

The background features a dark blue gradient with a starry space pattern. Overlaid on this are several technical diagrams, including circular gauges with numerical scales (e.g., 40, 150, 170, 180, 190, 200, 220, 230, 240, 250, 260) and various circular and curved lines, some with arrows, suggesting a scientific or engineering context.

# INNOVATING BEYOND ZERO

AN INTRODUCTION TO:

RADIOACTIVITY

RADIATION

EFFECTS OF RADIATION ON THE HUMAN BODY

LEGAL LIMITS FOR RADIATION EXPOSURE

# Periodic Table of the Elements

1 IA <b>H</b> Hydrogen 1.008 1	2 IIA <b>He</b> Helium 4.003 2											13 IIIA <b>B</b> Boron 10.81 13	14 IVA <b>C</b> Carbon 12.01 14	15 VA <b>N</b> Nitrogen 14.007 15	16 VIA <b>O</b> Oxygen 16.00 16	17 VIIA <b>F</b> Fluorine 18.998 17	18 VIIIA <b>Ne</b> Neon 20.180 20
3 <b>Li</b> Lithium 6.94 3	4 <b>Be</b> Beryllium 9.012 4											13 <b>Al</b> Aluminum 26.982 13	14 <b>Si</b> Silicon 28.085 14	15 <b>P</b> Phosphorus 30.974 15	16 <b>S</b> Sulfur 32.06 16	17 <b>Cl</b> Chlorine 35.45 17	18 <b>Ar</b> Argon 39.948 18
11 <b>Na</b> Sodium 22.98976928 11	12 <b>Mg</b> Magnesium 24.305 12	3 IIIB <b>Sc</b> Scandium 44.955908 21	4 IVB <b>Ti</b> Titanium 47.867 22	5 VB <b>V</b> Vanadium 50.942 23	6 VIB <b>Cr</b> Chromium 51.9961 24	7 VIIB <b>Mn</b> Manganese 54.938044 25	8 VIIIB <b>Fe</b> Iron 55.845 26	9 VIIIB <b>Co</b> Cobalt 58.933 27	10 VIIIB <b>Ni</b> Nickel 58.693 28	11 IB <b>Cu</b> Copper 63.546 29	12 IIB <b>Zn</b> Zinc 65.38 30	13 <b>Ga</b> Gallium 69.723 31	14 <b>Ge</b> Germanium 72.630 32	15 <b>As</b> Arsenic 74.922 33	16 <b>Se</b> Selenium 78.971 34	17 <b>Br</b> Bromine 79.904 35	18 <b>Kr</b> Krypton 83.798 36
19 <b>K</b> Potassium 39.0983 19	20 <b>Ca</b> Calcium 40.078 20	39 <b>Y</b> Yttrium 88.90584 39	40 <b>Zr</b> Zirconium 91.224 40	41 <b>Nb</b> Niobium 92.90637 41	42 <b>Mo</b> Molybdenum 95.95 42	43 <b>Tc</b> Technetium (98) 98.9062 43	44 <b>Ru</b> Ruthenium 101.07 44	45 <b>Rh</b> Rhodium 102.91 45	46 <b>Pd</b> Palladium 106.42 46	47 <b>Ag</b> Silver 107.87 47	48 <b>Cd</b> Cadmium 112.41 48	49 <b>In</b> Indium 114.82 49	50 <b>Sn</b> Tin 118.71 50	51 <b>Sb</b> Antimony 121.76 51	52 <b>Te</b> Tellurium 127.60 52	53 <b>I</b> Iodine 126.90 53	54 <b>Xe</b> Xenon 131.29 54
37 <b>Rb</b> Rubidium 85.468 37	38 <b>Sr</b> Strontium 87.62 38	57-71 Lanthanides	72 <b>Hf</b> Hafnium 178.49 72	73 <b>Ta</b> Tantalum 180.94788 73	74 <b>W</b> Tungsten 183.84 74	75 <b>Re</b> Rhenium 186.21 75	76 <b>Os</b> Osmium 191.22 76	77 <b>Ir</b> Iridium 192.22 77	78 <b>Pt</b> Platinum 195.08 78	79 <b>Au</b> Gold 196.967 79	80 <b>Hg</b> Mercury 200.59 80	81 <b>Tl</b> Thallium 204.38 81	82 <b>Pb</b> Lead 207.2 82	83 <b>Bi</b> Bismuth 208.98 83	84 <b>Po</b> Polonium 209 84	85 <b>At</b> Astatine 210 85	86 <b>Rn</b> Radon 222 86
87 <b>Fr</b> Francium 223 87	88 <b>Ra</b> Radium 226 88	89-103 Actinides	104 <b>Rf</b> Rutherfordium (261) 261 104	105 <b>Db</b> Dubnium (262) 262 105	106 <b>Sg</b> Seaborgium (263) 263 106	107 <b>Bh</b> Bohrium (264) 264 107	108 <b>Hs</b> Hassium (271) 271 108	109 <b>Mt</b> Meitnerium (270) 270 109	110 <b>Ds</b> Darmstadtium (285) 285 110	111 <b>Rg</b> Roentgenium (282) 282 111	112 <b>Cn</b> Copernicium (285) 285 112	113 <b>Nh</b> Nihonium (286) 286 113	114 <b>Fl</b> Flerovium (289) 289 114	115 <b>Mc</b> Moscovium (291) 291 115	116 <b>Lv</b> Livermorium (293) 293 116	117 <b>Ts</b> Tennessine (294) 294 117	118 <b>Og</b> Oganesson (294) 294 118

Atomic Number → 1  
Symbol ← H  
Name → Hydrogen  
Atomic Weight ← 1.008  
Electrons per shell → 1

State of matter (color of name)  
GAS LIQUID SOLID UNKNOWN

Subcategory in the metal-metalloid-nonmetal trend (color of background)

- Alkali metals
- Alkaline earth metals
- Transition metals
- Lanthanides
- Actinides
- Post-transition metals
- Metalloids
- Reactive nonmetals
- Noble gases
- Unknown chemical properties

57 <b>La</b> Lanthanum 138.91 57	58 <b>Ce</b> Cerium 140.12 58	59 <b>Pr</b> Praseodymium 140.91 59	60 <b>Nd</b> Neodymium 144.24 60	61 <b>Pm</b> Promethium (145) 145 61	62 <b>Sm</b> Samarium 150.36 62	63 <b>Eu</b> Europium 151.96 63	64 <b>Gd</b> Gadolinium 157.25 64	65 <b>Tb</b> Terbium 158.93 65	66 <b>Dy</b> Dysprosium 162.50 66	67 <b>Ho</b> Holmium 164.93 67	68 <b>Er</b> Erbium 167.26 68	69 <b>Tm</b> Thulium 168.93 69	70 <b>Yb</b> Ytterbium 173.05 70	71 <b>Lu</b> Lutetium 174.96 71
89 <b>Ac</b> Actinium (227) 227 89	90 <b>Th</b> Thorium 232.04 90	91 <b>Pa</b> Protactinium 231.04 91	92 <b>U</b> Uranium 238.03 92	93 <b>Np</b> Neptunium (237) 237 93	94 <b>Pu</b> Plutonium (244) 244 94	95 <b>Am</b> Americium (243) 243 95	96 <b>Cm</b> Curium (247) 247 96	97 <b>Bk</b> Berkelium (247) 247 97	98 <b>Cf</b> Californium (251) 251 98	99 <b>Es</b> Einsteinium (252) 252 99	100 <b>Fm</b> Fermium (257) 257 100	101 <b>Md</b> Mendelevium (258) 258 101	102 <b>No</b> Nobelium (259) 259 102	103 <b>Lr</b> Lawrencium (260) 260 103



# WHICH ELEMENTS ARE RADIOACTIVE?

- Virtually all elements have unstable (radioactive) isotopes.
- 38 elements have no stable isotopes (Atomic Number 43, 61, &  $>83$ ).

# RADIOACTIVE ISOTOPES DECAY (CHANGE THEIR ATOMIC NUMBER AND MIGHT CHANGE MASS) BY ONE OF FOUR PROCESSES.

- Alpha Decay
  - Beta Decay
  - Positron Emission
  - Electron Capture
- 
- Radioactive decay may or may not be accompanied by a Gamma ray.



# ALPHA DECAY

- Helium atom ejected.
- Atomic Number decreases by 2.
- Mass decreases by 4.

# BETA DECAY

- An electron is ejected from a neutron.
- The neutron becomes a proton.
- Atomic number increases by 1.
- Mass remains the same.



# POSITRON EMISSION

- A positron is ejected from a proton.
- The proton becomes a neutron.
- Atomic number decreases by 1.
- Mass remains the same.

# ELECTRON CAPTURE

- An orbital electron is captured by a proton.
- The proton becomes a neutron.
- Atomic number decreases by 1.
- Mass remains the same.



# RADIOACTIVE ELEMENTS

1 <b>H</b> Hydrogen Stable																	2 <b>He</b> Helium Stable						
3 <b>Li</b> Lithium Stable	4 <b>Be</b> Beryllium Stable																	5 <b>B</b> Boron Stable	6 <b>C</b> Carbon Stable	7 <b>N</b> Nitrogen Stable	8 <b>O</b> Oxygen Stable	9 <b>F</b> Fluorine Stable	10 <b>Ne</b> Neon Stable
11 <b>Na</b> Sodium Stable	12 <b>Mg</b> Magnesium Stable																	13 <b>Al</b> Aluminum Stable	14 <b>Si</b> Silicon Stable	15 <b>P</b> Phosphorus Stable	16 <b>S</b> Sulfur Stable	17 <b>Cl</b> Chlorine Stable	18 <b>Ar</b> Argon Stable
19 <b>K</b> Potassium Stable	20 <b>Ca</b> Calcium Stable	21 <b>Sc</b> Scandium Stable	22 <b>Ti</b> Titanium Stable	23 <b>V</b> Vanadium Stable	24 <b>Cr</b> Chromium Stable	25 <b>Mn</b> Manganese Stable	26 <b>Fe</b> Iron Stable	27 <b>Co</b> Cobalt Stable	28 <b>Ni</b> Nickel Stable	29 <b>Cu</b> Copper Stable	30 <b>Zn</b> Zinc Stable	31 <b>Ga</b> Gallium Stable	32 <b>Ge</b> Germanium Stable	33 <b>As</b> Arsenic Stable	34 <b>Se</b> Selenium Stable	35 <b>Br</b> Bromine Stable	36 <b>Kr</b> Krypton Stable						
37 <b>Rb</b> Rubidium Stable	38 <b>Sr</b> Strontium Stable	39 <b>Y</b> Yttrium Stable	40 <b>Zr</b> Zirconium Stable	41 <b>Nb</b> Niobium Stable	42 <b>Mo</b> Molybdenum Stable	43 <b>Tc</b> Technetium 4.21 x 10 <sup>6</sup> y	44 <b>Ru</b> Ruthenium Stable	45 <b>Rh</b> Rhodium Stable	46 <b>Pd</b> Palladium Stable	47 <b>Ag</b> Silver Stable	48 <b>Cd</b> Cadmium Stable	49 <b>In</b> Indium Stable	50 <b>Sn</b> Tin Stable	51 <b>Sb</b> Antimony Stable	52 <b>Te</b> Tellurium Stable	53 <b>I</b> Iodine Stable	54 <b>Xe</b> Xenon Stable						
55 <b>Cs</b> Cesium Stable	56 <b>Ba</b> Barium Stable	57-71	72 <b>Hf</b> Hafnium Stable	73 <b>Ta</b> Tantalum Stable	74 <b>W</b> Tungsten Stable	75 <b>Re</b> Rhenium Stable	76 <b>Os</b> Osmium Stable	77 <b>Ir</b> Iridium Stable	78 <b>Pt</b> Platinum Stable	79 <b>Au</b> Gold Stable	80 <b>Hg</b> Mercury Stable	81 <b>Tl</b> Thallium Stable	82 <b>Pb</b> Lead Stable	83 <b>Bi</b> Bismuth Stable	84 <b>Po</b> Polonium 102 y	85 <b>At</b> Astatine 8.1 hr	86 <b>Rn</b> Radon 3.82 d						
87 <b>Fr</b> Francium 22 min	88 <b>Ra</b> Radium 1600 y	89-103	104 <b>Rf</b> Rutherfordium 13 hr	105 <b>Db</b> Dubnium 32 hr	106 <b>Sg</b> Seaborgium 2.4 min	107 <b>Bh</b> Bohrium 17 s	108 <b>Hs</b> Hassium 9.7 s	109 <b>Mt</b> Meitnerium 0.72 s	110 <b>Ds</b> Darmstadtium 11.1 s	111 <b>Rg</b> Roentgenium 26 s	112 <b>Cn</b> Copernicium 29 s	113 <b>Nh</b> Nihonium 0.48 s	114 <b>Fl</b> Flerovium 2.65 s	115 <b>Mc</b> Moscovium 87 ms	116 <b>Lv</b> Livermorium 61 ms	117 <b>Ts</b> Tennessine unknown	118 <b>Og</b> Oganesson 1.8 ms						

57 <b>La</b> Lanthanum Stable	58 <b>Ce</b> Cerium Stable	59 <b>Pr</b> Praseodymium Stable	60 <b>Nd</b> Neodymium Stable	61 <b>Pm</b> Promethium 17.4 y	62 <b>Sm</b> Samarium Stable	63 <b>Eu</b> Europium Stable	64 <b>Gd</b> Gadolinium Stable	65 <b>Tb</b> Terbium Stable	66 <b>Dy</b> Dysprosium Stable	67 <b>Ho</b> Holmium Stable	68 <b>Er</b> Erbium Stable	69 <b>Tm</b> Thulium Stable	70 <b>Yb</b> Ytterbium Stable	71 <b>Lu</b> Lutetium Stable
89 <b>Ac</b> Actinium 21.77 y	90 <b>Th</b> Thorium 7.54 x 10 <sup>4</sup> y	91 <b>Pa</b> Protactinium 3.28 x 10 <sup>4</sup> y	92 <b>U</b> Uranium 2.34 x 10 <sup>8</sup> y	93 <b>Np</b> Neptunium 2.14 x 10 <sup>6</sup> y	94 <b>Pu</b> Plutonium 8.00 x 10 <sup>7</sup> y	95 <b>Am</b> Americium 7370 y	96 <b>Cm</b> Curium 1.56 x 10 <sup>7</sup> y	97 <b>Bk</b> Berkelium 1380 y	98 <b>Cf</b> Californium 898 y	99 <b>Es</b> Einsteinium 471.7 d	100 <b>Fm</b> Fermium 100.5 d	101 <b>Md</b> Mendelevium 51.5 d	102 <b>No</b> Nobelium 58 min	103 <b>Lr</b> Lawrencium 4 hr

# HOW LONG DO RADIOACTIVE ISOTOPES LAST?

- Some last billions of years.
- Some only last a fraction of a second.
- The half-life of an isotope is the time it takes for half the mass of a sample to decay to other isotopes.



# EXAMPLE HALF-LIVES

- Nitrogen-16: 7.13 seconds.
- Cesium-133: 2 years.
- Cobalt-60: 5.3 years.
- Plutonium-239: 24,100 thousand years.
- Technium-99: 211,000 years.
- Uranium-235: 700 million years.
- Uranium-238: 4.5 billion years

# TYPES OF RADIATION FROM NUCLEAR POWER PLANTS

1. Neutron – average of 2.4 high energy neutrons per fission of U-235, with 2 “fission fragments” one about 3/5 mass of U-235 the other about 2/5 (ie CS-133 and Tc-99).
2. Gamma – from fission and decay of fission products & activated structural materials.
3. Beta – from decay of fission products & activated structural materials.
4. Alpha – from decay of fission products.



# PARTICLE RADIATION EFFECTS ON THE BODY

- High energy ionized particles (Alpha or Beta) passing through a cell strip electrons from atoms in the cell creating free radicals.
- Free radicals are very reactive chemically.
- Subsequent chemical reactions damage cells in various ways.

# GAMMA RADIATION EFFECTS ON THE BODY

- Gamma rays are not physical particles.
- Gamma rays interact with atoms along their path releasing high energy electrons.
- These electrons behave like Alpha and Beta particles.



# NEUTRON RADIATION EFFECTS ON THE BODY

- Neutrons collide with the nucleus of atoms causing them to recoil and lose their electrons (they become ionized).
- These ionized particles behave like Alpha and Beta particles.

# RADIATION MEASUREMENT UNITS

- RAD – Radiation Absorbed Dose, a measurement of how much energy absorbed by a gram of material.
- There is a difference between how much biological damage is done by 1 RAD depending on the type of radiation. This is accounted for by a “Quality Factor” (QF).



# ROENTGEN EQUIVALENT IN MAN

- REM –Roentgen Equivalent in Man.  $1\text{REM} = 1\text{RAD} \times \text{QF}$ .
- Quality Factors:
  - Gamma and Beta = 1.
  - Alpha = 20.
  - Neutron = 10.

# LEGAL LIMITS FOR RADIATION OCCUPATIONAL RADIATION WORKER EXPOSURE

- Whole body: 5 REM per year
- Any organ: 50 REM per year
- Skin: 50 REM per year
- Extremity: 50 REM per year
- Lens of eye: 15 REM per year



# LEGAL LIMITS FOR OCCUPATIONAL RADIATION EXPOSURE TO THE PUBLIC

- Whole body: 0.1 REM per year

## Background Annual Average Radiation Doses to the U.S. Population

Radiation Source	Average Annual Whole Body Dose (mrem/year)
<b>Natural:</b> Cosmic	26
Terrestrial	29
Radon	200
Internal (K-40, C-14, etc.)	40
<b>Manmade:</b> Diagnostic X-Ray	39
Nuclear Medicine	14
Consumer Products	11
All Others (fallout, nuclear power plants, air travel, occupational, etc.)	2
<b>Average Annual Total</b>	<b>361 mrem/year</b>

**Tobacco (If You Smoke, Add ~ 280 mrem)**

The tobacco in cigarettes contains lead-210. Lead-210 is a naturally occurring radionuclide that precipitates out of the atmosphere and deposits on the leaves of tobacco. When the tobacco is inhaled, the smoker receives a dose from the inhaled lead-210 as well as polonium-210, the decay product of lead-210. Lead-210 is deposited on the surfaces of bones and polonium-210 is deposited in the liver, kidney and spleen.



Table 11.9.2: The Effects of a Single Radiation Dose on a 70 kg Human

Dose (rem)	Symptoms/Effects
< 5	no observable effect
5–20	possible chromosomal damage
20–100	temporary reduction in white blood cell count
50–100	temporary sterility in men (up to a year)
100–200	mild radiation sickness, vomiting, diarrhea, fatigue; immune system suppressed; bone growth in children retarded
> 300	permanent sterility in women
> 500	fatal to 50% within 30 days; destruction of bone marrow and intestine
> 3000	fatal within hours

Radiation doses of 600 rem and higher are invariably fatal, while a dose of 500 rem kills half the exposed subjects within 30 days. Smaller doses ( $\leq 50$  rem) appear to cause only limited health effects, even though they correspond to tens of years of natural radiation. This does not, however, mean that such doses have no ill effects; they may cause long-term health problems, such as cancer or genetic changes that affect offspring. The possible detrimental effects of the much smaller doses attributable to artificial sources ( $< 100$  mrem/yr) are more difficult to assess.