Benign! Nuclear power radiation

by Robert Hargraves, PhD

Abstract

The root cause of nuclear power cost and opposition is excessive fear of radiation. This essay explores true observed radiation, effects, harm, and benefits, summarized here, proven later.

Doesn't radiation from nuclear power plants causes cancer?
No, its radiation damage rates are slower than biological repair rates.

Isn't the nuclear waste harmful to future generations?
No, we can store used fuel in ground-level casks as penetrating radiation decays away. You'd then have to eat the waste to get sick.

Don't nuclear power plants cost too much?
Yes, because regulators' rules were written using the precautionary principle, not today's scientific observations.

Radiation is a weak carcinogen. After the WW II atomic bombings of Japan we all feared globally destructive nuclear war. To intensify that fear NGOs and nations exaggerated geneticists' idea that even trivial amounts of radiation constantly degraded human genes through generations, even to birthing three-eyed monsters. When that fiction was disproven, the radiation fear of choice became cancer.

Governments and regulators strove to protect voters from the vague harm of invisible radiation, creating rules and procedures to keep people away from any radiation from nuclear power. These rules constantly became more strict and cumbersome.

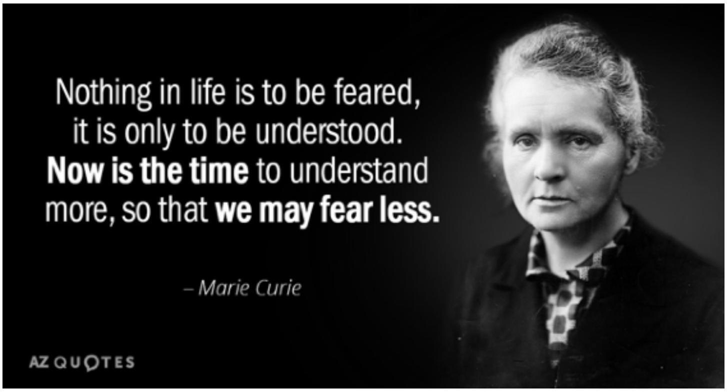
These radiation exposure rules from worldwide regulators such as the US Environmental Protection Agency and Nuclear Regulatory Commission created the problem of high cost and long build times, making *new nuclear* power too expensive. In reality, nuclear power can be the least expensive reliable energy source, at $0.03/kWh, if we educate the public, politicians, and regulators.

Fear can kill. Radiation from the triple Fukushima nuclear reactor meltdown killed no one, but Japan's fearful government killed[1] over 1,600 people with hasty, unnecessary evacuations.

Nuclear power optimism is on the rise. Will people return to nuclear fear after the next failure leaks some radioactive material out? Perfection is impossible. Radiation releases will happen. Airplanes do crash. People still fly. They understand authentic risks and benefits.

Two Westinghouse AP1000 nuclear power reactors has been powered up in Georgia. Will these be the last commercial US nuclear power plants?

Radiation fear



*Wisdom of woman awarded **two** Nobel prizes.*[2]

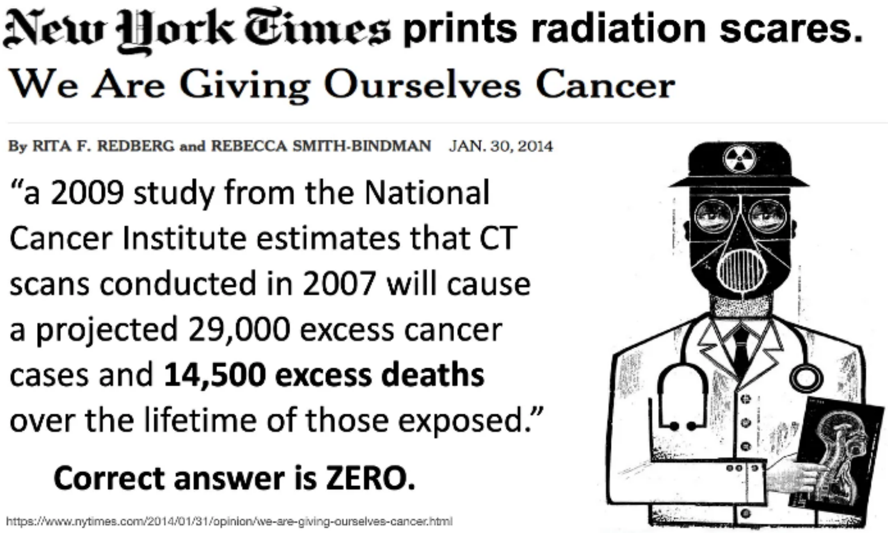
Ionizing radiation harms by displacing electrons, breaking molecular bonds in cells. Radiation dose is measured in Sieverts (Sv) or Grays, which are watt-seconds (joules) of energy absorbed, per kilogram of tissue.[3] These are the effects of intensive, brief absorbed doses of radiation.

- 10 Sv is deadly,
- 1 Sv risks non-fatal acute radiation sickness,
- 0.1 Sv slightly increases future cancer risk.

Regulators mistakenly claim any radiation exposure is potentially harmful, so set unreasonably low limits, hoping to calm fearful people. Media headlines frighten people about any radiation leaks, no matter how small, in order to gain attention with headlines.

Nuclear power growth, now in vogue, will end with the next radiation release unless we replace today's regulators with institutions that balance benefits against quantified radiation doses and observed effects.

The near century of concessions lowering 1934 radiation limits from 0.002 Sv per **day** to 0.001 Sv per **year** has not reduced harm. Lowered limits have increased public fear, along with evidence-free rulings that all radiation is potentially fatal.

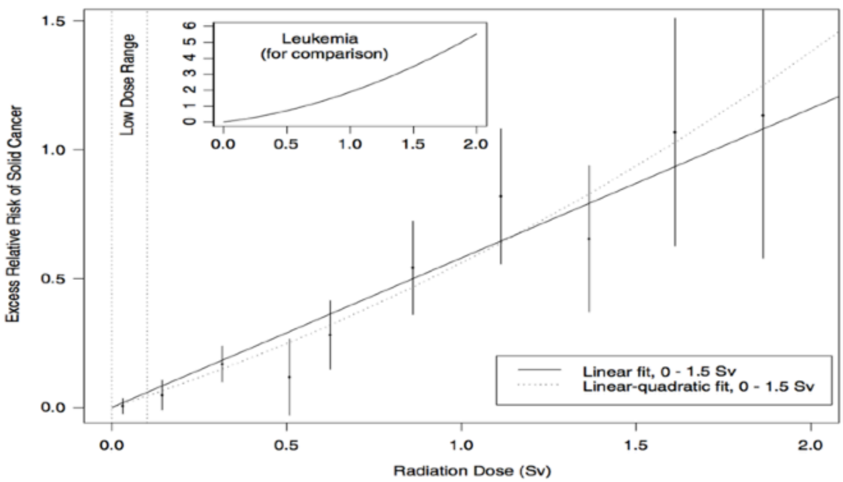


Newspapers often highlight unsubstantiated claims of radiation harm, such as this New York Times fright[4] about CT scans, "a 2009 study from the National Cancer Institute estimates that CT scans conducted in 2007 will cause a projected 29,000 excess cancer cases and 14,500 excess deaths over the lifetime of those exposed." The correct number is likely zero.

Atomic bomb survivors

After the 1945 atomic bombing of Hiroshima and Nagasaki, people and nations became concerned about the destruction of possible world-wide nuclear war. In 1950 began a studies of the health of the atom bomb survivors. The work was undertaken to make people more aware of the possible long term effects of radiation on genetics, and to increase fear of nuclear warfare. The Radiation Effects Research Foundation (RERF) maintains the data and publishes papers that explore linkages between cancer and radiation exposure. Radiation doses, by individual, were estimated after asking people where they were at the time of the bomb explosions, five years before.

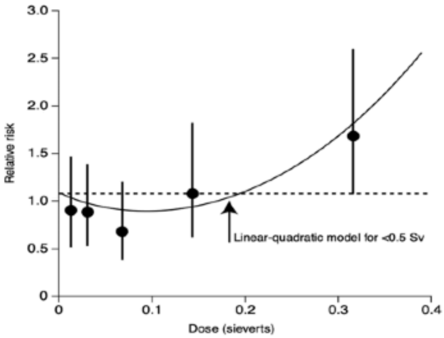
The US National Academies used REFR data to claim that the risk of solid cancer is directly proportional to absorbed radiation dose. They promote the LNT (linear no threshold) model of health effects of radiation, which maintains the chance of cancer is directly proportionate to radiation exposure, and thus there is no safe dose of radiation. They published[5] this following chart of cancer risk for bomb survivors.



Excess cancer risk for people irradiated by the atomic bomb

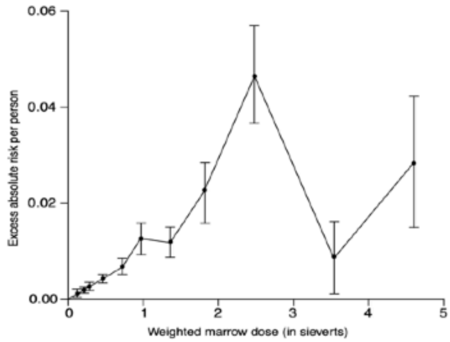
However, the data point in the low dose range of exposures less than 0.1 Sv does not show evidence that such low doses case cancer. Few in the radiation science community endorse this LNT model of low dose radiation effects, but LNT remains the official policy of the US EPA, NRC, and many other organizations in the radiation protection industry.

FIGURE 1a
Mortality from Leukemia in Hiroshima and Nagasaki—Data as Presented by UNSCEAR



Source: UNSCEAR 1994, p. 257.

FIGURE 1b
Mortality from Leukemia in Hiroshima and Nagasaki—NCRP Version of the Same Data

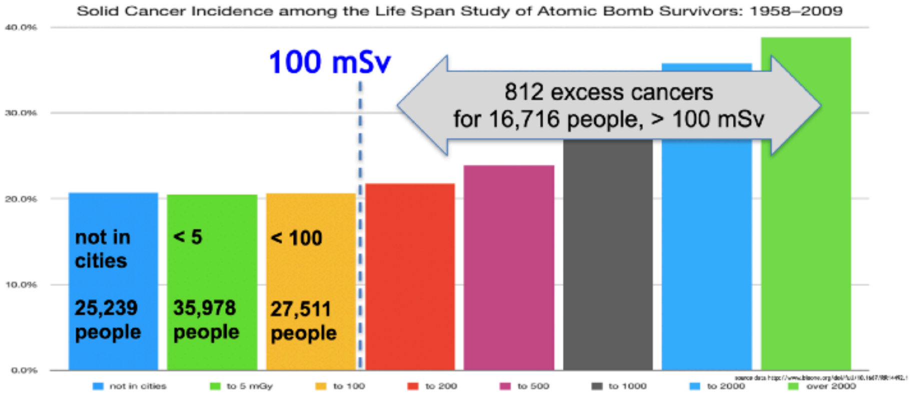


Source: NCRP Report No. 136, p. 146.

National Council on Radiation Protection hides data refuting LNT.

A 2001 article[6] by Jaworowski and Waligorski illustrated how many scientists were misinforming governments with information tailored to continue the simplistic LNT model. They misled people into fearing that even low level radiation was potentially deadly. The right side of their graphic shows the NCRP's (National Council on Radiation Protection) seemingly linear relationship between leukemia mortality and radiation exposure for survivors of the atomic bombing, evidencing their support for LNT.

The left hand side shows the UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) with much more detailed information about the effects of low dose radiation. There is clearly no evidence of increased leukemia mortality from radiation doses under 0.1 Sv (100 mSv). Clearly the LNT model is wrong.



A-bomb survivors' exposures < 0.1 Sv caused no excess cancers.

The chart above uses bomb survivor cancer data to display that cancer rate increases from radiation, if any, are unobservable at doses < 0 .1 Sv. The leftmost, blue bar represents residents who happened not to be in the cities when the two atomic bombs exploded.

Regulators' rules

Regulators' rules generally mimic the recommendations[7] of the International Commission on Radiation Protection (ICRP), which recommends public exposures be < 0.001 Sv per year.

Radiation workers are permitted < 0.05 Sv/year, if limited to < 0.1 Sv per 5 year period. This reveals mistaken beliefs that some radiation damage persists for 5 years.

Thousands of peer-reviewed publications disprove the LNT theory that harm is proportionate to radiation, even at low exposures. To explore the science of the LNT controversy I recommend reading Thormod Henriksen *Radiation and Health*[8] and William Sacks et al (2016) *Epidemiology Without Biology*[9], available at no charge.

Authoritarian science

Although science and logic say a single counter example invalidates a theory, most regulators simply ignore published disproofs because LNT is established public policy, "written in stone" says one bureaucrat.

The French Academy of Sciences reached a different conclusion[10] from the National Academies, the NRC, and EPA.

> "Epidemiological studies have been carried out to determine the possible carcinogenic risk of doses lower than 0.1 Sv, and they have not been able to detect statistically significant risks even on large cohorts or populations."

The US NRC dismisses[11] France's conclusion which conflicts with US established policy:

> "The French Academy of Sciences report focuses on the radiobiological science and does not try to interpret these results in a policy context."

In the US, policy trumps science. One result of France's science-based policy is that France gets ~ 80% of its electricity from nuclear power and is the largest electric power exporter in Europe. France is planning to build as many as 14 nuclear power plants by 2050.[12]

US bases nuclear regulation on policy, France on detectable cancer incidence.

Groupthink

Groupthink "occurs within a group of people in which the desire for harmony or conformity in the group results in an irrational or dysfunctional decision-making outcome. Cohesiveness, or the desire for cohesiveness, in a group may produce a tendency among its members to agree at all costs. This causes the group to minimize conflict and reach a consensus decision without critical evaluation."[13]

Groupthink has suppressed critical thinking at NGOs including ICRP, UNSCEAR, IAEA, US National Academies, and NCRP. US agencies EPA, NRC, Canada's CNSC, and many countries' regulators also put imagined safety of LNT and the precautionary principle above scientific observation and cost-benefit analyses.

Scientists not engaging in LNT groupthink include members[14] of Scientists for Accurate Radiation Information. Their articles provide evidence disputing LNT, but are are ignored by the 'group'.

University of Massachusetts Amherst Professor Edward Calabrese[15], an expert on toxicology, has spent decades of his career writing hundreds of scientific articles uncovering the sordid history of the creation and propagation of the LNT model of radiation harm. He documents errors, ethical lapses, and downright fraud as scientists competed for more grant money and a Nobel prize. Calabrese recently published a review of the scientific errors and unethical behavior justifying LNT[16].

John Cardarelli was head of the Health Physics Society[17], *specialists in radiation protection*. He produced a series of video interviews[18] with Calabrese, detailing errors and fabrications[19]. These caught the attention of Steve Milloy, who posted on his website, junkscience.com[20],

> *Emails Reveal: Bureaucrats censor radiation risk science fraud…* "emails uncovered via the Freedom of Information Act that expose the inner workings of a little-known bureaucracy dedicated to keeping in place the so-called "linear non-threshold model" (LNT). The LNT is used by regulatory agencies to set permitted exposure standards for radiation."

The 'group' then undertook to formally censure HPS President Cardarelli for producing the Calabrese videos and for writing to US Senators on HPS letterhead.

ALARA (as low as reasonable achievable)

Even radiation limits less than 0.001 Sv/year do not satisfy regulators. If all radiation exposures are potentially harmful, then ALARA is a corollary. Their ALARA[21] (as low as reasonably achievable) rule magnifies radiation fear by claiming that even lower exposures may cause cancers, though not statistically observable. The "reasonably achievable" qualification is vague. No engineer can design to it. The regulators' pronouncements are unchallengeable.

ALARA creates an unpredictable cost for nuclear power plants. Suppose the reactor has 5 inches of lead shielding so no one is exposed to radiation exceeding 0.001 Sv/year. Would it be "reasonable" to add another inch of lead shielding? Yes, especially if frightened residents swarm the regulator's local discussion meeting. Yes, even if the added cost makes the plant unprofitable and the power project is scuttled. The ALARA rule can be applied repeatedly. Add yet another inch of lead?

In this way the cost of nuclear power has been ratcheted up to meet (rather than undercut) the electricity market price, with many power plant projects dropping out of competition. New nuclear power plants can deliver electricity at 3 cents/kWh, but not with ALARA raising the price to be barely competitive.

Here's an ALARA example by Ted Rockwell, who was technical director of Hyman Rickover's project to create the first nuclear power plant, inside a submarine[22].

> "A forklift at the Idaho National Engineering Laboratory moved a small spent fuel cask from the storage pool to the hot cell. The cask had not been properly drained and some pool water was dribbled onto the blacktop along the way. Despite the fact that some characters had taken a midnight swim in such a pool in the days when I used to visit there and were none the worse for it, storage pool water is defined as a hazardous contaminant. It was deemed necessary therefore to dig up the entire path of the forklift, creating a trench two feet wide by a half mile long that was dubbed Toomer's Creek, after the unfortunate worker whose job it was to ensure that the cask was fully drained.
>
> "The Bannock Paving Company was hired to repave the entire road. Bannock used slag from the local phosphate plants as aggregate in the blacktop, which had proved to be highly satisfactory in many of the roads in the Pocatello, Idaho area. After the job was complete, it was learned that the aggregate was naturally high in thorium, and was more radioactive that the material that had been dug up, marked with the dreaded radiation symbol, and hauled away for expensive, long-term burial."

Collective person-dose

Regulators such as NRC compound their mistakes with the person-dose concept. Regulators' LNT model predicts a worker legally exposed to 0.050 Sv would have a 0.5% excess chance of cancer. Thus by LNT proportionality 1,000 so-exposed workers would have 5 excess cancers. The NRC counts up the number of such fictitious cancers by power plant and ranks power plants in order by person-doses, forcing competition among low-ranked power plant operators to reduce trivial doses, thus raising nuclear power costs.

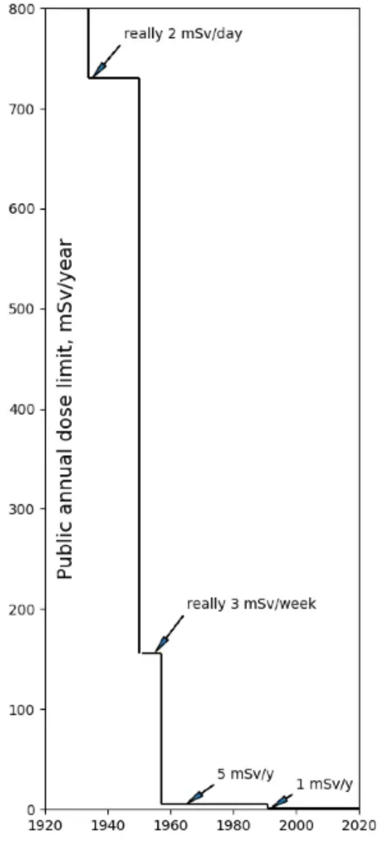
My parody: Always wear sunscreen when viewing a full moon, because it might cause skin cancer, even though the incidence rate is too low to observe. Full sunlight of 98,000 lux can cause cancerous sunburn in 15 minutes, so moonlight at 0.1 lux might cause cancer 1 in every 980,000 quarter-hour person-exposures, or once every 28 moonlight-years. Perhaps 32 million people watched the March 2024 eclipse of the full moon, leading to 32 excess skin cancers.

After snickering, realize that EPA policy is that all potential carcinogens risks follow the LNT, linear no threshold, model.

Regulatory creep

Quoting Jack Devanney, “Through 1951, the International Commission on Radiological Protection (ICRP) dose rate limit for the general public was 0.002 Sv per **day.** However, in 1951, the ICRP changed the recommended limit to 0.003 Sv per **week**, based on claims of genetic mutations at low doses.

The mutation claims turned out to be without foundation[23] so nuclear power opponents refocused on cancer. In 1957, the American counterpart of the ICRP, the National Council for Radiation Protection (NCRP), added a limit of 0.05 Sv per **year** for nuclear workers and 0.005 Sv per year for the public.”



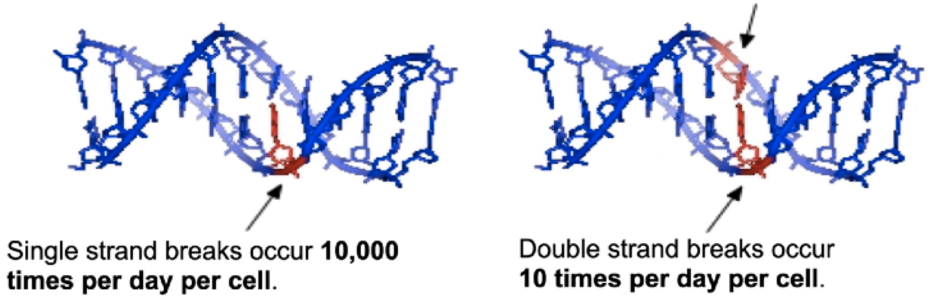
Regulators’ evidence-free reductions in radiation safety limits[24]

Regulators' changes to exposure limits were based on consensus with NGOs (groupthink), iterative application of the precautionary principle, not harm observations.

Radiation ignorance creates fear

U.S. regulations now limit public radiation exposure from nuclear power to 0.001 Sv accumulated over a whole year. The limit is 100x smaller than a brief, intensive 0.1 Sv dose that might[25] cause statistically observable future cancers, and 1000x smaller than one possibly requiring medical[26] attention. This excessive safety margin in both time and in absorbed energy was created by continually reducing limits in an attempt to reassure frightened people. Instead, most people now view 0.001 Sv as dangerous.

DNA Dynamics



DNA strand breaks occur frequently, from metabolism.

Within cells, DNA strands break frequently, caused by ionizing oxygen molecules created from natural metabolism. The human body has about 30 trillion cells. A radiation dose rate of 0.1 Sv per year creates an additional 12 single strand DNA breaks per cell per day, but these are quickly repaired because the opposite DNA half strand is a mirror image. Single strand DNA breaks do not harm health.

Such a 0.1 Sv/year dose would create about 1 double strand DNA break per year per cell, and these are generally repaired. Unrepaired cells generally die by suicide (apoptosis) or stop reproducing (senescence). Double strand breaks create the possibility that DNA may be misrepaired in a way that permits a mutated cell to reproduce and lead to clinical cancer years later. Two double strand breaks close together in a DNA strand create higher chances of reconnection errors and future cancer.

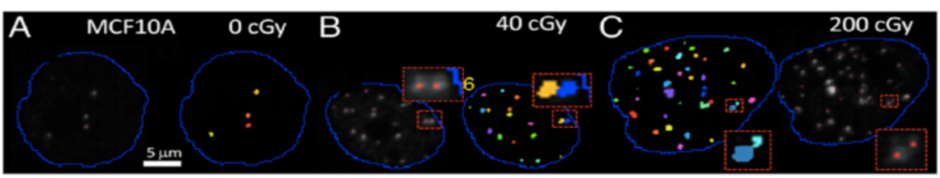
2015 Nobel Prize in chemistry awardees

The science of how DNA repair happens was unravelled by three scientists who were awarded the Nobel Prize[27] in chemistry in 2015.

- Paul Modrich: how cells correct errors that occur when DNA is replicated during cell division.
- Tomas Lindahl: excision repair — the cellular mechanism that repairs damaged DNA during the cell cycle.
- Ariz Sancar: mapping the mechanism cells use to repair ultraviolet damage to DNA.

The Nobel Prize confirms that radiation-damaged cells do repair themselves. The regulators' 0.001 Sv public limit erroneously counts all radiation absorbed over an entire year, as if the harm were cumulative, without any biological repair during the year.

DNA repair[28] begins in seconds to minutes after exposure, and cellular repair within hours.



Clusters of DNA double-strand-break sensing and repair proteins

Scientists at UC Berkeley recorded time-lapse images of DNA double strand breaks causing clusters of repairing proteins to form and act in time scales of minutes to hours. The number of repair centers was proportional to absorbed radiation at doses in the low dose range 0.01 to 1 Sv, but less than proportional at doses higher than 2 Sv.

Thus repairability decreases at higher doses that overwhelm the ability of the cell to create repair centers that correct DNA errors. Thus repairability is enhanced at low doses. Thus harm is not linear, and LNT is wrong.

Radiation rate accidents

Through mistakes and accidents, people have occasionally been subjected to high levels of ionizing radiation. Jack Devanney coalesced data from multiple sources in the table below. The green rows indicate events where no harm came to the subject. Inspecting the column *Dose rate mSv/day* reveals no harm to people undergoing radiation dose rates of 0.02 Sv per day. Allowing a 10:1 safety factor suggests a radiation tolerance limit of 0.002 Sv per day (about 0.000080 Sv per hour) would be a rational protection regulation.

Group	Size	Period	Cumulative dose mSv	Dose rate mSv/day	Result
Atom bomb survivors					
Leuk 5-150[22]	33,459	seconds	5 to 150	5 to 150	Insignificant decrease in leukemia
Leuk 150-300[22]	5,463	seconds	150 to 300	150 - 300	Insignificant increase in leukemia.
Leuk 300+[22]	6,793	seconds	300-5000+	300-5000+	Significant increase in leukemia.
Solid 5-20[4]	14,555	seconds	5 to 20	5 to 20	Insignificant decrease in solid cancers.
Solid 20-40[4]	6,411	seconds	20 to 40	20 to 40	Solid cancers same as control
Solid 40-125[4]	10,970	seconds	40 to 125	40 to 125	Insignificant increase in solid cancers.
Solid 125+[4]	16,166	seconds	125+	125+	Significant increase in solid cancers.
Louis Slotin[13]	1	seconds	21000	21000	Died in 9 days
H. Daghlian[13]	1	seconds	5900	5900	Died in 25 days
Norway tech[7]	1	< hour	38500	38500	Died in 13 days
Tokaimura[13]	3	seconds	3000-17000	3000-17000	>10,000 mSv died
Goiania[?]	≈46	hrs or less	1000-6000	1000-6000	50% mortality abv 4000 mSv
Thai scrap[?]	≈10	hrs or less	1000-6000	1000-6000	100% mortality abv 6000 mSv
Chern firemen+[23]	134	<2 hrs	1000-16000	1000-16000	Sigmoid mortality, 50% mortality at 6000 mSv.
Chernobyl liquidators[9]	220,000	2 min to 90 days	1-1500	nil to 1500 most < 2	Low/high dose rate mushed together. 6% increase in cancer. Decrease in mortality.
Litvinenko[?]	1	3 weeks	96,000	4,000	Died in 23 days
Belarus kids[27]	13,127	2-3 weeks	ave 780 max 48k	39-2400	45 thyroid cancer, eventual 50? deaths
Ukraine kids[21]	11,611	2-3 weeks	ave 560 max 33k	28-1600	87 thyroid cancer, eventual 50? deaths
Eben Byers[12]	1	2 years	366,000	300	Horrible bone cancer. Died in 3 years.
Evans radium hi[5]	127	10 years	>80000	80+	Cancers. Hi mortality >200 mSv/d
Dial painters hi[20]	273	up to 15 yrs	190000-440000	35 to 80+	96 bone cancers
Evans radium mid[5]	17	10 years	20000-80000	20 to 80	Abnormalities. Nil clinical symptoms.
Dial painters lo[20]	2,110	up to 15 yrs	200 - 160000	up to 30	Zero bone cancers.
Evans radium lo[5]	59	10 years	up to 20000	max 20	Nil abnormalities.
Albert Stevens[18]	1	20 years	61,000	8	Died at age 79 of heart failure.
UPPU Club[25]	26	≈10y	up to 7200	0.03-2	Lower mortality than coworkers.
Taipei Apt hi[?, 8]	1,100	18 years	up to 4000	up to 3	Decrease in cancer, maybe non-rad.
Taipei Apt mid[?, 8]	900	18 years	ave 420	up to .160	Decrease in cancer, maybe non-rad.
Taipei Apt low[?, 8]	8,000	18 years	ave 120	up to .050	Decrease in cancer, maybe non-rad.
Keralans[14]	69,956	10-15 yrs	50-650	.016 to .160	Insignificant decrease in cancer
NRX Clean Up[?]	≈1000	90s jumps	up to 200	up to 150	Insignificant decrease in cancer

Observed health effects of accidental radiation exposures[29]

Jack Devanney's substack has[30] many short articles on aspects of nuclear power. More detail is at his book site, *Why Nuclear Power Has Been A Flop*[31].

Radiation therapy for cancer

Radiation oncologists kill cancer cells using intense beams of X-rays focused on the cancer. These X-ray beams must also pass through healthy skin and tissues, so the X-ray source is rotated about to come from various directions, minimizing damage to healthy tissue while converging on the cancer.

Rather than administering the full, cancer-killing radiation dose at once, the dose is given in smaller fractions of 2 to 20 Sv, at intervals of 1 to 2 days, to lessen damage to normal cells. Their DNA repairs more quickly than that of cancer cells. There is a small risk that cancer develops in the healthy, irradiated tissue.[32]

Fractionated cancer radiation therapy disproves LNT millions of times per year.

Rotating X-ray beam focused on cancer delivers up to 80 Sv.

We must distinguish damage and biological harm. Radiation damages cells. Life’s biology repairs damage. Unrepaired damage can lead to clinical harm, such as cancer. Sunlight reddens skin and biology seeks to repair it. Unrepaired cells may lead to skin cancer.

Radiation damage is proportional to radiation. Life’s biology repairs most damage in hours to days. Misrepaired damage can lead to bodily harm when high radiation causes repair centers to be overwhelmed. We don’t observe harm below intensive radiation doses of 0.1 Sv nor dose rates below 0.020 Sv per day.

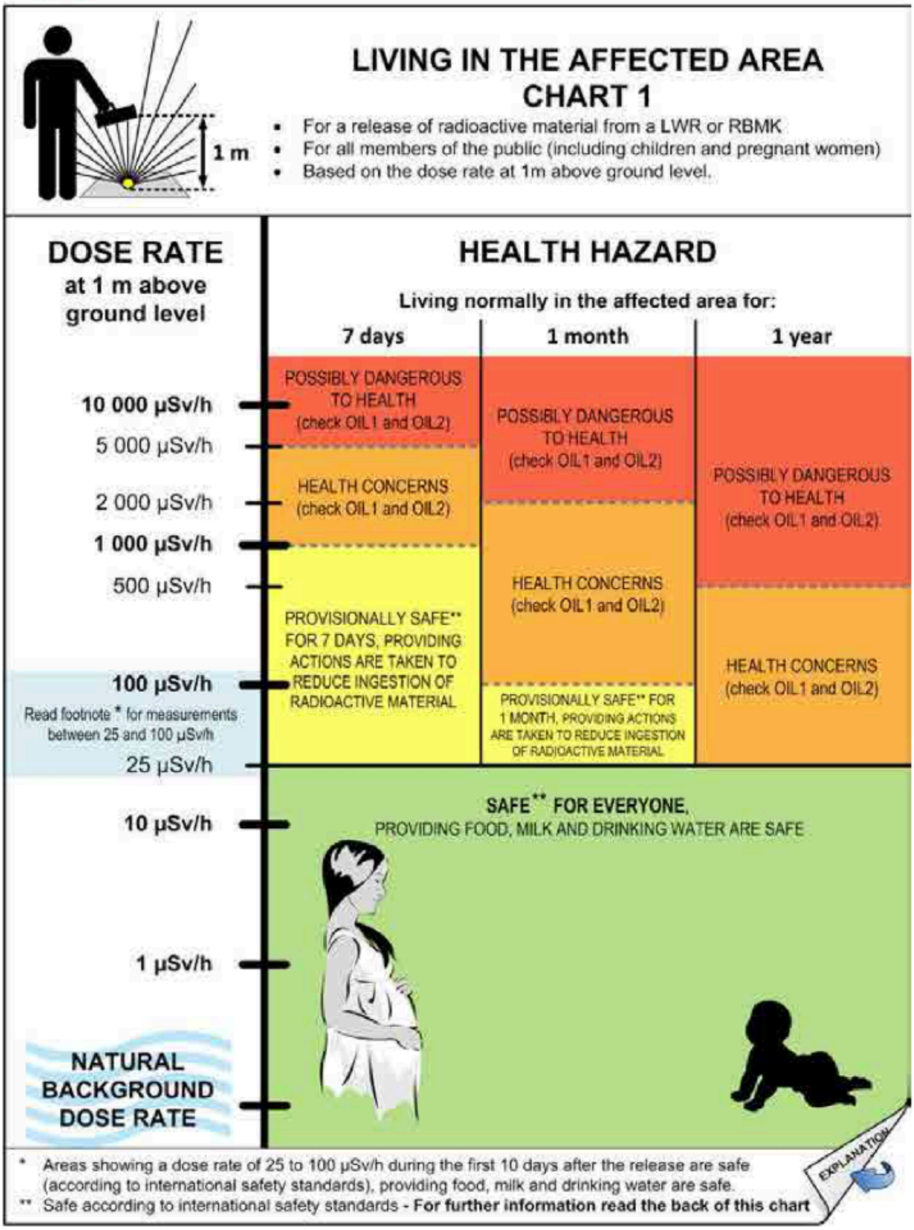
Nuclear power accident guidance

Regulators sit in offices debating how to protect the public against unobservable health harm from low levels of radiation. In a real, radiation-releasing event the onsite first responders have to act promptly to protect people.

Radiation from the triple Fukushima nuclear reactor meltdown killed no citizens, but Japan's government's ignorant actions killed[33] over 1,600 people with unnecessary evacuations.

To prevent such future mistakes, International Atomic Energy Agency (IAEA) published[34] *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor* to protect the public from real radiation harm rather than creating harm with actions based on regulators' limits.

This following chart of IAEA advice is directed to onsite accident responders working to protect people's lives and health, not to enforce radiation limits promulgated by political regulators.



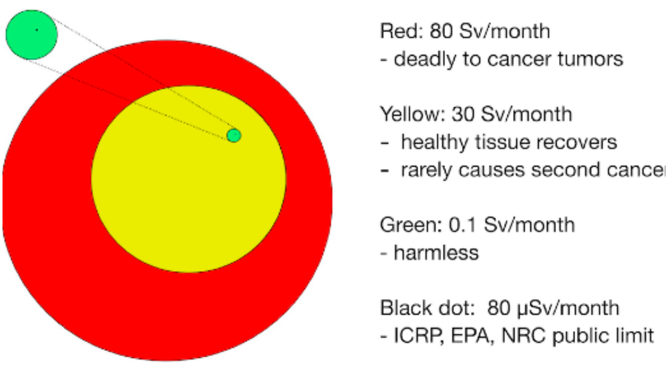
Hazard from living in an affected area following a radiation release

"Chart 1" above helps guide the accident response team and the public. IAEA's green SAFE FOR EVERYONE, year-long, dose rate is 25 µSv/h (0.000025 Sv per hour). Such a radiation exposure dose rate over a whole year totals to 0.2 Sv, which is 200x the regulators' limit of 0.001 Sv/year, yet is safe.

Chart 1 deems **25 µSv/h** "safe" because the body repairs damage much more rapidly than that level of radiation damages it.

Jack Devanney's article[35] tabulates observed harms and radiation doses to actual people in several studies. He observes that dose rates under 0.02 Sv/day did not exhibit statistically significant, detectable harm. The body's intrinsic repair rate exceeds the radiation damage rate. A 10:1 safety margin suggests 0.002 Sv/day radiation safety limit. That is **80 µSv/h** (0.000080 Sv per hour), about three times the IAEA SAFE FOR EVERYONE rate of 25 µSv/h.

In 1934, the NCRP (National Commission on Radiation Protection) also advised[36] limiting radiation exposure **80 µSv/h** (0.2 R/day, in old units). Nearly 50 years later, NCRP founder Lauriston Taylor wrote[37], "No one has been identifiably injured by radiation while working within the first numerical standards set by the NCRP and then the ICRP in 1934."



What level of radiation is safe? 0.1 Sv/month: Allison.

Wade Allison's book[38] notes that intensive radiation doses of 0.1 Sv have a 100% safety record. He allows for a month-long repair period to arrive at a dose rate safety limit of 0.1 Sv per month, or about **140 µSv/h** levelized to hours. A rate of 140 µSv/h is actually more protective than 0.1 Sv/month, which allows for the full 0.1 Sv dose to be absorbed all at once.

Regulators overstate radiation harm by orders of magnitude in two ways.

- **100x error of transcendency of policy over scientific observation:** 0.001 Sv per year regulatory limit vs intensive 0.1 Sv observed cancer threshold.
- **52x error of ignoring biological repair time:** year-long biological damage assumption vs conservative typical healing time.

Radiation dose rate limits

Regulators should abandon cumulative, yearlong dose limits, and instead set dose rate limits consistent with biological repair times. Certainly the ALARA rule should be dropped. Below are justifiable limits to ongoing radiation exposure rates:

- 25 μSv/h (0.000025 Sv per hour) from IAEA's Chart 1
- 80 μSv/h implied by Devanney's article 2 mSv per day analysis
- 130 μSv/h, Allison's 0.1 Sv/month observation, levelized to hours
- 80 μSv/h, 0.1 R/day 1934 advice by NCRP, levelized to hours

Radiation rates are expressed in hours, because much DNA repair takes place in an hour or so, and because most radiation meters display dose rates in μSv/h. I recommend a tolerance limit of **80 μSv/h** (0.000080 Sv per hour), a tenth of highest radiation dose rate observed to create no harm.

Japan mistakenly ordered evacuations near Fukushima where exposures were exceeded 2 μSv/h. The US EPA also recommends relocation at 2 μSv/h. Yet the IAEA Chart 1 says 25 μSv/h is safe for a year.

Radiation rates after historic accidents

Around **Three Mile Island** reactor accident the cumulative dose averaged only 0.00015 Sv, so there was no need to evacuate anyone. Nevertheless the accident was a factor in ending nuclear power plants construction in the U.S.

The **Chernobyl** accident was deadly; 30 onsite workers with intensive doses over 2 Sv died. Cleanup workers exposed up to 0.3 Sv or more had slightly higher rates of cancer. Radioactive iodine dispersed into the food chain may have caused over 1,400 thyroid cancers[39], leading to the deaths of 15 children. No other increases in public cancer rates were observed. Perhaps 200,000 people were evacuated. Radiation rates in the Chernobyl zone[40] are now under 0.000010 Sv per hour, not harmful to the 1,000 stubborn babushkas and others who still live there.

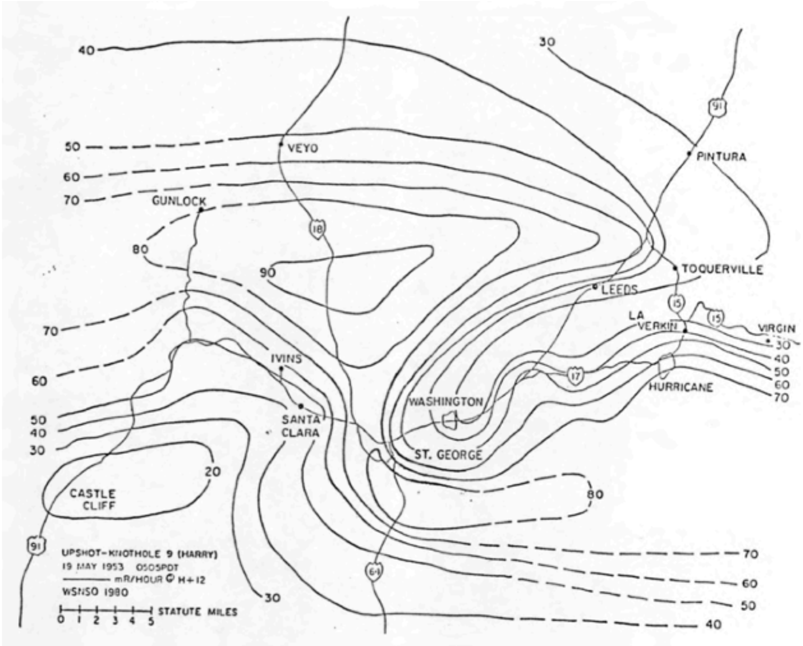
The children's thyroid cancers could have been avoided by warning people not to consume milk and vegetables produced in areas contaminated by radioactive fallout for three months, until the radioactive iodine-131 became harmless because of its 8 day decay half-life.

Within the stricken **Fukushima** power plants site, radiation peaked[41] at 0.1 Sv per hour, dropping 90% in 10 hours. Outside the plant IAEA reported[42] peak measured radiation of 0.000170 Sv per hour from a plume 30 km northwest of the site. Even that is below the 0.020 Sv per day shown as harmless in Devanney's table of accidental radiation rates.

By the next month radiation dropped to less than 91 µSv/h[43] everywhere, provisionally safe by IAEA Chart 1 except in possible hot spots. There was no need to evacuate 164,000 people[44], which led to the deaths[45] of over 1,600, and there was certainly no need to do it hastily. Radiation killed no one. Fear killed 1,600. 15,000 people died from the earthquake and tsunami.

The Dirty Harry atomic bomb test in 1953 dropped two to three times as much radioactive fallout on the residents of **St. George, Utah**, than people near Fukushima were exposed to. There was no evacuation. People were asked to stay indoors that day.

On the map below the "50" contour line passing through St. George indicates a radiation rate of 500 µSv/h (0.0005 Sv per hour). That is below maximum dose rates observed to be harmless, 0.020 Sv per day (800 µSv/h). The maximum rate in the area was 0.0035 Sv per hour (3,500 µSv/h) on May 19, dropping to 50 µSv/h 5 days later. There was no increase in cancer rates.[46]



St George, Utah: detailed fallout pattern[47]; 50 mR/h = 500 μSv/h

In a radiation releasing accident at a nuclear power plant, radiation rates also fall quickly as short-lived isotopes decay and radiation levels drop.

It's **dose rate, not cumulative dose, that matters**. Harm results when dose rate exceeds damage repair rate.

Nearly **all radiation regulations are unscientific** because they ignore damage repair. Regulators' radiation limits are expressed as year-cumulative dose, as if repair took a full year. Doses to radiation workers are limited to 0.050 Sv per year and 0.1 Sv per 5 year period, as if some repair took 5 years. There is no evidence for such long periods.

Instead, regulators' mistaken understandings actually causes harm by impeding expansion of 24x7, CO2-free, affordable, reliable nuclear power. Regulators also raise energy costs, diminishing prosperity, which leads to better health and longevity. WHO estimates that particulate emissions from burning fossil fuels for energy cause 7 million deaths per year.

Regulation reform

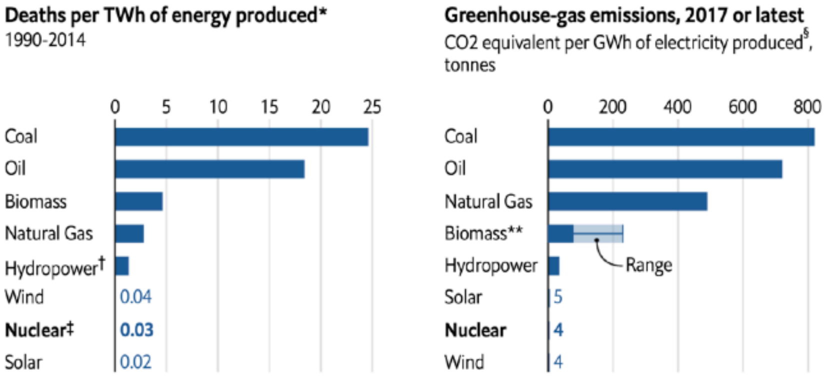
With the completion of the two Georgia AP1000 power reactors, there are no commercial nuclear power plants being built in the US, though 61 are under construction[48] in other countries, where 115 more are planned. US natural gas generated electricity is cheap. In the US ALARA and the NRC have ratcheted up the cost of nuclear power to make its electricity too expensive to compete with natural gas.

Congress did pass new laws to try to reform NRC, such as the 2019 Nuclear Energy Innovation and Modernization Act[49], ineffectually directing “the NRC to develop new processes for licensing nuclear reactors, including staged licensing of advanced nuclear reactors.” This only caused NRC to draft more complex regulations. The Advance Act of 2024 changes the mission statement of the NRC to "not unnecessarily limit" nuclear power, but balancing costs and benefits was resisted by the NRC. There is no change in radiation limits, LNT, nor ALARA.

The solution is to eliminate the NRC and treat nuclear power plants the same way other power plants are regulated. The plant operator is responsible for any damage caused by the plant. The operator buys insurance. To gauge risk and set rates, the insurance company hires experts like Underwriters Laboratory to assess the design, operation, and management of the power plant. The operator pays insurance premiums. After a radiation accident people sue for compensation, insurance companies resist paying, and the courts adjudicate.

For example, the Middletown, Connecticut, Kleen Energy natural gas plant blew up in 2010. It killed six people when workers tried to clean debris from pipes by whooshing 2,000 cubic meters of flammable natural gas through them out into the open air. The liability for compensation is churning through the courts[50], with awards measured in tens of millions of dollars. Accidents happen. Safety procedures will improve. Natural gas power plants are still being built.

With insurance underwriting reform each power plant can insure itself, with no need for the Price Anderson Act[51], which extends liability for one plant’s radiation accident to all other US nuclear power plants.



Nuclear power is safe. Economist July 19, 2022[52]

There is nothing particularly dangerous about nuclear power plants compared to natural hydroelectric power dams or natural gas power plants. Historically, world-wide, nuclear power is among the safest electricity sources.

However, the LNT model of possible health harm from radiation enables lawyers to claim that all persons experiencing increased radiation exposure are due compensation. This is compounded by decades of fear, misinformation, and likely sympathetic juries who believe all radiation is dangerous.

The case against Roundup (glyphosate) weed killer illustrates the fallacious tort process under today's US legal system[53]. In many courts the *Frye* standard for evidence allows consensus of scientists to admit experts to opine about a causal connection between product and cancer. The modern *Daubert*[54] standard allows expert testimony based on scientifically valid reasoning, properly applied to the facts at issue.

However in the Roundup case, even though the plaintiffs were not able to prove specific causation, eliminating other possible cancer causes, they did succeed in proving a failure to warn. The award against Roundup's owner is over $2 billion, with 40,000 more cases to go.

The aforementioned 'groupthink' alliances will make it easy for lawyers to assemble a pro-LNT panel of experts.

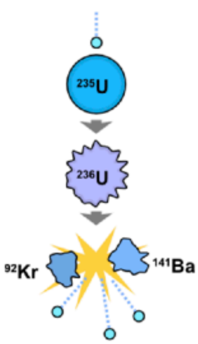
Many Utah and Nevada residents complained of cancer from the thousand-plus atomic bomb detonations conducted in the desert. To end the controversy Congress passed the *Radiation Exposure Compensation Act*[55], awarding $50,000 to those downwind of the Nevada test site, without evidence of caused harm. These sorts of awards, meant to be soothing, are mistakenly seen by the public as confirming evidence that low dose radiation causes harm.

To reap the benefits of *new nuclear* power the US must pass reforms that deny liability and compensation for radiation exposures below 0.000080 Sv per hour (80 µS/h), a level a tenth that below which ongoing radiation harm might possibly be observed.

What about the waste?

“What about the waste” I’m frequently asked. Fortunately it’s a beautifully small problem, because the amount of used uranium fuel is so small. Why? The energy in uranium fuel is a million times denser than fossil fuel energy. However used fuel dangerously radioactive, at first! Let’s review what happens when uranium-235 fissions.

Uranium-235 is split into fission products, releasing energy.



Fission example

The total mass of the resulting

barium-141 <— fission product
krypton-92 <— fission product
neutrons (3)

is a bit less than the mass of the U-235 + neutron.

By Einstein’s famous $e = mc^2$

releases 166 MeV of energy, then 34 MeV more by decay of Kr and Ba fission products.

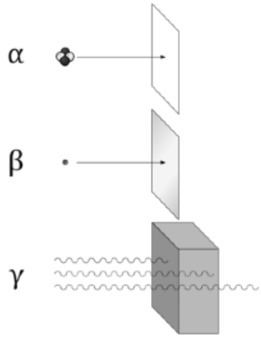
1 tonne U-235 fissioned -> 79,000 TJ heat,
= 2.6 GW-years heat, to make 1 GW-year electricity

Radioactive fission products stabilize hours to years later.

Danger to people comes from the temporarily radioactive, energetic fission products. Uranium, plutonium, and other heavy metals are much less hazardous because they are long lived and thus less radioactive.

Water absorbs decay radiation

Emanating from used fuel are alpha, beta, and gamma particles, distinguished by their ability to penetrate matter. The gammas are penetrating.



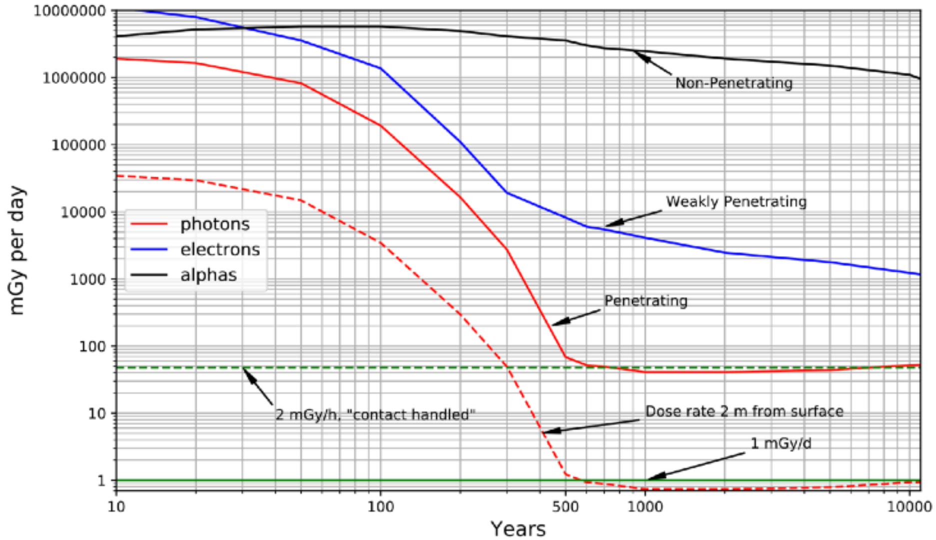
Energetic, heavy alpha particles (He nuclei) from U, Np, Pu.. decay do not penetrate epidermis.

Beta particles, electrons ejected as neutron-rich isotopes become stable, do not penetrate metal foil. Beta decay can also emits gammas.

Gamma radiation, photons from nuclei energy level changes, are absorbed by dense material such as bone to make X-ray images.

The fission products decay according to their various half-lives, creating both weak beta and penetrating gamma radiation. Alpha particles come from leftover uranium and plutonium decays. This chart below shows how each decay. The dashed line shows the dose rate from all 2 meters from unshielded used fuel. Air absorbs both alphas and betas. Radiation dose units are mGy/year, which are the same as mSv/year for gammas.

At 600 years after the end of year 1, 99.999% of all the photon emitters are gone, and the unshielded dose rate dropped to 40 μSv/h, half my recommended safety limit of 80 μSv/h.



99.999% of penetrating photons are gone in 600 years.[56]

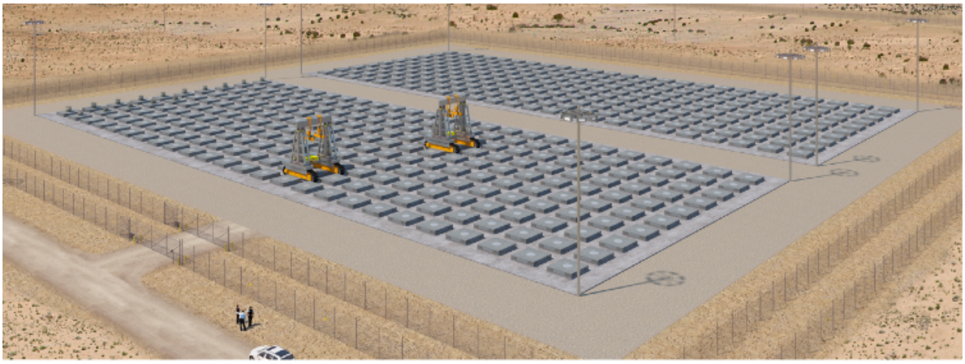
The used fuel is typically kept under water for years, then moved by machines into metal cans in concrete casks that intercept radiation.

Used fuel casks intercept the harmful radiation.[57]

After 600 years you'd have to eat used fuel to harm yourself.

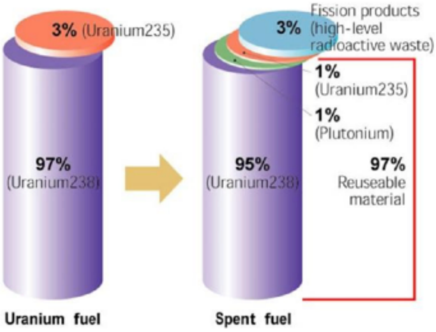
Published claims that radioactive fuel is dangerous for tens of thousands of years are **deceptive**, based on **ingestion**. Yes, alphas and betas decaying inside you on intestines' or lungs' surfaces can ionize molecules in living cells and perhaps cause cancer. You wouldn't eat arsenic, either. After 600 years used fuel is just another poison.[58]

Today nuclear power plants maintain above ground casks to store used fuel at the plant site. Cask storage is an inexpensive and simple way to solve the “waste” problem. Casks will not last 600 years, so the radioactive materials will have to be repackaged, perhaps every 100 years. By then radioactivity and decay heat will be substantially lessened, so fewer casks will be needed at each repackaging event.



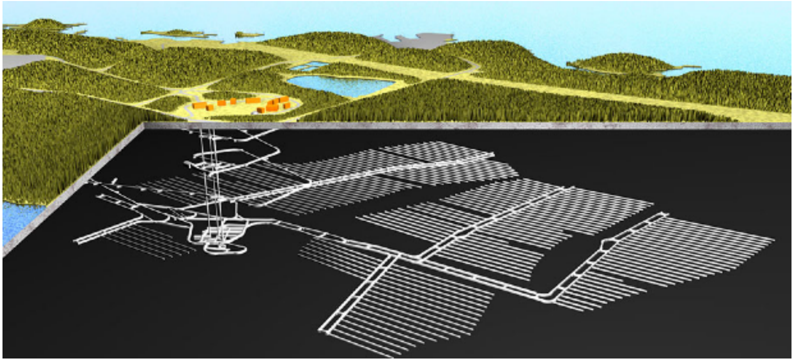
Holtec HI-STORE Consolidated Interim Storage Facility[59]

Holtec has already designed an NRC-licensed used fuel storage facility. Used fuel is stored in stainless steel cylinders lowered into a field of surface level concrete sockets with concrete caps. The image below shows machinery to insert and remove the containment cylinders. The facility could include equipment for repackaging aged used fuel. The cost of perpetual storage should be about $0.50/MWh. The US government has been taxing electric power at $1/MWh to establish a disposal fund.



97% of used fuel can be reused in new reactors.

Centuries old used fuel radioactivity has reduced sufficiently that it can be readily handled and fabricated into new fuels for new nuclear reactors that use uranium-238 and plutonium fuel.



Deep geologic used fuel repository at Onkalo, Finland[60]

Deep underground storage is a politically popular, very expensive, counterproductive way to set aside relatively benign used fuel, counterproductive because deep storage reinforces the perception that the waste is hazardous for millennia. It is if you eat it, but no more than lead, arsenic, and other mined heavy metals.

The US wasted $9 billion to build the now-abandoned Yucca Mountain site. The radiation exposure limits for 10,000 years were 0.02 μSv/h, an order of magnitude below natural background rates, one 4,000th of my recommended regulatory tolerance limit.

The Onkalo, Finland, repository construction is nearing operation[61] at an estimated cost of $3.4 billion. It's likely to grow; it will cost an order of magnitude more than dry cask storage.

Jim Conca wrote in Forbes[62], "The repository is in 2 billion-year-old igneous Finnish bedrock. About one hundred deposition tunnels will be excavated during the 100-year operational period. The repository will total a length of about 35 kilometers, with each tunnel being about 4.5 meters high, 3.5 meters wide and 350 meters long, each holding about 30 canisters."

Wasting this much money on deep geological storage simply endorses the public misunderstanding that all radiation is harmful, and that repositories should shield the public from trivial radiation exposure rates of 0.02 μSv/h, when 80 μSv/h is a rational safety limit. LNT, ALARA and regulator groupthink are the culprits.

Nuclear waste is not a problem.

1. There's not much used fuel, a few kilograms per person per lifetime.
2. We need to cool freshly used fuel a few years, under water.
3. It's then cheap to store used fuel in ground-level casks 600 years.
4. We can re-use easily handled, aged fuel later.

Concluding actions

End precautionary principle regulation.

Insist all regulations be based on observed harm effects. This will end the disproven regulation policies, LNT and ALARA.

Avoid groupthink; take responsibility to analyze observed data.

Weigh benefits against costs.

Set radiation tolerance dose rate to 80 μSv/h (0.002 Sv per day), a tenth of rates observed to be harmless to health.

Replace agencies, officials, and staff that apply obsolete policies contrary to evidence.

Regulate nuclear power plants as other power plants are regulated.

Hold the plant operator responsible for harm resulting from public radiation rates exceeding the tolerance dose rate.

Limit liability to observed harm, to enable insurability, just as airlines do.

Replace CO2-emitting power plants with nuclear power plants.

36% of combustion heat is used to make electricity. Evolving to nuclear power will eliminate 36% of CO2 emissions.

Unleash competitive private enterprise to drop reliable electricity costs to 3¢/kWh, cheaper than coal or LNG, obviating energy subsidies, increasing economic productivity.

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