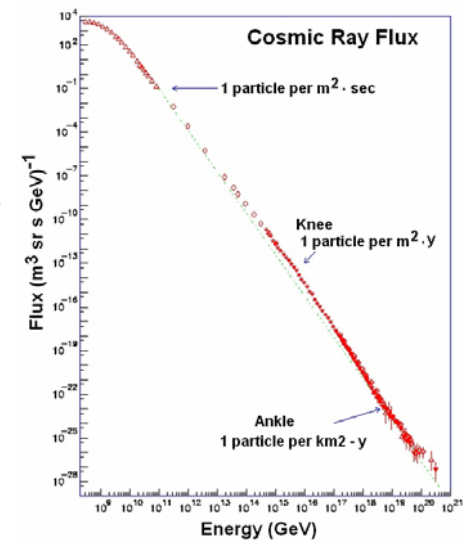


## Natural Radiation Cosmic

Physics 6605

## Cosmic Ray Flux

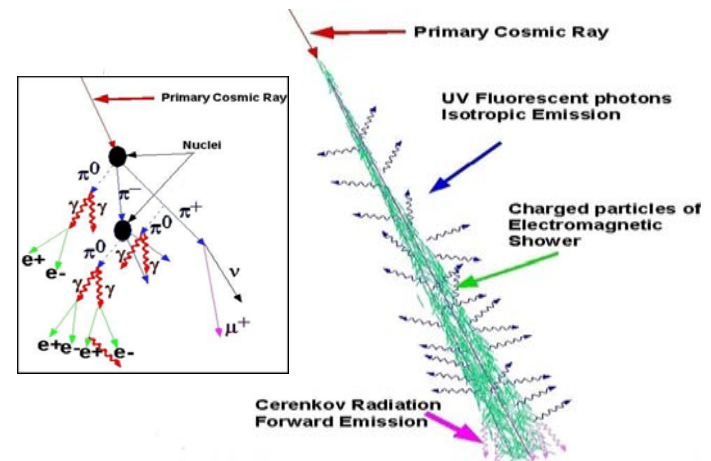
- Extends over a wide energy range
- Almost featureless
- “knee”  $3 \times 10^{15}$  eV
- Flux is ~isotropic due to galactic magnetic fields.

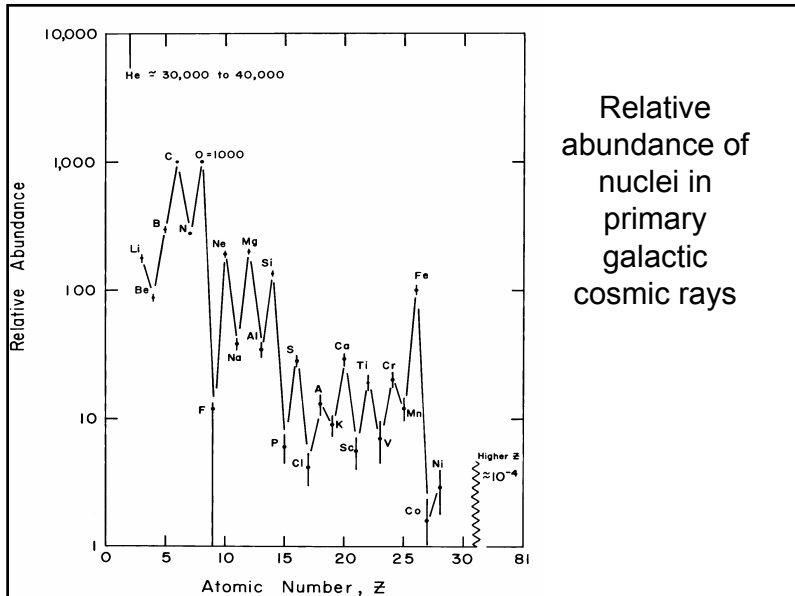


## Cosmic Radiation

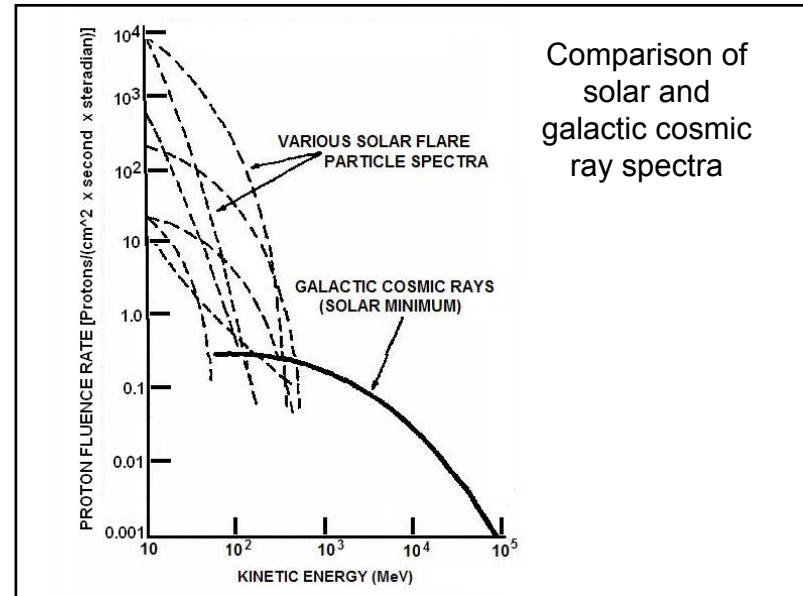
- Components are designated as galactic or solar depending on origin
- Galactic flux is protons (87%), alphas (11%), heavier nuclei (1%), and electrons (1%)
- The atmosphere is a significant shield for cosmic rays, attenuating by a factor of 1000
- Energies of most galactic particles are in the range of  $10^8$  to  $10^{11}$  eV but range to  $\sim 10^{21}$  eV
- Normal solar wind is protons with energy around 1 keV

## Cosmic Ray Air Showers





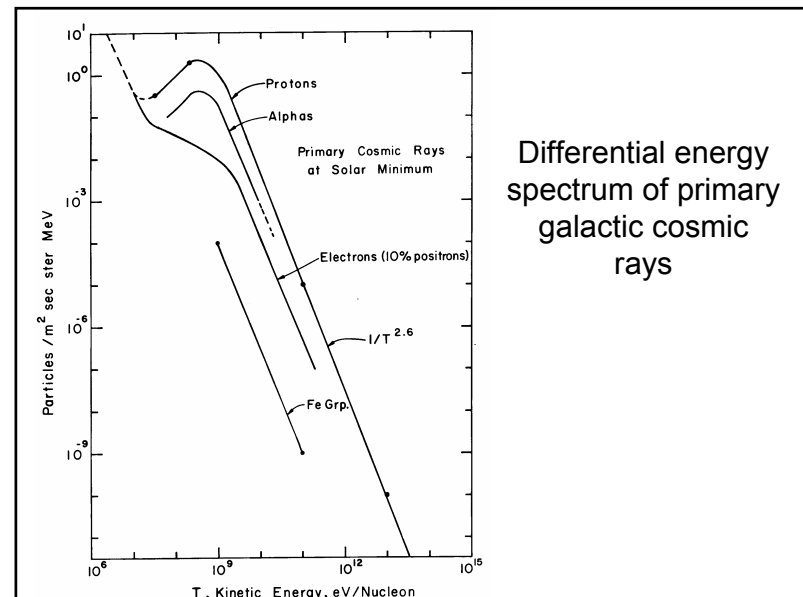
Relative abundance of nuclei in primary galactic cosmic rays



Comparison of solar and galactic cosmic ray spectra

## Cosmic Radiation

- Solar flares produce alphas and protons with energies to nearly 1000 MeV but most in range of 1-100 MeV
  - Radiations that cause ionization at earth's surface are galactic in origin, not solar
- High solar activity perturbs interplanetary magnetic fields
  - High solar activity actually reduces cosmic ray doses, especially at high altitude
    - Variation amounts to a factor of 3
  - Effect at earth's surface is less, about 10%

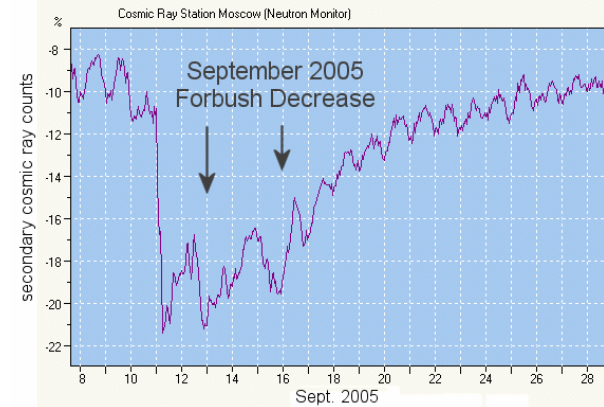


Differential energy spectrum of primary galactic cosmic rays

## Cosmic Radiation

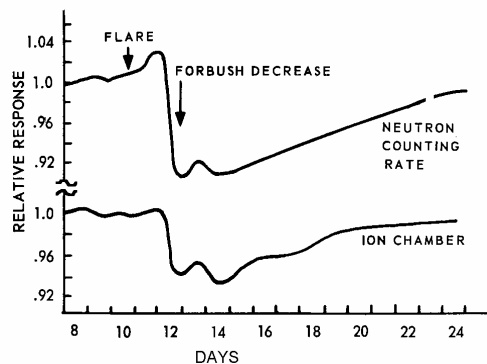
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## Illustrations of Forbush Decrease



[http://science.nasa.gov/science-news/science-at-nasa/2005/07oct\\_afraid/](http://science.nasa.gov/science-news/science-at-nasa/2005/07oct_afraid/)

## Illustrations of Forbush Decrease



## Cosmic Radiation

- Cosmic ray interactions in atmosphere create neutrons, protons and pions
- Pion decay results in the production of electrons, photons and muons
- Muons are the largest dose contributors near earth's surface
- Cosmic radiation is responsible for 30-50% of the dose from natural penetrating radiation on the surface
- Doses are measured with ion chambers

# Measurements of Neutron Spectra

(Gordon et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 6, 2004)

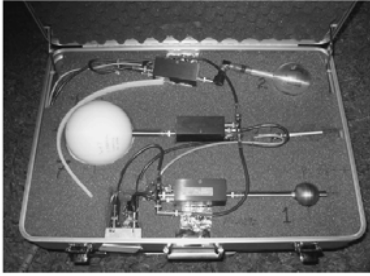
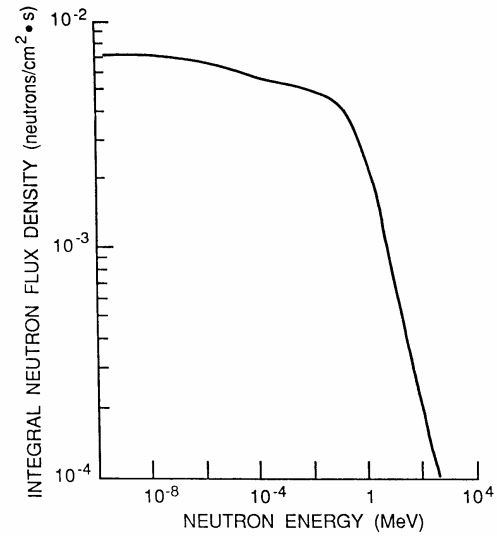


Fig. 1. Three neutron detectors along with their charge-sensitive preamplifiers in a lightweight aluminum suitcase.



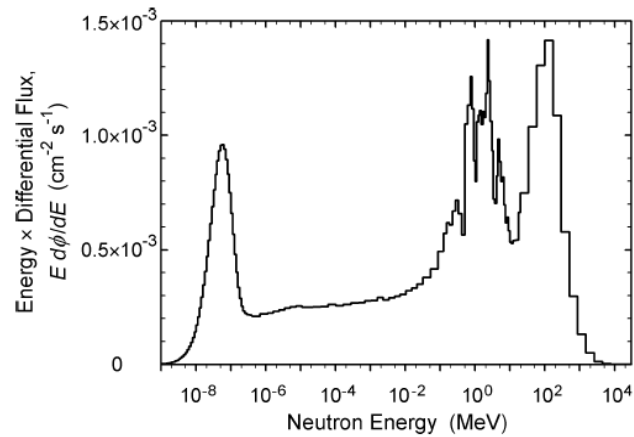
Fig. 2. Fourteen-element Bonner sphere spectrometer located on the roof of the IBM T.J. Watson Research Center. The suitcases and connector ends of the large detectors were covered in plastic bags to prevent water damage.



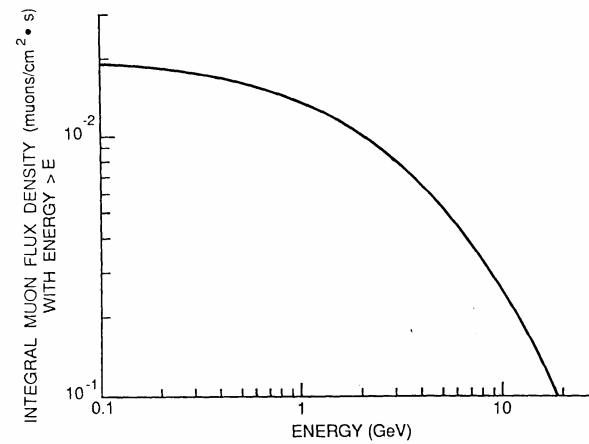
Integral cosmic ray neutron flux

# Ground Level Cosmic Ray Neutron Energy Spectrum

(Gordon et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 6, 2004)



# Integral cosmic ray muon flux



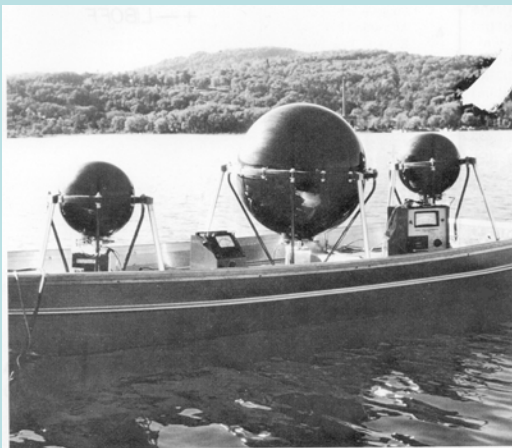
## Cosmic Radiation

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## Commercial PIC



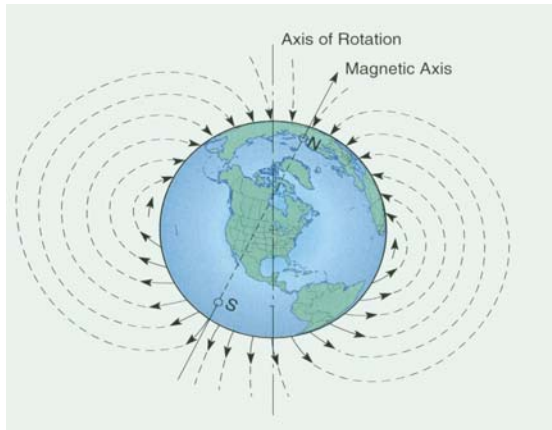
## Measuring Cosmic Ray Dose



## Cosmic Radiation

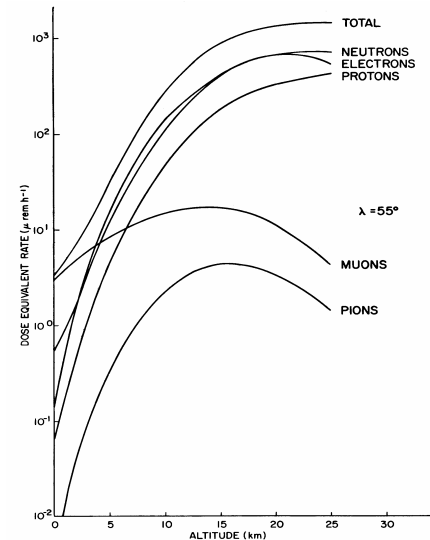
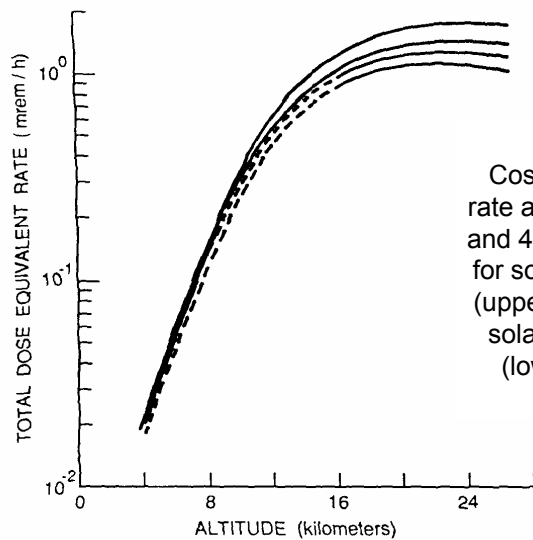
- Latitude affects cosmic ray dose rates slightly because earth's magnetic field affects charged particle trajectories
  - Dose rate variation is about 2% over US
- Elevation is a more important influence
- Dose rate variations are about a factor of 3 over habitable elevations

## Earth's Magnetic Field Lines

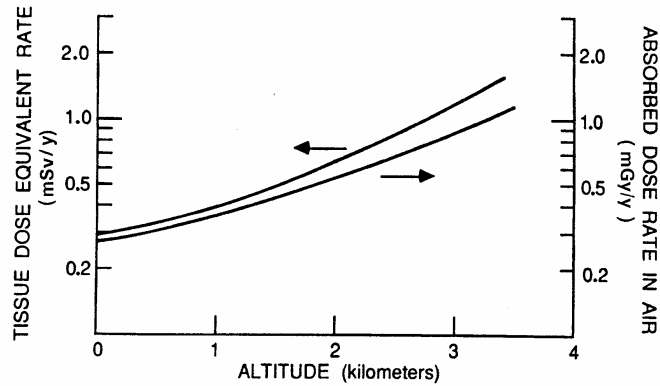


## Cosmic Radiation

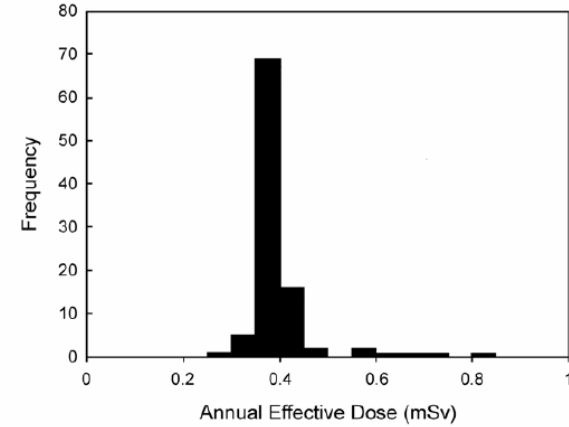
- Latitude affects cosmic ray dose rates slightly because earth's magnetic field affects charged particle trajectories
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### Comparison of absorbed dose and dose equivalent for cosmic rays vs. altitude



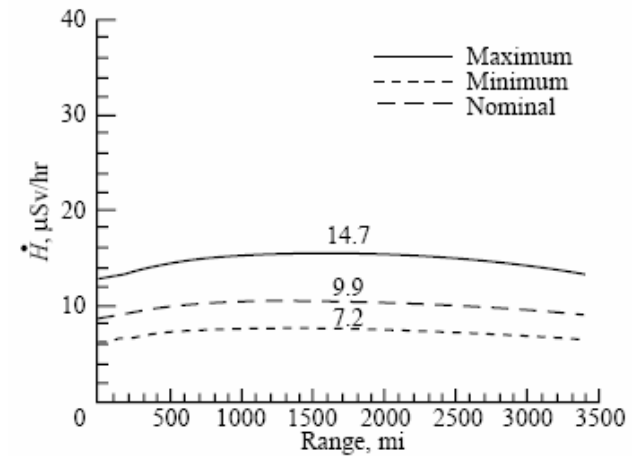
Frequency distribution for average outdoor values of annual effective dose from space radiation in 99 of the most populated U.S. urban areas (NCRP Report 160)



## Cosmic Radiation

- Average population dose in US has been calculated
  - Cosmic radiation vs elevation data combined with population vs elevation data
  - A 20% reduction is applied for shielding by structures
  - 1987 NCRP result was 26 mrem  $y^{-1}$
  - 2009 NCRP result was 34 mrad  $y^{-1}$

### Air Travel

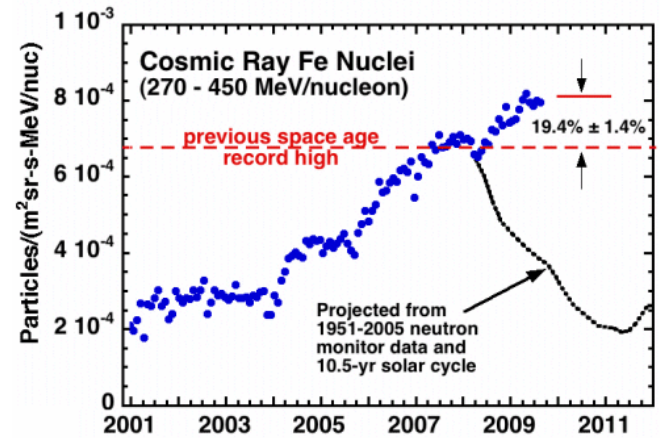


Dose rates in an aircraft flying London to New York at a cruise altitude of 39,000 ft (NASA Technical Paper 3524,1995)

## Air Travel

- Ambient dose equivalent rate ranges from 8 to 10  $\mu\text{Sv/h}$  (0.8 – 1 mrem/h) on the London to NYC route
- Other estimates (NCRP) for flights were
  - 25  $\mu\text{Sv}$  for a 5 hour continental US flight
  - 100  $\mu\text{Sv}$  for a 10 hour trans-polar flight
  - Aircraft crew members receive annual doses up to several mSv
- Grajewski et al. (2002) estimated that flight attendants fly about 600 h/y and receive 1.5 to 1.7 mSv
- Civilian supersonic passenger aircraft carried detectors to warn of solar flares

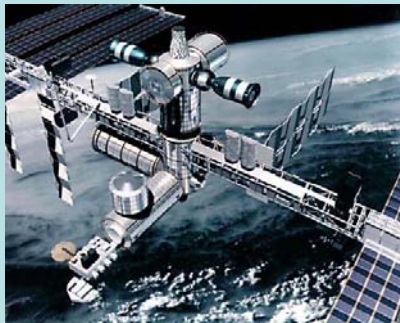
## NASA recently discovered an anomaly in predicted cosmic ray levels



[http://science.nasa.gov/headlines/y2009/29sep\\_cosmicrays.htm](http://science.nasa.gov/headlines/y2009/29sep_cosmicrays.htm)

## Space Travel

- Typical space flights result in doses of 0.1 to 1 rem per mission
- There is a potential for up to 100 rem exposures to astronauts in the event of a major solar flare



- While 100 rem carries a demonstrated cancer risk, it is still small in the context of other risks of space flight

## Cosmogenic Radionuclides

- Cosmogenic radionuclides are produced by
  - Spallation reactions
  - Neutron absorption
- Most are produced in the atmosphere but some are produced in earth's crust near surface
- Cosmogenics are ubiquitous wherever atmosphere interacts with bio- and lithosphere
- Cosmogenics have also been measured in tissue samples from astronauts

## Cosmogenic Radionuclides

- Chlorine-36 is produced in seawater and crust by activation of Cl-35
  - Cl-36 is of little dose consequence but is an important environmental tracer
- Tritium is a natural, cosmogenic nuclide but earth's natural inventory has been increased by nuclear activities, mostly weapons testing
  - Is produced by spallation of nitrogen and oxygen
- Is of little dose consequence

## Cosmogenic Radionuclides

- Beryllium-7 is produced by spallation of nitrogen and oxygen
  - It is of little dose consequence
- It will show up on air monitors

TABLE 3.11—Dose equivalent rates ( $\mu\text{Sv/y}$ )<sup>a</sup> from cosmogenic  $^3\text{H}$  and  $^{14}\text{C}$  for a reference adult<sup>b</sup>

Radionuclide	Soft tissue	Bone lining	Bone marrow	Fat
$^3\text{H}$	0.01	0.01	0.01	0.01
$^{14}\text{C}$	10	8	30	40

## Cosmogenic Radionuclides

- Carbon-14 is also cosmogenic
  - Produced by neutron absorption by nitrogen
  - Is important to archeology as the basis for carbon dating
  - Weapons testing has doubled global atmospheric inventory of C-14 but it is declining due mostly to exchange in oceans
- Carbon-14 is most important of cosmogenics for dose to humans
  - Doses are 1-4 mrem per year to various tissues with highest to fat and bone tissue

