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Health risks of the releases of radioactivity from the Fukushima Daiichi nuclear reactors: Are they a concern for residents of the United States?

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Earlier this week the Comprehensive Nuclear Test Ban Treaty Organization modeled how the dispersion of radioactive plumes from the Daiichi reactors would reach the west coast of North America.[2] Measureable concentrations of radiation from the reactors have been detected in California, as well as the East coast. At the same time, the Chair of the US Nuclear Regulatory Commission said at a White House press briefing that "You just aren't going to have any radiological material that, by the time it traveled those large distances, could present any risk to the American public."

What is one to think? Is there really no risk whatsoever to the American public, as the Nuclear Regulatory Commission chairman claims? Actually, things are more complicated than what he says, even though he is mostly right (at the moment – things could get worse, or they might not). [3] Ultimately, the answer will depend on what happens at these reactors, including when events there can be brought fully under control. This factsheet is meant to help you make sense of the issues that can influence exposure and harm from ionizing

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[2] http://www.nytimes.com/interactive/2011/03/16/science/plume-graphic.html?ref=science

[3] I am focusing here on residents of the United States. The answer would be different to the basic question for people in other places, and especially in Japan – and the answer will vary in Japan depending on ones location, age, sex, and a variety of other factors. The answer would also be different if one is working at the Daiichi sites.

radiation released from these reactors as the crisis continues to unfold. Hopefully it will also help you make sense of the inevitable debates that will arise about the safety of nuclear reactors and spent fuel storage in the United States in the aftermath of the accident in Japan.

For better or worse, to understand the health risks it helps to know about different types of ionizing radiation and how they are measured. So, this factsheet starts with some basic terminology before giving a summary of what is known about health effects from ionizing radiation. Take a breath, and be patient – I tried to make it two pages, but it got a lot longer! Understanding what to worry about depends on understanding the details of how things work.[4]

What is ionizing radiation?

The physics and chemistry of radiation can be confusing, and the extensive terminology associated with radiation makes the problem much worse. Here are some basic definitions of terms that you may now be hearing about.

Radiation is energy that moves through space. **Ionizing radiation** has enough energy to remove electrons from atoms, break apart the nucleus of atoms, and break apart molecules (non-ionizing radiation, like those from a microwave oven or radio just move or vibrate the electrons or atoms). Ionizing radiation includes x-rays. It is also emitted when an unstable nucleus of an atom rearranges itself into a more stable state. Briefly, a stable atom has an equal number of protons and neutrons in its nucleus. An atom can have a different number of neutrons, however, and this can make it an unstable *isotope* of the atom.[5] When the isotope has this instability, it is radioactive, meaning that it will spontaneously rearrange itself at some point in the future.[6] When it does, it will emit ionizing radiation. This process of re-arrangement is called radioactive decay, and it is the underlying mechanism by which both the energy released from nuclear reactors and their health effects can occur. Remember this – it is important later on when we consider the health risks.

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[4] For those of you who really want to dig into the issue of radiation health effects from low level ionizing radiation, there is this overview: Russ, A., Burns, C., Tuler, S., and Taylor, O. 2006. *Health risks of ionizing radiation: An overview of epidemiological studies*. Worcester, MA: Community-Based Hazard Management Program, The George Perkins Marsh Institute, Clark University. It is available on the web at: http://www.seri-us.org/content/health-risks-ionizing-radiation-report

[5] For example, stable iodine has 53 protons and 53 neutrons. An atom is defined by the number of protons it has; iodine is iodine because it has 53 protons. Iodine-131, for example, an important isotope in nuclear fallout and nuclear reactor meltdowns, has 53 protons and 78 neutrons. We call it Iodine-131 because the combined number of protons and neutrons is 131.

[6] Technically, this can require a series of steps. For example, Uranium-235 has a "decay series" through multiple isotopes, all of which are unstable and release some radiation, before a stable isotope of lead is formed (see: http://periodictable.com/Isotopes/092.235/index.p.full.html). Iodine-131 decays directly into xenon-131, which is stable. Strontium-90, which the body treats like calcium, decays into yttrium-90, and this isotope decays by via a beta particle. Because it is a beta emitter, yttrium-90 carries a risk of burning eyes and skin. For additional information, see: http://www.bt.cdc.gov/radiation/isotopes/

There are three types of ionizing radiation that are of immediate concern, in the context of the Daiichi reactor releases. It is important to understand the differences, because the health risks associated with each are different – as are the opportunities for protecting against them.

Radioactive substances in nuclear reactors emit alpha particles, beta particles and gamma rays, as shown in the figure below.[7] **Alpha particles** are relatively large and can only travel short distances, but they can cause a lot of damage. They are easily stopped by skin and other barriers (like clothing). Alpha particles are most dangerous when they are in close proximity to cells such as when inhaled. Plutonium 239 is an alpha emitter and as such is highly carcinogenic when deposited in the lungs. **Beta particles** are high-speed electrons that can penetrate deeper than an alpha particle into tissue. *Alpha and beta particles cause biological damage when they enter the body through inhalation, ingestion, absorption though the skin, or through a cut in the skin.* Beta particles can cause severe skin burns without being inhaled or ingested. Iodine-131 is both a beta and gamma emitter, and is dangerous to the thyroid because the thyroid gland uses iodine to produce thyroid hormones and it makes no distinction between radioactive iodine or nonradioactive iodine (it will use either). **Gamma rays** are packets of energy (i.e., a photon) that can pass through the body. As they pass through the body they can react with molecules (cells). If a gamma photon is absorbed by the body, the energy is transferred to the tissues and can cause damage. The more energetic the gamma photon, the more damage it causes if it is absorbed. Protection from gamma rays takes significantly more effort – more barriers. This is the form of radiation that requires spent fuel rods to be immersed in at least several feet of water (in addition to any requirements for cooling). Gamma rays can even penetrate through concrete.

The problem – for people exposed to them – with all three forms of ionizing radiation is that when the energy they contain hits tissue, the energy is released and always causes some damage to the tissue. This happens by damaging molecules, breaking and creating chemical bonds, and producing free radicals (which then go on to create their own damage). This can damage cellular DNA leading to cancer. If damage is caused to cells in the reproductive organs mutations and malformations may occur. Of course, there are cellular mechanisms that can also repair damage to the DNA. The mechanisms of damage and repair are very complicated and not completely understood.[8]

However, what is clear is that there is no lower limit of exposure under which there is no damage and which can be considered "safe." Any amount of radiation will damage cells and it is the delicate balance of repair mechanisms that determines the ultimate outcome of health or disease. There are many factors that come into play. It is like dropping a raw egg. Sometimes it breaks, sometimes it does not. Whether or not it breaks depends on a variety

[7] There are also other modes of radioactive decay, e.g., positron emission, neutron emissions, and other decay modes, but I am not going to discuss them here.

[8] The state of knowledge about these issues is detailed in a report from the US National Research Council (2005): Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington, DC: National Academies Press.

of factors like how it lands (on the side or the edge), the height from which it drops, what it lands on, etc. (I know, we have hens and sometimes I drop the eggs).

In order to make sense of how much damage may result from exposure to ionizing radiation we have to consider units of measurement. The **gray** is a unit of absorbed dose (previously this was called the **rad**). This relates to the amount of energy actually deposited in some material, and is used for any type of radiation and any material. The **sievert** is used to express effective dose, a measure of the potential for biological damage from some amount of radiation (previously this was called the **rem**). For gamma radiation the absorbed dose is the same as the effective dose. Alpha particles have a greater biological effect because they deposit energy more densely (i.e., an alpha particle is more likely to cause complex DNA damage that is difficult to repair). Thus, for alpha particles the biologically effective dose can be 5-20 times higher than the absorbed dose. Think of it this way: more bang for the buck.

The Table below gives some values for some different exposures.[9] When doses and exposures are low, units of micro-sieverts (μSv, one millionth of a sievert) or milli-sieverts (mSv, one thousandth of a sievert) might be used. Measures of *dose rates* refer to exposure over time, such as exposure per hour (e.g., milli-sieverts per hour), per year, per lifetime (e.g., cumulative lifetime exposure). Dose *rates* do matter because faster delivery of radiation can have a relatively stronger impact in some cases (overwhelming the repair mechanisms). In other words, getting the same dose in 1 hour is usually worse than getting the same dose stretched out over the course of a year.

Conversions for Grays, Rads, Sieverts, and Rems

Gray	**Rad**
1 Gy	100 rad
1 mGy (milli gray, 0.001 Gy)	0.1 rad
1 μGY (micro gray, 0.000001 Gy)	0.1 mrad

Sievert	**Rem**
1 Sv	100 rem
1 mSv (milli-sievert, 0.001 Sv)	0.1 rem = 100 mrem
1 μSv (micro-sievert, 0.000001)	0.1 mrem

[9] Now, here is some more confusing terminology. You'll hear about exposure and dose. **Exposure** refers to how much of something one is in contact with. Think of this as what is outside of you, in the environment. **Dose** refers to how much is received or absorbed. It is what is inside of you, what your body uptakes from the environment. When it comes to ionizing radiation – or medications, toxins, etc. – what ultimately matters is the dose. You will notice that in the media and in many informational materials that exposure and dose are often used inter-changeably. This is because, of course, exposure and dose are related and because exposure is a good approximation of how high doses can be (so it's a conservative estimate).

Some examples of dose rates and doses[10]

Radiation *dose rate*	Source
Per hour	
12 mSv/hour	Reported value at Daiichi plant boundary (15 March)
250 mSv/hour	Reported level 100 feet above Daiichi reactor, stopping use of helicopters (18 March)
400 m Sv/hour	Reported value at the Japanese nuclear site (15 March)
Per year	
1 mSv/year	Maximum exposure limit for non-occupational exposures (i.e., member of the public) in the United States by a facility licensed by the Nuclear Regulatory Commission
2-3 mSv/year	Average background from natural sources
6.2 mSv/year	Average American exposure from natural *and* human caused sources according to the US Nuclear Regulatory Commission
1-10 mSv/year	Average exposure by airline flight crews
20 mSv/year	Current limit (averaged) for nuclear industry employees
50 mSv/year	Maximum occupational radiation exposure to adults working with radioactive material in United States by a facility licensed by the Nuclear Regulatory Commission
Radiation *dose*	**Source**
0.001 mSv	X Ray (extremity)
0.1 mSv	X Ray (chest)
0.4 mSv	Mammography
1.5 mSv	X Ray (spine)
2 mSv	CT Scan (head)
30 mSv	CT Scan (abdomen and pelvis)
250 mSv	US limit for police officers, firefighters and other emergency workers engaged in life-saving activity
350 mSv *per lifetime*	Criterion for relocating people after Chernobyl accident
1,000 mSv (or 1 sievert)	Radiation sickness can occur, causing nausea, vomiting, diarrhea and skin blisters
More than 6 Sv	Probable death (1000mSv/hour for 3 hours causes a 50% fatality rate and for 6 hours essentially a 100% fatality rate)

[10] Note that these are averages or expected values in medical testing. Actual values can vary, depending on the specific treatment and the person. Data from: World Nuclear Association; http://www.radiologyinfo.org/en/pdf/sfty_xray.pdf; *New York Times* articles between 15-18 March; Stabin, M. 2009. Medical Radiation Sources, Health Physics Society; Russ, A., Burns, C., Tuler, S., and Taylor, O. 2006. *Health risks of ionizing radiation: An overview of epidemiological studies*. Worcester, MA: Community-Based Hazard Management Program, The George Perkins Marsh Institute, Clark University; Bottollier-Depois JF et al. 2000. Assessing exposure to cosmic radiation during long-haul flights, *Radiation Research* 153(5 Pt. 1):526-32.

What are the potential health effects from ionizing radiation?

Cancer is the outcome that is usually talked about. In fact, cancer is the most often studied harm associated with exposure to ionizing radiation. That is because increased rates of cancer are can be easier to detect (compared to background rates) compared to most other kinds of diseases. However, other kinds of diseases can be associated with low level exposures to ionizing radiation, including cataracts, heart disease, thyroid disease, and high blood pressure.[11] These kinds of effects are much harder to study, and so they are not usually part of the conversation about radiation health effects.

We are exposed to ionizing radiation in a number of ways. There is background radiation, of course (see sidebar). These are unavoidable, although there are ways that we can decrease or increase our exposure to them (e.g., by changing our behaviors). We may also receive exposures from medical procedures, including radiation therapy to treat cancer, mammograms, x-rays, CT scans, and coronary angiograms. They are usually received because we need them and expect the benefits to outweigh the risks. We are also exposed to ionizing radiation from the legacy of nuclear weapons testing, routine releases from nuclear power plants, and accidents at nuclear power plants.

It is important to know that there is no such thing as a "safe" level of exposure. The scientific consensus is that exposure to ionizing radiation at any level carries some

Background radiation

The largest proportion of radiation around the world is emitted by natural sources. Most of the exposure typically received by the public is produced by cosmic rays, terrestrial radiation, and internally deposited natural radionuclides. Radon alone, one source of background radiation that enters indoor environments from the soil and irradiates the lung through inhalation, accounts for over fifty percent of the world's total estimated effective dose of radiation. While these exposures are termed "natural radiation" this does not indicate an inherently benign nature. Claims that human-made exposures are the same or only a fraction higher than natural radiation levels imply that the effects are insignificant, and this is a false assurance. A substantial body of research suggests that natural radiation can be harmful. Even though they are natural, what we do can increase or decrease our exposures (e.g., choice of technologies, how we construct our homes, activities we engage in). As we increase our exposure through intensified dependence on mineral processing, airplane flights, phosphate and potassium fertilizers and fossil fuels, we also increase our exposure and related health risks.

There is considerable variability in individual annual exposure according to geology, elevation, and other factors. Smokers, for example, are exposed to roughly twice as much radiation as nonsmokers due to radionuclides in tobacco smoke. Some of us fly in airplanes a lot more than others (and some of us might even be astronauts). Few natural radiation studies have been able to fully attribute health effects to background radiation exposure, which by its nature is often received over a prolonged period of time and at low levels. According to our best understanding of radiation, the effect of background sources is probably subtle; many researchers admit that other variables easily confound study results and conceal the radiation effect being tested (such as nonbackground radiation such as nuclear weapons testing fallout), a phenomenon which epidemiologists refer to as the "signal-to-noise problem."

[11] For example, Akahoshi, M. 2009. Ischemic heart disease among atomic bomb survivors: Possible mechanism(s) linking ischemic heart disease and radiation exposure, *Radiation Health Risk Sciences*, Part 3, pgs. 63-6.

risk of harm.[12] Low doses carry less chance of harm. Higher doses carry more chance of harm. For those that like the technical descriptions, this is referred to as the "linear, no threshold model."

Absolute claims that a certain exposure is "not harmful to the public" are, to be blunt, incorrect. Actually, it is implying a value judgment: that the levels of exposure (and doses) are not viewed as significant enough to warrant concern. A judgment like this is often based on two (related) beliefs:

- Exposure levels *below regulatory standards* are not dangerous to public health. Regulatory standards are basically government determinations of how much harm society is willing to tolerate from some sort of hazard (i.e., exposure to toxin). Except in rare examples, regulatory standards reflect complex trade-offs between the kinds of harms we want to avoid (e.g., additional cancers in a population), economic costs, and our values about what is important.[13,14] In other words, assertions that even a small level of radiation "will not harm human health" is really an assertion that "the levels will not cause intolerable levels of harm among the public, even though there is a small risk." Furthermore, arguments have been put forward that regulatory standards for radiation exposures are not always protective enough.[15]

- The existing science suggests that the harm likely to occur in an exposed ***population*** will be "small" compared to what are the "normal" rates of, say, cancer. Or, that the extra chance of an individual developing cancer from that exposure is small, compared to all other causes of developing that cancer. So, when a public official says the public is safe, or that there are not risks, they are saying that in comparison to other things that threaten public health – such as air pollution, smoking, etc.

Another thing to realize is that most studies are about what happens to groups of people, not to specific individuals. That is because there is always some chance or randomness to what happens to a specific individual that is exposed to ionizing radiation. The science that informs much of our understanding of radiation effects on health is from studies of survivors of the US nuclear bomb attacks on Hiroshima and Nagasaki during World War II.[16] These like many other studies are often in the form of epidemiological studies of low-

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[12] US National Research Council 2005. *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: National Academies Press.

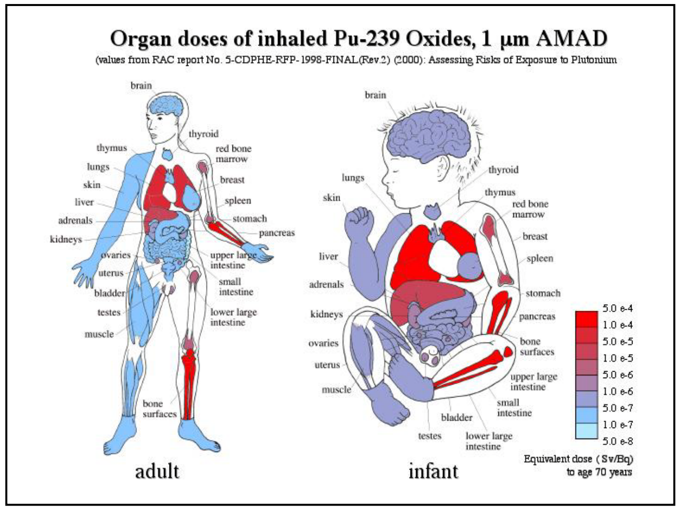
[13] *New York Times*, As U.S. Agencies Put More Value on a Life, Businesses Fret, 16 February, 2011.

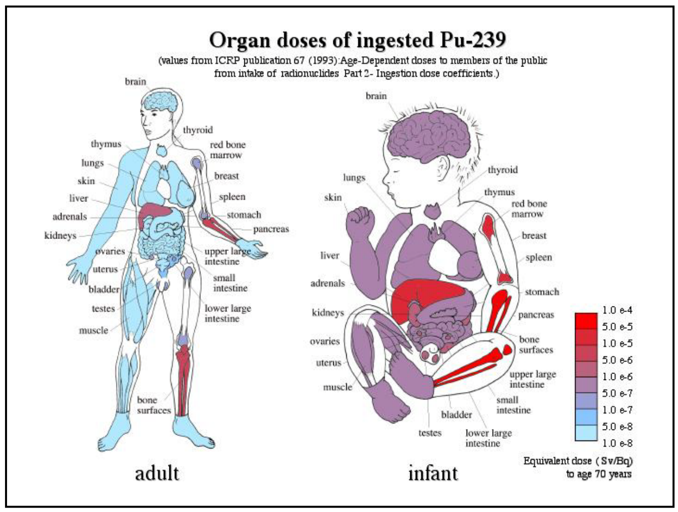
[14] Who decides what is tolerable, how such standards are established, and how they *should* be established is something I have a lot to say about, but this is not the place. See also Pinkau, K. and Renn, O. (Editors) 1998. *Environmental Standards: Scientific Foundations and Rational Procedures of Regulation with Emphasis on Radiological Risk Management*. Boston: Kluwer.

[15] Makhijani, A. 2009. *The use of reference man in radiation protection standards and guidance with recommendations for change*. Takoma Park, MD: Institute for Energy and Environmental Research. Available on web at: http://www.ieer.org/reports/referenceman.pdf.

[16] The exposures from the atomic bombs was essentially a one-time event, like a large x-ray, since the bombs were exploded high in the air. Chernobyl and the current situation are quite different and we have much less information on long term exposure rates with ingested radiation.

dose radiation exposure.[17] For low doses, these studies are often inconclusive and it is difficult or impossible to show links of causation with certainty. Studies can be inconclusive when there is poor information about the actual exposures or who was exposed (both problems tend to cause underestimations of the real effect). Some commentators in the media make claims that there were no increases in, say, leukemia after the Chernobyl accident. This is also why some people claim that exposures below 0.1 gray (10 rad) are safe (or 0.1 sieverts and 10 rem). That is because the studies have not *detected* an increase of the disease in the population. But, the truth is that *the absence of an observed effect is not proof of no effect*. If it is a good study, it can be an indication of a small overall effect. If it is a poorly designed study (e.g., exposure histories are now known, difficulties differentiating between who was exposed and who not) then the meaning of the results are highly questionable.





The risk of harm, like cancer, is affected by a number of variables, including how we are exposed, the form of ionizing radiation (alpha, beta, gamma), the isotope, who we are, what we eat, and, of course, where we are.

How we are exposed matters. We can be exposed to an *external* source, such as CT scans and cosmic radiation (gamma rays). We can also ingest or inhale particles (alpha and beta particles). This is called an *internal* source. When the source is inside of us, we receive a dose for as long as it is in our body. It can also depend on whether we inhale or ingest a radioactive particle, as the figures below suggest. For example, inhaled particles are more likely to damage the lungs, as one might expect.

The form of ionizing radiation matters. Hopefully, this is clear from what you just read. Alpha emitters transfer more energy to tissue than gamma rays. In other words, they can cause more damage to cells, DNA, etc., which in turn can lead to, for example, cancer. In addition, isotopes with shorter half-lives are more likely to transfer their energy when they

[17] See report cited above, by Russ et al. 2006, as well as the National Research Council 2006 BEIR VII report also cited above.

are absorbed in the body. This is one reason why there is lots of attention to iodine-131, which has a half-life of 8 days. A rule of thumb used is that environmental concentrations remain potentially harmful until a period of 10 half-lives has passed; in the case of iodine-131 this would be 80 days.

The isotope matters. Isotopes are really just variations on an element. For example, there are different isotopes of iodine, and the body doesn't care – it will use any isotope of iodine when it needs iodine. That is why in a nuclear accident people might take potassium-iodide – they fill the body's need for iodine with "safe" isotopes and block out the use of "unsafe" isotopes, like iodine-131.[18] Most of the time, however, we cannot easily block absorption of an isotope into our tissues. And, depending on the location of the tissue and its need for different elements, it might stay in our bodies for a long time. For example, the body treats strontium like calcium, so it can accumulate in bones. Strontium-90 is one of the elements released in nuclear accidents and explosions, and when it decays it gives off beta radiation.[19] It has a half-life of 29 years. Plutonium particles also accumulate preferentially in certain tissues; this is illustrated by the figures, which show relative concentrations in different tissues of adults and infants (more red means more likely that plutonium will be incorporated into the tissue).[20] Inhaled plutonium can enter the lungs, and when it decays via an alpha particle, lung tissue is damaged. Plutonium can also enter the blood stream via the lungs and travel to the kidneys, for example, Plutonium is of particular concern at the Daiichi reactors because some of the fuel used in reactor #3 is a mixed-oxide fuel (which contains more plutonium than the usual uranium-based fuels).

Who we are matters. Different individuals can be more or less sensitive to the harmful effects of ionizing radiation. Rapidly growing or dividing cells are most sensitive to radiation damage. For example, it is well known that children are more sensitive to many types of exposures, including radioactive iodine that can harm the thyroid. This is also clearly demonstrated in the figures for plutonium exposure shown here. Fetuses are at higher risk (early studies of the harmful effects of ionizing radiation where about x-rays to pregnant women).

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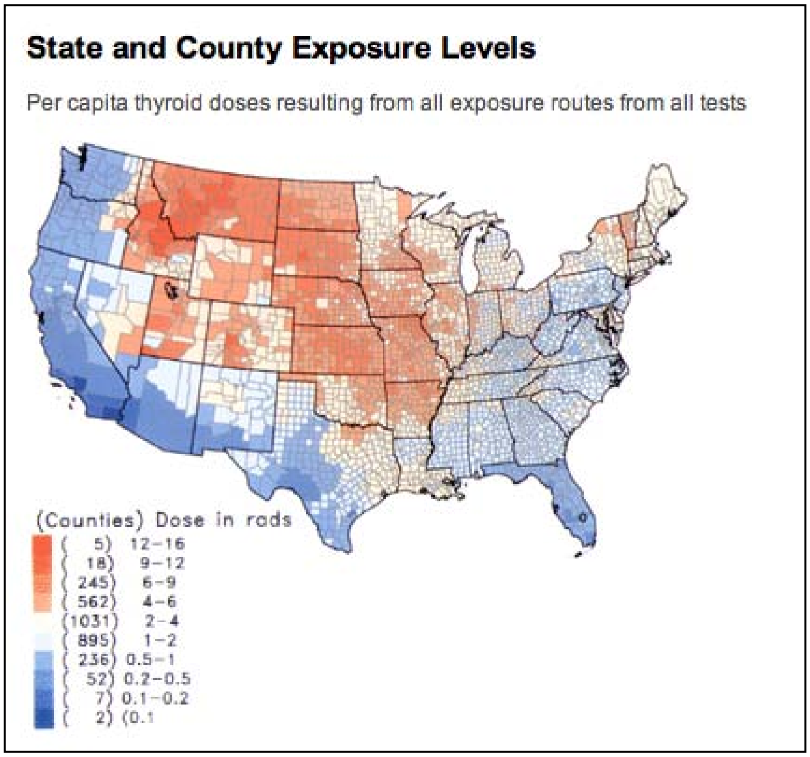
[18] For example, see the website of the Centers for Disease Control and Prevention: http://www.bt.cdc.gov/radiation/ki.asp

[19] See http://www.bt.cdc.gov/radiation/isotopes/strontium/index.asp

[20] These figures were created by Abel Russ, when he worked at the George Perkins Marsh Institute, Clark University, Worcester, MA. Additional information about plutonium can be found at: http://www.bt.cdc.gov/radiation/isotopes/plutonium/index.asp

What we eat matters. Radioactive elements can accumulate in plants and animal tissues, just as they do in human tissue. For example, cows can eat grass contaminated by iodine-131, which can then be passed into milk. People who drink fresh milk can receive higher doses than those who drink commercially processed milk. The delay in getting milk to market allows more decay to occur. There are also reports that spinach and other food products in Japan have higher than normal concentrations of radioactive isotopes.

Where we are matters. Exposures to background radiation vary by elevation and location. But, more to the point here, exposures can vary because of the way that radioactive materials are dispersed from a source. If the radioactive materials are ejected high into the atmosphere then they can travel far and wide because of winds (like the jet stream). At lower altitudes, they might not be carried as far. Fallout from Chernobyl was widespread throughout Europe because the fire at the reactor ejected the plume high into the atmosphere. When steam is released to relieve pressure in a reactor (like at Daiichi) the radiation is not likely to be carried as far. This is the problem of dispersion, and there are a lot of complexities. For example, fallout from nuclear weapons tests in Nevada was generally higher closer to Nevada. But a closer look reveals that "hot spots" can be all over the place – in New York, Vermont, Tennessee, etc. as shown in the map of iodine-131 deposition from US nuclear weapons tests.[21] One of the factors determining the location of a "hot spot" is where it rained at the same time as the radioactive plume was passing overhead. This is true for all fallout contaminants, including cesium-137.[22]



Based on all of this, the appropriate question is not "are the levels safe or not." The appropriate question to ask is: What is the risk of harm to whom?

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[21] Fallout of iodine-131 was assessed in a report by the National Cancer Institute. Information – including a way to estimate personal doses – is available on the web at: http://www.cancer.gov/cancertopics/causes/i131. National Cancer Institute. 1997. *Estimated exposures and thyroid doses received by the American people from 131I in fallout following Nevada atmospheric nuclear bomb tests*, US Department of Health and Human Services, National Institutes of Health, National Cancer Institute. NIH Publication No. 97-4264.

[22] Simon, S., Bouville, A., and Land, C. 2006. Fallout from Nuclear Weapons Tests and Cancer Risks, *American Scientist* 94:48-57.

So, what's a sievert to me, my family, my community…?

To date the claims from US and Canadian authorities that there are very low to no risks to North American populations from the Daiichi releases are probably true. This is not to belittle the concerns that people might have about the risks of nuclear power (or spent fuel stored in pools) and the broad range of health, social, and economic consequences of events like those unfolding in Japan – but in regard to the health effects of exposures in the US the public health risks are low. It is more probable that the risks to people in Japan will be greater. The potential for harm are certainly greater to the emergency responders working on or near the site, and we will no doubt hear much more about the consequences of their exposures as first responders.[23]

As discussed above, any exposure to ionizing radiation carries some risk. Since we are always exposed to some radiation (natural and non-natural sources) we have some "background" risk; according to the BEIR VII report approximately 42 of every 100 people will be diagnosed with cancer during their lifetimes.[24] The BEIR VII report also estimated that:

- The number of additional ***deaths*** from solid cancers would be between 200–830 (best estimate 410) in men and 300–1200 (best estimate 610) in women per 100,000 people who received a dose of 100 mSv (and where the 100,000 people are representative of the US population in terms of age distribution). There would be an estimated 20–220 (best estimate 70) additional deaths for leukemia in men and 10–190 (best estimate 50) additional deaths from leukemia in women who received a dose of 100mSv.

- The additional ***incidence*** of solid cancers would be between 400–1600 (best estimate 800) in men and 690–2500 (best estimate 1300) in women per 100,000 people who received a dose of 100 mSv (and where the 100,000 people are representative of the US population in terms of age distribution). There would be an estimated 30–300 (best estimate 100) additional deaths for leukemia in men and 20–250 (best estimate 70) additional deaths from leukemia in women who received a dose of 100mSv.

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[23] High rates of cancer and non-cancer diseases have been documented in workers at the Chernobyl site, for example. For a review see pgs. 132-133 in Russ, A., Burns, C., Tuler, S., and Taylor, O. 2006. *Health risks of ionizing radiation: An overview of epidemiological studies*. Worcester, MA: Community-Based Hazard Management Program, The George Perkins Marsh Institute, Clark University. It is available on the web at: http://www.seri-us.org/content/health-risks-ionizing-radiation-report

[24] US National Research Council 2005. *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: National Academies Press.

But, what about the releases from the Daiichi reactors? What are the risks to people in the United States? This we do not know for sure. So far, however, the reported levels of radiation from this accident that have reached North America are very low – much lower than the 100mSv or 1mSv values used in the example in the side bar. The exposures, and ultimately the health effects, from the Daiichi reactors will depend on many factors.

> **Another way to estimate the risks of cancer from exposures to ionizing radiation**
>
> This is like a math word problem, except you get the answer right away. According to the BEIR VII report, the average cancer occurrence risk for females is 0.14 cancers per sievert and for men it is 0.09 cancers per sievert. So, lets assume we have 1 million people, with a distribution of ages typical of the United States population. If half of them are men and half are women and they all experience a dose of 100 mSv, then how many additional cancers would be expected? Well, 500,000 men * 0.09 cancers/sievert * .1 sievert dose = 7,000 additional cancers in the men. 500,000 women * 0.14 cancers/sievert * .1 sievert dose = 4,500 additional cancers in the women. That gives a total of 11,000 additional cancers in the 1 million people exposed. If the doses were 1 millisievert (0.001 Sv), doing the math would give an expected 111 additional cancers in that group of 1 million people.

It will depend on whether or not primary containment at the reactors fails. If primary containment fails (and it appears that at least two reactors this may be the case) ionizing radiation may be released in large amounts. How this comes about will mean a great deal to how far radioactive materials are dispersed. If there are fires, particles may be ejected high into the atmosphere. Early efforts to vent the reactors have already caused some regional dispersion of radioactive particles. This is why levels higher than background have been observed in Tokyo and within exclusion (evacuation) zone around the plant.

It will depend on what happens at the spent fuel pools. This is potentially a much more serious issue than the reactors themselves. This is because there is essentially no containment of the spent fuel pools and because spent fuel can contain substantially more highly radioactive materials than the material in the core of the reactor. In addition, fires in spent fuel pools have much greater potential to disperse radioactive materials both in the immediate vicinity and more widely.[25]

It will depend on weather patterns, and specifically on wind direction. The dynamics of releases and weather patterns (e.g., wind directions) will have much to do with where people might be exposed and how people might be exposed (e.g., food consumption, inhalation). However, Japan is several thousand miles from North American.[26] The plume concentrations will be diluted by the time they reach the west coast and then move east across the continent.

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[25] The risks associated with fires in spent fuel pools have been summarized by Arjun Makhijani, including a review of reports by Brookhaven National Laboratory and the National Academy of Sciences. This memo is available on the web at: http://www.ieer.org/comments/Daiichi-Fukushima-reactors_IEERstatement.pdf. According to the Brookhaven National Lab report a fire in spent fuel pools could causes between 1,300 and 31,900 latent cancer fatalities within 50 miles of a plant and between 1,900 and 138,000 within a radius of 500 miles of a plant. Also see http://www.ips-dc.org/blog/safeguarding_spent_fuel_pools_in_the_united_states.

[26] From the Union of Concerned Scientists: http://allthingsnuclear.org/tagged/Japan_nuclear

This conclusion may disappoint if what you really wanted to know is what will happen to *you*. Given the lack of accurate information about exposures, other causes of disease, and the low levels of exposure it is unlikely that future epidemiology studies will be able to detect whether there are will be any significant increases in the rates of diseases in North America, such as cancer, as a result of this accident.[27] And, we don't know what will happen to specific individuals that might be exposed to these low levels of radiation. Except in the rarest of circumstances science cannot tell us what will happen to specific individuals from exposure to ionizing radiation.

[27] This relates to the issue of statistical power. For a hopefully easy to understand explanation of statistical power, see Community Guide to Environmental Health Research Methods, at http://www.seri-us.org/content/community-guide-environmental-health