NUCLEAR POWER AND NUCLEAR WEAPONS
A BEGINNER'S GUIDE -- IN PICTURES AND DIAGRAMS

PART 1: WHAT IS RADIATION? WHY IS IT DANGEROUS?

PART 2: (MIS)HANDLING WHAT’S LEFT BEHIND

PART 3: VIRTUAL MUSEUM OF NUCLEAR EVENTS

+ 4 MORE!
+ 7 MORE!
+ 3 MORE!

BY ACE HOFFMAN © 2022
The number of protons (1 to 118) in the nucleus of an atom determines the element. Isotopes of the same element have different numbers of neutrons in their nuclei. Only Hydrogen (H) can have zero neutrons, or H can have one or two neutrons. When it has one neutron it is called Deuterium. With two neutrons it is called Tritium and is radioactive.

About 99% of the human body is built from the eleven elements highlighted with green letters. Other elements that are (or may be) necessary in trace amounts are outlined in green.

The body cannot distinguish radioactive isotopes from stable isotopes of the same element. Eleven of the most common elements with radioactive isotopes have been highlighted with red and yellow boxes. Elements in the same column are chemically similar. Thus, radioactive Strontium atoms are mistaken by the body for useful Calcium atoms and radioactive Cesium is mistaken for Potassium.
All radioactive isotopes are hazardous to humans and other living things. Unstable (i.e., “radioactive”) elements such as U-235 and Pu-239 have many more neutrons than protons in their nuclei. When their nuclei are split (i.e., “fissioned”) by bombarding them with neutrons, most of their “daughter” products are also unstable isotopes (i.e., they are also radioactive). The decay chain continues down the periodic table to smaller and smaller elements until a stable element is reached. Each step releases energy in the form of alpha or beta particles, gamma rays, and/or x-rays.

Through fission and/or activation (absorbing neutrons), nuclear bombs and nuclear power plants create thousands of previously non-existent (on earth) radioactive isotopes with a wide variety of half-lives.
A half-life is a statistical value

A half-life is the time it takes for half the atoms in a pure sample of a single isotope of an element to decay into some other element. After one half-life, half the atoms of the original isotope will still be unchanged. After two half-lives, a quarter of them will still be unchanged. When a specific atom will decay is unpredictable.

In the chart on the right, four common decay chains are shown. Decays by release of an alpha particle are shown going down; decays by release of a beta particle are shown going to the right. Most alpha and beta decays are accompanied by one or more gamma ray emissions and possibly by x-ray emissions as well.

Alpha particles consist of two protons and two neutrons. The alpha particle becomes a helium atom after slowing down and grabbing two electrons from surrounding atoms. With the loss of two protons, the original atom becomes a smaller, lighter element in the Periodic Table of the Elements.

A beta particle becomes an electron when it slows down. In the original atom, a neutron becomes a proton, and the element increases one place in the Periodic Table.

If you start with 1,000,000,000 (one billion) atoms, after 20 half-lives about 1000 atoms of the original isotope will remain (about one millionth (0.000095%) of the initial amount).
“Spent” nuclear fuel is far more hazardous than “fresh” nuclear fuel.

Nuclear reactions release enormous amounts of energy, which can be used to produce heat or to see things that are otherwise hidden or invisible. But radioactivity has a very dark side too, because all that energy is concentrated in a very small area. It can break any chemical bond in any living creature on earth. Even the so-called “weak” nuclear reactions (such as a tritium atom decay) is thousands of times stronger than any molecular bond. Radiation damages any living creature -- or any container you leave it in.

### Nuclear Fission

- Neutron 8 MeV
- U^{235}\rightarrow Ba^{137}, Mo^{96}
- Gamma-rays, Neutrons, Beta-particles
- Energy released is about 200 MeV
- Result: Two radioactive fission fragments (lighter elements), gamma rays, neutrinos, beta particles, and more neutrons.

### Chain Reaction

- **Initial Neutron**
- **Fission Fragment**
- **Energy released**
- **Neutron loss**
- **Secondary Neutrons**

**Speed of chain reaction:**

- **Controlled**: (Unless there’s a meltdown)
- **Exponential**: (and very, very rapid)

### Neutron Activation

A single neutron, generated by nuclear fission, is absorbed by a U^{238} atom. U^{238} is not fissionable, but it can absorb a neutron.

\[ \ldots \rightarrow U^{238} \rightarrow U^{239} \]

At first the atom becomes a U^{239} isotope but soon it will emit several beta particles. (This usually happens over a couple of weeks.) In the nucleus of the atom, two neutrons become protons. The atom becomes a Pu^{239} isotope, which is fissionable.

\[ U^{239} \rightarrow Pu^{239} \]

### Fission vs Fusion

#### Fission

- U^{238} \rightarrow Ba^{137}, Mo^{96} + 215 MeV
- Deuterium \rightarrow He^{3}, H^{2} + 17.6 MeV
- Tritium \rightarrow He^{3}, H^{2} \%

#### Fusion

There's division and confusion about fission and fusion.

Both reactions generate heat, which can be used to boil water, and both produce radioactive waste.

### Element 94: Plutonium

A Pu^{239} atom is much more hazardous for several reasons. U^{238} has a half-life of ~4.468 billion years. Pu^{239} has a half-life of ~24,110 years: ~195,317 times shorter! Pu^{239} is approximately that much more hazardous than U^{238} from the radiation.

Additionally, a Pu^{239} nucleus is surrounded by a cloud of 94 electrons, and the outer shells (the outermost electrons) wreak havoc on surrounding atoms and molecules.

Electron Configuration:

[\text{Rn}] 5f^6 7s^2

Graphics assembled and / or colorized by Ace Hoffman.
MECHANISMS FOR RADIATION DAMAGE

“In the typical nuclear environment, the average energy of a neutron is about 2 MeV while the threshold energy to displace an atom from its lattice position in metals is just 20-40 eV; this means that about 50,000 atoms are displaced in a typical collision.”

About 10% of these displacements remain out of position.
Source: Stanford University report

Common threats to metals in a nuclear environment include embrittlement, swelling from void formation, creep, phase transitions, and swelling due to gas bubbles.
Source: Stanford University report

Swelled and damaged fuel pellets.

One radiation-initiated collision event can lead to a cascade of additional collision events, leading to embrittlement and parts failures.
Source: Helmholtz Labs

Alpha particles and beta particles are highly charged, (+2 electron volts (eV) for alpha, -1 eV for beta). These particles do not need to collide with other charged particles to knock them out of their proper location -- they can cause damage at a distance. Gamma rays do not have a charge, but if they do hit a nucleus or an electron, they are also very damaging.

One alpha particle consists of two neutrons and two protons. It is about 8,000 times heavier than one beta particle. (A beta particle at the same scale would be smaller than the period at the end of this sentence.)

Typical electron positions around a hydrogen nucleus.

This is a very high resolution image of a human cell. Human cells contain a curled-up strand of DNA that would be about six feet long if stretched out. Cells can be easily damaged by alpha or beta particles or gamma rays, leading to cancer and other health effects.

Alpha radiation from Plutonium in ape lung.

Photo: Lawrence Livermore Laboratory
**Hidden Effects of Radiation**

**Inflammation**

Your body’s ability to repair itself is remarkable, but NOT infinite. Your DNA is most vulnerable during cell division.

Inflammation occurs when your body uses its white blood cells and other tools to fight an invading organism or poison. When a cell gets infected, it goes into an inflammatory mode, which is easy to see with a microscope. But when you examine the body’s defense system closely, it is not as simple as your immune system. Your immune system has the ability to destroy high-grade cancerous cells, but that does not mean there isn’t a significant amount of damage. This damage can cause premature aging, neurodegenerative diseases, cardiovascular problems, and many other diseases.

**Leftover / Recoil Damage**

Tritium (H) and other radioactive isotopes also cause damage by the recoil of the remaining nucleus after a decay.

Additionally, whatever the new element is, it’s not the element that might have been part of some complex protein molecule, for instance, or DNA, etc.

**Catalytic Damage**

Many radioactive elements are significant catalysts, as well as heavy metal hazards, in addition to their radiological threat. The nuclear process releases these dangerous elements into the environment where they have been shown to mimic hormones in mice, and to cause diseases of serious ailments. Catalytic effects of DU are considered one possible factor in “Gulf War Syndrome.”

**Daughter Products**

After a radioactive atom decays, it may or may not decay a second time, or more. Each step releases ionizing energy of some sort. How an isotope decays, and what it decays into, must be considered when comparing dangers of various radioactive exposure. After a nuclear isotope decays, the atom will be “ionized,” and so on down the ladder of energy levels, one atom ionizing another, in a long sequence.

When tritium decays, the decayed atom might be part of a water molecule. The left-over OH molecule is a free radical and is particularly hazardous to living cells because it is a strong oxidizer and can suddenly appear anywhere in the body when created by this method.

**Bystander Effect**

When one cell in your body is damaged, the death or altered behavior of that cell can cause other cells to also fail. When mice were irradiated on just the lower half of their bodies, they developed brain tumors.

**Hot Particles**

A single particle of Depleted Uranium one milligram in size is very small. Many U.S. soldiers, enemy combatants and civilians caught in the crossfire, have far more than that loaded in their bodies. Such particles are known as “hot” particles and leave a path of destruction in their wake.

Despite DU’s long half-life of 4.5 billion years, its incredibly high density, there are still enough atoms of DU in one milligram, (530,000,000,000,000,000,000) so that more than a million atoms will decay every day.

... THERE ARE MANY OTHER HIDDEN AND SUBTLE EFFECTS OF RADIATION POISONING . . .

Written, designed, and colored by Ace Hoffman

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Uranium is mined all over the world. In New Mexico and other parts of the southwestern United States, hundreds of abandoned uranium mines poison the earth, air and water (and the people who live nearby) from the “tailings” that have been left behind. But mine tailings have only a tiny fraction of the toxic radioactivity of the fission and activation products that nuclear reactors produce -- some with extremely short half-lives, others with half-lives of eons...

**NUCLEAR FUEL CYCLE**

- **Prospecting for Uranium Ore**
- **Mining the Uranium Ore**
- **Milling to U₃O₈ (“yellowcake”)**
- **Conversion to UF₆ (“hex”)**
- **U²³⁵ Enrichment**
- **“K-25”**
- **Fuel / Bomb Fabrication**
- **Reactors**
- **Spent Fuel Pools**
- **Dry Storage Casks**

**MILITARY/INDUSTRIAL COMPLEX**
- **NUCLEAR PATHWAYS**
- **HAZARDS & PROBLEMS**

**CARBON-BASED, GLOBAL WARMING ENERGY IS USED TO ENABLE NUCLEAR REACTORS, ATOMIC AND RADIOACTIVE WEAPONS, TRANSPORTATION AND WASTE HANDLING**
Why “Becquerels” don’t tell the whole story...

Units of Measure for Radioactivity

- **Becquerels**: A count of decays
- **Grays**: An energy density
- **Sieverts**: A damage assessment

The number of apples that fall in a given unit of time can be compared to the curie or Bq (decays per second).

The total energy of all the apples that hit the sleeper in a given unit of time can be compared to rads or grays (absorbed dose).

The effect on the body, depending on the size, weight, and speed of the apples, can be compared to rems or sieverts (effective dose).

If you only talk about Becquerels (Bq), chances are you’ll minimize other people’s understanding of the dangers from radiation. There’s a lot more to it...

Other important factors include:

- What type of radiation is emitted? (Alpha, Beta, Gamma, X-ray, Neutron, etc.)?
- What energy level is the emission? (What is its wavelength?)
- What is the electrical charge of the emission (Positive, Negative, or Neutral?)
- For particles, how much kinetic energy does it have? (What does it weigh?)
- What element released the emission?
- What element(s) does it decay to? (What is its entire decay chain?)
- What molecules are each of those elements likely to combine with?
- What is the element’s biological affinity? (Do living things seek it out?)
- Is the emission internal or external?
- ...and many more...

Radiation Conversion Factors

- 1 rad = an absorbed dose of 0.01 joules (J) of energy per kilogram (kg) of tissue, or 100 erg per gram
- 1 rad = 1,000 millirad
- 1 gray (Gy) = 100 rad = 1 J / kg
- 1 roentgen = 0.876 rads (in air)
- 1 rem = 1.07185 roentgen (rem stands for “roentgen equivalent in man”)
- 1 rem = 1,000 millirem
- 1 sievert = 100 rem
- 1 becquerel = 1 disintegration per second
- 1 curie = 37,000,000,000 disintegrations per second
- 1 curie = 37,000,000,000 becquerel
- 1 becquerel = 2.7411 curies
- 1 becquerel = 27 picocuries
- 1 curie = 1,000,000,000,000 picocuries
- 1 picocurie = 0.037 disintegrations per second
- 1 microcurie = 37,000 disintegrations per second
- 1 megacurie = 1,000,000 curies
- 1 kilocurie = 1,000 curies
San Onofre has more than three million pounds of nuclear waste sitting on the beach in San Clemente, California. The waste is packed into 123 stainless steel containers just 5/8th inch thick.

What could go wrong? Lots of things...

San Onofre’s sea wall is a lot like this one...

But look what happened in March, 2011:

Not pretty? Then hide it underground!

There is enough highly toxic radioactive spent fuel nuclear waste in America for 10,000 dry casks, each as big as a school bus (about 3,000 casks have been loaded so far).
Large ships were pushed far inland by the tsunami that devastated Japan and inundated the Fukushima Daiichi nuclear reactors.

San Onofre Nuclear Waste Dump is also vulnerable.

This “ghost ship” washed up six years after the Tohoku earthquake and tsunami... on U.S. shores!
In addition to creating tsunamis directly, earthquakes can also trigger underwater landslides, which can create enormous local tsunamis hundreds of feet high. SoCalEd claims their dry casks can survive 125 feet* of submersion, but that might not be nearly enough.

* This figure applies only to the 73 Holtec casks. This author was told by the SCE spokesperson at the time that the original 50 horizontal casks are only designed to withstand 50 feet of submersion.
The ECCS at Monticello was completely unavailable for the first few decades! Fortunately, it wasn’t needed in that time.

The Monticello ECCS was never tested (no ECCS has ever been fully tested). After several decades of plant operation, the ECCS was finally properly inspected. Massive baffles (to prevent backflow) had been bolted shut for transport from the manufacturer. After installation, the bolts were supposed to be removed, but they never were!

Improper maintenance, lax oversight, falsified records, and lying to the public (and even to the regulators) are common occurrences at every nuclear power plant.

In normal businesses, these would all be serious “red flags.”

But in the nuclear industry, it’s just how things are done.

Operating nuclear reactor licenses are being extended to 60, 80 and even 100 years or more, because building new reactors is too expensive to be competitive with wind, solar, etc.

But the old reactors are full of rusted-out components and even have components that have never been tested at full size!

No one knows if a nuclear reactor can survive an airplane strike from a large jet aircraft intentionally flown into the reactor by a crazed pilot or terrorist. It is considered a “beyond design basis” event!

But in reality, everyone in the nuclear industry knows that no reactor has EVER been designed to handle that!
Commercial jet turbine shafts weigh more than a ton. Landing gear, engine mounts and other parts are also extremely large, dense metal parts.

Large jet accidents can happen anywhere. But also, there have been seven suicide-mass murder large jet crashes already this century*.

* Four on 9-11, plus GermanWings, MH-370 (probable), and the China Airlines crash in 2022 (also probable suicide-mass murder).
With nuclear energy and nuclear weapons, an accident anywhere...

Is an accident everywhere.

Smoke gets in your eyes:

Left: Plume from Sept. 2007 brush fire barely spreads as it travels over 200 km. across the Mojave Desert. Right: Plumes from Oct. 2007 fires drift out to sea.

Radioactive plumes are odorless, colorless, tasteless (except in very high doses) but can cause permanent evacuations and latent cancers hundreds of miles away.

Flag flying north...

If you live anywhere near the San Onofre Nuclear Waste Dump and there is a spent fuel fire or other accident, you will be in the path of its poisons at some point...

Flag flying south...

Flag in calm winds...

Photos by Ace Hoffman
Nuclear Waste is a terrible thing to have to mind...
For hundreds of thousands of years...

Top row: Mountains of Fukushima nuclear waste in black bags, blue bags, and enormous tanks of liquid.

Middle row: Above ground vertical spent fuel, in-ground spent fuel, above-ground horizontal spent fuel.

Left: 24 fuel assemblies are placed in a typical canister.

Soviet-era dry cask storage.

Left: Typical fuel assembly (too "hot" to handle!)
Hanford, WA Nuclear Waste Storage Tanks

There are 177 tanks at Hanford, containing various toxic brews of rad waste...

Shown under construction in the 1940s; now well beyond expected years of use.

Some tanks are already leaking radioactive effluents into the groundwater.

Welding inside a tank under construction.

Currently there are three “Superfund” areas at the Hanford “reservation.” A fourth “Superfund” area has been cleaned up...at least, enough to be taken off the list...

Images collected by Ace Hoffman
Holtec illustration of a rail car for nuclear spent fuel transportation.

US DOE / US Navy spent fuel transport system.

Baltimore Tunnel fire (aka Howard Street Tunnel Fire, July, 2001) reached an estimated 1800 °F: Hot enough to burst a nuclear waste shipping canister. Peak temperatures in the Caldecott Tunnel fire (April, 1982) were estimated to be even higher: 2,000 °F.

NRC regulations only require a transport cask to survive a 1,475 °F for 30 minutes...

I-35W Bridge Collapse (August, 2007) onto a river, a road, and a rail line. A dry cask transport container would hardly survive -- either on or under this!

Mianus River Bridge Collapse (June, 1983). Much further drop than a transport cask can survive.
Which are you going to choose?

Both systems can generate *plenty* of electricity.

But one only costs a few hundred million dollars to build, while the other costs dozens of billions. One uses materials that can be recycled and used again. The other requires armed guards starting before it is even turned on, and then leaves extremely hazardous radioactive waste which must be isolated from the environment for a quarter of a million years (and no one knows how to do that).
Trinity was the first of many atmospheric, underwater, and underground explosions.

America exploded 1151 nuclear bombs before testing was abandoned by most countries.

From Hiroshima to Three Mile Island to Chernobyl to Fukushima to...San Onofre?

Many precise measurements have already been made...

Virtual Museum of Nuclear Events
Virtual Museum of Nuclear Events

Despite decades of global opposition, money and power still make the wrong choice.
There are many connections between nuclear waste from nuclear power plants and nuclear weapons. Nuclear weapons are made from isotopes extracted from nuclear waste. And worse: Nuclear weapons can vaporize nuclear waste, creating a global health catastrophe.
Books on nuclear topics published from 1945 through 2008
(from the private collection of Ace Hoffman)