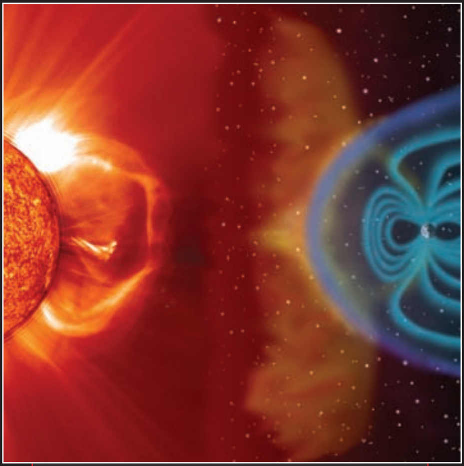
National Aeronautics and Space Administration

Space Faring
The Radiation Challenge

An Interdisciplinary Guide
on Radiation Biology
for grades 9 through 12



Module 4:

Applications to Life on Earth

Educational Product	
Educators and Students	Grades 9–12

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Radiation Educator Guide

Module 4:
Applications to Life on Earth

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MODULE 4: Applications to Life on Earth: Radiation as a Tool

Now that we have an understanding of radiation, its biological effects, and radiation countermeasures, it is important to learn about the beneficial uses of radiation. In this section, we will discuss examples of how ionizing radiation is used at clinics and hospitals to diagnose disease and injury, and summarize several radiation and radioactive isotope applications.

The Discovery of X-rays

Wilhelm Conrad Röntgen is chiefly associated with his discovery of x-rays. In 1895, Röntgen was carrying out experiments with a cathode ray electron generator (a sealed glass vacuum tube). He shielded the glowing tube with thick cardboard and was surprised to notice that sensitized paper at some distance from the tube would still glow–evidently as a result of radiation from the generator. Röntgen placed his hand between the generator and the coated paper on the wall and was astonished to observe that the shadow of the bones in his hand had projected on the paper as well! He repeated this experiment and created a "röntgenogram" of his wife's hand–the first ever x-ray image on film. For this work, Röntgen was awarded the first Nobel Prize in Physics in 1901. To this day, radiographs (x-ray images of a patient's body) are essential tools in the treatment of disease and injury.

Figure 1: An early x-ray image.

Fluoroscopy

For certain kinds of health conditions, simple radiographs may be insufficient. Fluoroscopy is commonly used when real-time observation or medical interventions are required. Although it exposes a patient to a much higher dose of radiation than a conventional x-ray, fluoroscopy allows a doctor to observe an x-ray image of a patient's body in real time. This technique enables doctors to observe surgical procedures, such as the following:

- Angioplasty—the mechanical widening of a narrowed or fully obstructed blood vessel. Sometimes, a small inflatable balloon is used to improve blood flow in the obstructed area.
- Heart bypass grafting—a surgery that uses arteries or veins from other parts of the patient's body to graft a detour or "bypass" around the blocked part of a coronary artery, restoring the blood supply to the heart muscle.
- Coronary angiography—an x-ray examination of chambers, blood vessels, and blood flow in the heart.

Fluoroscopy also allows for real-time study of gastrointestinal processes.

Figure 2: A fluoroscope.

Figure 3: A CAT Scan image of a human head.

CT Scanners

Another technique that is based on x-ray technology is computed axial tomography, also known as CT or CAT scan. Interestingly, the data imaging techniques previously used on the spacecraft Mariner 4, which flew by Mars in 1964, eventually lead to medical applications in CAT scans, diagnostic radiography, brain and cardiac angiography and ultrasound technologies.[1] CT scanners use x-ray equipment to gather x-ray images from different angles around the body in spirals or slices. Computers are then used to assemble the images for a three-dimensional visualization of the patient's internal anatomy. The dose received during one CT scan is approximately the same as 2-3 chest x-rays equivalents. The same image processing technology has evolved and is used for applications like crop forecasting, planetary surface characterization, mapmaking, water evaluation, and disaster management.

Figure 4: The Siemens Symbia SPECT/CT scanner. Image Credit: Impact Scan.

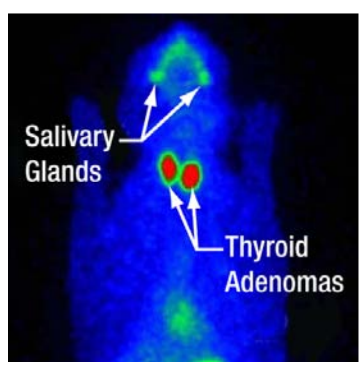


Figure 5: In this SPECT scintigram, the radioisotope has selectively concentrated at abnormal areas in the thyroid of a cat.

1 http://www.jpl.nasa.gov/history/index_beginnings.htm

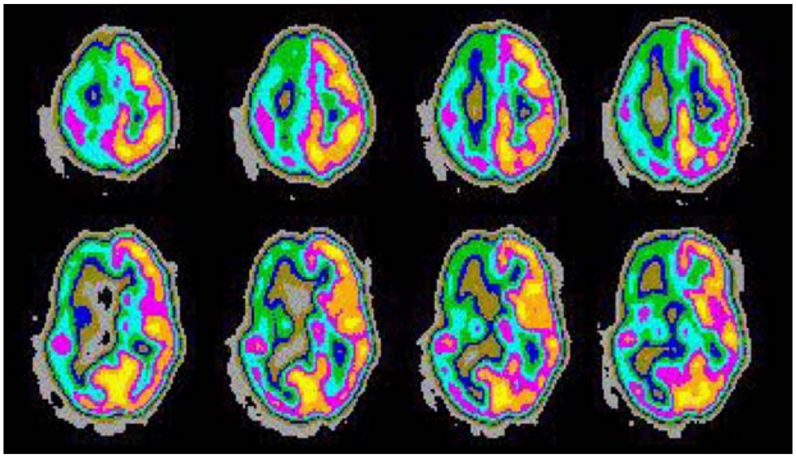


Figure 6: A PET image of an epilepsy patient.

Nuclear Medicine

Since the discovery of x-rays, scientists and doctors have worked together to develop tools that allow for imaging of internal anatomy and soft tissues. In nuclear medicine, doctors use a variety of imaging tools with radioactive substances to image a patient's internal anatomy and function. This is accomplished by introducing radioactive elements (radioisotopes) into the body of a patient by injection, inhalation, ingestion, or topical application. Different radioisotopes then preferentially concentrate in certain organs. For example, radioactive iodine-131 collects in the thyroid gland (see figure 5).[2] As each radioisotope decays, it gives off radiation (such as gamma rays), which can be observed by a gamma ray camera or detector. Variations in radiation intensity in the body will activate film or a detector array to create an image. Typically, the radioisotopes have relatively short half-lives and decay rapidly, which helps to minimize the exposure to damaging radiation. In general, total doses are very low.

Two examples of high-powered imaging tools in nuclear medicine that use the tomographic approach are the single photon emission computed tomography (SPECT) and positron emission tomography (PET) scanners. These instruments are especially suited to monitoring dynamic processes like cell metabolism or blood flow in the heart and lungs. Both use a gamma ray camera to detect gamma ray photons emitted from the radioisotopes used in the body. In each slice of figure 6, PET images reveal changes in blood flow that are correlated with epilepsy in the right side of a patient's brain. SPECT technology is commonly used in brain scans but it can also be used to observe other organs such as the heart. The image that is acquired with a gamma camera or SPECT is called a scintigram. Figures 7 and 8 show how SPECT imagery can be useful in visualizing along each axis of the heart and brain to compare its internal structure and function.

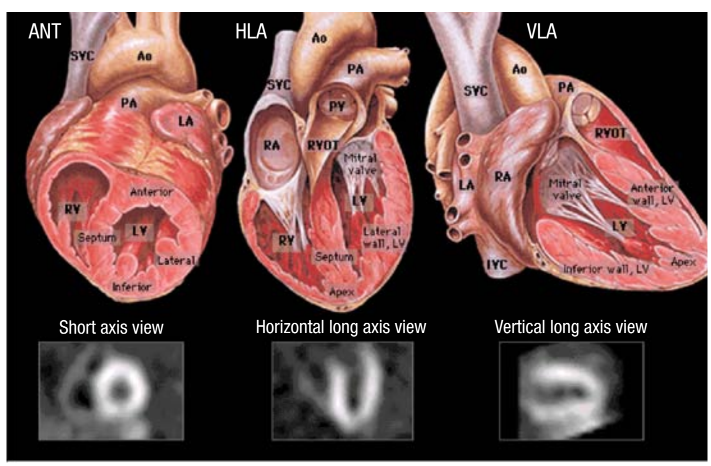


Figure 7: In this nuclear myocardial perfusion tomogram, the SPECT images are compared with drawings that are similar in cross-sectional view. Image Credit: Yale School of Medicine.

2 http://rst.gsfc.nasa.gov/Intro/Part2_26d.html

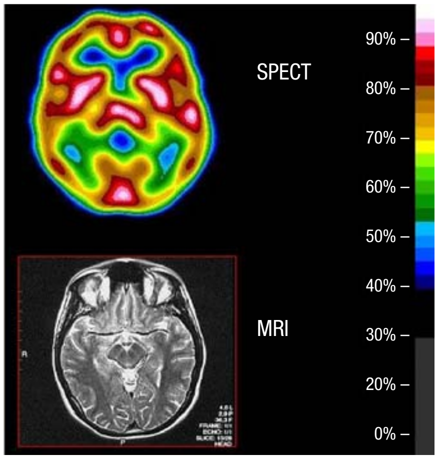


Figure 8: In this normal brain, SPECT and MRI transverse images can be used to compare structure and function. Image Credit: Dr. Robert Kohn.

Figure 9: An MRI scanner.

Magnetic Resonance Imaging

Not all medical imaging tools use x-rays or gamma rays. Magnetic resonance imaging (MRI) scans use low energy radio waves and strong magnetic fields to excite magnetic resonance in tissue atoms. MRI scans are commonly used to differentiate subtle differences within soft tissue regions of the body (differences in concentrations of water and fat give rise to different MRI signals in these regions). As in a CT scan, all or part of the patient's body is placed inside a large cylinder during the MRI. A strong magnetic field is applied, which causes some of the molecules in the patient to align themselves along the direction of the field. This causes the hydrogen-containing compounds within the body to resonate at radio-frequency signals, which are picked up by a detector. A computer converts it to an image, which can be color-coded. In some cases, it is useful to combine MRI imagery with SPECT scintigrams to compare anatomical structures with their function (see figure 8).

Radiation Therapy

When surgery alone cannot entirely remove a cancerous tumor, radiation therapy is sometimes used in conjunction with the surgery. Intraoperative radiation therapy (IORT) delivers a high dose of radiation to cancerous tumors while they are exposed during surgery. Other techniques like three-dimensional conformal radiation therapy (3-D CRT) use radiation only. In 3-D CRT (also known as gamma-knife surgery), computers with specialized software use the information from CT Scans or MRIs to create beams of radiation that conform to the shape of a tumor. Once the exact location, size, and shape of the tumor is known, the computer instructs the linear accelerator to bombard the tumor with the conformal radiation. This technique is particularly useful in treating prostate cancer, lung cancer, and certain brain tumors. Another example of conformal radiation therapy is intensity-modulated radiation therapy (IMRT), which precisely varies the intensity of the radiation beams used during treatment. Greater radiation intensity is directed at larger areas of the tumor, while weaker beams are directed to smaller areas of the tumor. This helps to reduce the amount of radiation used and limits the amount of radiation exposure to healthy tissue. In some cases, radiation is also combined with heat in treatments to kill cancer.

Figure 10: Radiation therapy uses radiation to treat disease. Image Credit: Mayo Clinic.

Figure 11: Tiny capsules filled with cesium-131 are implanted in or near a tumor. X-rays emitted by the cesium kill the cancer cells. Image Credit: Pacific Northwest National Lab.

Brachytherapy

In each of the previously discussed examples, radiation is delivered from a source external to the patient's body. However, there are internal forms of radiation therapy like brachytherapy, which is designed to deliver a high dose radiation from inside the body. Brachytherapy involves placing a protected source of radiation (such as iridium-192 or cesium-131 that has been encased in tubes, wires, or capsules, see figure 11) directly within the tumor or very near to it.

Side Effects of Radiation Therapy

Exposure to radiation can cause negative side effects, ranging from dry mouth, difficulty swallowing, changes in taste, nausea, vomiting, diarrhea, irritated skin, hair loss, chest tightness, cough, shortness of breath, fatigue, or ear aches. In addition, physiological complications like bone marrow suppression may result. This can cause anemia, low white blood cell count, and low platelet count. Secondary malignancies or treatment-associated cancers can sometimes occur in patients years after radiation therapy. Some patients experience damage to healthy tissues that leads to cognitive impairment, or the loss of the ability to remember, learn, and complete certain tasks. As a result, a great deal of research focuses on maximizing the benefits of tumor killing radiation while minimizing its effects on healthy tissue surrounding the tumor. It is important to note that the location and intensity of radiation exposure affects the nature of negative side effects.

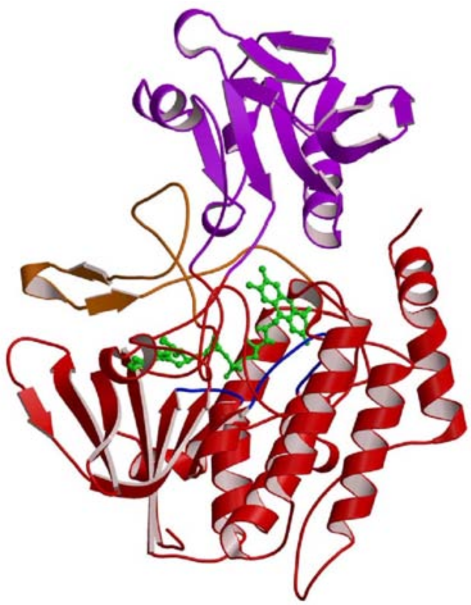


Figure 12: Radiation can be used to learn about the shape of enzymes. Image Credit: Brookhaven National Lab.

Biotechnological and Chemical Uses

There is a great deal of ongoing biochemical research that uses radiation sources. Much of this work investigates the molecular mechanisms responsible for biological processes. For example, scientists use high-intensity x-ray beams in crystallography to produce images of the crystal structures[3] of biochemicals such as the flavin-containing monooxygenase seen in figure 12. By studying the crystal structure of biochemicals, scientists are able to create step-by-step snapshots of chemicals at different stages of catalytic action. Crystallography is also used to create three-dimensional structures of particular proteins with the purpose of designing drugs that interact specifically with these proteins. Other researchers use radioactive isotopes in chemistry labs to track the path a chemical follows during a chemical reaction. To accomplish this, radioactive isotopes are incorporated into reactants, the chemicals are mixed, and the reaction is carefully monitored over time. This procedure is particularly useful for tracing underground rivers, following blood supply to a brain tumor, visualizing brain function itself, or the development of an embryo.

Radiometric Dating

Radiometric dating is a technique used to date both physical and biological matter. It is based on knowing the decay rates of naturally occurring isotopes. Radioactive decay is a spontaneous process in which an unstable atom emits particles (electrons or much heavier alpha particles–helium nuclei) from its nucleus to create a different form (an isotope) of the same element. The rate of decay is expressed in terms of an isotope's half-life, or the time it takes for one-half of the radioactive isotope in a sample to decay. Most radioactive isotopes have rapid rates of decay (short half-lives) and lose their radioactivity within a few days or years. Some isotopes decay much more slowly over millions or billions of years, and serve scientists as "geologic clocks."[4] Geologists can determine the age of a geologic formation or fossil by using a mathematical formula in Figure 13.[5]

Figure 13: The half-life of naturally occurring radioactive substances in a sample can be used to determine the age of the sample. Image Credit: USGS.

$$t = \frac{1}{\lambda} \ln\left(1 + \frac{D}{P}\right)$$

where t is the age of the rock or mineral specimen
D is the number of atoms of a daughter product today,
P is the number of atoms of the parent isotope today,
In is the natural logarithm (logarithm to base e), and
λ is the appropriate decay constant

(The decay constant for each parent isotope is related to its half-life,

$t_{1/2}$ by the following expression: $t_{1/2} = \frac{\ln 2}{\lambda}$

3 http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=06-76
4 http://pubs.usgs.gov/gip/geotime/radiometric.html
5 http://pubs.usgs.gov/gip/geotime/radiometric.html

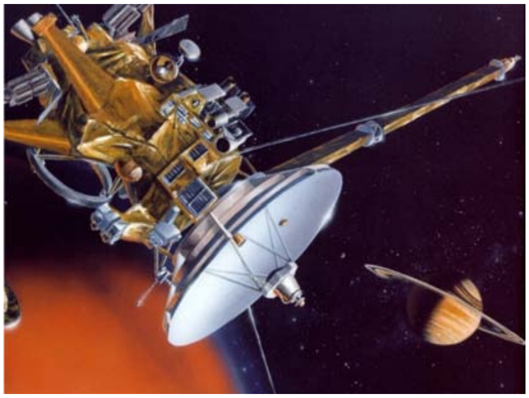


Figure 14: The Cassini spacecraft.

Consumer Products

Many common consumer products are manufactured with, or naturally contain, radioactive material. Examples include smoke detectors, watches, clocks, ceramics, glass, camera lenses, fertilizers, and gas lantern mantles. Foods that have a low sodium salt substitute may contain potassium-40. In the 1920s, some products were sold as radium-containing "cure-alls!"

Power Sources

Heat produced from the decay of radioactive substances can be used to generate electricity by means of radioisotope thermoelectric generators (RTGs). The Pioneer, Viking, Voyager, Galileo, Ulysses, and Cassini (figure 14)[6] spacecrafts all used this technology.[7] On larger scales, electrical energy can also be produced through fission of radioactive materials like uranium-238.

Sterilization and Food Irradiation

In biology or tissue culture laboratories, UV radiation is an essential part of everyday operations in facilities that require sterile conditions during cell plating, tissue handling, or specimen transfer. Prior to sensitive operations, UV radiation is used to sterilize surfaces to ensure clean working conditions before the operations begin. Notice the bright blue light in the picture in figure 15. It is a UV light inside a laminar flow hood. When it is turned on, the internal work volume of the hood is being sterilized.

One method of preserving fresh or packaged food is to expose it to ionizing radiation, which is a process known as cold pasteurization. This process kills any microbes that could cause spoilage or disease to the consumer. Food sterilization by radiation is the most studied food preservation process and has been shown to be safe and reliable.

Figure 15: UV lights inside a laminar flow hood at NASA Ames.

6. http://solarsystem.nasa.gov/multimedia/gallery.cfm?Category=Spacecraft&Page=15
7 http://nuclear.energy.gov/space/neSpace2a.html

Activity IVa: Researching Radiation as a Useful Tool

In this activity, we suggest that the students gather information about a tool, technique, or product that contains or uses radiation or radioactive materials and give an oral presentation on their findings. If possible, have the students include the topics discussed in Modules 1, 2, and 3.

Objectives:

- Present in detail an application of radiation or radioactive isotopes.

Discussion Questions:

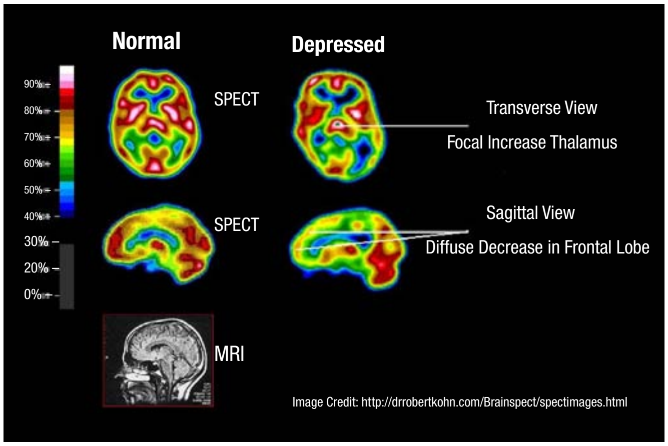
- How are x-rays useful?
- How is radiation used with cancer patients?
- How can gamma rays be used to preserve food?
- Do cell phones give off radiation? If so, how much, and is it harmful?
- How can radioactive materials be used to determine the age of a rock?
- What is the difference between a SPECT, a CT scan, and radiation therapy?

Research Question:

How has radiation and radioactive materials enhanced our understanding of biological structures and their function?

Methods:

Have the students research a nuclear medicine technique or radiation/radioisotope application in which they are interested. Require the students to develop a poster presentation or electronic presentation for the class that incorporates the concepts of Modules 1, 2, 3, and 4.



Activity IVb: Investigating Nuclear Medicine Imagery

In this activity, we suggest that the students research nuclear medicine imagery. If possible, have the students include the topics discussed in Modules 1, 2, and 3.

Objectives:

- Compare and contrast differences between brain activity on SPECT images.
- Create a chart that discusses normal and abnormal brain SPECT imagery.

Discussion Questions:

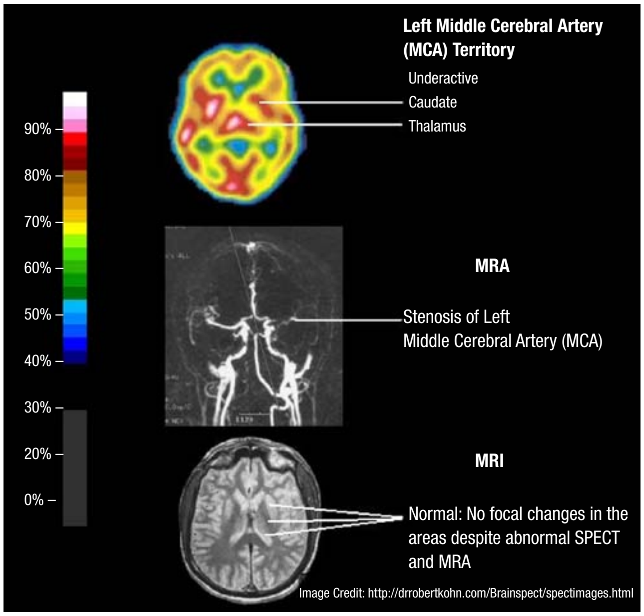
- How do the most active areas in the brain compare with those least active?
- What is the difference between a SPECT, a CT scan, and radiation therapy?
- How do the different parts of the brain affect human behavior?
- How can a SPECT image be used to diagnose a mental health disease?

Research Question:

How can imagery of the human brain help a doctor to diagnose and treat brain disorders?

Methods:

Have the students compare the images of normal brain activity with that of depressed (abnormal) brain activity (or other conditions).



In this example, a patient has suffered a stroke. An MRI, a magnetic resonance angiogram (MRA), and a SPECT image of a patient's brain were used to diagnose the cause of the patient's symptoms. Notice that MRI did not show abnormalities, whereas the problems are more readily seen in the MRA and SPECT images.

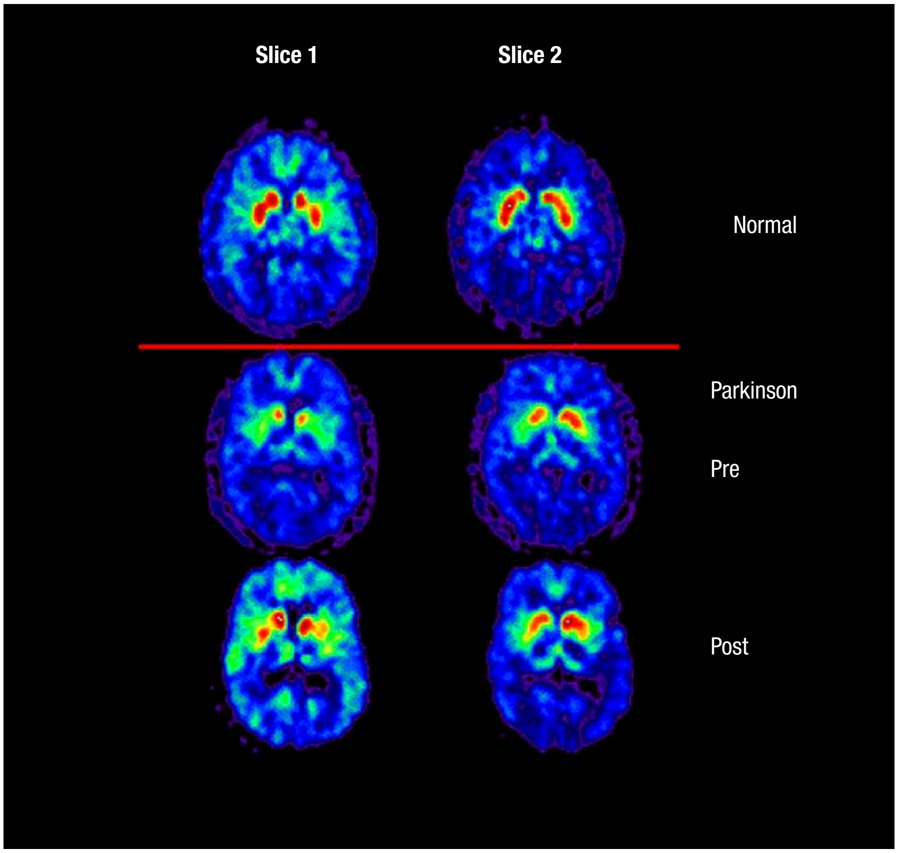


Image credit: NASA

Additional Images: from **http://rst.gsfc.nasa.gov/Intro/Part2_26d.html**
With this PET scan, you can show students how observing brain activity over time can aid a doctor in the diagnosis and treatment of disease. In this example, a patient diagnosed with Parkinson's disease has responded favorably to treatment. Notice that the pre-treatment image slices along the same regions of the brain differ significantly as compared to those of a normal brain, whereas the post treatment images are similar to the normal brain images.

References:

Another website that provides students a tutorial on PET imagery can be found at:
http://science.education.nih.gov/supplements/nih2/addiction/activities/lesson1_analyzing2.htm

Tutorial of the long-term effects of drugs on the brain, with SPECT and PET imagery:
http://science.education.nih.gov/supplements/nih2/addiction/activities/lesson4.htm

Appendix 1: Additional Websites

Module 4: Applications to Life on Earth: Radiation as a Tool

For more NASA-related radiation benefits, see:
http://exploration.nasa.gov/documents/Benefits1.pdf

For more information on radiometric dating, see:
http://pubs.usgs.gov/gip/geotime/radiometric.html

Appendix 2: National Education Standards[8] by Module

Module 4: Applications to Life on Earth

Content Standards: 9-12

Content Standard F:

Science in Personal and Social Perspectives

Science and technology in local, national, and global challenges

8 http://lab.nap.edu/html/nses/6a.html

Space Faring:
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   College/University - ______ Undergraduate ______ Graduate

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   Number of Others:
   ______ Administrators/Staff ______ Parents ______ Professional Groups
   ______ General Public ______ Civic Groups ______ Other

2. What is your home 5- or 9-digit zip code? –

3. This is a valuable educator guide?
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4. The information provided in the product is relevant to my role in education.
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Fold along line and tape closed.

5. How would you rate the effectiveness of the product in teaching the intended standards.
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   ❏ Demonstration
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   ❏ Hands-On Activities
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   ❏ Interdisciplinary Activity
   ❏ Lecture
   ❏ Science and Mathematics Standards Integration
   ❏ Team Activities
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7. Where did you learn about this educator guide?
   ❏ NASA Educator Resource Center
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   ❏ Institution/School System
   ❏ Fellow Educator
   ❏ Workshop/Conference
   ❏ Other: Please specify:

8. What features of this educator guide did you find particularly helpful?

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