Slides for Background Radiation

22.01 – Intro to Radiation

November 23rd, 2015

Tissue Weighting Factors

Turner, J. E. *Atoms, Radiation, and Radiation Protection*. Wiley-VCH, 2007.

- One loose end from last lecture – different tissues respond differently to the same dose and exposure
- Why do you think this is so?

Tissue or Organ	w_T
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder*	0.05

Calculating Dose in Sieverts

<u>Effective dose to one organ</u>

$$H_T = \sum_R w_R D_{T,R}.$$

Dose in Gy or Rad

Dose to tissue

<u>Radiation weight integral</u>

$$w_R \cong \overline{Q} = \frac{1}{D} \int_0^\infty Q(L) D(L) \, \mathrm{d}L,$$

Quality at energy L

Dose at energy L

<u>Effective dose to whole body</u>

$$E = \sum_T w_T H_T = H_T \sum_T w_T = H_T,$$

Tissue weighting factor

Example Calculation

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See Ch. 14 in Turner, J. E. *Atoms, Radiation, and Radiation Protection*. Wiley-VCH, 2007. Example calculations about a worker's radiation dose and NCRP/ICRP annual limits.

Increased Health Risks

From Turner, p. 458

Table 14.3 Probability Coefficients for Stochastic Effects (per Sv effective dose)

Detriment	Adult Workers (10^{-2} Sv^{-1})	Whole Population (10^{-2} Sv^{-1})
Fatal cancer	4.0	5.0
Nonfatal cancer	0.8	1.0
Severe genetic effects	0.8	1.3
Total	5.6	7.3

Source: ICRP Publication 60 and NCRP Report No. 116.

How Much Is Too Much?

Turner, p. 459

NCRP recommendation for lifetime occupational radiation exposure:

> The Council . . . recommends that the numerical value of the individual worker's lifetime effective dose in tens of mSv be limited to the value of his or her age in years (not including medical and natural background exposure).

Time distribution of exposure over a working career:

> The Council recommends that the annual occupational effective dose be limited to 50 mSv (not including medical and background exposure).

How Much Is Too Much?

Turner, p. 460

NCRP recommendation for individual exposure to man-made sources (excluding natural background and medical exposures):

> For continuous (or frequent) exposure, it is recommended that the annual effective dose not exceed 1 mSv . . . Furthermore, a maximum annual effective dose limit of 5 mSv is recommended to provide for infrequent annual exposures. . . .

How Much Is Enough?

From Turner, p. 461

Table 14.4 Exposure Limits from NCRP Report No. 116 and ICRP Publication 60

	NCRP-116	ICRP-60
Occupational Exposure		
Effective Dose		
Annual	50 mSv	50 mSv
Cumulative	10 mSv × age (y)	100 mSv in 5 y
Equivalent Dose		
Annual	150 mSv lens of eye; 500 mSv skin, hands, feet	150 mSv lens of eye; 500 mSv skin, hands, feet
Exposure of Public		
Effective Dose		
Annual	1 mSv if continuous 5 mSv if infrequent	1 mSv; higher if needed, provided 5-y annual average ⩽1 mSv
Equivalent Dose		
Annual	15 mSv lens of eye; 50 mSv skin, hands, feet	15 mSv lens of eye; 50 mSv skin, hands, feet

How Much Is "Nothing?"

NCRP Report No. 116 defines "Negligible Individual Dose" (NID), without corresponding risk level:

> The Council . . . recommends that an annual effective dose of 0.01 mSv be considered a Negligible Individual Dose (NID) per source or practice.

ICRP Publication 60 does not make a related recommendation.

Normal Background Levels

https://radwatch.berkeley.edu/rad101

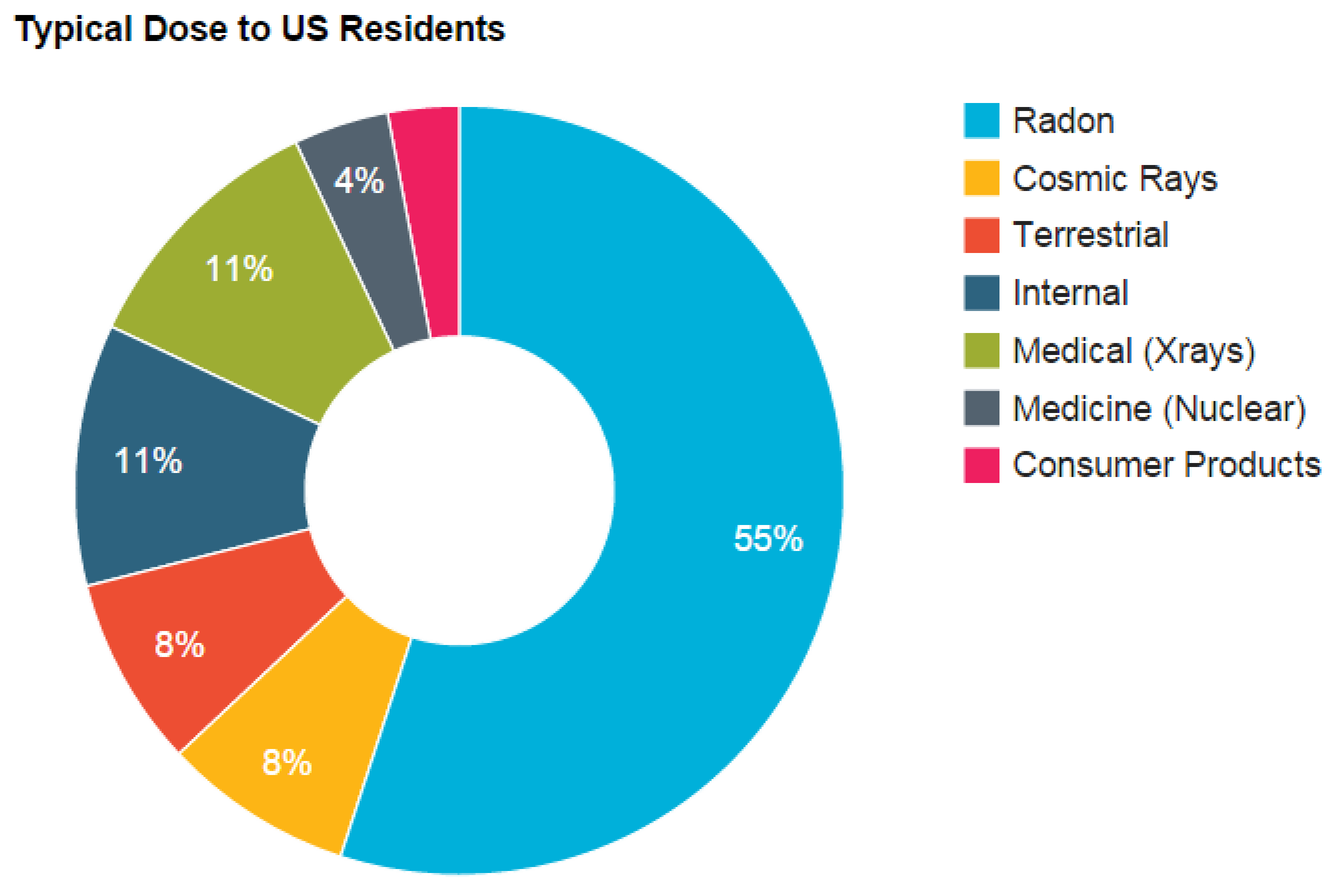
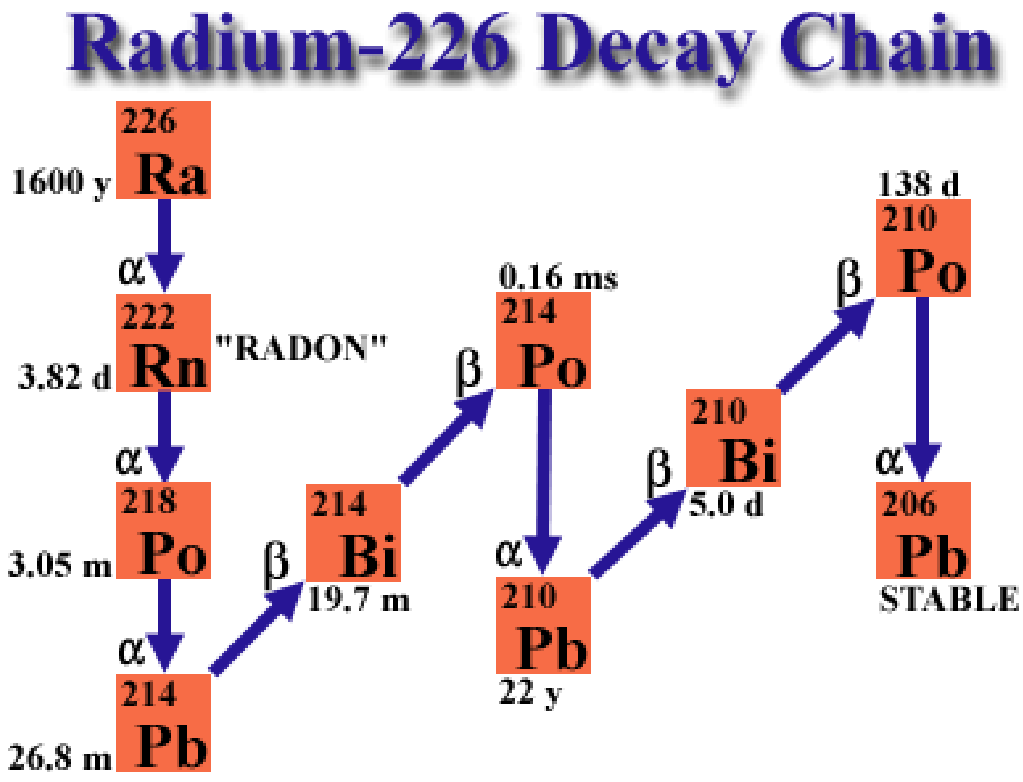


Image by Ryan Pavlovsky. Courtesy of Berkely RadWatch. Used with permission.

Natural Sources – Radon

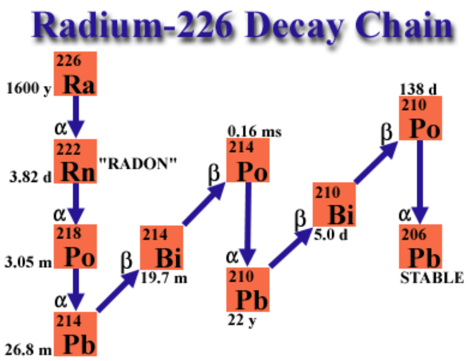
http://www.nist.gov/pml/general/curie/1927.cfm

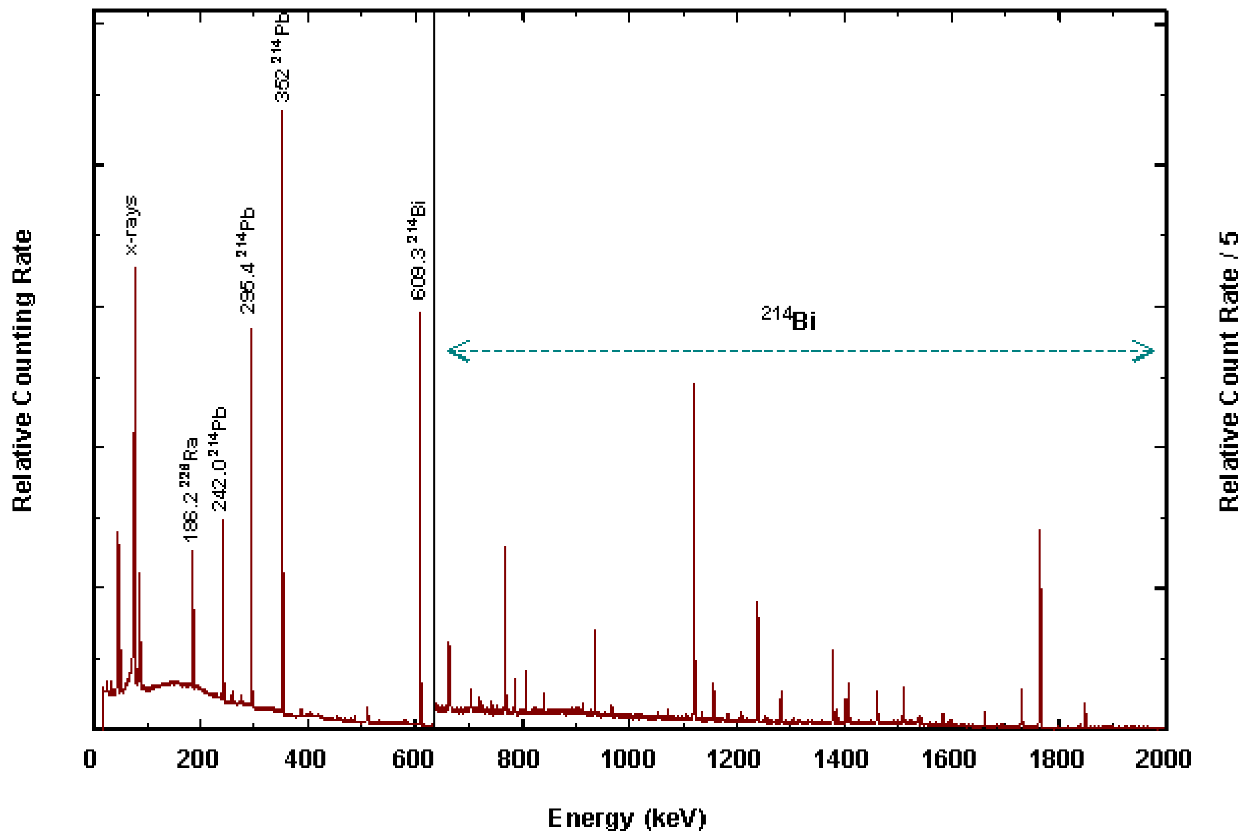


Public domain image, from U.S. NIST.

Natural Sources – Radon

http://www.nist.gov/pml/general/curie/1927.cfm





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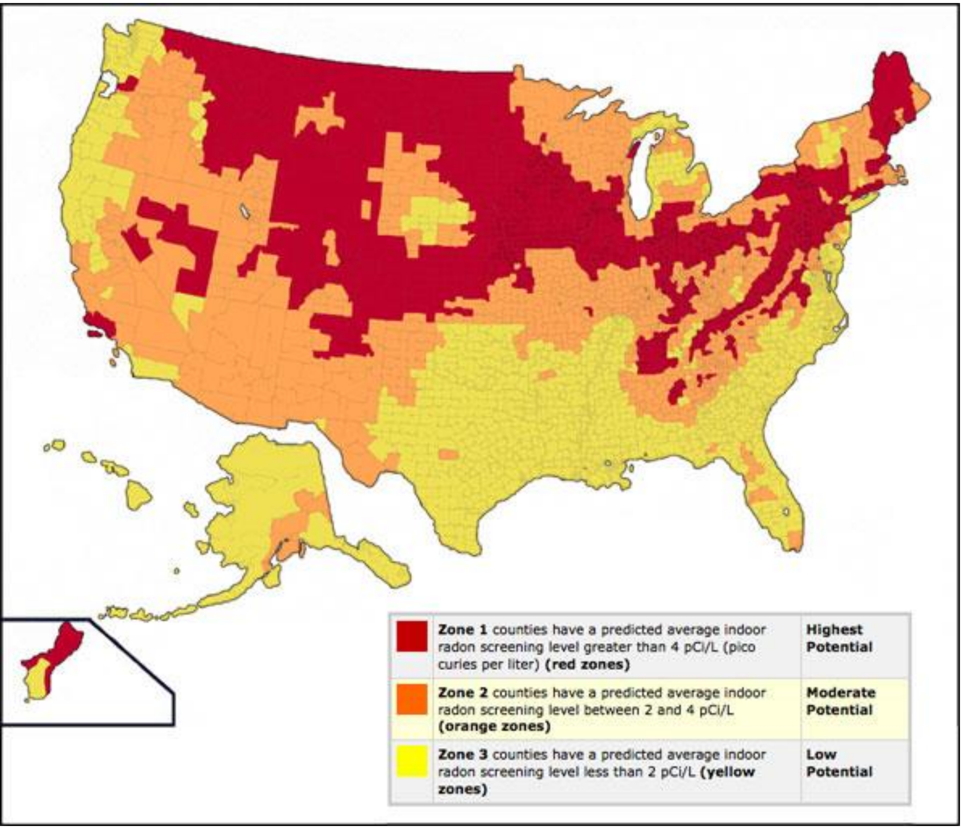
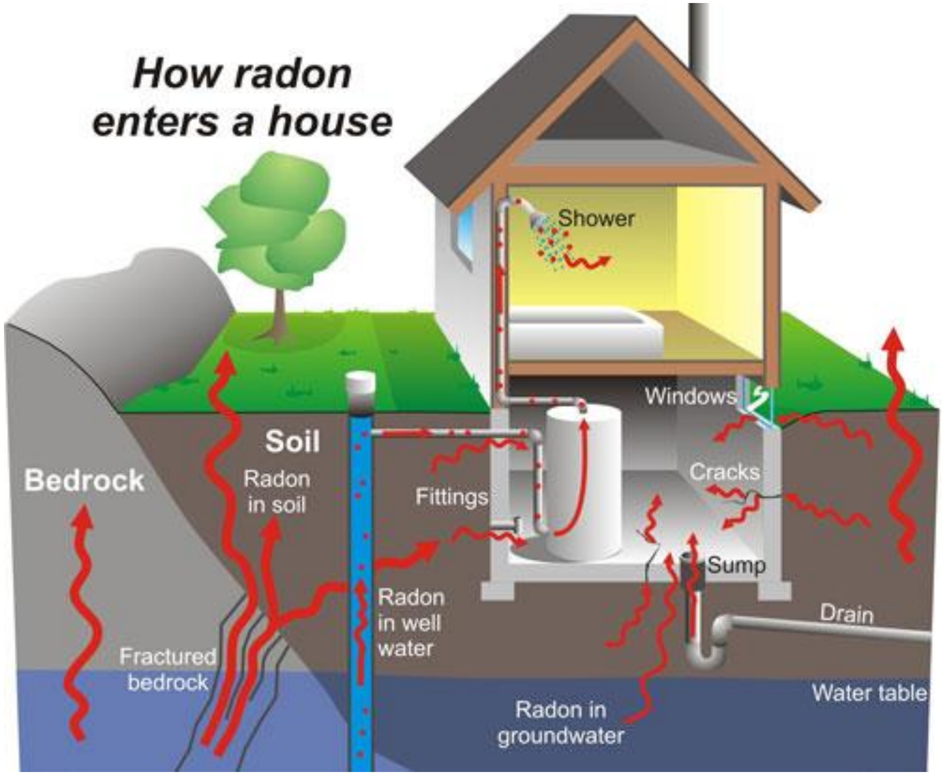
Radon Map of the U.S.



Public domain image, from U.S. EPA.



Relative Radon Risk

Radon Risk Evaluation Chart

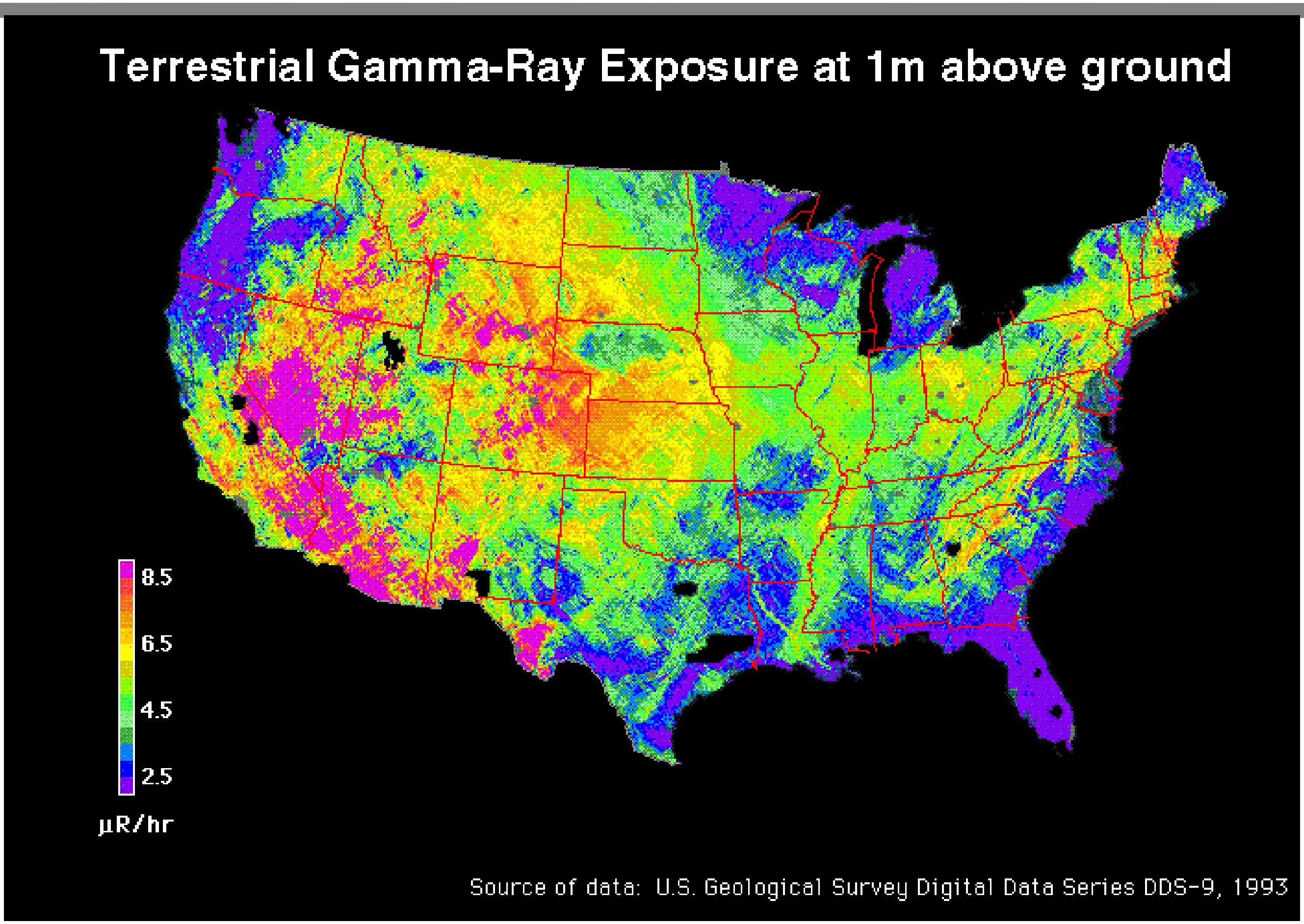
pCi/l	WL	Estimated number of lung cancer deaths due to radon exposure (out of 1000)	Comparable exposure levels	Comparable risk
200	1	440—770	1000 times average outdoor level	More than 60 times non-smoker risk
				4 pack-a-day smoker
100	0.5	270—630	100 times average indoor level	
				20,000 chest x-rays per year
40	0.2	120—380		
				2 pack-a-day smoker
20	0.1	60—210	100 times average outdoor level	
				1 pack-a-day smoker
10	0.05	30—120	10 times average indoor level	
				5 times non-smoker risk
4	0.02	13—50		
				200 chest x-rays per year
2	0.01	7—30	10 times average outdoor level	
				Non-smoker risk of dying from lung cancer
1	0.005	3—13	Average indoor level	
0.2	0.001	1—3	Average outdoor level	20 chest x-rays per year

Public domain image.

From EPA Publication OPA-86-004: "A Citizen's Guide to Radon: What It Is and What To Do About It." August 1986.

Exposure Sources

USGS graph of the computed terrestrial gamma ray flux at 1m from the ground.
Duval, Joseph S., Carson, John M. et al. 2005.



Exposure Sources

USGS National Map

Public domain image.

The Primordial Nuclides

Shultis, J. K., and R. E. Faw. *Fundamentals of Nuclear Science and Engineering*, 2nd Edition. CRC Press, 2007.

Table 5.2. The 17 isolated primordial radionuclides. Data taken from GE-NE [1996].

Radionuclide & the Decay Modes		Half-life (years)	% El. Abund.	Radionuclide & the Decay Modes		Half-life (years)	% El. Abund.
$^{40}_{19}K$	β^- EC β^+	1.27×10^9	0.0117	$^{50}_{23}V$	β^- EC	1.4×10^{17}	0.250
$^{87}_{37}Rb$	β^-	4.88×10^{10}	27.84	$^{113}_{48}Cd$	β^-	9×10^{15}	12.22
$^{115}_{49}In$	β^-	4.4×10^{14}	95.71	$^{123}_{52}Te$	EC	$> 1.3 \times 10^{13}$	0.908
$^{138}_{57}La$	EC β^-	1.05×10^{11}	0.090	$^{144}_{60}Nd$	α	2.38×10^{15}	23.80
$^{147}_{62}Sm$	α	1.06×10^{11}	15.0	$^{148}_{62}Sm$	α	7×10^{15}	11.3
$^{152}_{64}Gd$	α	1.1×10^{14}	0.20	$^{176}_{71}Lu$	β^-	3.78×10^{10}	2.59
$^{174}_{72}Hf$	α	2.0×10^{15}	0.162	$^{180}_{73}Ta$	EC β^+	$> 1.2 \times 10^{15}$	0.012
$^{187}_{75}Re$	β^-	4.3×10^{10}	62.60	$^{186}_{76}Os$	α	2×10^{15}	1.58
$^{190}_{78}Pt$	α	6.5×10^{11}	0.01				

Nuclides in Building Materials

Data from http://www.physics.isu.edu/radinf/natural.htm

(NCRP 94, 1987, except where noted)						
Material	Uranium		Thorium		Potassium	
	ppm	mBq/g (pCi/g)	ppm	mBq/g (pCi/g)	ppm	mBq/g (pCi/g)
Granite	4.7	63 (1.7)	2	8 (0.22)	4.0	1184 (32)
Sandstone	0.45	6 (0.2)	1.7	7 (0.19)	1.4	414 (11.2)
Cement	3.4	46 (1.2)	5.1	21 (0.57)	0.8	237 (6.4)
Limestone concrete	2.3	31 (0.8)	2.1	8.5 (0.23)	0.3	89 (2.4)
Sandstone concrete	0.8	11 (0.3)	2.1	8.5 (0.23)	1.3	385 (10.4)
Dry wallboard	1.0	14 (0.4)	3	12 (0.32)	0.3	89 (2.4)
By-product gypsum	13.7	186 (5.0)	16.1	66 (1.78)	0.02	5.9 (0.2)
Natural gypsum	1.1	15 (0.4)	1.8	7.4 (0.2)	0.5	148 (4)
Wood	-	-	-	-	11.3	3330 (90)
Clay Brick	8.2	111 (3)	10.8	44 (1.2)	2.3	666 (18)

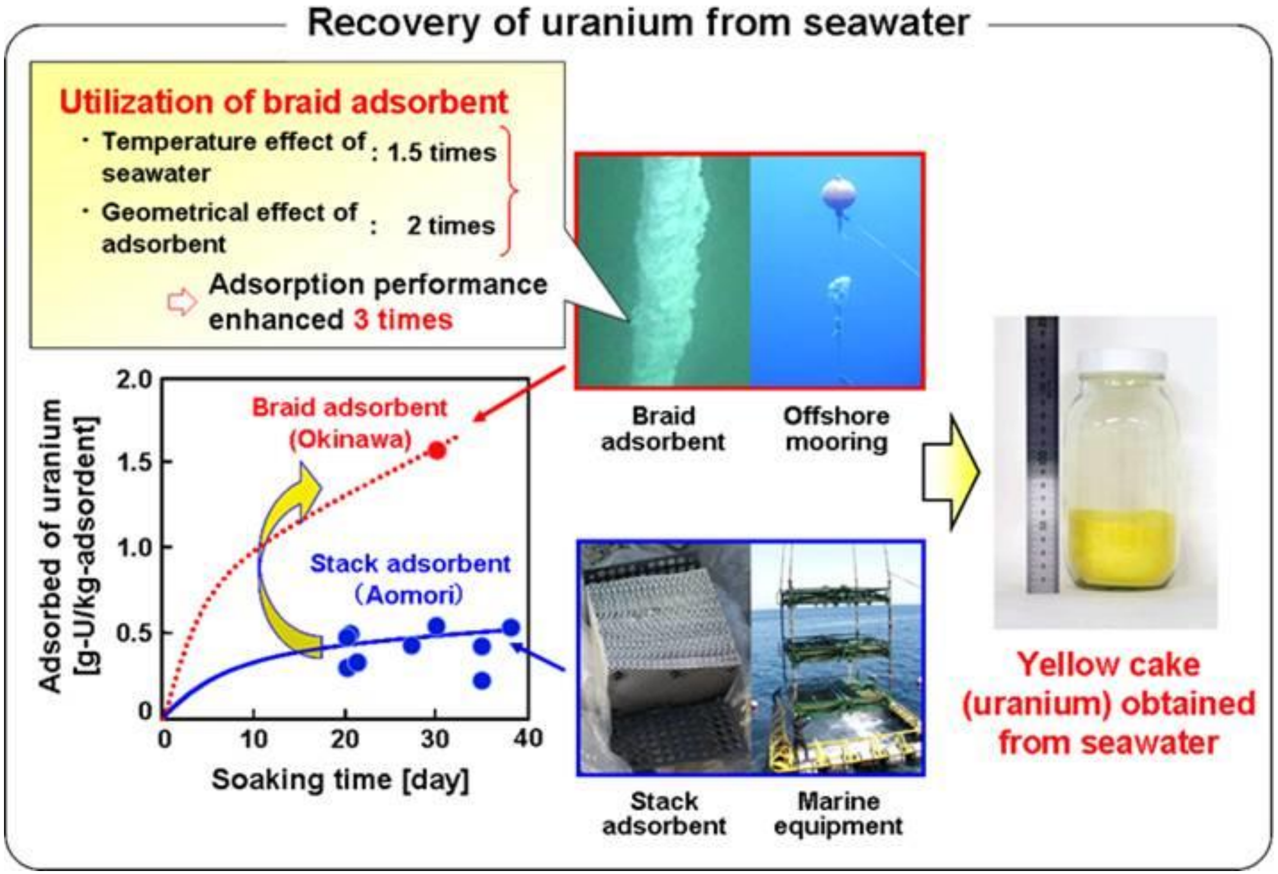
Nuclides in Seawater

Data from http://www.physics.isu.edu/radinf/natural.htm

Nuclide	Activity used in calculation	Activity in Ocean		
		Pacific	Atlantic	All Oceans
Uranium	0.9 pCi/L (33 mBq/L)	6×10^{8} Ci (22 EBq)	3×10^{8} Ci (11 EBq)	1.1×10^{9} Ci (41 EBq)
Potassium 40	300 pCi/L (11 Bq/L)	2×10^{11} Ci (7400 EBq)	9×10^{10} Ci (3300 EBq)	3.8×10^{11} Ci (14000 EBq)
Tritium	0.016 pCi/L (0.6 mBq/L)	1×10^{7} Ci (370 PBq)	5×10^{6} Ci (190 PBq)	2×10^{7} Ci (740 PBq)
Carbon 14	0.135 pCi/L (5 mBq/L)	8×10^{7} Ci (3 EBq)	4×10^{7} Ci (1.5 EBq)	1.8×10^{8} Ci (6.7 EBq)
Rubidium 87	28 pCi/L (1.1 Bq/L)	1.9×10^{10} Ci (700 EBq)	9×10^{9} Ci (330 EBq)	3.6×10^{10}

Uranium from Seawater?

http://nextbigfuture.com/2007_11_04_archive.html



Uranium from Seawater!

Chemical Science

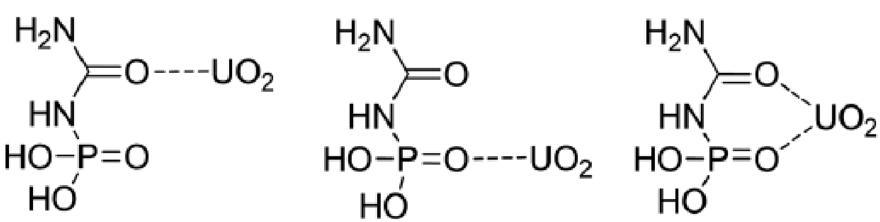
RSC Publishing

EDGE ARTICLE

View Article Online
View Journal | View Issue

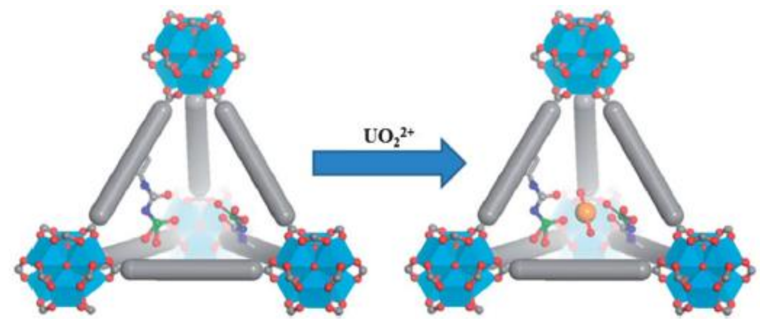
Highly porous and stable metal–organic frameworks for uranium extraction†

Cite this: *Chem. Sci.*, 2013, **4**, 2396



I **II** **III**

Fig. 6 Three uranyl binding motifs for carbamoylphosphoramidic acid investigated by DFT calculations: uranyl bound to carbonyl oxygen (**I**), uranyl bound to phosphoryl oxygen (**II**), and bidentate uranyl coordination (**III**).



ig. 9 Simplified schematic depicting the uranyl-binding pocket formed in the etrahedron of the MOFs. UO_2^{2+} is coordinated in a monodentate fashion to the hosphoryl oxygen. Distances between oxygen range from 4.5–4.8 Å, accommodating U–O bond lengths appropriate for binding motif **II–II**.

Radioactivity in the Body

Data from http://www.physics.isu.edu/radinf/natural.htm

Nuclide	Total Mass of Nuclide Found in the Body	Total Activity of Nuclide Found in the Body	Daily Intake of Nuclides
Uranium	90 µg	30 pCi (1.1 Bq)	1.9 µg
Thorium	30 µg	3 pCi (0.11 Bq)	3 µg
Potassium 40	17 mg	120 nCi (4.4 kBq)	0.39 mg
Radium	31 pg	30 pCi (1.1 Bq)	2.3 pg
Carbon 14	22 ng	0.1 µCi (3.7 kBq)	1.8 ng
Tritium	0.06 pg	0.6 nCi (23 Bq)	0.003 pg
Polonium	0.2 pg	1 nCi (37 Bq)	~0.6 f

Medical Procedures

Typical Effective Radiation Dose from Diagnostic X Ray—Single Exposure (Mettler 2008)

Mettler FA Jr, et al. *Radiology* 248(1):254-263; 2008.

Exam	Effective Dose mSv (mrem)
Chest	0.1 (10)
Cervical Spine	0.2 (20)
Thoracic Spine	1.0 (100)
Lumbar Spine	1.5 (150)
Pelvis	0.7 (70)
Abdomen or Hip	0.6 (60)
Mammogram (2 view)	0.36 (36)
Dental Bitewing	0.005 (0.5)
Dental (panoramic)	0.01 (1)
DEXA (whole body)	0.001 (0.1)
Skull	0.1 (10)
Hand or Foot	0.005 (0.5)

Examinations and Procedures	Effective Dose mSv (mrem)
Intravenous Pyelogram	3.0 (300)
Upper GI	6.0 (600)
Barium Enema	7.0 (700)
Abdomen Kidney, Ureter, Bladder (KUB)	0.7 (70)
CT Head	2.0 (200)
CT Chest	7.0 (700)
CT Abdomen/Pelvis	10.0 (1,000)
Whole-Body CT Screening	10.0 (1,000)
CT Biopsy	1.0 (100)
Calcium Scoring	2.0 (200)
Coronary Angiography	20.0 (2,000)
Cardiac Diagnostic & Intervention	30.0 (3,000)
Pacemaker Placement	1.0 (100)
Peripheral Vascular Angioplasties	5.0 (500)
Noncardiac Embolization	55.0 (5,500)
Vertebroplasty	16.0 (1,600)

More Medical Procedures

Mettler FA Jr, et al. *Radiology* 248(1):254-263; 2008.

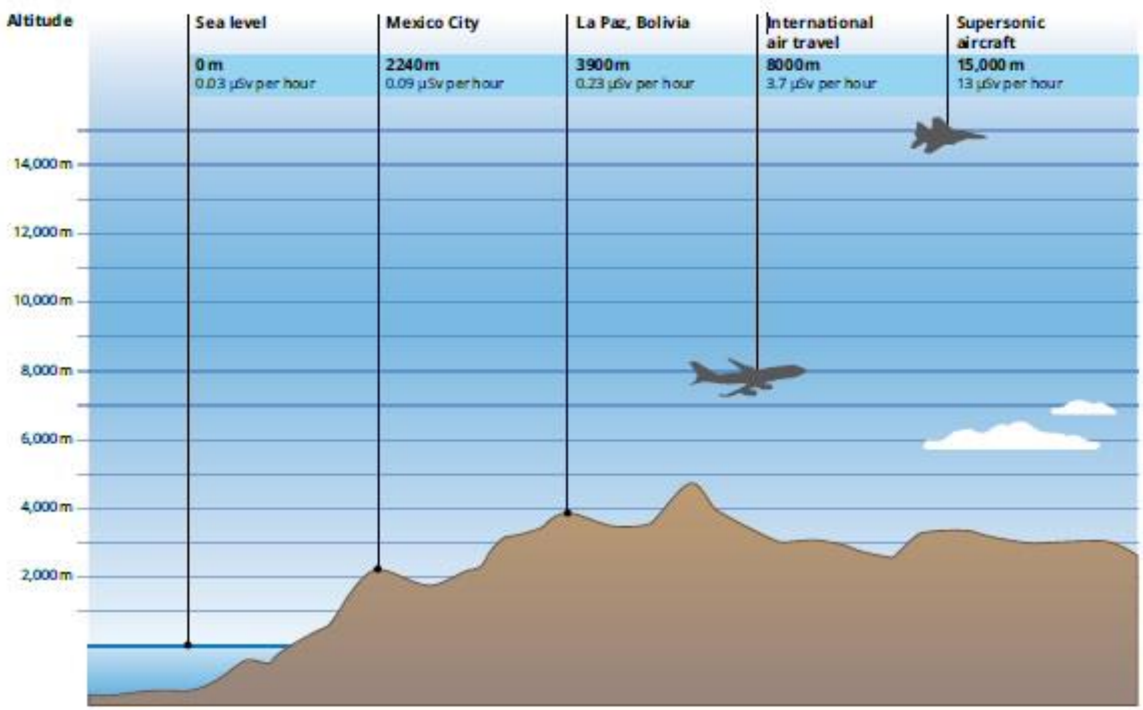
Typical Effective Radiation Dose from Nuclear Medicine Examinations (Mettler 2008)

Nuclear Medicine Scan Radiopharmaceutical (common trade name)	Effective Dose mSv (mrem)
Brain (PET) ^{18}F FDG	14.1 (1,410)
Brain (perfusion) ^{99m}Tc HMPAO	6.9 (690)
Hepatobiliary (liver flow) ^{99m}Tc Sulfur Colloid	2.1 (210)
Bone ^{99m}Tc MDP	6.3 (630)
Lung Perfusion/Ventilation ^{99m}Tc MAA & ^{133}Xe	2.5 (250)
Kidney (filtration rate) ^{99m}Tc DTPA	1.8 (180)
Kidney (tubular function) ^{99m}Tc MAG3	2.2 (220)
Tumor/Infection ^{67}Ga	2.5 (250)
Heart (stress-rest) ^{99m}Tc sestamibi (Cardiolite)	9.4 (940)
Heart (stress-rest) ^{201}Tl chloride	41.0 (4,100)
Heart (stress-rest) ^{99m}Tc tetrofosmin (Myoview)	11.0 (1,100)
Various PET Studies ^{18}F FDG	14.0 (1,400)

Radiation from Altitude

http://www.ansto.gov.au/NuclearFacts/Whatisradiation/

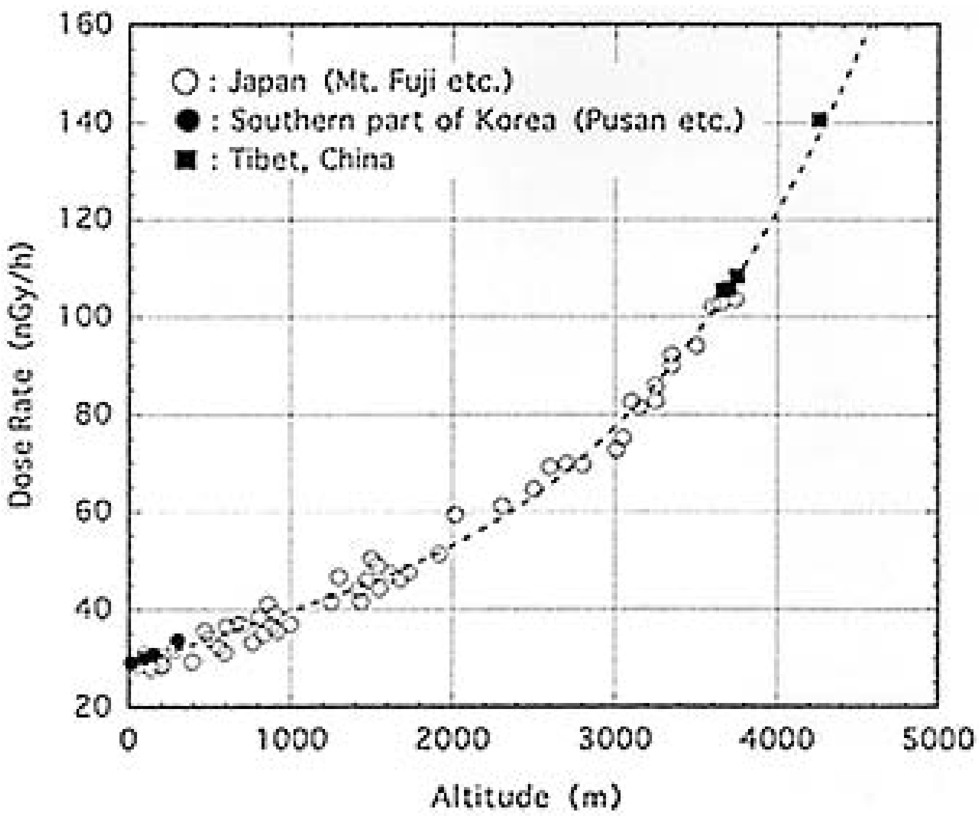
Cosmic radiation dose rates at different altitudes



Cosmic radiation dose rates at different altitudes.

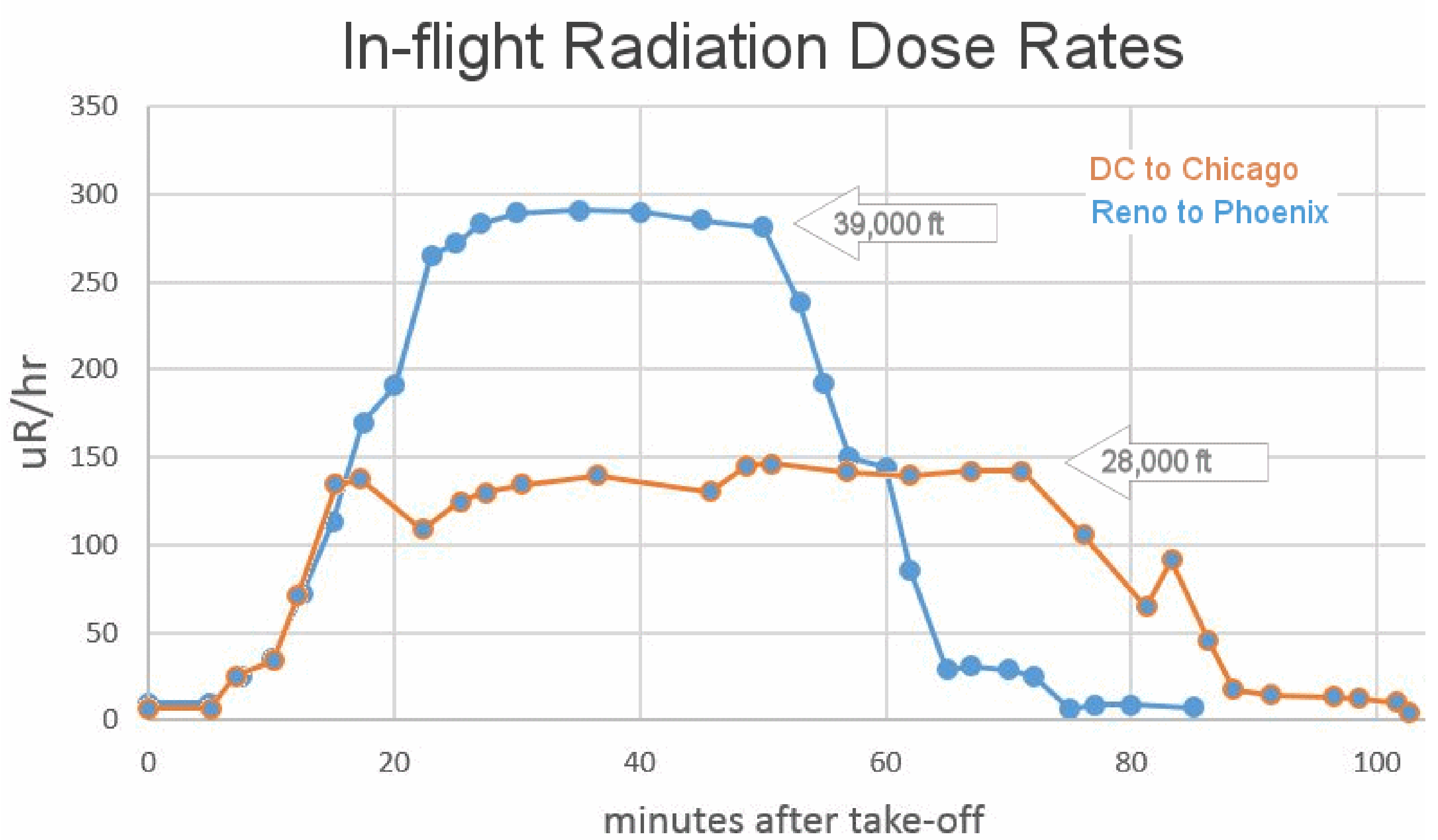
Radiation from Flying

http://www.nirs.go.jp/publication/annual_reports_en/1998/5/072.html



Radiation from Flying

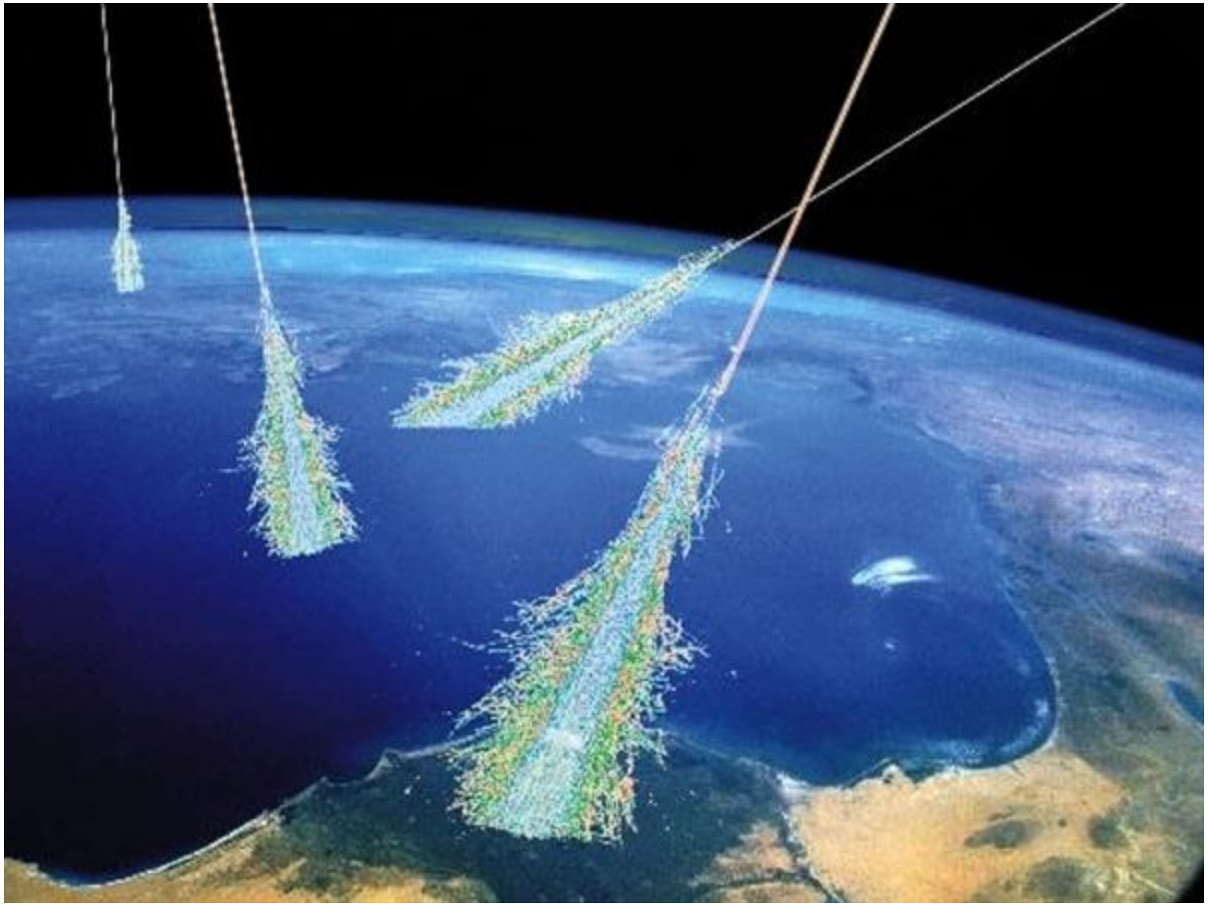
http://www.spaceweather.com – Nov. 16, 2014



Courtesy of Spaceweather.com. Used with permission.

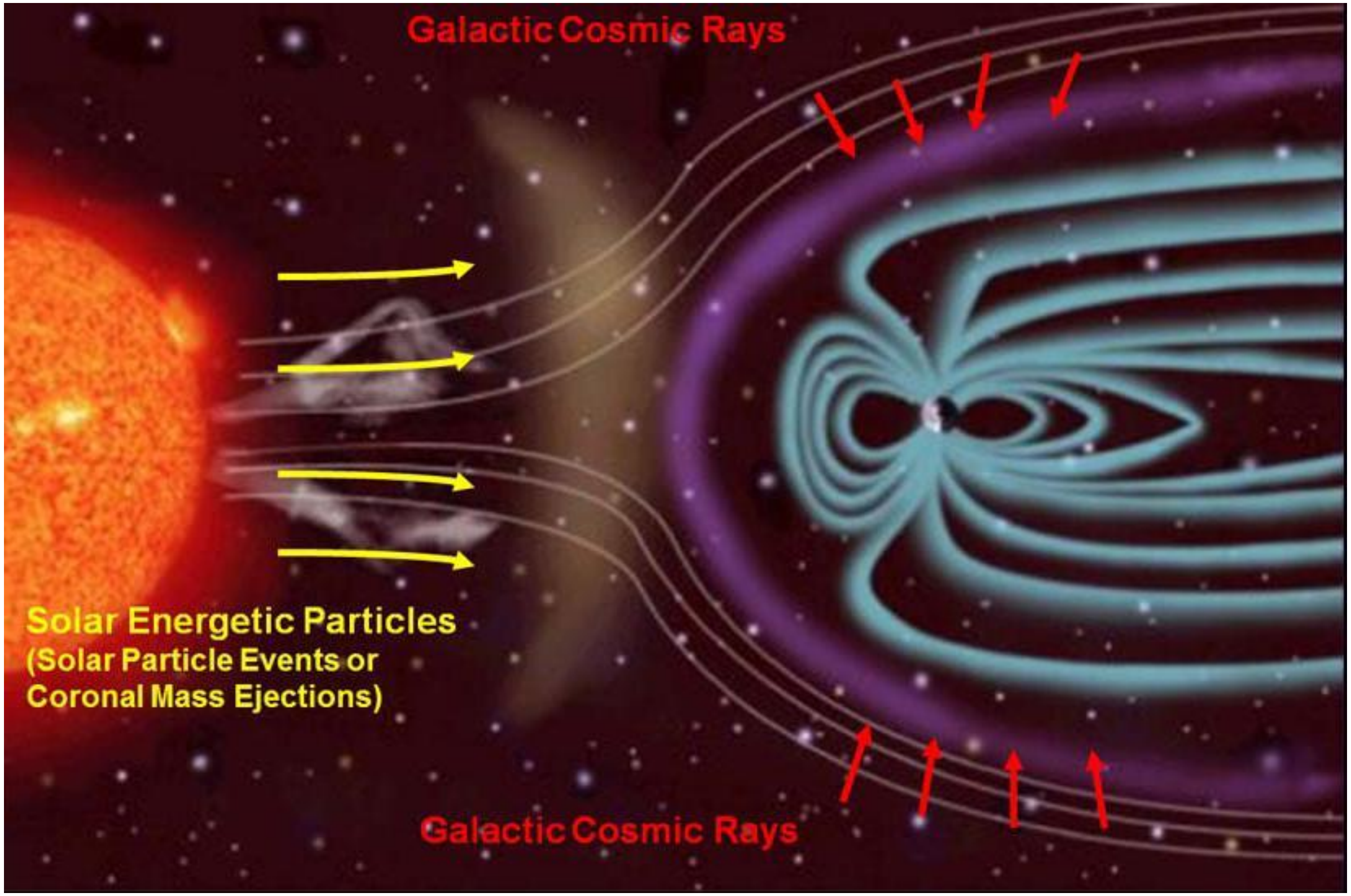
Cosmic Rays – Origin

http://apod.nasa.gov/apod/ap060814.html
Illustration by Simon Swordy



Cosmic Rays – Origin

http://photojournal.jpl.nasa.gov/jpeg/PIA16938.jpg



Public domain image, from NASA.

Solar Cosmic Ions – Origin

Klein, K-L., and G. Trottet. *Space Science Reviews* 95: 215–225, 2001

Abstract

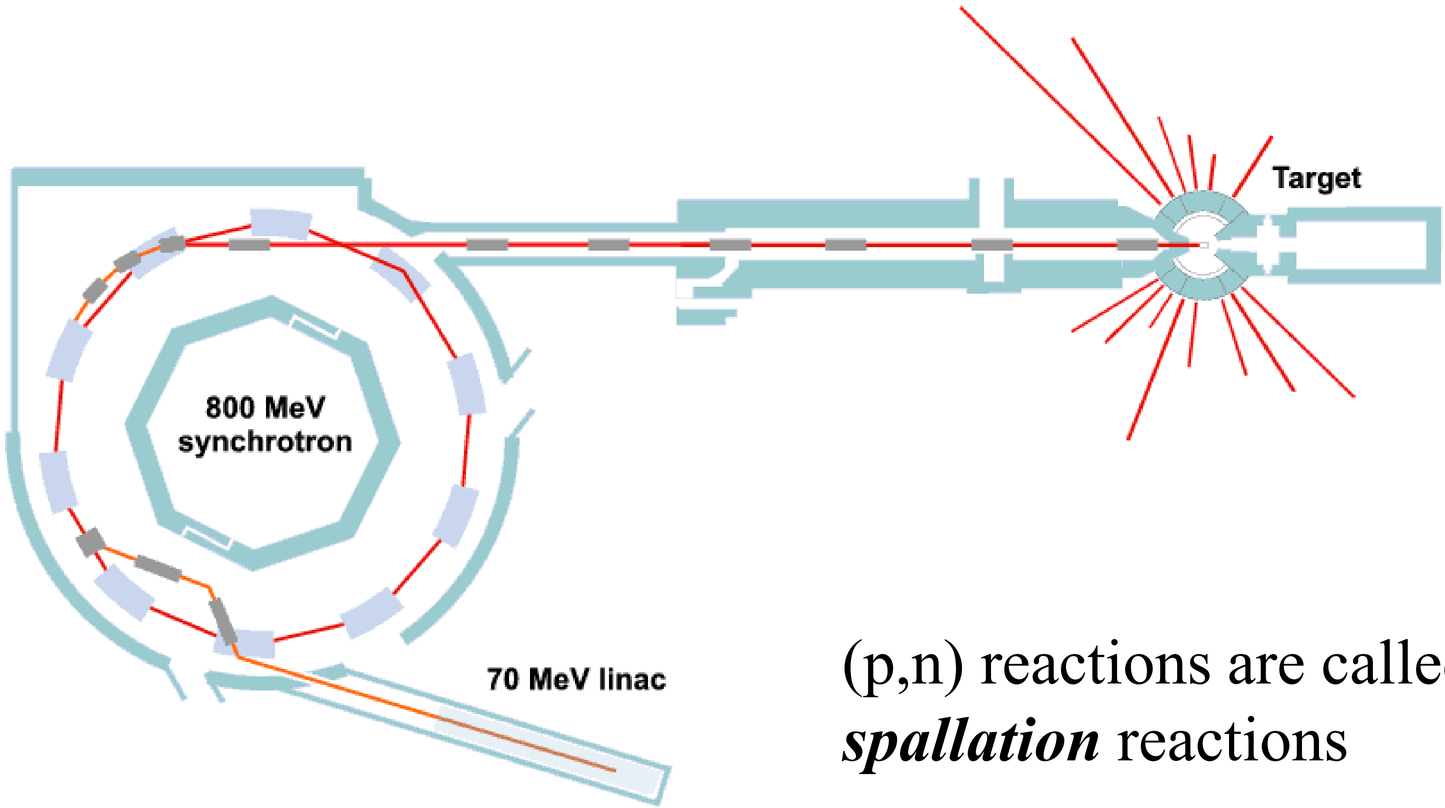
We review evidence that led to the view that acceleration at shock waves driven by coronal mass ejections (CMEs) is responsible for large particle events detected at 1 AU. It appears that even if the CME bow shock acceleration is a possible model for the origin of rather low energy ions, it faces difficulties on account of the production of ions far above 1 MeV: (i) although shock waves have been demonstrated to accelerate ions to energies of some MeV nucl^{-1} in the interplanetary medium, their ability to achieve relativistic energies in the solar environment is unproven; (ii) SEP events producing particle enhancements at energies 100 MeV are also accompanied by flares; those accompanied only by fast CMEs have no proton signatures above 50 MeV. We emphasize detailed studies of individual high energy particle events which provide strong evidence that **time-extended particle acceleration which occurs in the corona after the impulsive flare contributes to particle fluxes in space. It appears thus that the CME bow shock scenario has been overvalued and that long lasting coronal energy release processes have to be taken into account when searching for the origin of high energy SEP events.**

Making Cosmogenic Nuclides

- Protons enter the atmosphere
- ***Spallation*** occurs, releasing neutrons
- Neutrons combine with key nuclides to produce ^{3}H, ^{14}C
  - $^{14}N(n,p)^{14}C$
  - $^{14}N(n,^{3}H)^{12}C$

Spallation Sources on Earth

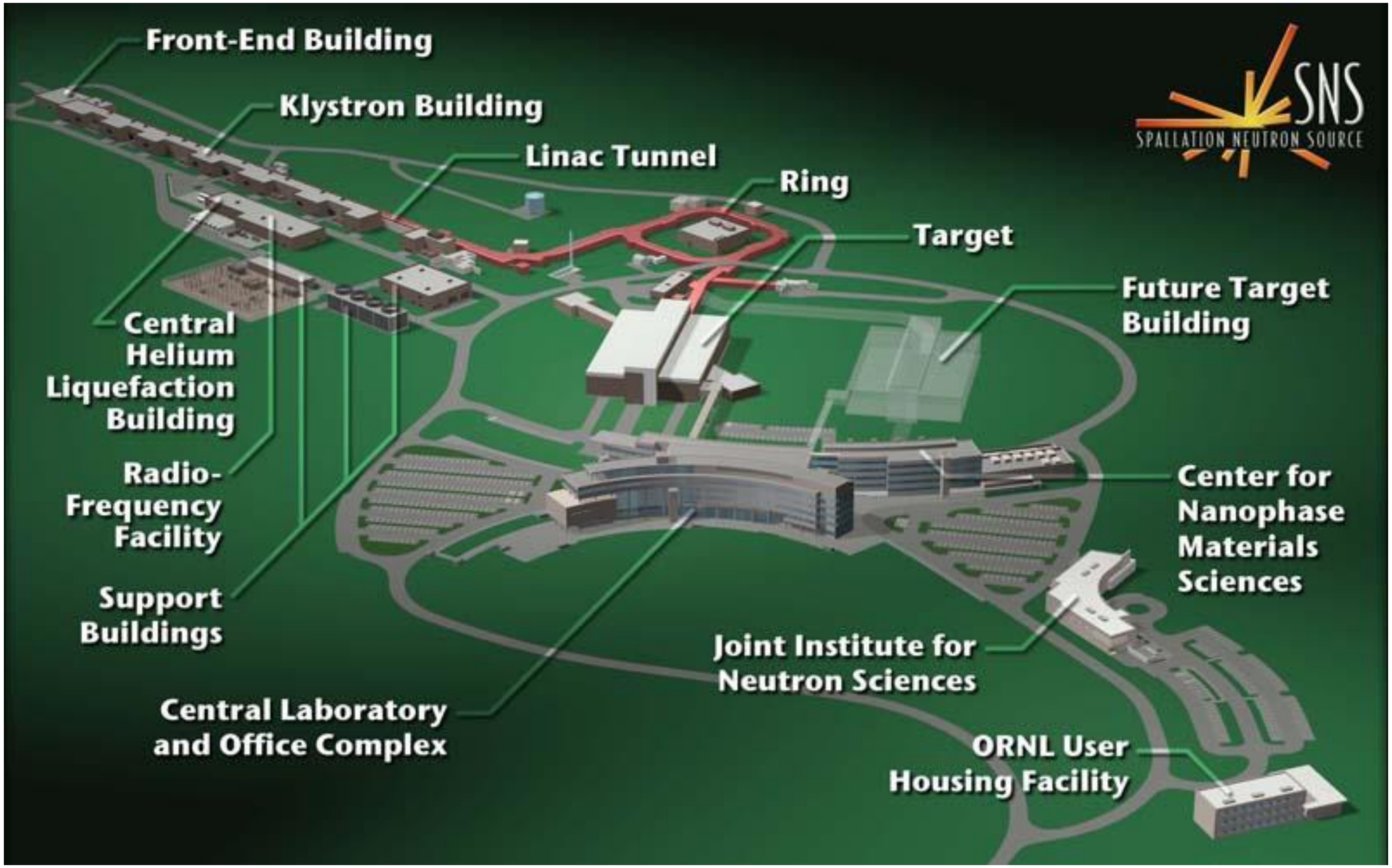
http://pd.chem.ucl.ac.uk/pdnn/inst3/pulsed.htm



(p,n) reactions are called ***spallation*** reactions

Spallation on Earth – The SNS

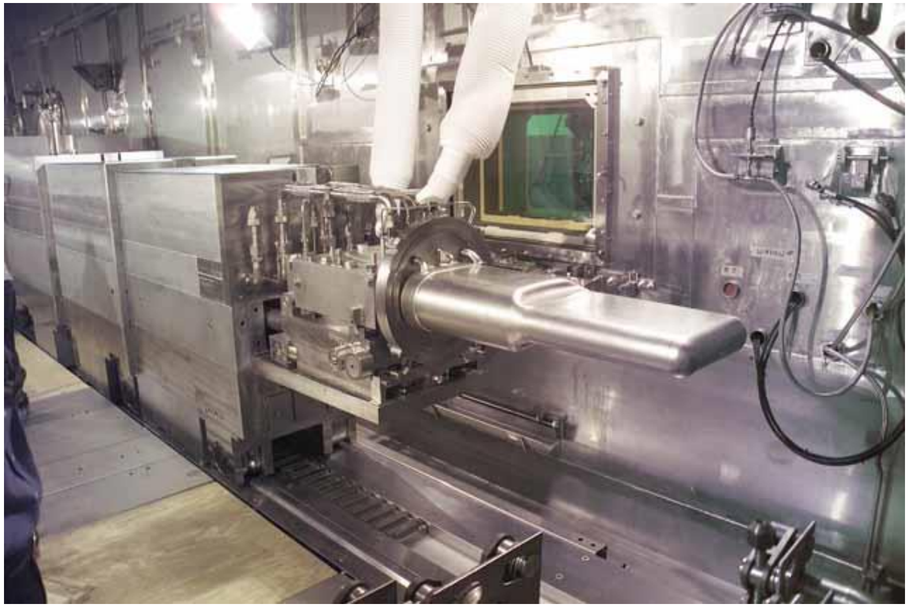
http://neutrons2.ornl.gov/facilities/SNS/works.shtml



Courtesy of Oak Ridge National Laboratory, U.S. Dept. of Energy.

Spallation on Earth – The SNS

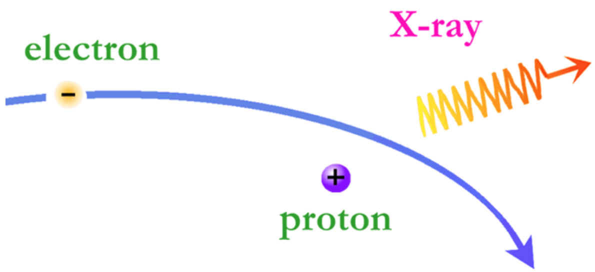
http://neutrons2.ornl.gov/facilities/SNS/works.shtml



Nuclear Craziness from Electrons

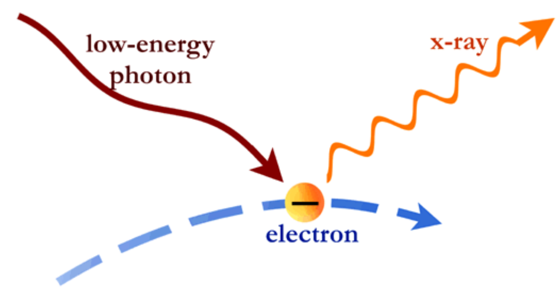
http://chandra.harvard.edu/resources/illustrations/x-raysLight.html

Electrons can also create high-energy gamma rays by…



Bremsstrahlung

Synchrotron Radiation



Inverse Compton Scattering

Inverse Compton Scattering

http://eud.gsfc.nasa.gov/Volker.Beckmann/school/download/Longair_Radiation3.pdf

Identifying Radio Sources with Inverse Compton Scattering

http://eud.gsfc.nasa.gov/Volker.Beckmann/school/download/Longair_Radiation3.pdf

What Happens to the Electrons?

http://eud.gsfc.nasa.gov/Volker.Beckmann/school/download/Longair_Radiation3.pdf

Proton Collisions Create Pions

http://eud.gsfc.nasa.gov/Volker.Beckmann/school/download/Longair_Radiation3.pdf

See p. 25 in http://eud.gsfc.nasa.gov/Volker.Beckmann/school/download/Longair_Radiation3.pdf

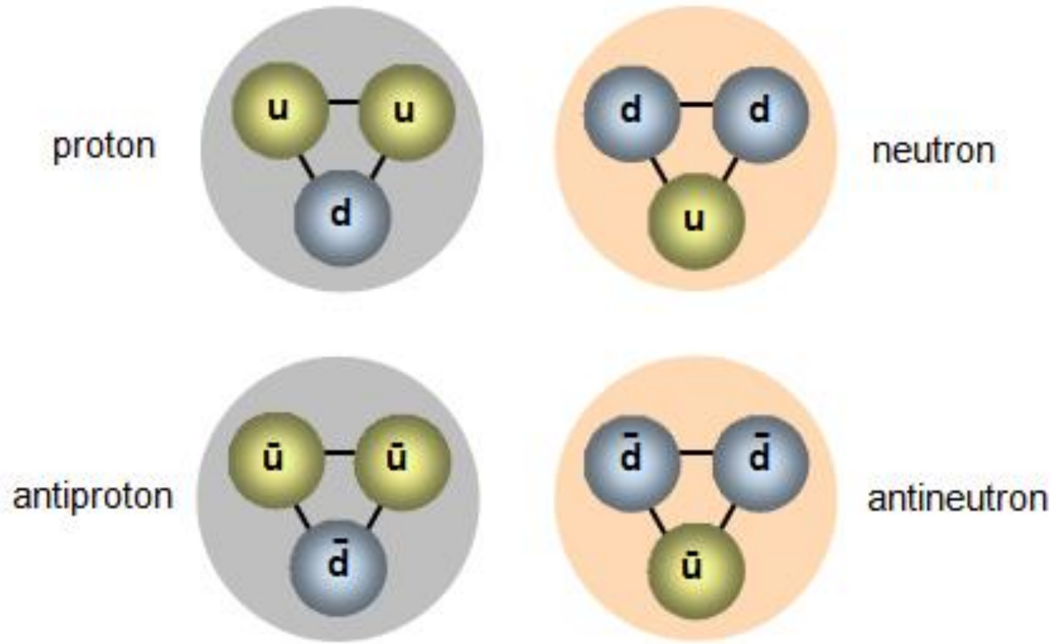
Neutral Pions Create Gammas

http://eud.gsfc.nasa.gov/Volker.Beckmann/school/download/Longair_Radiation3.pdf

Pions – A Short Detour into Subatomic Physics

http://schoolphysics.co.uk/age16-19/Nuclear%20physics/Nuclear%20structure/text/Quarks_/index.html

Quarks (and antiquarks)



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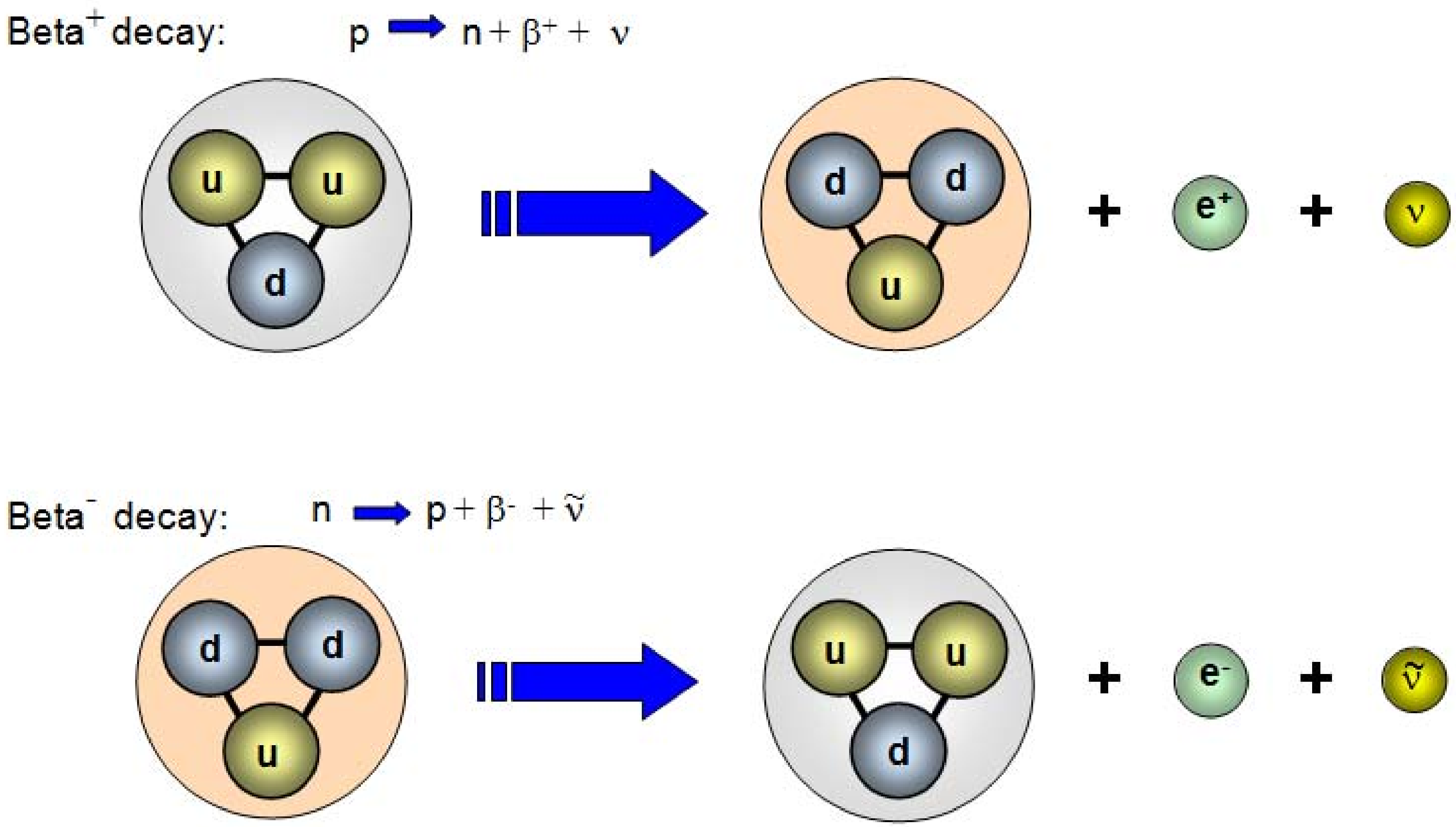

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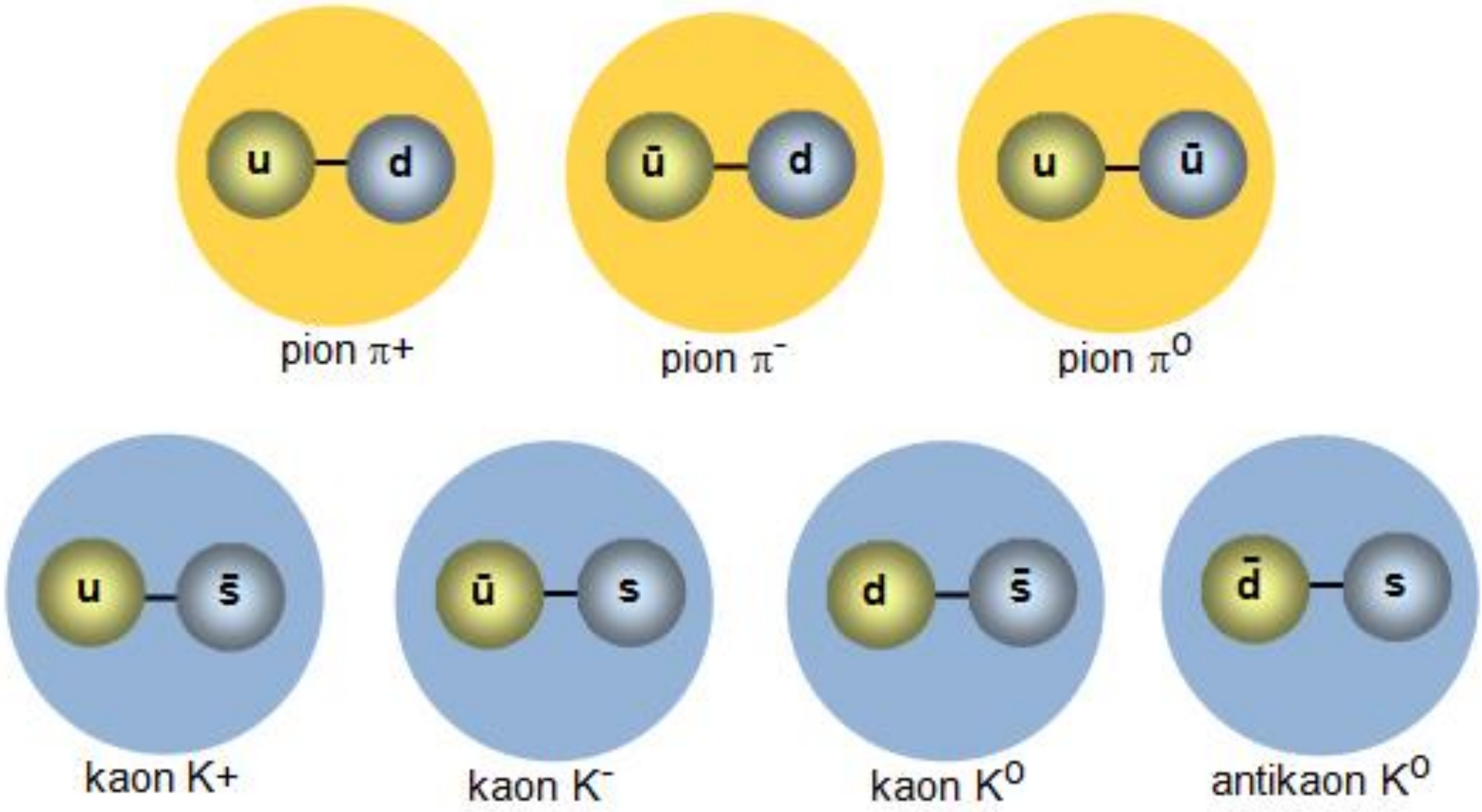
Pions – A Short Detour into Subatomic Physics

http://schoolphysics.co.uk/age16-19/Nuclear%20physics/Nuclear%20structure/text/Quarks_/index.html



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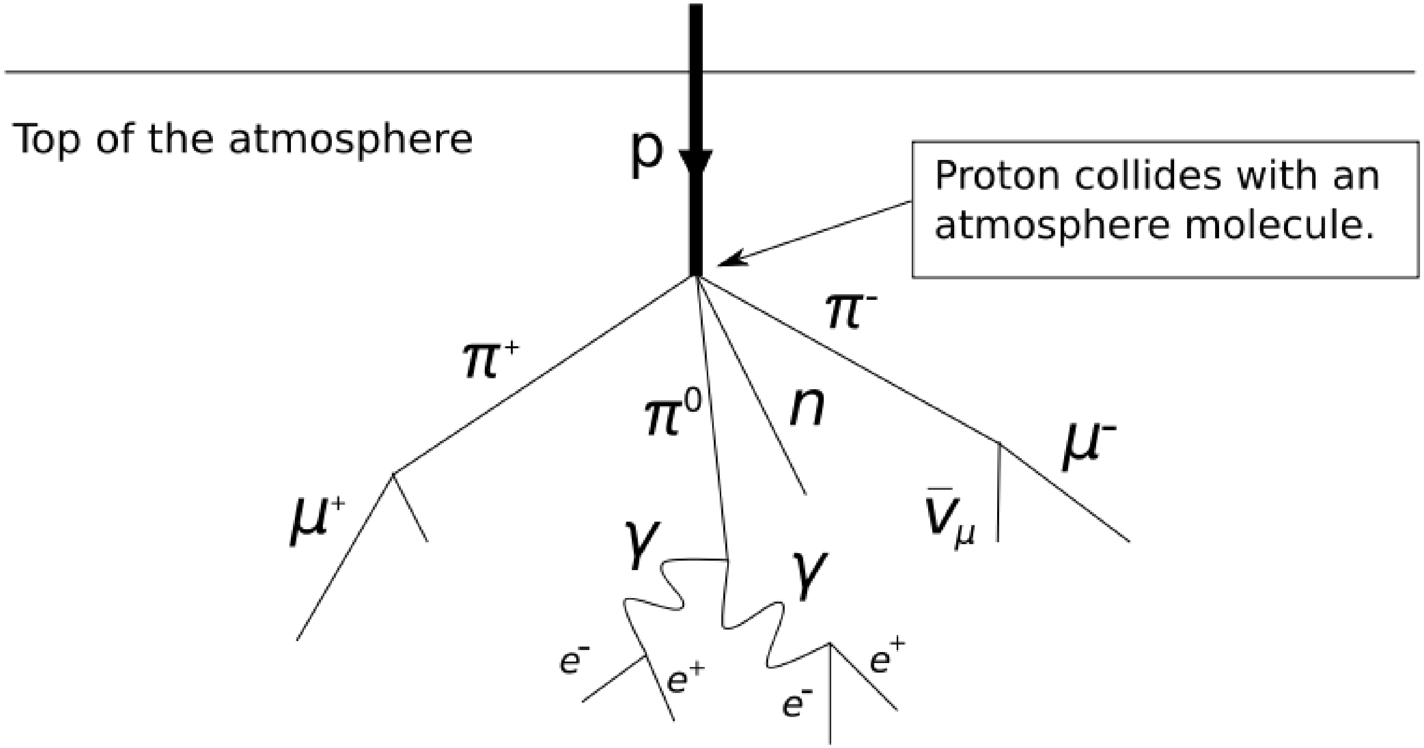
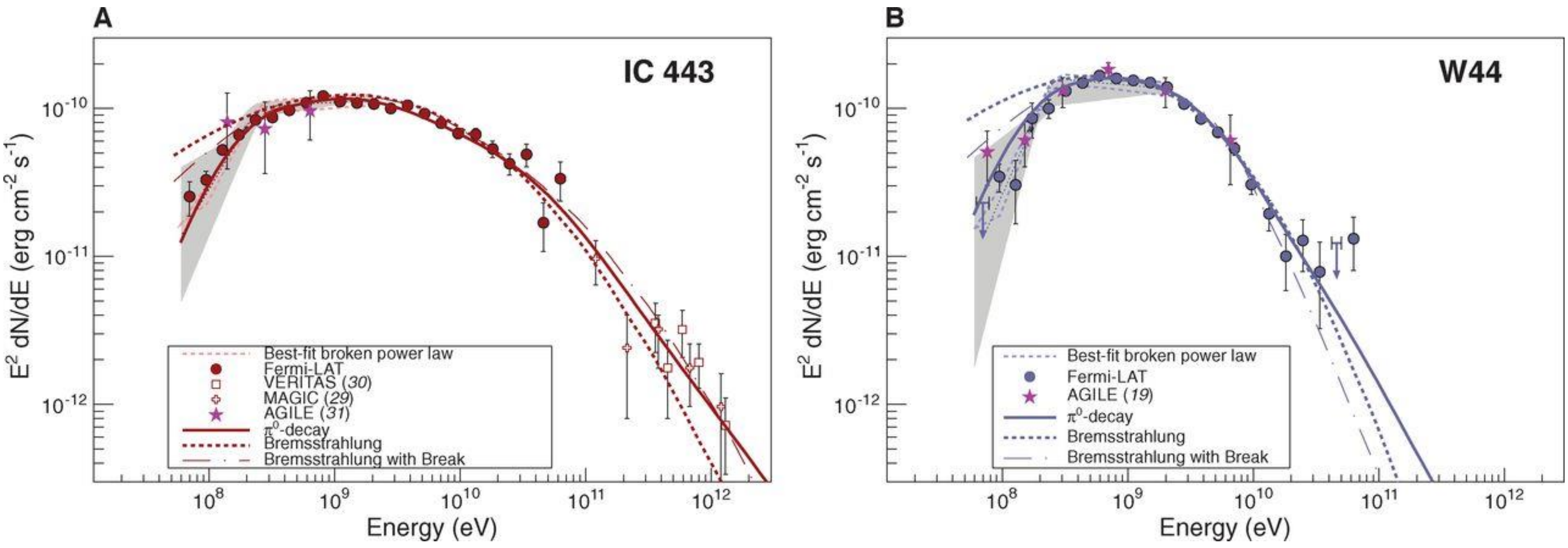
Galactic Cosmic Ray Origins

"Atmospheric Collision" by User:SyntaxError55, Wikimedia Commons



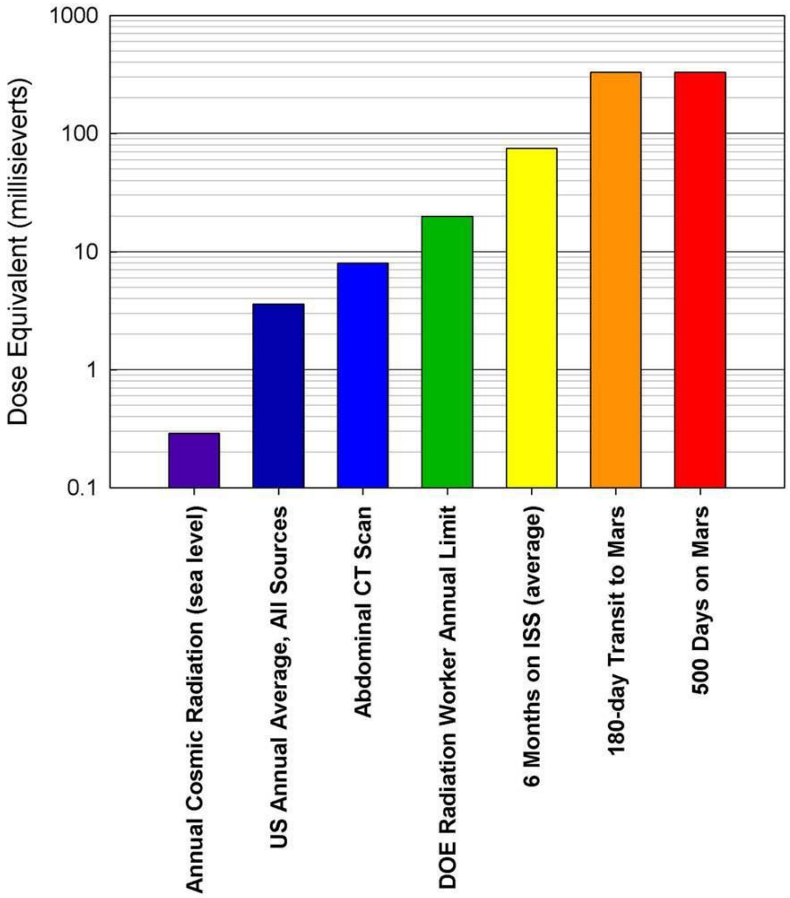
Evidence for Pion Decay

Ackerman, M., et al. *Science* 339 no. 6121 (2013): 807-811
doi:10.1126/science.1231160



What About Space Travel?

http://photojournal.jpl.nasa.gov/jpeg/PIA17601.jpg



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