Chapter 2
Nuclear Fables and Facts

Many misconceptions have entered the nuclear folklore in recent decades. Major fables propagated by opponents of nuclear power are summarized here, and countered with facts. These facts are based on studies and data published by professional societies, representing some 250,000 diploma-ed engineers from around the world. Factual statements are backed up by data in later chapters. Some controversial issues were already touched upon briefly in Chapter 1.

2.1 Fable (1): "Nuclear Reactors are Like Nuclear Bombs"

Fact: This half-truth is frequently suggested by newspaper journalists who have little or no background in science and engineering. It is as erroneous and flawed as assuming that nitro-glycerin medicine used by heart-patients is as dangerous as nitroglycerin used in explosives, or that dihydrogen-oxide (water) is a dangerous chemical that kills (drowns) many people and should be banned. The uranium in a reactor is dispersed through a collection of fuel elements through which a coolant passes that absorbs the heat from fissioning uranium and which drives turbogenerators. Nuclear reactors are designed so fissioning rates due to neutron multiplications are balanced and controlled by neutron-absorbing "control rods", yielding steady heat production. In today's reactors, if the core gets too hot, thermal expansion of moderator/coolant reduces neutron multiplication ("negative reactivity"), *and the reactor shuts itself down automatically*. This happens even if control rods are accidentally stuck and not instantly inserted in the core as would normally occur if a pre-set temperature is exceeded. In other words, the reactor *always* shuts down if it gets too hot. In a worst-case accident scenario,

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when the emergency-core-cooling system also fails, the afterheat from decaying radioactive fission products can melt the fuel elements in a reactor core, but an explosion is physically impossible. Some vapors could develop but they will be contained and adsorbed.

The design of a nuclear fission *weapon* is entirely different. It comprises two halves, four quarters, or some other configuration, each with highly enriched nearly critical fissionable uranium or plutonium. When slammed together for instance by springs or chemical explosives, neutron multiplication runs away and a sudden production of enormous amounts of fission heat is initiated. This heat instantly evaporates all bomb material. If detonated in the atmosphere, it induces a shock-wave that overturns and destroys any object in its path within a radius of a few kilometers. The physical arrangement that can cause a nuclear weapon to explode is *totally absent* in a power reactor. It is physically impossible for a reactor to explode like a bomb, just as it is impossible for a nitroglycerin-carrying heart-patient to be ignited and explode.

2.2 Fable (2): "We Don't Need More Nuclear Power; There Is Plenty of Natural Gas, Oil, and Coal"

Fact: In the 1990s, demand versus supply curves of natural gas and oil (petrol) in the USA crossed over, as predicted by Hubbert (Ref. I-13). Increased oil imports from foreign sources have balanced US demands since then, but increased worldwide demand is now starting to exceed discoveries of new oil deposits. With these trends, oil and gas production is expected to peak around 2015 ("peak-oil"). Thereafter petroleum fuels will become increasingly in serious short supply. Coal, if substituted for oil and uranium to provide all global energy needs might last for 150 years. But if GEN-IV breeder reactors are put into service, uranium and thorium can supply the world with electricity and synfuels for at least 3,000 years in place of oil, gas, and coal. Like petrol, coal-burning power plants produce enormous amounts of air pollution and emit globe-warming carbon dioxide gas. Once oil is depleted, coal is more valuable as raw material for making organic chemicals, and should not be burnt. Non-air-polluting nuclear plants presently produce 20% of all US electric power. To avoid global warming, they should ultimately replace coal-burning power plants. The NEI (Nuclear Energy Institute) fact-based cost figures for electricity in ¢/kWh for 2005 are: 1.71 (0.45) for nuclear, 1.85 (1.36) for coal, 4.06 (3.44) for natural gas, and 4.41 (3.74) for oil, where parentheses give fuel and fuel loading costs (Ref. II-10). Clearly, aside from the not-too-distant threat of no more oil, nuclear energy is competitive and affordable despite false claims to the contrary by anti-nuclear propaganda.

2.3 Fable (3): "Nuclear Power Plants Create Lots of "Dangerous" Radioactive Waste, Which We Don't Know How to Transport or Store Safely. Coal-Fired Power Plants Are Much More Bio-Friendly"

Fact: This is one of the oldest stale fabrications parroted by anti-nuclear faithfuls. Instead of dispersing the combustion products into the atmosphere as is done by coal-burning plants, the radioactive fission waste produced by nuclear plants is always contained and mostly solid. Small quantities of gaseous fission products such as xenon-133 and krypton-85 diffuse into special plenums inside solid reactor fuel elements and are periodically vented and retrieved for valuable use in other nuclear applications. Useless nuclear waste is ultimately placed in some underground repository after removal of valuable radioisotopes and un-burnt uranium fuel. Most nuclear power plants are refueled once every 2 years with uranium encapsulated in solid fuel elements which are shipped in a few trucks. During refueling, the spent fuel elements containing internal fission-product wastes and un-burnt uranium are pulled out of the reactor core and replaced with fresh fuel elements. After a certain cool-down period in a pond, spent fuel elements are placed in collision-proof casks for transport to a nuclear fuel reprocessing plant. Here, after removal of valuable un-burnt fuel and non-radioactive or short-lived radioactive species, non-usable long-life radio-isotopes are concentrated and shipped in special containers to a repository with underground storage vaults. The quantity of final radioactive fission waste has been enormously exaggerated by anti-nuclear bigots. For a 1,000 MW(e) reactor, it amounts to about 1,200 kg per year whose volume is about 0.15 m^3 (5.3 ft^3) equal to that of one household-garbage-can, or one aspirin tablet per person per year who uses electricity from a nuclear plant.

The *annual* fission product waste from *all* 104 nuclear power plants in the USA, which produce nearly *one trillion* (10^{12}) kilowatt-hours of electricity per year, can be extracted, concentrated, and compacted as ceramic marbles in 200 drums, for underground storage in a national nuclear waste repository such as Yucca Mountain in the Nevada desert. Because of anti-nuclear politicking, completion of the Yucca facility which was supposed to have been ready by 2000, has suffered long delays. Even though collision-proof casks will be used which have been extensively crash-tested, anti-nuclear activists still oppose transportation of nuclear wastes over US highways and railroads. This has forced nuclear plant operators to temporarily store used fuel elements in water-shielding swimming pools until Yucca is operational. If properly prepared, temporary swimming-pool storage of spent fuel elements is safe. But it is still better to store final waste in one place rather than at a 100 different sites. Aside from civilian nuclear power plants, the US Nuclear Navy has similar spent-fuel loads to dispose of and has done so safely without problems for half a century. There appears to be a misconception among nuclear-power opponents that "dangerous" radioactive waste can somehow explode like uranium through nuclear fission. *Radioactive waste can not explode and is not fissionable. It only suffers* *from slow nuclear decay*, which entails emissions of betas (= fast electrons) and gammas (= high-energy photons similar to x-rays).

When uranium fissions, its energy is conducted through solid material to heat adjacent water or gas that runs the steam or gas turbines. In this heat transfer, radioactive fission products stay in the solid fuel elements, in contrast to coal burning, where species embedded in coal are sent into the atmosphere when coal is burning with oxygen from the air. As mentioned, fissioned uranium products can not undergo further fission or explode. After the original kinetic energy burst from a uranium fission, the fission products only generate low-level heat from internal radioactive decay. Even if a spent fuel element were exposed to air during its transport in a collision-proof cask (e.g. if a terrorist fired a bullet into the cask), the solid form of the radioactive products in fuel elements prevents their entry into the air. The heavy steel casks are designed to tolerate external bomb blasts and it would take a cask-piercing missile with high explosives to vaporize a fuel element into radio-active aerosols.

Coal power requires continuous coal transports using hundreds of railroad cars and the release of tons of carbon-dioxide and natural radioactive elements into the atmosphere. A 1,000 MWe coal-fired power plant which consumes four million tons of coal per year, releases annually 900 lb of coal-entrained uranium, 530 lb of mercury, 120 million lb of sulfur oxides (SO_x), 59 million lb of nitrogen oxides (NO_x), and 22 billion lb (~11 million tons) of carbon dioxide (CO_2) into the biosphere. Comparing the safety of mining coal versus uranium, one finds that many more accidents occur in coal mines with loss of life. Also the daily transportation of 12,000 t of coal by 120 railroad cars is more accident-prone than the monthly uranium transport of 2 t of uranium yellow-cake with one or two trucks needed to fuel a 1,000 MWe U-235 burning reactor (Section 6.3.2). Coal is also more valuable as a raw material for making plastics and other organics when oil is gone. It should not be burned (Section 2.5).

2.4 Fable (4): "Nuclear Power Is Not Needed. "Free" Renewable Solar, Wind, Hydro, and Geothermal Power Will Do. The Utilities and Government Should Invest More in Them"

Fact: A 1,200 MW(e) nuclear plant (e = electric) operating with a 90% capacity factor, produces 9,500 million kWh of electricity per year, compared to about 40 million kWh/year from a large SOLAR-2 station generating 15 MW(e) peak sunshine power with a 30% year-averaged collection factor. Thus it takes 238 SOLAR-2 stations occupying 25,000 acres (100 km^2) of land and an investment of \$10 billion, to replace *one* nuclear plant occupying 40 acres of land, costing \$2.5 billion (2005 dollars). Solar energy is *not* free. Energy production has three cost components: fuel, maintenance, and capital write-off. While fuel costs are zero, it takes large maintenance crews and vehicles to keep solar panels or mirrors free from dust, rain stains, and bird droppings, and to replace panels or mirrors that are eroded or damaged by sand-, dust-, rain-, and snow-storms or hail. Also storage batteries whose electrodes require periodic replacements must be maintained. Many square kilometers of solar collector or photo-voltaic surfaces and a million storage batteries require enormous capital investments whose write-off costs dwarf the fuel costs for equivalent nuclear electricity. With 10-year solar-cell replacement cycles, one finds that hazardous chemical wastes in manufacturing silicon, cadmium-telluride, or copper-indium-diselenide for solar cells far exceed uranium fuel wastes, when one compares 238 SOLAR-2 stations with one nuclear plant, each producing a year-averaged 1,000 MW(e).

Regarding wind power, one comes to similar conclusions. Five-hundred 2 MW(e) wind-turbines costing \$1.0 billion, put on 25,000 acres (100 km^2), could yield 1,000 MW(e) of electric power at full capacity. However the wind is not always blowing and typical year-averaged utilization factors for wind-farms are 25% to provide 1,000 MW(e) on average for a whole year, electric storage batteries are needed which add costs, and four times as many wind-turbines must be placed on 100,000 windy acres (400 km^2). In short, one needs 2,000 wind turbines of 2 MW(e) capacity at a cost of \$4 billion + \$2 billion for buffer energy storage systems, or a total of \$6 billion to provide an average 1,000 MW(e) year around. The typical capacity factor of a nuclear plant is 90%, so a 1,200 MW(e) reactor costing \$2.5 billion can provide 1,000 MW(e) continuously during a year. Here all costs are round numbers in 2005 US dollars. Besides the high cost of maintaining 2,000 windmills, wind-farms have the problem of killing hundreds of birds, ruining local ecosystems, and spoiling nature's scenery.

In summary, while the sun and wind may provide free fuel, it is not steady and highly diluted compared to enormously concentrated, reliable nuclear fission energy. To deliver large quantities of solar and wind-generated electricity, great expanses of energy collection equipment are required which vastly increase maintenance and capital costs relative to nuclear power plants. Solar and wind farms are very useful in providing electricity for small communities in remote locations (e.g. Alaska) or for low-power applications. However they cannot economically replace nuclear or coal-fired power plants to feed an industrialized city with sufficient energy for producing steel, aluminum, bridges, buildings, or to synthesize massive quantities of portable fuels for moving our transportation fleets of cars, trucks, ships, and aircraft.

As a final example, let us compare in round numbers what it takes to generate a total of one trillion equivalent electrical watts (1 TWe = 10^{12} Watts-electrical) of total energy presently consumed in the US, using either wind, solar, or nuclear power. With solar power, one finds that one must build 238,000 advanced SOLAR-2 plants, each producing a year-averaged 4.5 MWe, and costing \$10 trillion to provide a year-averaged one million MWe. This exceeds the US gross domestic product (GDP) of \$9 trillion. Similarly to deliver one million MWe (= 1 TWe) of wind-power averaged over a year, requires 2,000,000 wind-turbines of 2 MWe peak power at a cost of \$6 trillion. This compares with 1,000 nuclear power plants of 1,200 MWe each, which feed 1 TWe to the entire USA with 85% capacity factor, costing \$2.5 trillion. It is rather obvious what capital investors will prefer when choosing between \$2.5,

\$6, and \$10 trillion. Note there are already 438 nuclear power plants worldwide and 104 in the USA. The latter provide 20% of all electric grid power in the USA.

Hydroelectric power generation is maxed out in the USA. Most suitable rivers have already been dammed to feed hydroelectric turbogenerators; in fact environmentalists want to dismantle some hydroelectric dams. In Cobb, California, a geothermal power plant generating 55 MWe in the 1960s, experienced large drops in steam pressure and after 6 years was shut down. Some recent geothermal projects are more promising but only useful in a few locations for perhaps a few decades.

2.5 Fable (5): "We Only Have 50 Years of Uranium Ore to Sustain a World Fueled by Fission Power. Coal Reserves Would Last at Least 150 Years, so We Should Concentrate on Cleaning Up Coal Power"

Fact: The oft-quoted 50-year limit on uranium availability is based on "burning" the fissionable U-235 isotope of uranium only. Breeder reactors have been developed at a slightly higher capital cost than U-235 burners, which consume U-238 as well as U-235 via in-core conversion of non-fissionable U-238 to fissionable plutonium-239. This happens after U-238 absorbs a neutron (Section 6.2.2). Since uranium ore contains 140 times more U-238 than U-235, consumption of U-238 (→ Pu-239) gives the world uranium-based electricity for $140 \times 50 = 7{,}000$ years, or about 2,100 years with 30% recovery utilization. Thorium, after neutron absorption, yields fissionable U-233, whose reserves can provide another 3,000 years of nuclear energy. Several experimental breeder reactors have been built and are being evaluated in France, Japan, Russia, and the US. They are presently about 10% more expensive than "burners" but will replace the latter in a few decades.

Coal is an alternative raw-material source for making industrial hydrocarbons such as plastics. Presently, oil provides the raw chemicals for manufacturing plastics, in addition to supplying petrol for the world's transportation fleets. When oil reserves are gone after 2050, it would be foolish to burn coal to deliver electricity, when non-polluting uranium fission power is available to generate all needed electricity. Coal burning also emits globe-warming carbon dioxide and other air-pollutants. It should not be burned.

2.6 Fable (6): "We Should Wait for Development of Nuclear Fusion Which Produces No Radioactivity"

Fact: Fusion reactors *do* generate radioactive isotopes in containment materials due to neutron activation. They burn deuterium and tritium making helium and neutrons. Removable neutron-absorbing inner linings have been proposed for fusion reactor chambers and these will become radioactive. Making fusion viable for nuclear power generation is much more difficult than generating electric power from fission. The minimum plant size to extract energy from a controlled fusion reaction (a miniature sun) is many times that of a uranium fission reactor. It is estimated it will take at least another 50 years of research and development before the first fusion power plant might be built if ever. We have waited 50 years already for a net-electric-energy-producing fusion pilot plant, and the no-oil period is approaching fast. Clearly we must proceed now with the expansion of proven uranium fission breeder technology.

2.7 Fable (7): "Hydrogen-Consuming Fuel-Cell Engines and Electric Energy Storage Batteries Can Replace Petrol-Burning Automobile Engines in the Future; Nuclear Is Not Needed"

Fact: To be able to replace all present petrol-burning auto engines with fuel-cell engines, will depend on (nuclear) electricity or heat to produce the massive quantities of gaseous hydrogen (H_2) fuel needed for these new engines. Fuel-cell enthusiasts neglect to mention that H_2 gas is not a primary earth resource like oil, and must be manufactured. One needs electricity or heat from power plants to make lots of hydrogen. In effect this means that non-portable nuclear, solar, or wind energy must be transformed into portable hydrogen energy. The production of hydrogen fuel to replace petrol presently used in transportation fleets can be achieved by electrolysis or chemical reduction of water (H_2O), yielding hydrogen (H_2) and oxygen (O_2). Based on geological estimates of uranium, thorium, and coal reserves, providing primary electricity or heat for this can be sustained globally by nuclear power for more than 3,000 years or by coal-fired plants for about 150 years. In remote locations, solar and wind farms might also produce some hydrogen by electrolysis when oil is gone. But to replace the world-wide tera-watt quantities of presently used petrol and petrol-burning engines with hydrogen and fuel-cell engines is only economically feasible with nuclear- or coal-based "mother" power plants.

There are at least five practical propulsion systems that could replace present automobile engines when oil is depleted. These are: (a) combustion engines burning synthetically made fuels (synfuels) instead of petrol, (b) hydrogen-consuming fuel-cell engines, (c) high-energy flywheels, (d) electric battery packs, and (e) steam engines. Solar- and wind-driven cars are fun for sports but cannot transport large numbers of people and goods. For long-haul transport, future cars, trucks, ships, trains, and airplanes will most likely be propelled by synfuel-burning internal combustion engines (ICEs) or hydrogen-consuming fuel-cell engines (FCEs). ICEs or FCEs can be run by combustion of H_2 fuel with atmospheric oxygen to move pistons or make electricity, and exhaust only water. That is, the water used for making H_2 fuel by electrolysis is returned to water again in the exhaust. This is an eco-friendly cycle in contrast to globe-warming carbon-dioxide exhausts from petrol-burning ICEs.

Experimental electric fuel-cell car engines have been developed and have confirmed their superior energy utilization efficiency of about 70% versus 30% for combustion engines. But one big obstacle to the large-scale introduction of clean H_2-fuel-cell-powered cars is the H_2 storage problem (Section 5.1.1). Replacement of the space presently occupied by an automobile fuel tank with the best H_2-adsorbing bladder or compressed-gas tank, results in a vehicle that can be driven for only 1 h or 100 km (60 miles). A porous bladder sucks up hydrogen gas and adsorbs it on its inner surfaces, releasing it again when slightly heated. Present techniques for H_2 bladder storage or gaseous high-compression still need a fivefold density increase to make H_2-fuel-cell-powered cars range-competitive with present-day petrol-fueled autos. An insulated fuel tank with liquefied hydrogen might be used instead, but liquefying and distributing hydrogen more than doubles its cost. There is a better solution to the hydrogen storage problem however. This solution is to compress H_2 with N_2 (air) to make liquid ammonia (NH_3) at 12 atm pressure. This process is less expensive than H_2 liquefaction. A hydrogen-carrying liquid synfuel that can be mass-produced from electrolyzed water and air with the assistance of nuclear power is thus ammonia. Ammonia can run solid oxide fuel cells (SOFCs) directly, but to empower fuel-cells with PEMs (= proton electron membranes; Section 5.2.2) it must be decomposed back to hydrogen and nitrogen on a catalytic electrode surface. Another big advantage of ammonia is that it can also fuel the well-developed ICE. ICEs will probably remain in use for some time as vehicle movers until FCEs become more practical and affordable. Bio-alcohol and bio-diesel obtained from sun-grown corn, sugarcane, algae, or other vegetation, which are harvested and processed with (nuclear) electricity may also be economically viable when oil is gone. To be efficient, the energy packed into a portable synfuel must not greatly exceed the amount of electric energy needed for its manufacture, but reasonable conversion losses are acceptable.

It has been proposed to distribute H_2 gas through pipelines to people's garages where it could be compressed into either ultra-high-pressure (600 atm) cylinders to be carried on-board automobiles, or stored in H_2-adsorbing bladder fuel tanks. Or it could be liquefied by cryogenic refrigerators and stored in an ultra-cold (20 K) insulated fuel tank. It was also thought that utility tap water might be electrolyzed to hydrogen and oxygen with available electric grid power in people's garages during the night and the hydrogen transferred to a special H_2 fuel tank. However pipeline delivery or production of H_2 in garages is quite expensive and not very safe. Even if H_2 were to be generated from water at public fueling stations and one could refill fuel tanks with compressed hydrogen gas or liquefied hydrogen, one finds that such schemes are fraught with safety problems and rather expensive. Manufacture and distribution of ammonia instead of pure hydrogen appears presently the most practical and economic solution for providing long-haul transport vehicles with hydrogenous synfuels. Because it will take a few decades before sufficient nuclear power capacity becomes available for the production of mega-tons of ammonia synfuel to replace petrol, there will probably be an interim period (from 2020 to 2040) during which liquefied natgas (mostly methane, CH_4) will be used to empower long-haul transportation vehicles and hybrid automobiles. However like oil, natgas will also be exhausted soon after 2050.

Besides H_2 storage, another big problem with fuel-cells is electrode fouling and cost. Progressive fouling of fuel-cell electrodes may require their periodic replacement, like worn spark-plug replacements in today's combustion engines. This may be acceptable if the costs are reasonable, but so far the only well-performing electrodes contain very expensive platinum. Should further development of FCEs for automobile propulsion prove difficult, use of well-developed ICEs might be continued for some time by fueling them with manufactured portable "synfuels" like ammonia instead of petrol, after oil and gas reserves are gone. With assistance of electric power, coal and water could be converted to syn-petrol (synthetic petrol) as is presently done in South-Africa's SASOL plants. However it is more prudent to preserve coal as a raw material for making organic materials when oil is gone (Section 9.2.6).

A nuclear power plant does not fit in a car of course but its generated electric energy can be converted into synthetic fuel energy to run transportation vehicles. To make abundant uranium-generated energy available for automotive use, some losses are justified when this energy is step-wise converted and locked up in portable synfuels and biofuels. In a no-oil world, sustainable (nuclear) electricity must be used to help extract alcohol from sun-grown bio-fuel vegetation. It must manufacture fertilizers, operate farm machinery, and provide energy for fermentation, distillation, processing, etc. Combustion energies of bio-alcohol or bio-diesel fuels are generally less than the electric energy used for producing them, so a pure bio-alcohol-only economy is unsustainable. Use of bio-fuels is practical only if its production is aided by grid electricity from nuclear, solar, or wind power. One big limitation on producing large quantities of bio-fuels is competition for arable lands needed for growing food crops.

Burning methane (CH_4) or ethanol (C_2H_5OH) in a combustion engine still produces undesirable carbon dioxide (CO_2) emissions, while hydrazine (N_2H_4) or ammonia (NH_3) synfuels (e.g. for aviation) may generate unhealthy NO_x gases. Even if pure H_2 is used as synfuel in an internal combustion engine, high temperatures can cause formation and exhausts of NO_x from reactions of oxygen (O_2) with nitrogen (N_2) which are both present in air. Fortunately well-developed catalytic NO_x converters and scrubbers are available today that can remedy NO_x problems should they arise, thereby making synfuel-burning ICEs attractive if fuel-cells remain problematic.

Electric storage batteries and flywheels are other possible means for providing automotive power. However the most advanced flywheel systems and lightest (lithium) battery packs developed to date are only able to provide enough energy to drive a small car a 100 km (60 miles). Flywheel or electric storage systems face the problem of diminishing returns: more energy storage to achieve a longer driving range means more battery or flywheel mass, which means more batteries and flywheels, etc. (Sections 5.1.2 and 5.1.3). However for short-distance automobile travel such as commuting to and from work, the use of an electric battery which can be charged in garages and parking places is quite feasible. Presently the most practical car of the future appears to be the "electric plug-in hybrid" which runs on a battery for distances up to 100 km (60 miles) and is powered by a synfuel-burning ICE for longer ranges up to 600 km (400 miles). Energy from the ICE can either keep charging the battery and run the car electrically, or it can move the car mechanically via a crankshaft when the battery is exhausted. Unless a major breakthrough occurs that increases the kilowatt-hours/kilogram capacity of batteries and flywheels more than fivefold, at present it appears that combustion engines running on ammonia and bio-alcohol synfuels (or mixtures dubbed "almonia") are most promising to empower the next generation of long-haul transportation vehicles, and to enable hybrid passenger autos to achieve a range of 600 km (400 miles) on one tank-full of synfuel. In the transitional interim period between 2020 and 2040, before sufficient nuclear power plants are built to produce the needed giga-tons of ammonia, almonia, or hydrogen synfuels, use of compressed natgas (mostly methane, CH_4) might be best for fueling long-haul land and sea transports. Natgas reserves are somewhat more abundant than oil, but they too will eventually be exhausted not long after mid-century. For propelling aircraft, liquid ammonia and/or stabilized hydrazine are more suitable than compressed natgas, so the aviation industry will probably spearhead such synfuels sooner.

2.8 Fable (8): "Nuclear Reactor Operations Are Unsafe"

Fact: Two "maximum credible" nuclear power plant accidents involving core meltdowns occurred in the last 50 years, one at Three Mile Island (TMI) and the other at Chernobyl. They proved the soundness and safety of US and Western-Europe designed reactors, while they high-lighted the poor regard for safety and accident prevention under the former USSR regime. The Chernobyl power reactor had no heavy steel and concrete containment vessel as required in all other countries, and was housed in a hangar. It also used graphite (very pure carbon) as moderator, which has a positive temperature coefficient of reactivity. In layman's terms this means that when the Chernobyl reactor core accidentally heated up beyond the desired level, it promoted increased uranium fissioning which can cause a run-away power surge followed by a meltdown, unless halted by insertion of neutron-absorbing control rods. In contrast in Western Europe and the USA, civilian reactors using water as moderator and coolant have negative coefficients of reactivity. When they get too hot the chain reaction terminates automatically and the reactor shuts itself down.

The TMI accident happened because operators mistakenly forced it to overheat (thinking they were lowering the power level), causing the core to partially melt. However the safety features designed in the water-moderated TMI reactor fulfilled their function. The containment vessel held all radioactive core material in place. Except for minor escapes of tritium gas, no nuclear fall-out occurred. In the Chernobyl accident, maintenance technicians pulled out control rods in error, inducing runaway fissioning in the reactor core. The graphite moderator (a form of coal) got very hot and started burning with oxygen from the air as in a coal fire, because there was no containment vessel and thus an unrestricted inflow of air. Firemen who had never been briefed about nuclear reactors tried to put out the fire but unknowingly exposed themselves to lethal levels of radiation. The three maintenance technicians instrumental in starting the Chernobyl accident were killed instantly by flying debris, while 28 firemen and rescue-workers died from radiation overdoses within months. Heart attacks killed 3 more, while 11 succumbed from medical complications years later. Another 30 rescue-workers exposed at the Chernobyl site suffered permanent disabilities (Section 7.6 and Ref. II-20).

The fear of nuclear power plant accidents seems irrational when compared to air and car accidents. Air and car crashes kill thousands of people each year, yet few people want to abolish cars and airplanes. In the past 50 years, less than a hundred people worldwide died in nuclear accidents, even though nuclear power provides 20% of all electricity in the USA, 85% in France, and 15% worldwide. To produce clean non-air-polluting electricity in the USA, it is imperative that more nuclear power plants be built to replace coal- and natgas-fired units. The latter will be inoperable when gas reserves are depleted.

2.9 Fable (9): "The Longer the Lifetime of a Radioactive Element, the More Dangerous It Is for Man"

Fact: Just the opposite is true. The intensity of radiation from a gram of radioactive material is lower the longer its decay lifetime. Conversely it is higher, the shorter its half-life is. We are surrounded by natural long-lifetime radioactive materials on our planet. In fact, each human is internally radioactive because of potassium (K) and carbon (C) present in every human cell. Natural potassium has 0.12% radioactive potassium-40 (K-40) isotope in it and omni-present carbon has the radioactive C-14 isotope in ppb (parts per billion) concentrations. K-40 emits beta and gamma radiation and decays with a half-life of a billion years while C-14 decays with a half-life of 5,700 years by emission of only a beta (= high-energy electron). This compares with a four billion year half-life for uranium-238 decay by the emission of alpha particles and gammas. Both alpha and beta particles are totally stopped by our skin and only massless gammas can penetrate it to some degree. A recent uproar in Europe over depleted uranium-238 used in military projectiles shows the technical ignorance of "green" politicians who are easily brain-washed by anti-nuclear propaganda. Another lament has been the alarm over mildly radioactive "yellow-cake", a uranium oxide produced after mining and pre-processing of natural uranium. It is not a "nuclear explosive" as some mistakenly seem to believe. Yellow-cake is as harmless as natural potassium-carrying minerals or thorium-oxide mantles used in Coleman lanterns whose radioactivity is comparable to what we already have inside our bodies. Besides unremitting exposure to internal K-40 and C-14 radiation, man is constantly bathed in natural radiation coming from cosmic sources and from the earth. He has evolved just fine with all this radiation. Recent studies show mild radiations may even be beneficial (Ref. II-16).

2.10 Fable (10): "Thousands of People Will Die After a Nuclear Plant Meltdown"

Fact: There have been two major nuclear reactor meltdown accidents since the beginning of the nuclear power era, one in the USA and one in Russia. The actual fatalities are zero deaths in the USA from the Three Mile Island (TMI) accident, and 46 in the former USSR at Chernobyl in the Ukraine (see Section 7.6 and Ref. II-20). The author personally visited Chernobyl and the regional hospital near Pripyat, and talked to local residents and operators of the three Chernobyl reactors (only one had a melt-down). Shortly after the Chernobyl accident, scare-mongers announced that thousands would die later from fall-out radiation. This is total nonsense. Actual nuclear fall-out victims in the Chernobyl region were children who drank contaminated milk from cows that had eaten contaminated grass (avoidable if authorities had warned farmers). Some of these children accumulated radioactive iodine in their thyroids. By administration of iodine-displacement therapy and waiting till the radioactivity subsided (Iodine-131 has an 8-day half-life), the affliction disappeared for most of them after a few months. Of an estimated 3,000 people exposed to fall-out, a dozen or so people were reported to have died 10–20 years later allegedly (but not proven) from exposure to Chernobyl's nuclear fall-out.

Claims of thousands of future cancers due to Chernobyl fall-out made by anti-nuclear groups are based on distorted probability calculations not acceptable to statisticians. Under-reported pre-Chernobyl cancers, and cancer cases due to modern chemicals which cannot be distinguished from nuclear-fallout-generated cancers, produce flawed statistics. As all mortals do, most of the 140,000 evacuated inhabitants in the direct fall-out path of Chernobyl's radioactive plume will die between ages 60 and 100. Based on world-wide cancer-death statistics, at least 28,000 (~20%) of them are expected to die from cancer *due to non-nuclear causes*. Anti-nuclear propaganda claims *all* these deaths will be due to Chernobyl, a totally untenable charge. It is akin to claiming that coffee kills 20% of all people, based on the fact that 20% of all people drink coffee and all will ultimately die.

2.11 Fable (11): "Exposure to "Radiation" Can Cause Long-Term After-Effects in One's Body"

Fact: The word "radiation" is repeatedly misused by lay people and substituted for radioactive particles (see below). This causes a lot of confusion. In physics, gamma radiation from radioactive processes falls in the same class as visible light radiation, infrared heat radiation, and radio waves. All are made up of massless electromagnetic waves or photons that are evanescent and which can be absorbed or reflected only once. They do not "stick" as some people mistakenly believe. Like heat which emits infrared photons, a little bit of radiation is harmless and even beneficial (e.g. a heating pad), but too much can kill you (heat in an industrial furnace incinerates you). Nuclear reactor cores emanate alpha and beta particles, neutrons, and gammas. Emanations that possess mass such as the beta particles (which are fast electrons) and alphas (helium ions), are stopped by less than a millimeter of metal, or concrete, while neutrons are absorbed or reflected back into the reactor core. Only gamma radiation emitted by decaying fission products requires thicker stopping materials. Massless gamma radiation is similar to massless solar ultraviolet light, except the photon frequency and energy is higher. Reactors have enough shielding around them to absorb most massless gammas, allowing only an insignificant harmless number to get through.

A person's exposure to a beam of gamma photons emitted by a radioactive compound can cause breakage of a few biochemical bonds in body tissue. However the body does not differentiate between broken biomolecular bonds from a skin-scratch, a knife-cut, cosmic radiation, or from gamma photons. A scratch may be more detrimental than gamma damage since broken bonds are closer together in a scratch, while molecular breakages due to gammas are spread out. Most people have no idea what it means when told they have been exposed to "100 millirems of radiation". This number can be put in perspective by knowing that body damage from a 2 cm long × 0.1 cm deep scratch on one's skin causes biomolecular bond breakages equivalent to about 100 millirems (Section 7.2). The human body repairs broken bonds rapidly and has done so during a million years of evolution in a radiation-rich environment.

A much more important nuclear safety concern is inhalation or ingestion of radioactive particles or dust present in the "fall-out" plume of atomic bombs or in the debris cloud from the meltdown of a reactor without a containment vessel such as Chernobyl. In this case such particles can "stick" inside the body and expose it internally to emitted alpha, beta, and gamma radiation. Some body organs (e.g. thyroid gland) and bones have an affinity for certain uranium fission products, mainly radioactive iodine, cesium, and strontium. The body can extract these elements from inhaled or ingested radioactive dust, and concentrate them unless they are eliminated. When lodged in the body, decaying radio-isotopes steadily emit betas and gammas in surrounding tissue that will irritate or destroy it. This is exploited in nuclear medicine to kill cancer cells, but in that case cancerous tissue is selectively targeted. Some "anti-radiation" pills are available today that can force the body to expel certain undesirable elements like radioactive iodine.

In the unlikely event one is in the path of the debris cloud from an atomic bomb or Chernobyl-like reactor fire, the best protection against fall-out is to enter a shelter with closed windows. If outside, one should filter the air one breathes using a wet handkerchief or gas mask, and wash off all dust by taking a swim or shower after the cloud has passed. If available, one should take anti-radiation pills. Of course the best protection is to run or drive away from the usually slow-moving cloud.

To avoid possible radioactive fallout from nuclear melt-downs entirely, *all* power reactors in the world today must and do have a steel and concrete containment vessel surrounding them. This vessel must keep all nuclear reactor debris contained under the worst imaginable ("maximum credible") accident such as a core meltdown, an M-7 earthquake, airplane crash, (non-nuclear) bomb attack, sabotage, etc. The (almost incredible) Three-Mile-Island (TMI) accident proved its effectiveness in limiting damage.

2.12 Fable (12): "Nuclear Plants Consume Millions of Gallons of Water, Depriving Others of This Commodity"

Fact: This fable is one of the latest fabrications composed by opponents of nuclear energy. Cooling water for a power plant, whether nuclear, coal-, or natgas-fired, provides the low-temperature limit needed to move and condense steam that drives electricity-generating turbines in the so-called Carnot cycle. It is like the radiator cooling water for automobile engines that rejects low-temperature heat so as to move pistons and thus the car in an engine's four-stroke Otto cycle (Section 5.2.1). By the second law of thermodynamics, without a low-temperature heat dump one cannot generate electricity or provide mechanical motion using cycled high-temperature steam or gas.

Cooling-water should not be confused with reactor core coolant. The latter is the electricity-generating working fluid which is often also water but can be another liquid or gas (Chap. 6). The high-temperature reactor-heated working fluid, after passing through a turbine, is cooled down to a lower temperature in a heat exchanger where it transfers its heat to a secondary cooling-water circuit outside the reactor. The cooled low-temperature working fluid is then circulated back to the reactor core where it is reheated. If near an ocean or river, cooling-water can be used once-through, but for inland locations, one recycles water through cooling towers and/or cooling ponds. While some water is evaporated and lost during the cooling process, most is collected at the bottom of a cooling tower or far end of a cooling pond and re-used. Instead of water-cooling which is least costly, one can also air-cool the working fluid at the low point of the cycle. However air-cooling requires large expensive heat exchangers and fans. The millions of gallons of water that are circulated to cool exhausted steam in a power plant has nothing to do with nuclear fission and is necessary for any heat-based power plant if one wants to generate electricity. Only photo-voltaic solar cells can generate electricity without cooling. Solar concentrator systems also require water or air cooling, and even wind power needs large atmospheric temperature gradients that move air and induce strong winds.

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