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EVACUATION CRITERIA AFTER A NUCLEAR ACCIDENT: A PERSONAL PERSPECTIVE

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□ In any decision involving radiation a risk-risk or risk-benefit comparison should be done. This can be either explicit or implicit. When the adverse effect of an alternate action is less than the planned action, such as medical use of X rays or nuclear power in ordinary operation, the comparison is simple. But in this paper I argue that with the situation faced by the Japanese in Fukushima, the assumption that the risk of an alternate action is small is false. The risks of unnecessary evacuation exceeded the risk of radiation cancers hypothetically produced by staying in place. This was not realized by those that had to make a decision within hours. This realization suggests important changes, worldwide, in the guidelines for radiation protection in accident situations.

Key words: Evacuation, Nuclear, accident, radiation, risk.

BACKGROUND

There is an extraordinary large literature on the effects of radiation on health but surprisingly little on the effect on public health of an accident or of deliberate sabotage or terrorist attack. For example there is no discussion at all in the radiation protection handbook in Harvard University (Harvard 2002). Yet a proper understanding is crucially important for public acceptance of nuclear technologies. In this paper I examine some historical experience of radiation use and various accidents to show that the recommendations are overly complex and ignore problems other than radiation. I summarize from the enormous data pool at our disposal the facts that I consider to be important. The reaction to the Fukushima accident was incorrect and detrimental to sound public health. In this I use the perspective of a Risk-Benefit analyst who constantly compares the risks of an action (or inaction) with risks of alternative actions or inactions.

MEDICAL USE OF X RAYS

Very soon after Roentgen's discovery of X rays in 1895, physicians used them for diagnostic purposes. Although very early it was realized that they caused skin and other lesions, the fantastic ability to see within

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the body was so important that physicians correctly argued that the benefits of the x ray use overshadowed any harm. But this only addressed one part of the risk-benefit calculation. Others, physicists in particular, pointed out that the same benefit could be achieved with far less harm by more careful use of shielding, more sensitive film and so forth.

In the 1920s there was more interest in controlling the use of radiation. In 1927 the International Commission on Radiological Protection (ICRP) was formed. This is a non governmental body but most governments heed its recommendations. But the advice of ICRP and physicists was not fully heeded till about 1970. In l961 for example I had an (unnecessary) chest X ray at Stanford University and measured my dose. About 1 rem. Now the same X ray would take 7 mrem. But a CAT scan today is nearly 1 rem (0.1 Sv). In addition the US Environmental Protection Agency (EPA) realized that there is a risk posed by a number of radioactive materials in the environment. I found that the justification for the regulations they proposed was not well argued and in my public comments I proposed a justification based upon the health effects data (Wilson 2000a,b).

HIROSHIMA AND NAGASAKI: DISTINCTION BETWEEN ACUTE PROBLEMS AND CHRONIC PROBLEMS

The studies find a crucial distinction between the results of radiation exposure in a short period (integrated over a week or two) and the acute effects that it causes, and radiation over a long period of a few years and the chronic effects that causes. The acute effect of Acute Radiation Sickness starts with a reduction in white blood cell counts and can then lead to tissue damage. It is generally accepted that this occurs at radiation levels above 100 rems (1 Sv) with an LD50 (least dose at which 50% of people die) if 400 rems (4 Sv), (formerly believed to be 250 rems) which can be extended to 500 rems (5 Sv) by a blood transfusion. The first major example of a death from Acute Radiation Sickness was Dr Harry Daghlian who was exposed on 21 August 1945 in a nuclear criticality accident and died some days later. It is not always realized that prompt evacuation is only needed to avoid Acute Radiation Sickness (sometimes Acute Radiation Syndrome) (CDC 2011).

Hiroshima and Nagasaki provide the data from which effects of radiation are usually determined. As occurs with all chronic effects, they are determined at a high radiation level and a model is used to describe what happens at the lower level. A discussion of the underlying toxicology and the models it suggests was made in 1980 (NCRP 1980). But the usual (conservative) model suggests low dose linearity. This comes from the realization that if a medical outcome of a pollutant or action is indistinguishable from one that occurs naturally, any addition to natural incidence is proportional to the dose at low doses (Crump *et al.* 1976; Guess

et al. 1977; Crawford and Wilson 1996). Indeed this is also a consequence of the usual application of the multistage theory of cancer as described over 50 years ago (Armitage and Doll 1954). Scientists tend now to recognize a more general statement: Understanding effects at low doses cannot be separated from a general understanding of what causes the "natural" levels of cancer. It is vitally important for perspective to realize that this argument also applies to cancers caused by chemical pollutants also, and even to lung problems caused by air pollution – a fact not realized by most of the public and not incorporated into regulations (Crawford and Wilson 1996).

But there are assumptions and approximations. In the justification I used the word "indistinguishable". They must be biologically indistinguishable and not merely that a pathologist cannot distinguish. There is only one paper to my knowledge on this fundamental point. Cancers that occur after radiation therapy have a different DNA structure (Le Beau *et al.* 1986). Unfortunately there seems to be no interest in exploring this further either for radiation cancers or chemically produced cancers. The coefficient of the linear term is determined from data at high doses. Also the dose in Hiroshima and Nagasaki was over a short period and it is probable that doses over a long period produce smaller effects. There are animal studies that suggest a factor between 2 and 10 but only two data sets. The occupational doses at Ozerk in 1948 as the Russians were rushing to make a bomb before the "wicked Americans" killed them, (Shlyakhter and Wilson 1991; Shilnikova *et al.* 2003) and the Russians exposed at Techa River (Burmistrov, *et al.* 2000; Krestinina *et al.* 2005), after the waste pond overflowed. A detailed discussion of how toxicologists considered other dose response models can be found in an NCRP report (NCRP 1980) and in an ICRP report (ICRP 1990).

According to the above theoretical model, if someone gets a dose just below the LD50 he can still get chronic problems of which the most important is cancer. At an integrated dose of 200 rems there is a 10-20% increase in cancer probability. This depends upon a dose integrated over a long time - of the order of years. It can therefore rise well above 200 rems without causing Acute Radiation Sickness. The natural incidence of fatal cancers is about 20% so that no one who gets less than 100 rems will double his natural incidence and he cannot rightly claim that it is "more likely than not" that his cancer is due to radiation. Low dose linearity was used in the BEIR VII report to the US National Academy of Sciences/National Research Council (NRC 2006). Here I simplify their Table 1 as my Table 1. At 100 milliSievert, 0.1 Sv or 10 rems the increase in fatal cancer probability is 4% or 20% of the natural fatal cancer rate. The number of digits in each entry is high but they are not significant. Alas there is no easily available table where age is broken out.

TABLE 1. The table shows the estimated number of cancer and deaths calculated to result in 100,000 persons (with an age distribution similar to that of the entire U.S. population) exposed to 100 mSv (10 Rems). The estimates are accompanied by 95% subjective confidence intervals shown in parentheses that reflect the most important uncertainty sources including statistical variations, uncertainty in adjusting risk for exposure at low dosed and dose rates, and uncertainty in the method of transporting data from a Japanese to a U.S. population. For comparison, the number of calculated deaths in the absence of exposure is listed in Table 1; BEIR VII (NRC 2006).

	All Solid Cancer		Leukemia	
	Males	Females	Males	Females
Excess deaths from exposure to 100 mSv (10 Rems)	410 (200-830)	610 (300-1200)	70 (20-220)	50 (10-190)
Number of deaths in the absence of exposure	22,100	17,500	710	530

The radionuclides that are produced by nuclear fission are well known, as are their melting points and boiling points. A listing can be found, for example in Table 2 of the report of a study Severe Accidents at Nuclear Power Plants that was carried out for the American Physical Society (Wilson *et al.* 1985) reproduced here as Table 2. Most of the entries in this table are barely relevant to this argument. But I call attention to the isotopes of iodine and of cesium. The former is normally gaseous and is easily released and the latter, although normally solid, is soon evaporated in an accident. Only in the high temperature of a nuclear explosion would it be likely to emit large quantities of strontium, uranium or plutonium. Cesium unlike these chemicals, does not stay in the body and irradiates it roughly uniformly which simplifies the understanding. The last column of this table tells us the amount in the first 7 days after an accident. Unfortunately, although reporting on avoiding nuclear accidents, that committee did not explain how this table should be used in practice.

NUCLEAR POWER - NORMAL OPERATION

Physicists and engineers have for decades been urging careful use of radioactive materials. A modern nuclear power station emits very little radioactivity. Indeed it is often stated (correctly) that a coal fired power station in its particulate emissions emits more. Also the exposure to the plant workers can be kept low without sacrificing performance. Health physicists have set standards which are low and can be met with little cost. The benefit of a low radiation exposure is not limited by a high cost to the consumer of electricity. This leads to a very simple risk benefit calculation. Likewise the risk benefit calculation for laboratory use of radioactive materials is governed by such a simple risk benefit calculation with a reduction to a level "As Low as Reasonably Achievable" (ALARA) first

TABLE 2. Radioactive inventories and whole-body dose conversion factors (3200 MW$_t$_PWR) (Table II.B.3; APS 1985).

Radionuclides	Half-life t$_{1/2}$ (days)	Shutdown inventory (10^6 Ci)	Cloud D_c/χ_o (rem m^3/Ci s)	Inhalation, κ_i (rem/Ci inhaled) (0–50 yr)	Ground D_g/S (rem m^2/Ci)
Noble gases					
Kr-85	3950.0	0.56	0.475 $E-03$	0.310 $E+00$	
Kr-85m	0.183	24.0	0.364 $E-01$	0.260 $E+00$	
Kr-87	0.0528	47 .0	0.181 $E+00$	0.100 $E+01$	
Kr-88	0.117	68.0	0.467 $E+00$	0.230 $E+01$	
Xe-133	5.28	170.0	0.906 $E-02$	0.700 $E+00$	
X-135	0.384	34.0	0.567 $E-01$	0.120 $E+01$	
Iodines					
1-131	8.05	85.0	0.872 $E-01$	0.600 $E+03$	0.708 $E+03$
1-132	0.0958	120.0	0.511 $E+00$	0.700 $E+02$	0.107 $E+03$
1-133	0.875	170.0	0.154 $E+00$	0.200 $E+03$	0.311 $E+03$
1-134	0.0366	190.0	0.533 $E+00$	0.300 $E+02$	0.414 $E+02$
1-135	0.280	150.0	0.419 $E+00$	0.150 $E+03$	0.285 $E+03$
Cesiums and rubidiums					
Cs-134	750.0	7.5	0.350 $E+00$	0.470 $E+05$	0.369 $E+04$
Cs-136	13.0	3.0	0.478 $E+00$	0.590 $E+04$	0.410 $E+04$
Cs-137	11000.0	4.7	0.122 $E+00$	0.360 $E+05$	0.131 $E+04$
Rb-86	18.7	0.026	0.207 $E-01$	0.660 $E+04$	0.185 $E+03$
Telluriums and antimony					
Te-127	0.391	5.9	0.936 $E-03$	0.340 $E+02$	0.813 $E+00$
Te-127m	109.0	1.1	0.110 $E-02$	0.240 $E+04$	0.584 $E+02$
Te-129	0.048	31.0	0.147 $E-01$	0.980 $E+01$	0.198 $E+01$
Te-129m	0.340	53	0.783 $E-02$	0.300 $E+04$	0.246 $E+03$
Te-131m	1.25	13.0	0.314 $E+00$	0.550 $E+03$	0.960 $E+03$
Te-132	3.25	120.0	0.475 $E-01$	0.150 $E+04$	0.308 $E+04$
Sb-I27	3.88	6.1	0.151 $E+00$	0.790 $E+03$	0.920 $E+03$
Sb-129	0.179	33.0	0.268 $E+00$	0.110 $E+03$	0.104 $E+03$

defined numerically by the Nuclear Regulatory Commission in 1975 to cost less than $1000 per man rem (NRC 1975a, b) (This was upgraded recently both for inflation and political correctness to $20 per person Sievert). NCRPM also suggested a number 100 times smaller for occupational doses.

But when the situation in a power plant is not normal all changes. The habits, rules, customs about radiation exposure should change accordingly and the change should be automatic and instantaneous and therefore prepared in advance. Advance preparation would have avoided a problem stated in about 1979 by John Dunster when head of the UK Health and Safety Executive; "There is no politician who would not prefer a dead body to a frightened voter". There was obviously no advanced preparation at Fukushima. The need to balance risks is similar to the physicians' situation in 1900-1970.

WINDSCALE, THREE MILE ISLAND AND CHERNOBYL

There were three reactor accidents from which lessons can be learned. At Windscale in 1957 a plutonium production reactor caught fire and iodine was released. Short-lived radioactive iodine (^{131}I with 10 day half life) can make the major immediate hazard with a well-known chain. Iodine can fall to the ground and be eaten by cows where it concentrates in the milk and babies drink the milk and concentrate the iodine in the thyroid. This has been realized for 60 years and at the Windscale accident in the UK in 1957 the government impounded and bought all milk downwind for a month (McGeoghegan *et al.* 2010; Wakeford, 2007). (Curiously the cows produced twice as much as usual, although this increase is not usually attributed to radiation!)

No one knows exactly how much iodine was ingested at Chernobyl, but a lot. 2,000 children got thyroid cancer of which 20 have died. No one need have got thyroid cancer if it were not for secrecy. There are anecdotes (which I believe) that a school teacher near Hohnichi (Belarus) and an army general in eastern Ukraine were reprimanded by the KGB for advising children not to drink milk for a month (the half life of the iodine is 10 days or so) and thereby causing a panic (Shlyakhter and Wilson 1992). This was, and is, far less likely to happen in an open society in Japan.

There is disagreement about the effects of potassium iodide. If ingested before radioactive iodine exposure it can reduce the ingestion of the radioactive substance. But there are suggestions that if taken after exposure to radioactive iodine it can lock in the radioactive iodine already taken. Moreover, there are other side effects particularly for pregnant women so it is wise not to take it unnecessarily.

At Three Mile Island (TMI) in 1979 there was a partial meltdown but mostly contained. I can find no report of what happened to the iodine, but believe that it combined with water to form HI which was pumped out of the containment into the turbine building where it stayed quietly on the floor.

After Chernobyl in 1986 scientists confirmed that the important releases for the long term effects are ^{134}Cs (two year half life) and ^{137}Cs (30 year half life). The measurements of radioactivity deposition confirms that deposition and therefore emission of ^{90}Sr and the transuranic elements was much less, even though the initial explosion dispersed them locally. The subsequent graphite fire must have reached thousands of degrees and almost all the cesium was evaporated, and that the radiation from the ground deposition is the important pathway with ingestion only about 25%. Evacuation from Pripyat was delayed 36 hours and Chistallogovka 3-4 days. This delay raised public criticism. But prompter evacuation would not have changed the integrated dose much. Only at

Chernobyl, and in the plant, did anyone get Acute Radiation Sickness. No one in the general public did.

One important feature for perspective and public understanding is that the effects on health of these low levels of radioactivity are calculated, and not measured. The calculated number is too small to be directly measured. Indeed the number might be zero if the radiation cancers are not identical with those occurring naturally or might even be less than 0 (beneficial). This is described by the word hormesis. There is no hormesis for those washed out to sea in the Tsunami. Those who wish to dramatize the effect tend to stress the total number of calculated fatal cancers. Typical numbers discussed are 4,000-8,000 in the Ukraine, Belarus and European Russia countries and 20,000 worldwide. The latter is to be compared with the billion or so naturally occurring cancers in the world in that time period. But when an accident has occurred, and in discussion about how to manage its consequences, the dose to each individual is appropriate.

FUKUSHIMA: ADVERSE EFFECTS ON HEALTH OF DISLOCATION OR EVACUATION

It has been noted in the medical community for many years that there are stresses and problems associated with relocation that can lead by themselves to adverse effects on public health. In 1975 I saw figures of a 5% increase in cancer probability. I note that in an accident situation this would only be a calculated increase but in that sense is directly comparable to any increase in cancer rate due to radiation. It is hard to find good numbers and I merely refer to a recent review (Uscher-Pine 2009). She opined (Uscher-Pine 2009): "Despite the frequency of post-disaster relocation and evidence of its effect on psychological morbidity, there is a relative paucity of studies; the few examples in the literature reveal weak study designs, inconsistent results, and inattention to physical health impacts and the challenges facing vulnerable populations. Further research guided by theory is needed to inform emergency preparedness and recovery policy."

In the 1980s Dr Crouch and I were interested in the comparison of carcinogenic potency of animals and men. We looked at the unexposed "control" rats and mice from the US National Toxicology program. The rate of cancer varied many percent. For example we found that in some experiments the lights in the cages were on continuously and these were rodents with an elevated "control" rate. In the large study of 30,000 mice at the National Center for Toxicological Research (NCTR), the ED01 or "Megamouse" study (Littlefield and Gaylor, 1985; SOT 1981) there was a variation in response according to where the cages were. Those on the top shelf got tumors later than those on lower shelves. I presume that is because their stress was less. But what counts as stress for a mouse is unclear.

Similarly stress from divorce and separation, or even merely lack of a partner, has been blamed for a 15% increase in the probability of cancer fatalities (Kravdal 2001). I take 5% increase in cancer probability from relocation as a reasonable "lower limit" to the increase of cancer with the stress of evacuation.

The "official" Kemeny report (Kemeny *et al.* 1979) after the TMI accident stated (inter alia): "We conclude that the most serious health effect of the accident (for any reason) was severe mental stress, which was short-lived. The highest levels of distress were found among those living within five miles of Three Miles Island and in families with preschool children."

Anecdotes in Japanese media have noted unexpected deaths in the elderly who have been evacuated. Significant numbers of the elderly in shelters have died unexpectedly. Maybe the calorie intake is below starvation level and not all have three meals a day. Lack of hot food, running water, crowding, poor toilet facilities and lack of water for cleaning people and locations, lack of fuel and lack of hospitals to accept admissions, ambulances or medical services except what appear to be medical personnel who are themselves local victims. Yet there is no indication that these possibilities were considered by those ordering an evacuation! A simple calculation shows that this can far exceed any benefit evacuation may bring. A recent unconfirmed and therefore anecdotal news report that 300 people have died from the Fukushima accident from non-radiation causes in two townships emphasizes the possible problems.

DOSES FROM FUKUSHIMA

Armed with this information I looked at the measurements from Fukushima Daiichi. I first looked at the data on the radiation spike measured at the gate of the Fukushima complex and integrated it (Fig. 1) (GRS 2011). The releases on Friday, Saturday, Sunday and Monday were not serious. Indeed, associated with these early releases was a publicly shown photograph of the explosion showing that the wind was blowing out to sea. This by itself suggests that attention be given to careful timing of gaseous releases. The big doses were on Tuesday, 15 March 2011 and Wednesday, 16 March 2011. The spikes were probably doses from noble gases. The integrated dose was large enough for concern - 0.02 Sv (or 2 rems). But even this is less than one year of normal occupational dose and it should not have prevented a radiation worker from going to or being near the plant. Indeed the report to International Atomic Energy Agency (IAEA 2011) states that the average for all power plant workers as of 23 May 2011 was only 7.7 mSv or 770 mrems, which is about the amount of a CAT scan.

Starting on Thursday, 16 March 2011 the reactors and the spent fuel pools were being cooled by seawater, and there has been no comparable release since that time. Taking the usual decay of ^{134}Cs and ^{137}Cs into
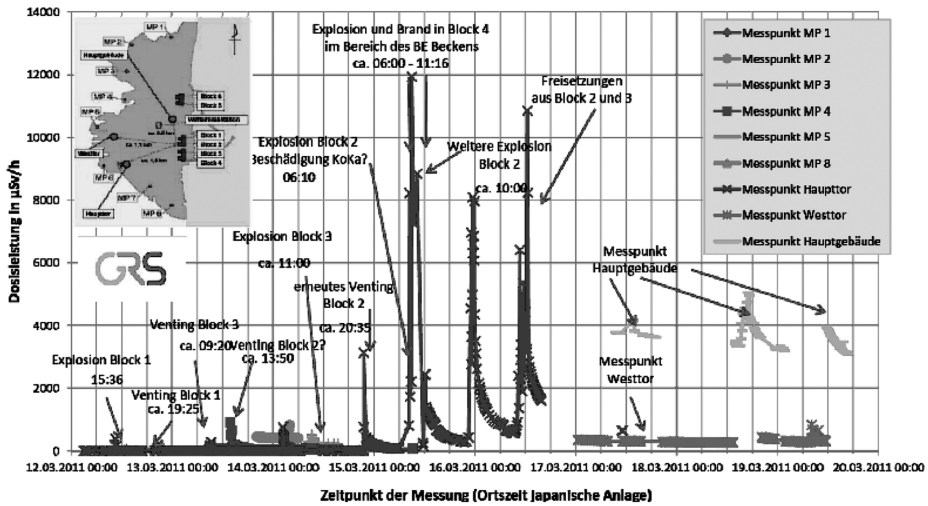
FIG. 1. Dose rates measured at main gate of Fukushima Daiichi (Figure 1; GRS 2011).

account one would expect an immediate drop, and my estimate would be for about 0.06 Sv (6 rems) at the main gate for the first year and falling more slowly thereafter. At three miles (5 km) this would be down a factor of 10. Although the details of who did what and why are confused, a fair independent source of information is available (INPO 2011)

I next looked at doses in the various other locations noted in the map of Fig. 2 They were listed by the Japanese Atomic Industrial Forum but the plots of the doses at these locations (Figs. 3 and 4) come from MEXT (2011) The newspapers emphasized the doses in the Ibaraki region on the way to Tokyo. The abscissa in that plot is μSv per hour. But the dose seems much smaller when the doses in the Ibaraki prefecture are plotted with a different abscissa and ordinate (Fig. 5). One μSv per hour, kept up for a year, would give 8,760 μSv, or 8.76 mSv or 876 mrems. What does this mean?

Many actions can give anyone a dose of 876 mrems:

• A single chest X ray in a major hospital as late as 1960.
• A CAT scan today.
• Seven months allowable occupational dose.
• 1/5 of what a Chernobyl clean up worker (liquidator) got.
• 1/100 of an astronaut's allowed dose.
• About the dose I got in 1991 from a day at Chernobyl mostly from inside the sarcophagus.

Any serious student should evaluate his own lifetime dose for comparison. I have been officially a "radiation worker" since 1946. Yet my integrated dose is almost all due to medical X rays – and I have no record of
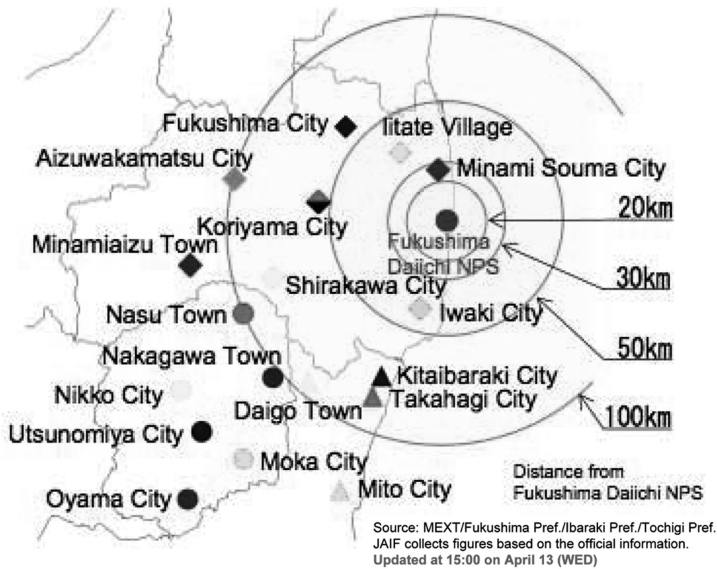
FIG. 2. Locations where Radiation Exposure was measured around Fukushima Daiichi NPS (MEXT 2011).
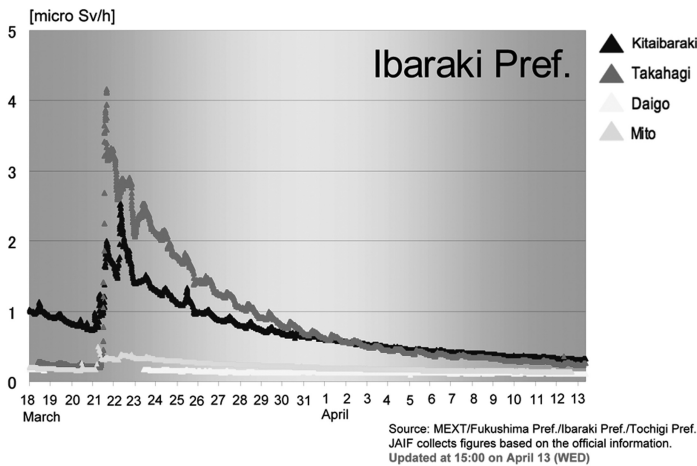

FIG. 3. Dose rate vs. time in Ibaraki prefecture (MEXT 2011).

these for the first 20 years and even now I have to keep the record myself. The American Nuclear Society has a website which enables a good estimate to be made online (ANS 2011). Ideally there would be such a program with the fatal cancer rates at different ages.

In the last year I received 2.4 rems (0.02 Sv). I believe it is absurd to evacuate to avoid this small a dose. Certainly evacuation should not be mandatory. Of course if we go further and consider age, evacuating an 85 year old for anything except Acute Radiation Sickness is really stupid. The graphs (Fig. 2, 3 and 4) from MEXT (2011) of radiation releases suggest
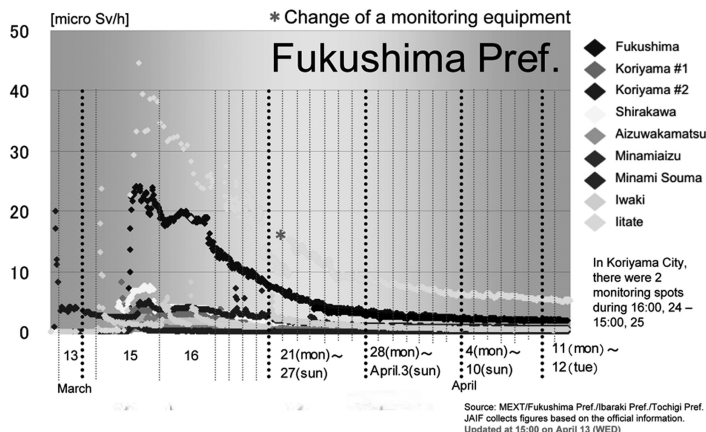
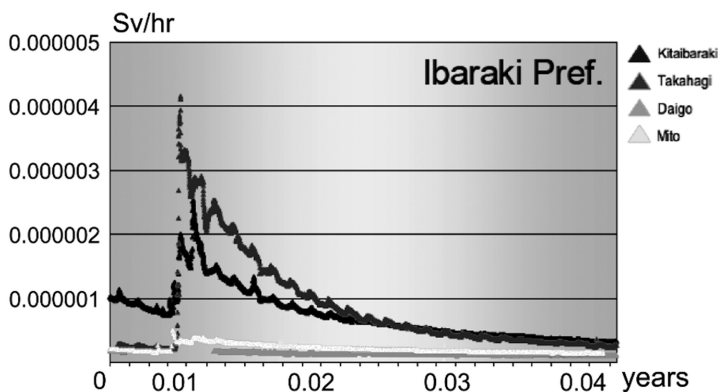**FIG. 4.** Dose rate vs. Time in Fukushima prefecture (MEXT 2011).

FIG. 5. Dose rate vs. time in Ibaraki prefecture with different ordinate and abscissa.

that no one in the Tochiki or Ibaraki prefectures should be concerned but naturally they will be interested.

For the area NW of the plant, the best description of the doses comes from the Ministry of Education, Culture, Sports, Science & Technology (MEXT 2011) in Japan.

Their map (Fig. 6) shows that the major deposition was to the NW of the plant toward Fukushima itself. MEXT integrated the doses to March 2012 using the usual model, giving the results shown in Fig. 6 and Table 3. The integrated doses are in milliSievert (mSv). The high-integrated doses are all in the Furaha County. Only one is higher than 0.2 Sv (20 rems) integrated to March 2012. These are for continued occupancy in the open. It can clearly be reduced by being indoors and by avoiding high dose hot spots. The lack of important doses in the south and southwest is clearly apparent.
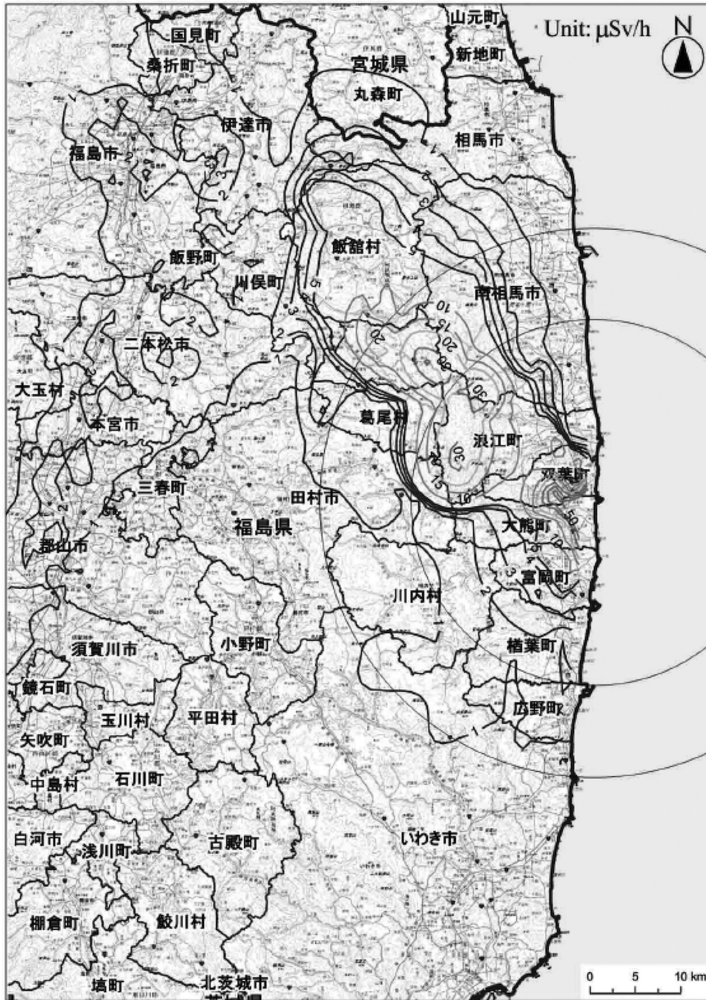
FIG. 6. Integrated radiation dose map of the area NW of the plant, in April 2011 (MEXT 2011).

For comparison 20 rems was the official dose allowed for the "liquidators" (clean up workers) after Chernobyl. According to the studies of effects of radiation (Table 1) this can add 1% or so to cancer probability. This is well below the variation in natural cancer incidence (up to 30%) from unknown causes.

There is no indication of any large deposition of either strontium or transuranic elements, which evaporate at a higher temperature, suggesting that the internal deposition by these elements can be ignored. From this MEXT used a theory to estimate the integrated dose to March 2011 shown in Table 3.

TABLE 3. Measurements at some specific locations with high exposures (MEXT 2011)

Name of Town	Location		Estimates of Integrated Dose	Latest Readings (Average)	Estimates of Integrated Dose as of March 11, 2012
	Direction	Distance	MSv	mSv/h	mSv
Akogi Kunugidaira, Futaba County	Northwest	24km	68.2	0.0374	224.9
Akogi, Ishigoya, Namie Town, Futaba County	Northwest	30km	37.1	0.0158	103.1
Akogi Teshichiro, Namie Town, Futaba County	Northwest	31km	32.9	0.0163	101.0
Onami Takinoiri, Fukushima City	Northwest	56km	3.8	0.0018	11.4
Aza Kitaaramaki, Hisanohama Town, Iwaki City	South	31km	1.0	0.0002	1.6
Takahagi, Ogawa Town, Iwaki City	South-Southwest	36km	0.6	0.0002	1.4

THE EVACUATION DECISION

The question the Japanese faced was whether and how much to evacuate. This decision had to be made within hours. They had not thought in advance. Then they panicked. It is unclear whether the evacuation was ordered by the government or merely suggested. But it was without analysis. But this is clearly understandable and forgivable given the history of radiation effects in Japan and the failure of the world community to provide guidance. Indeed for 30 years the world community has set guidelines which, I argue, are stupid.

They should have asked the questions:

- Is there an immediate reason to evacuate to avoid Acute Radiation Sickness? The measured doses give the answer NO. Indeed a subsequent independent report by INPO (2011) shows that the highest exposed worker received a dose 1/6 of the LD50.
- Would there be an appreciable increase in long term radiation dose by waiting a few days to analyze? Again the realization that Cesium was the problem would demand the answer NO.
- In retrospect was it sensible to evacuate people beyond three miles from the reactor, bearing in mind the competitive risks? I submit that here again the answer is NO.

- Would it have been wise to inform everyone and prepare for a voluntarily evacuation for those who wished it, which preparation could avoid the chaos that occurred in New Orleans after Katrina? Here the answer is definitely YES.
- Is there an adverse effect on health in evacuation? Here the answer is definitely YES although such effects are often ignored.

The answers at the end of each question are my own personal answers. I submit that the whole world nuclear power and safety community, including semi-political agencies like IAEA and the politicians themselves ponder the above.

American friends of the Japanese people should ask themselves the following questions:

- What is the role of friends who believe they are experts?
- Careful analysis along the lines of the early part of this report?
- Off the cuff remarks at a Senate budget hearing?

Dr Gregory B. Jaczko, Chairman of the Nuclear Regulatory Commission, gave the following testimony Jaczko to the US Congress on 17 March 2011: "Recently, the Nuclear Regulatory Commission (NRC) made a recommendation that based upon the available information that we have, that for a comparable situation in the United States, we would recommend an evacuation to a much larger radius than has been currently been provided in Japan. As a result of this recommendation, the ambassador in Japan has issued a statement to American citizens that we believe it is appropriate to evacuate to a larger distance up to approximately 50 miles." (Jaczko 2011)

This was repeated by President Obama, on Thursday, 17 March 2011, with the following news release: "President Obama made remarks from the White House Rose Garden on the nuclear crisis in Japan shortly after paying an unannounced visit to the Japanese Embassy. After expressing condolences to the Japanese people, the president confirmed calling for an evacuation of U.S. citizens within a 50 mile radius of the reactors in northeastern Japan." (Obama 2011)

These were unfortunate. I so stated in a formal *fax* to Dr Jaczko as soon as I saw the transcript but got no response I have been told that Jaczko was merely following an NRC rule: Keep the dose less than 500 mrems in the immediate accident and < 2 rems over the first year. I argue that the events at Fukushima demonstrate clearly how stupid, and counterproductive to public health, that rule is, and it becomes a matter of urgency to modify it.

RADIATION ACCIDENT MANAGEMENT

At Fukushima there was no proper management of radiation doses immediately the reactor situation was out of control (immediately after the tsunami). There seems to have been no realization in Japan, and probably no realization anywhere else, of the fact that radiation management after an accident should, even must, must differ from radiation management immediately before the accident.

Before TMI (before 1980) it was generally accepted that there were certain radiation levels that should not be exceeded. After TMI, and even more after Chernobyl the recommended levels were reduced. While it makes some sense to keep, for example, to 5 rems/yr (0.05 Sv/ yr) for a nuclear power worker in ordinary operation it is, I believe desirable to return to the higher figures as soon as an accident goes beyond normal operation. Thus it should be allowed for a worker to plan for 20 rems (0.2 Sv) for the whole accident, and indeed at Chernobyl 100,000 or more workers got this dose of 20 rems as "liquidators" (clean up workers). A one time dose of 80 rems (0.8 Sv) was allowed for an astronaut and for a rare individual "to save lives" 80 rems was allowed. It is reported that at Fukushima workers were pulled off the job in Sunday and Monday in the Fukushima accident before the Japanese belatedly restored the pre-1980 levels. This probably delayed a proper technical response to the accident. Although at all ages it is important to keep the radiation dose below that giving Acute Radiation Sickness, full use of older workers, particularly volunteers, should be taken. A person over 70 years old with a high accumulated radiation dose will develop cancer only after 20 years and then it is the least of his worries. (e.g. Harding *et al.* 2011)

It is unclear whether my recommendation of an immediate reversion to the pre-1980 radiation safety levels would have enabled the Tokyo Electric Power Company (TEPCO) to control the reactors any better in the crucial first day. I think they would and that is implied in INPO (2011).

A LESSER ISSUE: RESPONSIBILITY OF THE MEDIA.

News media have been the principal method of communicating with the public, and even with experts. At Three Mile Island, at Chernobyl and at the Tokyo incident the US media failed miserably and forgot their duty. Not one newspaper, nor Associate Press quoted the precise NRC press releases. None of the major newspapers even got the units correct. The Internet has improved this. Experts can find information directly. But there is still a responsibility to inform the public, and in particular to explain what the radiation dose levels mean, in terms of public health and to discuss the harrowing decisions those on the spot must make. In that I find the media lacking.

I next turn to accident prevention. The aim is to prevent the undesirable fission products ever coming into contact with the public. There are several barriers:

1. The fuel is in zirconium pellets which are in a zirconium tube. Although design criteria allowed 0.1% of these tubes to leak, probably none did before the accident.
2. If the first barrier fails, there is a pressure vessel which should hold them.
3. If the pressure vessel fails there is a containment vessel.

But, we must emphasize the importance of keeping barrier one intact if possible. Of course it is always important to stop an untoward event as early in the chain as possible. It is especially important because failure here makes it harder to control. In a Boiling Water Reactor (BWR) one can be close to the reactor in operation as I personally have been - one is shielded by the water in the pressure vessel. Once the first barrier fails, doses are higher outside the pressure vessel increasing radiation doses for a worker and making subsequent fixes harder.

MAN REMS (PERSON-SIEVERT) OR REMS MAN^{-1} (SV PERSON^{-1})?

In the preceding paragraphs I have emphasized the dose per person (rems man^{-1} or Sv per person) because that matches the decisions that I was discussing. Rosalyn Yalow, who won the Nobel Prize in medicine for radioimmunioassays repeatedly emphasized this in her lectures "Radioactivity in the Service of Man". But radiation protection experts frequently calculate the collective dose in Man-rems (or Person-Sieverts) because when using a linear dose response relationship and multiplying by the appropriate slope (coefficient) this gives the total societal impact. I do this for the next section on comparing disasters and also take a more optimistic slope allowing for a dose rate reduction factor.

COMPARISON TO OTHER WORLD DISASTERS

The effects of evacuation or not evacuating should be compared to 15,000 dead, and 15,000 missing direct, measurable and definite "dead bodies" from other earthquake and tsunami problems (Table 4).

My rough guess is that one can calculate (but never measure) 500 fatal cancers from radiation from Fukushima (originally my incorrect prediction was close to zero. But it could be zero or even slightly negative.). However Richard Garwin has recently calculated a figure of 5000 worldwide.

I emphasize that the calculated cancers are within the fluctuations of the natural cancer numbers and cannot ever be directly measured.

TABLE 4. Estimated Number of Deaths Compared to Other World Disasters.

Cause and Event	Estimated Number of Deaths
Fatal Cancers from Natural Background Exposures [1]	10,000,000 per year
	300,000,000 in average half lifetime
Arsenic Poisoning in Bangladesh [2]	500,000 from exposures 1970 to date
Earthquake in Haiti	200,000
Earthquake and Tsunami in Japan [3]	30,000
Fatal Cancers from Chernobyl in the Next 60 years [4]	7,500 in Belarus, Russia and Ukraine
	20,000 − 30,000 worldwide
Fatal Cancer from Three Mile Island [5]	0.7 total
Adverse Health Effects Due to the Evacuation Around Fukushima	5,000 upwards

[1] Including medical exposures; on a worldwide basis.
[2] Assuming everyone have pure water.
[3] Prompt deaths.
[4] Calculated excluding effects of stress.
[5] Calculated for the Kemeny Commission.

MY RECOMMENDATIONS FOR STUDY OF RADIATION EMERGENCIES

I have argued since 1980 that there should be detailed study of a number of fundamental issues. (These should be for other pollutant substances and actions also.)

1. Before 1980 the US Nuclear Regulatory Commission asked for an "Emergency Planning Zone" (not an evacuation zone) of 10 miles diameter. After TMI this became an "evacuation zone" without the detailed discussion such a decision requires. I, personally, was opposed to this implication for automatic evacuation, and testified to the Ontario Royal Commission and others that it was a mistake. I strongly urge the International Community to reexamine this requirement.
2. One should similarly reconsider the requirements for reentry into an area with higher than usual radiation levels after an accident.
3. Are cancers caused by radiation truly indistinguishable from naturally occurring cancers? Or is it just that a pathologist cannot distinguish? (use DNA analysis). Even if this were only done for another pollutant such as arsenic there would be an increased understanding of low dose effects.
4. What is the effect of dose rate? (I urge a careful look at such data as the Techa River and the Mayak workers)
5. What is the effect of disaster stress on cancer? In people? In animals?
6. Can one design a fuel cladding which does not oxidize and therefore does not release both hydrogen and energy?
7. Scientists must continually remind the public and public policy specialists about the effects and lack of effects about radiation. 40 years ago as nuclear power began to enter the world energy system, anti-nuclear activists took the stage. Their dramatic assertions of utter disas-

ter tend to dominate the media. It is important to publish detailed refutations of their extreme arguments. Ideally newspapers would do this but they do not. An example is the paper by Shihab-Eldin *et al.* (1992).

IMPLICATIONS FOR THE FUTURE

The need to reconsider the change the procedure in a risk analysis for the consequences of a serious accident after it has taken place should clearly be part of the training of every person operating a nuclear power reactor and health physicists on duty. But there is another implication. The world is concerned about possible release of a dirty bomb or radioactive dispersal device (RDD) or even a nuclear bomb itself by a terrorist, whether a state actor or non state actor. If it can be made clear to the public, including potential terrorists, that the effects of radiation release can be limited, such a procedure and target can be less attractive to a terrorist. It is also vital that every group of first responders have AT LEAST one person who understands radiation and is not afraid of entering a high radiation area.

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