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Proposed Resumption of Fuels Testing at INL's TREAT Reactor

By Tami Thatcher

The Department of Energy has issued an Environmental Assessment for proposed resumption of transient testing of nuclear fuels at the Transient Reactor Test Facility (TREAT) reactor at the Idaho National Laboratory.[1] Public comments are due January 10.

DOE states that "Transient testing of nuclear fuels is needed to improve current nuclear power plant performance and sustainability, to make new generation reactors more affordable, to develop nuclear fuels that are easier to recycle, safer and more efficient, and fuels that can't be as easily diverted for use in making nuclear weapons."[2]

The reality is that various "improvements" already made in current nuclear power reactor fuels have increased fuel burnup, significantly decreasing safety in reactors and spent fuel pools, increasing the difficulty of long term storage of nuclear spent fuel and increasing costs.[3]

The effort "to reduce the potential for proliferation of nuclear material" is destined to be as ineffective as various existing schemes supposedly to make plutonium unattractive by various short-lived contaminants.[4]

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[1] The draft TREAT Environmental Assessment is athttp://www.id.energy.gov/insideNEID/PDF/Draft%20RTT%20EA%2011-12-2013%20(Draft%20V1).pdf

[2] Additional information for the Department of Energy on the resumption of transient testing can be found at http://energy.gov/ne/articles/resumption-transient-testing.

[3] R. Alvarez, "The Storage and Disposal Challenges of High Burnup Spent Power Reactor Fuel," Institute for Policy Studies, January 3, 2014, http://www.ips-dc.org/reports/storage_and_disposal_challenges_of_high_burnup_spent_power_reactor_fuel

[4] R. Bari et al., "Proliferation Risk Reduction Study of Alternative Spent Fuel Processing," Brookhaven National Laboratory, BNL-90264-2009-CP, July 2009.

It is interesting that Japan's Monju reactor used information from tests conducted at TREAT. Monju, touted as the answer to Japan's energy problems, was idealistically named after a figure of perfect enlightenment and wisdom. The problem-prone Monju fast reactor had a serious sodium fire in 1995 and has generated less than one hour's worth of electricity since, despite billions of dollars being spent.[5] The promoter's of INL's TREAT restart are no less idealistic. And they are not about to be deterred by Japan's Monju or Fukushima experience.

DOE's EA sticks to arguments narrowly focused on radiation doses during plume passage following an accident ignoring the Nuclear Regulatory Commission's recent generic Waste Confidence EIS that included estimates of evacuation costs, relocation costs for displaced persons, property decontamination costs, loss of use of contaminated property through interdiction, crop and milk losses, and onsite property damage costs including onsite cleanup, decontamination and repair of facilities.[6]

The EA obscures the high likelihood of an accident and relies on DOE regulations to ensure adequate safety, despite DOE's documented history of ignoring its own regulations and its approval of inadequate safety analyses, particularly at MFC (remember ZPPR?).[7] [8]

Part of the trick is that TREAT goes even further with a muddled safety strategy that embraces a "no betterment functionally-equivalent replacement" approach to avoid upgrades of the 1958 design.[9]

Spending over $900 million[10] on new fuels research at TREAT is typical of the mindset of an industry that prefers new research over cleanup. Unattractive problems like MFC's shallowly buried and inadequately monitored cans of spent fuel and high level waste are left for the future.

Environmental monitoring issues such as the 2010 DOE oversight report that reported that INL lacked a technical basis for its environmental monitoring[11] are still waiting for DOE's response in 2014. DOE is counting on Idaho's complacency. And that is likely to be a safe bet.

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[5] http://www.japantimes.co.jp/news/2013/05/15/reference/monju-generating-only-misfortune/#.UsTNK7TaIm4

[6] "Waste Confidence Generic Environmental Impact Statement," draft for comment, NUREG-2157, September 2013. Page F-7.

[7] Plutonium Working Group Report on Environmental, Safety and Health Vulnerabilities Associated with the Department's Plutonium Storage, Vol. II, Part 5, Argonne National Laboratory-West Working Group Assessment Team Report, November 1994.

[8] DOE Office of Health, Safety and Security, Accident Investigation Report, Plutonium Contamination in Zero Power Physics Reactor Facility at the Idaho National Laboratory, November 8, 2011.

[9] "Safety Design Strategy for the Resumption of Transient Testing," INL/EXT-12-26455, Rev. 2, September 2013.

[10] "Alternatives Analysis for the Resumption of Transient Testing Program," INL/EXT-13-28597 Rev 2, November 2013.

[11] http://www.hss.doe.gov/IndepOversight/docs/reports/eshevals/2010/2010_INL_Environmental_Monitoring_final_May2010.pdf

INL and TREAT promoter group "Partnership for Science and Technology" claims that there is no connection between Japan's Monju experience and the need to invest in TREAT. PST president Mike Hart also says that "legitimate questions about high-burn fuels can be answered" and "the more we know, the safer we are." Hart says that DOE should not be faulted for not including the cost of public evacuation for the small releases from a TREAT accident particularly when no one lives at the INL border.[12]

The following is in response to PST's comments. The fuels research proposed for the INL TREAT reactor includes the goal of advancing the nuclear fuel cycle means research for sodium-cooled fast neutron reactors. The Monju experience is applicable. But, in order to make reactors safer, there will remain the risk of nuclear accidents that occur because of plants under-designed for natural phenomena hazards as happened at Japan's Fukushima Daiichi plant. And there will remain the other risks of nuclear accidents such as overconfident plant operators that inactivate plant safety systems as happened at Three Mile Island and Chernobyl.

Evacuation of people living near INL's borders may not be needed or be difficult. However, the Environmental Assessment recognizes that "in the event of an accident, contaminated areas would be secured and remediated to prevent food product ingestion." While the plume passage doses to the public may appear small, a thousandth of an accident involving the Advanced Test Reactor, the impact of widespread contamination, including crop interdiction and damage to the agricultural industry in the region needs to be included in the EA.

Modern safety standards take into account the level of consequence at the facility. The DOE is not specific about which of its own modest design criteria for TREAT it will be ignoring, just that they plan to ignore anything they wish since the 1950s when TREAT was built. The shortcut EA, by the way, was required by law to be a full Environmental Impact Statement.

Thatcher is a former nuclear safety analyst at INL and a nuclear safety consultant.

[12] Mike Hart, president, Partnership for Science and Technology letter to the editor printed in the Idaho Falls Post Register. This article is from an editorial printed in the Idaho Falls Post Register 01/10/2014 and a subsequent letter to the editor dated 02/04/2014 by Tami Thatcher.

The 2010 European Committee on Radiation Risk Report Highlights the Underestimation of Harm from Internal Radiation

by Tami Thatcher

To set the stage for a discussion of the 2010 report by the European Committee on Radiation Risk[13] and their views on problems with the International Commission on Radiological Protection (ICRP) radiation risk model, it is appropriate to remember Karl Morgan, a physicist at the Manhattan Project and Oak Ridge National Laboratory, where he was director of health physics from the late 1940s to 1972. Morgan had believed that radiation health physics was a profession dedicated to protecting human beings and the environment. Morgan, who played a formative role in the U.S. National Council on Radiation Protection (NCRP) and ICRP, said of these organizations: "I feel like a father who is ashamed of his children."[14]

In his book, *The Angry Genie*,[15] he writes about his "profession's prostitution" regarding the "hot particle" problem – small radioactive particles released into the environment and capable of causing extremely high local tissue doses to lung cells and the dangers of Tritium. Morgan believed the quality factor for Tritium should be much higher than the ICRP was willing to admit. He believed the quality factor for Tritium should be 5 and no lower than 3, to account for the increased biological damage. The ICRP knew that raising the quality factor (1.7 at the time) on Tritium would greatly impact the weapons business because of tighter restrictions on Tritium releases and it refused to do so. In fact, it lowered the quality factor on Tritium to 1.0, effectively increasing the maximum permissible exposure level. The ECRR finds the dose per Becquerel from Tritium in water to be 50 times more damaging to the human body than the ICRP. The

[13] ECRR – 2010 European Recommendations of the European Committee on Radiation Risk – The Health Effects of Exposure to Low Doses of Ionizing Radiation, Regulators' Edition: Brussels 2010.

http://www.euradcom.org/2011/ecrr2010.pdf

[14] ibid, p. 41.

[15] Karl Z. Morgan and Ken M. Peterson, "The Angry Genie – One Man's Walk Through the Nuclear Age," University of Oklahoma Press, Norman, 1999.

accident at Fukushima Dai-ichi is estimated to have released from 20 to 40 TBq[16] of Tritium into the ocean.[17]

Morgan, who died in 1999 at the age of 90, should be remembered for his testimony regarding what the government knew about the risks of exposure to radiation and what safety measures should have been followed regarding the Nevada atmospheric weapons tests. When asked about the knowledge that radioactive particles once in your body concentrate in radiosensitive tissues where cancers originate, he was asked "was this something known in the mid-40's?" Morgan responded "It's information that I learned back . . in say, 1925 to 1934." Morgan also told the judge for the Utah downwinders' case that he had traveled to the Nevada test site several times during the early 1950s: "I wasn't able to find any record of measurements that were made off-site in reference to internal dose. . . [I] saw no evidence of what I would consider an environmental monitoring program for the public . . . I saw no data from people off-site as far as total body or internal exposure. . . ." We'll return to the effects of nuclear weapons testing later in this article.

The European Committee on Radiation Risk (ECRR) was formed in 1998 because of criticisms of the ICRP risk models. The ECRR consists of scientists and risk specialists from within Europe but takes evidence from experts worldwide. It presented its findings in 2003 and again in 2010. The ECRR describes important flaws in the ICRP risk model and provides new weighting factors to modify the ICRP model.

The ECRR concludes that the ICRP model can significantly underestimate the health effects of internal radiation from ingestion of contaminated water, milk or food or from inhalation of radioactive material. The ICRP model is used throughout the U.S. nuclear industry to estimate the adverse health effects of radiation and to set exposure standards and allowable concentrations of radionuclides. The ICRP model is used in assessing the likelihood of a nuclear worker's cancer due to their estimated radiation exposure and determining eligibility for compensation under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA). Because of prevalent use of the ICRP model, its importance in nuclear worker dose assessment and public dose assessment from routine emissions, exposures and accident releases cannot be overstated. It matters to human health that the ICRP predictions of health effects[18] from radiation reflect the best scientific knowledge available.

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[16] 1 Bq (Becquerel) is 1 disintegration per second. 1 Curie is 37 GBq or 3.7E10 Bq. 1 TBq is 1 x 10^{12} Bq.

[17] "Fukushima is bad, but testing was worse, Ploughshares Blog, August 19, 2013. http://www.ploughshares.org/blog/2013-08-19/fukushima-bad-testing-was-worse

[18] International Commission on Radiological Protection, "Compendium of Dose Coefficients Based on ICRP Publication 60," ICRP Publication 119, Volume 41 Supplement 1 2012. http://www.icrp.org/docs/P%20119%20JAICRP%2041%28s%29%20Compendium%20of%20Dose%20Coefficients%20based%20on%20ICRP%20Publication%2060.pdf

The ECRR studies the effect of radiation on cells and recognizes that the most damage occurs when the same cell is subject to several radiation hits in succession. The result is that ECRR predicts much higher internal doses and higher predicted adverse health effects from internal radiation than the ICRP for internal radiation from Strontium-90, Tritium (H-3), Carbon-14, Plutonium and Americium, Ruthenium-106, and Cerium-144 (see its Table, p. 118 of the 2010 report). Cesium-137 is not given a higher internal dose weighting factor, but the ECRR report noted that there was found to be an 11 percent increase in cancer incidence per 100 kiloBecquerel/m^2 Cesium-137 soil contamination in Sweden within 5 years of the Chernobyl accident.[19] The study used detailed ground deposition maps of Cesium-137 contamination based on aerial gamma measurements, enrolled a cohort of over 1 million people, and controlled for confounding factors of age and population density.

The Sweden study does not assess how the Cesium contamination entered the body by food supply, but Sweden did monitor contamination in the food supply and had to compensate farmers and herders for their losses.[20] While less Strontium was expected than Cesium, it has been estimated that 2 to 3 percent of the fallout in Sweden was from Strontium-90.[21] While it is difficult to say whether the 11 percent increase in cancer incidence per 100 kiloBecquerel/m^2 will apply to the recently measured Cesium contamination levels of 60 to 300 kiloBecquerel/m^2 in Japan's densely populated cities of Fukushima and Koriyama,[22] the increase in cancer incidence was higher than predicted by the ICRP model.

The ECRR reviews sources of radiation exposure to examine the difference between natural background radiation and man-made artificial isotopes such as Strontium-90 and Plutonium-239, micrometer sized aggregates of isotopes called "hot particles", and altered forms or concentrations of natural isotopes such as depleted Uranium from military weapons extensively used in the Gulf region wars. They have found that the inhaled nanoparticles of Uranium are highly neurotoxic and that Uranium has a high affinity for DNA phosphate. Previous Uranium health effects have been discounted by the ICRP on the basis that there is no mechanism to account for such effects at the low doses involved. Uranium contamination has historically been ignored because it is a natural isotope, but the ECRR finds that depleted Uranium causes aneuploidy and micronuclei formation whereas the enriched Uranium causes chromosome aberrations, at levels of radiation exposure 1000 times lower than the conventional assessment.

The ICRP focuses only on fatal cancer. The ECRR examines fatal cancer, infant mortality, fetal death, and other causes of illness including heart disease which has been linked to Strontium.

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[19] Martin Tondel et al, Increase of regional total cancer incidence in north Sweden due to the Chernobyl accident? J. Epidemiol Community Health 2004;58 1011-1016.
www.ncbi.nlm.nih.gov/pmc/articles/PMC1732641/pdf/v058p01011.pdf

[20] Medvedev, Z., "The Legacy of Chernobyl," ISBN 0-393-30814-6, 1990. page 200.
[21] ibid.
[22] "Fukushima internal exposures low, study finds," World Nuclear News, April 11, 2013.

The ECRR examines recent reports of epidemiological evidence of increased risk of illness, particularly cancer and leukemia and shows that the ICRP models which are largely based on external acute radiation exposure significantly underestimate the health effects of internal radiation. In fact, the ICRP model is heavily based on the study of Hiroshima and Nagasaki atomic bomb survivors. The Japan atomic bomb survivor studies have been faulted for largely ignoring the first five years after the bombing and for being more applicable to large external radiation doses. The ICRP model averages the radiation transferred to a mass of tissue to determine the absorbed dose, discounting the effects which occur at the cell level when the radiation is concentrated on a small number of cells and underestimating the health risk in the case of inhalation and ingestion.

The history of the ICRP in actively ignoring evidence that is not in agreement with its own invalid physical models is described by the ECRR, proving that the ICRP models are not maintained in accordance with accepted scientific method.

The ECRR concludes that the epidemiologic evidence of internal exposures must take precedence over the flawed ICRP models in assessing radiation risk due to internal sources. There are many examples of harm to human health following radiation exposure that have been discounted using the ICRP model to state that such low doses could not have caused the harm.

A recent example of discounting the epidemiologic evidence is reported in Japan in December, 2013. Researchers found 59 out of 239,000 young people from the Fukushima Prefecture had thyroid cancer, when the rate from 1975 to 2008 was 5 to 11 people for every 1 million. The "experts are unsure if nuclear radiation is to blame . . . because they believe it is too soon for the exposure to have had an effect on them yet."[23]

Many past examples of dismissing adverse health effects of radiation exposure in the Department of Energy's weapons complex are described in *Dead Reckoning*,[24] a report by Steven Wing specifically about the investigation of health effects of Plutonium,[25] and by Tim Conner.[26] [27]

The ECRR also summarizes the problems plaguing many epidemiology studies that are so important to the study of radiation worker and public health. Some of the problems that have occurred in epidemiologic studies are highlighted below:

[23] "Cancer cases rise in Fukushima but experts unsure on the cause," Japan Daily Press, December 23, 2013.
[24] Geiger, H. J., "Dead Reckoning – A Critical Review of the Department of Energy's Epidemiologic Research," Physicians for Social Responsibility, 1992.
[25] Wing, S., "A Critical Review of the Department of Energy Efforts to Investigate the Human Health Effects of Plutonium," 1992. *rmpjc.org/wp-content/uploads/2012/02/Wing-Pu.doc*
[26] Connor, T., "Burdens of Proof, Science and Public Accountability in the Field of Environmental Epidemiology, with Focus on Low-Dose Radiation and Community Health Studies., 1997.
[27] Connor, T., Memo Re: The Hanford Thyroid Disease Study and the Case for Medical Monitoring, Northwest Environmental Education Foundation, February 8, 1999. http://www.state.nv.us/nucwaste/news/neef02.htm

- The wrong dose conversion factors are used to assess the significance of the doses (this is a key point from the ECRR).
- The dose estimates are believed to be known, but in reality are not representative of the doses actually received. (This happened in the U.S. regarding the Three Mile Island nuclear accident.[28])
- The control group (the group not exposed to radiation) has received elevated radiation levels, because of the distribution of contaminated food from fallout, for example.
- The control group may not be representative, i.e., the healthy worker effect means that this group needs to be compared to other healthy and economically similar workers. (When the healthy worker effect is accounted for, the ECRR notes that nuclear workers have double the risk of cancer within 5 years of working in the industry.)
- The sample group (the group exposed to radiation) is diluted with many people who have not received a elevated radiation exposure. (This is what happens when county statistics are used without regard for proximity to the nuclear facility and has been the historical basis for the NRC to state that nuclear plants don't cause cancer.[29] [30])
- Inadequate definition of endpoint, such as the focus by death from cancer while excluding the occurrence of cancer, or the exclusion of infant and perinatal mortality.
- The wrong conclusions are drawn from the data.
- The data has been tampered with, such as the withholding or falsification of data required by Soviet authorities in forbidding that medical professionals attribute the cause of illness to radiation or the withholding or inaccurate underreporting of the actual doses in dosimetry records by the Department of Energy.

Data tampering? Yes, in the former USSR, but in the United States? In a letter by Ernest Sternglass, PhD to Dr. Steven Chu, the Secretary of Energy:

> "Therefore, when it was discovered in the 1960's that small amounts of fission products produced much greater damage than had been expected, and not only leukemia and other forms of cancer but also premature births, low birth-weight and infant mortality, it was kept secret by our government for fear that it would endanger the deterrent value of the nuclear arsenal."[31]

[28] Wing, S., David Richardson, Donna Armstrong, and Douglas Crawford-Brown, A Reevaluation of Cancer Incidence Near the Three Mile Island Nuclear Plant: The Collision of Evidence and Assumptions, Volume 105, Number 1, January 1997, Environmental Health Perspectives.

[29] NCI (National Cancer Institute) 1990. Cancer in Populations Living near Nuclear Facilities. 017-042-00276-1. Washington, DC: Superintendent of Documents, U.S. Government Printing Office.

[30] The National Academies Press, Analysis of Cancer Risks in Populations Near Nuclear Facilities (Phase I), 2012. http://www.nap.edu/catalog.php?record_id=13388

[31] Ernest J. Sternglass, PhD, Professor Emeritus of Radiological Physics letter to Dr. Steven Chu, Secretary of Energy, February 7, 2009. http://www.radiation.org/reading/090423_ejs_to_doe.html

And, in Jay Gould's book *Deadly Deceit*,[32] an estimated 50,000 to 100,000 excess deaths occurred after releases from accidents at the Savannah River nuclear weapons facility in 1970. These 1970 Savannah River reactor meltdowns were revealed in Congressional hearing 18 years after they occurred. Among the many causes for the increased mortality, they found extraordinary increases in infant deaths from birth defects. While the government claims that no radiation was released as a result of the accidents, increased radiation in rainfall and in milk was recorded. Gould's book says that "the probability is less than one in a million that the divergence of South Carolina's annual infant mortality from the 1968-1973 U.S. trend was due to chance. After declining from 27.0 infant deaths per 1,000 live births in 1968 to 21.8 in 1971, infant mortality in South Carolina rose to 22.7 in 1973. Infant mortality fell steadily in the Southeast, from 24.9 in 1968 to 19.9 in 1973, and in the U.S. from 21.8 to 17.1."

Gould's book describes in depth how data in the *Monthly Vital Statistics Report* for 1971 contained peaks in infant mortality that disappeared in the later bound volumes of *Vital Statistics of the United States*. Normally such changes are marginal, but in this case, the shape of the monthly variations for both infant and total mortality in South Carolina were altered completely. Similar revisions also occurred after Three Mile Island and Chernobyl accidents.

Gould's book is in line with the ECRR as it says that the atmospheric nuclear weapons testing may explain the great epidemiological mystery, that in 1950 to 1965, mortality statistics inexplicably stopped getting better, after decades of improvements.

Comparisons of nuclear releases from an accident to the total releases of past nuclear weapons tests are usually made with the intend of minimizing the significance of the nuclear accident release. In past nuclear weapons tests, countries have exploded the equivalent of 29,000 Hiroshima size weapons in the earth's atmosphere, a figure that does not account for surface-level, underground, and underwater testing.[33] The ECRR concludes that the present cancer epidemic is a consequence of exposure to global atmospheric weapons fallout from 1959 to 1963. The ICRP predictions of cancer deaths from weapons fallout is 1,173,600 whereas the ECRR prediction is 61,600,000. Additionally, the ECRR health predictions for weapons fallout also includes 1,600,000 infant deaths, 1,900,000 fetal deaths and a 10% loss of life quality for other diseases for fallout up to 1989.

The total amount of Cesium-137 released by weapons testing is 950 PBq (10^{15} Bq). The Fukushima releases to date for Cesium-137 range from 4 to 90 PBq.[34] The releases to the Pacific

[32] Jay M. Gould and Benjamin A. Goldman, "Deadly Deceit – Low Level Radiation High Level Cover-Up, Four Walls, Eight Windows, New York, 1990.

[33] "Fukushima is bad, but testing was worse," Ploughshares Blog, August 19, 2013. http://www.ploughshares.org/blog/2013-08-19/fukushima-bad-testing-was-worse

[34] Buesseler, K.O. 2014. "Fukushima and ocean radioactivity." *Oceanography* 27(1):92–105, PBq is 10^{15} Bequerel.

http://dx.doi.org/10.5670/oceanog.2014.02. or http://www.tos.org/oceanography/archive/27-1_buesseler.pdf

ocean have been from atmospheric fallout rather than by direct release to the ocean. The highly nonuniform ocean contamination from Fukushima has been measured by researchers in an area 40 km from Japan in the NW Pacific ocean. In 2013, they found that the concentrations of Cesium-137, Iodine-129 and Tritium (H-3) in the Pacific ocean were above global fallout background by factors of about 1000, 50 and 3, respectively.[35]

The total amount of Strontium-90 released by weapons testing is 610 PBq.[36] The Fukushima releases for Strontium-90 were reported as 53 TBq (10^{12} Bq)[37] in 2012 but the increased levels of Strontium-90 contamination in wells sampled close to Fukushima indicate significant increases in the leaching of Strontium-90 from the melted cores to groundwater, then carried by groundwater to the ocean. The releases of Strontium-90 are less characterized not because Strontium-90 is less important than Cesium-137, but because of the difficulties of pre-concentrating and analyzing Strontium-90 in seawater. Cesium-137, a gamma emitter, is easier to measure than Strontium-90, a beta emitter, which must also be distinguished from other beta emitters. The ECRR finds that the dose per Becquerel of Strontium-90 is over 300 times that of the ICRP model.

The total amount of Strontium-90 that has already been released and will ultimately be released from the three melted cores at the Fukushima is unknown. But, if all of the Strontium-90 in the three melted cores were to be released, the total inventory in the range of 500 PBq is enormous.[38] This amount is comparable to the total weapons fallout of Strontium-90 of 610 PBq, of which 380 PBq was estimated as ending up in the oceans. Strontium-90 can be concentrated in the bones of fish.

That an accident at one nuclear complex can have such an effect on so much of the planet is staggering, and this is without considering the potential for something to go wrong with the precarious spent fuel at Fukushima, that contains more than 5 times the Cesium and Strontium released by weapons fallout.

The officially-sanctioned ICRP model masquerades as being scientifically based. It is being used to underestimate cancer and other detrimental health risks of radiation exposure, misrepresent

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[35] Povinec, P. P., et al., "Cesium, iodine and tritium in NW Pacific waters – a comparison of the Fukushima impact with global fallout," August 15, 2013, Biogeosciences. http://www.biogeosciences.net/10/5481/2013/bg-10-5481-2013.pdf

[36] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2001). *Sources and Effects of Ionizing Radiation: UNSCEAR 2000 Report to the General Assembly,Vol. 1. Sources.* United Nations, New York.

[37] Casacuberta, N. et al., ^{90}Sr and ^{89}Sr in Seawater off Japan as a Consequence of the Fukushima Dai-ichi Nuclear Accident, Biogeosciences, 10, 3649-3659, 2013. http://www.biogeosciences-discuss.net/10/2039/2013/bgd-10-2039-2013.pdf

[38] Nero, A., A Guidebook to Nuclear Reactors, University of California Press, 1979. Table 3-1 provides 7.8 million Curies per 1000 MWe in a light-water reactor. Fukushima units 1, 2 an 3 that melted were 460 MW, 784 MW and 784 MW capacity, totaling 1956 MW. Assuming the cores were nearing the end of their life, the amount of Strontium-90 in inventory would be 7.8 million Curies (or 280 PBq) per 1000 MW. This is about 560 PBq for the 3 Fukushima cores.

nuclear accident risks, dismiss actual health findings, and excuse inadequate monitoring of the contamination levels.