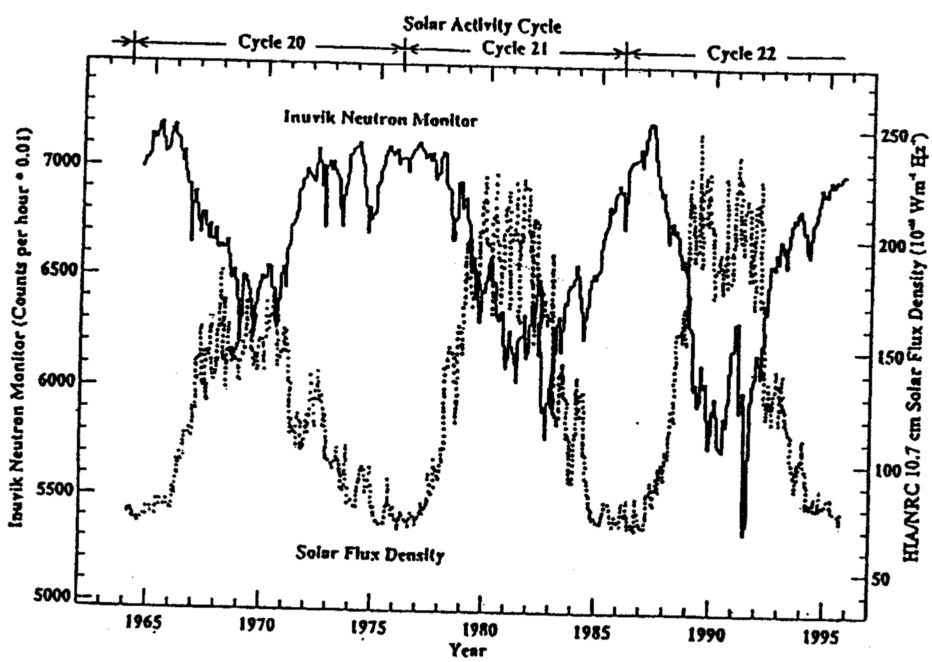


Figure 5. Cosmic ray intensity, and solar activity cycle over a 30 year period. During periods of high solar activity, fewer cosmic rays penetrate the atmosphere and make it to ground level. The cosmic ray data were recorded by the Inuvik neutron monitor. (Graph courtesy of the Solar - Terrestrial Physics Section, HIA)

Short term events are recorded by cosmic ray monitors as well as long term cycles. 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 from 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 they are seen by the neutron monitor. Thus, while galactic cosmic rays are less common during high solar activity, solar cosmic rays are more common. The flare is recorded as a 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.

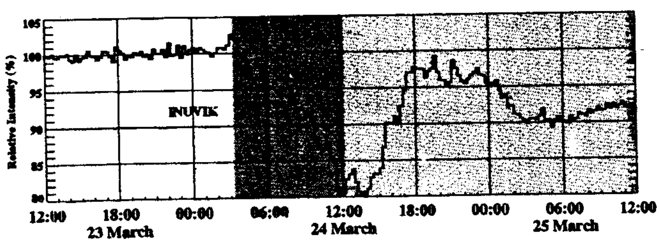


Figure 6. A large Forbush decrease was detected by the Inuvik neutron monitor between 3 AM and 12 noon on March 24, 1991, shown by the dark shaded area. A magnetic storm prevented many cosmic rays from entering the atmosphere. The cosmic ray intensity recovered within a few days. (Graph courtesy of the Solar - Terrestrial Physics Section, NRC Canada)

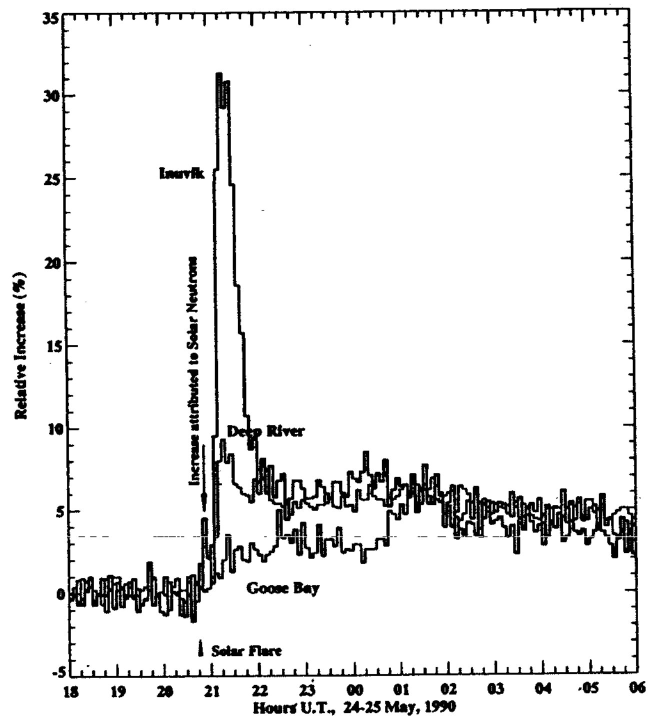


Figure 7. A large solar flare was recorded by Inuvik, Deep River, and Goose Bay neutron monitors on May 24, 1990. The flare is recorded as a sharp spike of intense cosmic rays, and then usually decreases within an hour. Monitors at different locations across the country recorded different strengths of cosmic rays. (Graph courtesy of the Solar - Terrestrial Physics Section, HIA)

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 behaviour. 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 1's and 0's. Computers must be designed to run constant checks to correct for any changes made, such as a '1' suddenly changed to a '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 than 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 who 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.

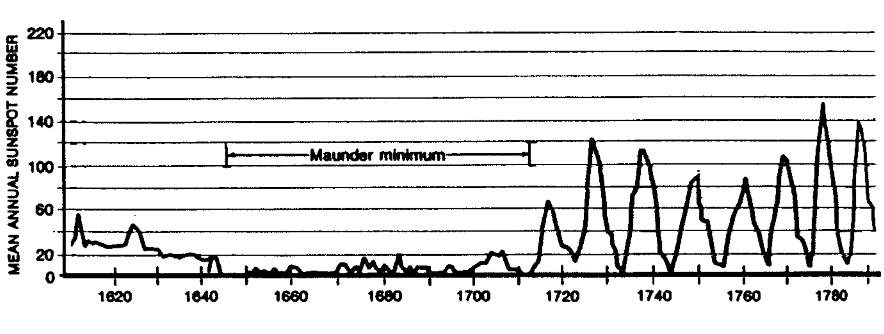


Figure 8. The Maunder minimum from 1645 to 1715. Few sunspots occurred during this time. Normally, solar activity and the number of sunspots increase about every 11 years. (Figure from Morgan and Morgan 1991)

Astronomy research

Satellites, and space craft flights 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 cosmic 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 photograph was taken from space, but the effect is the same from Earth.

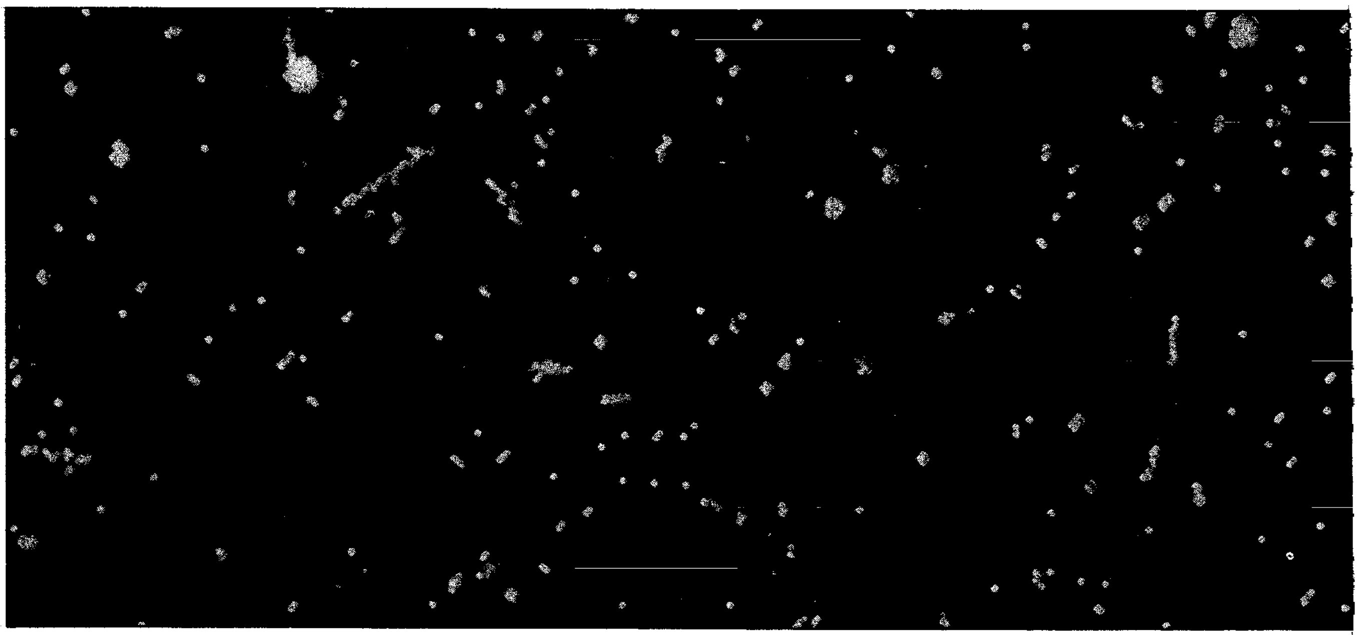


Figure 9 Photograph of stars and cosmic rays taken from the Hubble Space Telescope. The round objects are stars. The narrow streaks are cosmic rays that hit the detector on an angle during the 23 minute exposure. Many of the smaller bright spots are cosmic rays that hit the telescope at 90 degrees. (Photograph courtesy of the Dominion Astrophysical Observatory, HIA)

Radio communication

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. The changes in the magnetic field are detected by cosmic ray monitors. These currents are a major cause of corrosion in the Trans Alaska pipeline which runs south from Prudhoe Bay, Alaska.

Power outage

On March 13, 1989, six million people were affected when Quebec Hydro, a power company which services much of eastern Canada, experienced a massive black-out. 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 items 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 is *radioactive*, and produced from the collisions between cosmic rays and nitrogen atoms. C–14 atoms produced in the atmosphere become a part of carbon dioxide molecules, which 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 5500 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 colourful 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 experienced a massive black-out in March of 1989, the auroral borealis were reported seen over the Caribbean Sea.

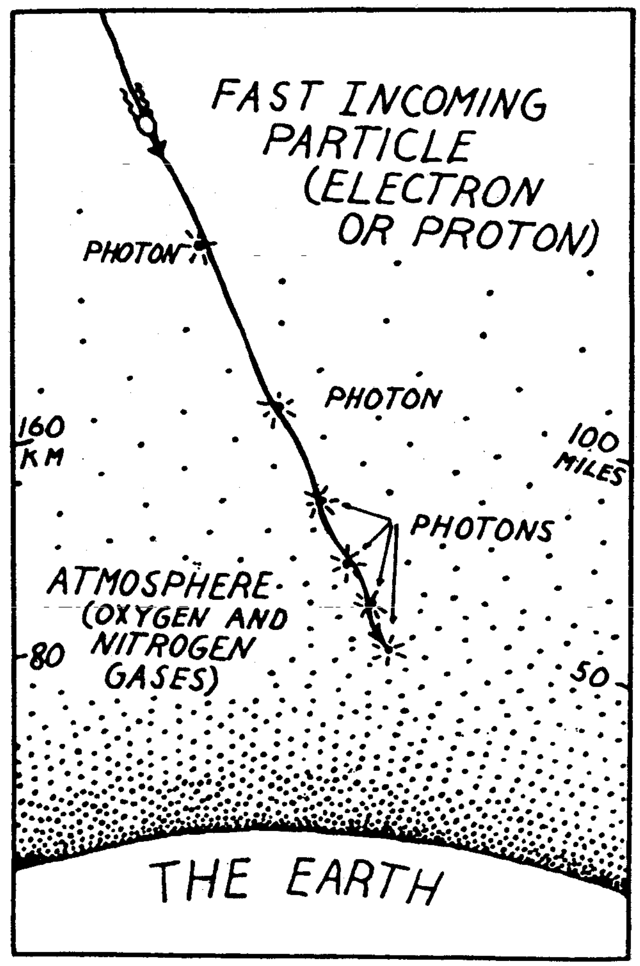


Figure 10. Fast incoming particles strike oxygen and nitrogen gases high in the atmosphere, producing the colourful Northern lights (photons). (Figure from Davis 1992)

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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For more information contact:

Aurora Research Institute
Box 1450
Inuvik, Northwest Territories
X0E 0T0
Canada

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