

How can we judge the radiation level?

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(Japanese: <http://www.irf.se/~yamau/jpn/1103-radiation.html>)

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Remarks: This guide is based on personal views of Dr Masatoshi Yamauchi, physicist. This guide is provided to support individuals on decision making and in no way is this to be taken as governmental standards. Information irrelevant to citizen safety (regarding a request to Japanese authorities and experts) is not translated. The summary and notes were reviewed by the original author and the contents were updated as of 6th April 2011. So this English version does not correspond in entirety to any Japanese documents provided by the original author. Any mistakes caused by translation and editing shall be attributed to translators and editor, not to the original author.

[original information]

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=== Old texts (in Japanese) are <http://www.irf.se/~yamau/jpn/1103-radiation2.html> (25th March to 4th April 2011) and <http://www.irf.se/~yamau/jpn/1103-radiation1.html> (18th-24th March 2011). ===

While Japanese governmental bodies such as National Institute of Radiological Sciences (NIRS: a part of Nuclear Disaster Countermeasure Office) announced “current radiation level is NOT critical,” they have not shown the criterion when one has to take action (**Red and Yellow Levels**). This makes people feel unsafe because just saying "safe" without showing criterion is not regarded as "proper information." For example (my work's case), we can operate satellites normal time because we know when we should switch off the satellite (this is the way we have the space-weather). So, I roughly estimated the **Red Level and Yellow Level against the real-time radiation measurement** and wind information (The most critical region is measured by Ministry of Education, Culture, Sports, Science and Technology (MEXT)). Since under critical situation the criterion must be comprehensible for ordinary people who do not understand the technical data very well, **this is a VERY ROUGH criterion for a worsening situation or a sudden incident** (as of 28th March 2011). In case some non-critical but high radiation level (e.g., a few micro-Sv/hour) continues for more than 3 weeks (≈500 hours), we need another guideline.

Red Level: One must take an action immediately.

Yellow Level: One must start preparing for an action.

Explanation follows after the summary.

For evacuation from residence

- (1) Red Level (adult): **Local radiation level** reaches at 1,000 micro-Sv/hour (= 1 milli-Sv/hour).
 - (2) Yellow Level (adult): **Local radiation level** reaches at 100 micro-Sv/hour (= 0.1 milli-Sv/hour).
 - (3) Red Level (Pregnant and children): **Local radiation level** reaches at 300 micro-Sv/hour (= 0.3 milli-Sv/hour) or **local radioactive dust level** reaches at 500 Bq/m³.
 - (4) Yellow Level (Pregnant and children): **Local radiation level** reaches at 30 micro-Sv/hour (= 0.03 milli-Sv/hour) or **local radioactive dust level** reaches at 50 Bq/m³.
 - (12) Yellow-Red Level: Daily baseline at the time of first week of April keeps 15 micro-Sv/hour for adult and 5 micro-Sv/hour for children.
- => * It is safe in general if local radiation level quickly increase to 3~10 micro-Sv/hour for adult (1~3 micro-Sv/hour for pregnant or children) unless this level continues more than 10 days.

For sheltering indoor, preferable concrete building (No need to evacuate from the shelter)

- (6) Red Level within 100 km downwind region from the nuclear site: Radiation level **near the nuclear plant** exceeds 50 milli-Sv/hour. Even outside the 100 km zone, one should watch the recent update.
- (7) Yellow Level within 100 km downwind region from the nuclear site: Radiation level **near the nuclear plant** increases more than 5 milli-Sv/hour. Even outside the 100 km zone, one should watch the recent update.
- (9) Red Level within 100 km radius from the nuclear site: Explosion event at the nuclear plant (e.g., hydrovolcanic explosion or hydrogen explosion). Even outside the 100 km zone, one should watch the recent update.

Supplement

- (5) If the radiation level near your residence is highest among the other points, the Red Level criterion for (1) and (3) should be reduced by 50%.
- (8) Yellow Level zone, you should avoid going outdoor in the morning/evening hours when the wind dies. The same applies for foggy weather.
- (10) System for Prediction of Environmental Emergency Dose Information (SPEEDI) simulation is hopeless for any future event because it calculates the past event only.
- (11) Do not take too serious about any simulation result (prediction) because they are very erroneous.

Explanation

§1: How to judge the radiation level that keeps changing:

Though various institutions estimated the upper values, it is problematic since they are accumulated amount. Actually the measurement values are those per hour. For the time being, let us take the figure of overall accumulated amount of 100 milli-Sv (Sv stands for Sievert). This value is the government / Tokyo Electric Power Company (TEPCO) standard that is considered acceptable for nuclear industry workers in emergency (Japanese government rose to 250 milli-Sv only for this time. Just for your information, international standards are 500 to 1,000 milli-Sv for nuclear industry workers and 20 to 100 milli-Sv for general citizens). This value is also the one with which scientific research shows that adult excluding pregnant female do not have large health risk when they are exposed (See review article by R. L. Brent (2009)).

It is appropriate to calculate the values at risk by dividing by 100 hours to consider the worse situation since it takes around half a day to one day between the time of evaluation and the time of recognizing deterioration around residential area (due to time loss already caused by sleeping and so on). You obtain 1 milli-Sv/hour by dividing 100 milli-Sv by 100 hours.

(1) When local “effective value” of radiation reaches 1,000 micro-Sv/hour (= 1 milli-Sv/hour), one should evacuate from the residence immediately = Red Level.

However, taking action after reaching this value means panic behaviors. It is considered that there are a couple of days to evacuate, by taking precautionary measures at an error-level of one order, suggested by fluctuation range so far. In other words, it is rational to take action when the radiation level exceeds the level of 10% of the value at risk.

(2) When local “effective value” of radiation reaches 100 micro-Sv/hour (= 0.1 milli-Sv/hour), one should start preparing evacuation from the residence = Yellow Level.

These values are the same as those listed in guideline (p. 57) of National Institute of Radiological Sciences, as well as US standard on instruction of emergency state and alert when radiation is detected on nuclear power plants (not residential area; See p. 88 of paper prepared by NSC).

Because Yellow Level becomes the value at risk when it remains for a long time, it is advisable to consider evacuation when Yellow Level continues for more than 10 days. It is also needed to consider evacuation when high level of radioactive ray remains if not Yellow Level, since it is not feasible to keep confining yourself indoor, but this issue is out of scope of this paper.

§2: Special consideration for pregnant and children:

NIRS, which is accident countermeasure headquarters, says 100 milli-Sv (accumulated amount) is enough to avoid health risk, but it is not precise. The above mentioned review paper of R. L. Brent (2009) shows that more than 1% of unborn children will be affected by 100 milli-Sv (accumulated amount). That is, this amount is not a value based on level of safety, but a value of risk over which statistically significant difference is observed. Then, to what degree safety allowance is needed compared to the case of adult? Figure 4 of the article depicts that value at risk in earlier period of pregnancy becomes low for certain disability: A baby suffers from the same disability with the 30% of radioactive ray compared to the value at risk in latter period of pregnancy (By the way, it seems there is no difference during late period of pregnancy to the period of adult). This follows it is rational to take 30% of the value at risk for adult case (30 milli-Sv) as a rule of thumb. It is rational to treat children as the unborn children during the early period of pregnancy since the risk of suffering from thyroid cancer gets high (the risk for children is higher than those for unborn children during the early period of pregnancy when it limits to thyroid cancer). Therefore

(3) Pregnant women and children should evacuate from the residence immediately when “effective value” around residential area reaches 300 micro-Sv/hour (= 0.3 milli-Sv/hour) = Red Level.

(4) Pregnant women and children should start preparing evacuation from the residence when

“effective value” around residential area reaches 30 micro-Sv/hour (= 0.03 milli-Sv/hour) = Yellow Level.

It is advisable to seriously consider evacuation when Yellow Level remains more than 10 days, as the case of (2).

In other words, you may be safe when the radiation levels are smaller than 10% of the values indicated in (2) and (4), i.e. 10 micro-Sv/hour for adult and 3 micro-Sv/hour for pregnant female in her early period of pregnancy, around the place of residence. It can be understood that in general the younger (the more active in cell division and ingesting nutrition) the person is, the more serious the effects of radiation to the person are.

So far I used “effective value,” which is higher than observed values. Measured value of radiation shows only radiation emitted from radioactive dust suspended outdoors, and does not include additional exposure caused by inhaling the dust. The report (p. 109) of NIRS reads that when the concentration of radioactive iodine (I-131) is 100 Bq/m³, the amounts of exposure via respiration are around 40 micro-Sv/hour (= 0.04 milli-Sv/hour) for 10-year-old child and around 20 micro-Sv/hour (= 0.02 milli-Sv/hour) for adult, respectively. In other words, the dust concentrations at risk corresponding to Red Level in the above (1) and (3) are 500 Bq/m³ for child and 5,000 Bq/m³ for adult, respectively (It is advisable to take safe values for child in this case). The challenge is the difficulty of measuring dust concentration. Although MEXT and Fukushima prefecture are monitoring, the number of monitoring posts is very insufficient (in particular for the area of high concentration). So far no solid relation exists between the density of radioactive dust in the air and the radiation level. For the time being, the rough empirical rule between radiation amount and dust amount officially disclosed reveals that the amount of radioactive ray that corresponds to 10 Bq/m³ of radioactive iodine (I-131) concentration is around 3 to 100 micro-Sv/hour. This amount is not serious for adult, but there is a possibility that the effect of inhaling dust affects more in case of child.

There is another remark for observation values of radiation. That is, the radiation value at a place of resident may not be the same as that at a place of observation. Moreover, the observation of MEXT shows that there is a large difference of radiation in a small distance and is found particularly in areas where high radiation is observed. For instance, fixed monitoring points 32 and 34 (only 3 km distance between the two) that are on the 30 km radius from the nuclear power plants show more than five times difference both in snap-shot value on 19:00 25th March 2011 and in integrated value during 23rd to 24th March 2011. The area of localized high concentration extends northwestern and southern directions from the nuclear power plants. In these areas, two times difference shall be taken into estimation between the value at a place of resident and the value at the nearest monitoring post (The error will be reduced since MEXT is studying the dangerous areas). Therefore it can be said as follows:

(5) If the radiation level near your residence is highest among the other points, the Red Level criterion for (1) and (3) should be reduced by 50%.

No change in the Yellow Level condition because MEXT shall initiate detailed measurement at Yellow Level area.

§3: Explosion or some incident at the nuclear plant:

The problem of Chernobyl accident was not direct emissions from the accident site, but

radioactive ray emitted from highly concentrated radioactive eruption cloud that were generated at the site and were moving. Fukushima Daiichi nuclear power plant has a similar risk (explosion at lower level or release of dense radioactive dust) in the future. Furthermore, any types of dust are naturally localized, making dense spots in the dust stream during the diffusive expansion from the plant up to the wind zone (> 100 m high) as well as during the transport by the wind. Therefore, we need to estimate the radiation risk by the dense radioactive dust that is carried by the wind.

In many cases, the wind steadily blows with quite large a speed when altitude is higher than 100 m in contrast to the ground surface (The reason that we do not feel the wind in the mountain is the place we stand is the ground surface however the altitude is high). In that case, the estimation of 10 m/second (around 40 km/hour) at the altitude higher than several hundreds of meters (the altitude the dust could reach) is appropriate (whereas maximum speed of the wind at 10 km height is 50 to 100 m/second). At this speed of the wind, highly concentrated radioactive dust does not diffuse, emitting radiation, for several hours (though it depends on the dust size). It does not decay by inverse-squared or inverse-cubed (it completely differs from the case of vacuum). For instance the smoke emitting from a chimney shows, on a day of weak wind (less than 5 m / second at the height of the chimney), the narrow part of the sausage-like smoke becomes clearer as the distance from the source, and hence you will see the highly concentrated portion does not diffuse very much compared to the distance from the source. In fact, the MEXT observation results (shown above) endorse the strong gradation of concentration.

Since this kind of high-density dust emits high level of radiation at the nuclear power plant, this anomaly will immediately be reported, giving people at the downwind region time for escaping to shelters nearby. The time-lag (for information reporting) is estimated two hours (= 80km) for foreigners and less than one hour for Japanese native speakers (= 30km). Of course, there might be reasoning that wider area of evacuation implies more people that shall be compensated by the national government later, but such political and court procedural examination is not made in this paper.

How can one know the downwind area in such a situation? The difficulty is that the wind directions differ by altitude; the direction on the ground surface could be completely opposite from that at 2000 m high in the worst case. The easiest way is to locate radiation measurers (simple dosimeter suffices) with 0.5 to 1 km interval along with circles that have radiuses of 10 km, 20 km and 30 km from the nuclear power plant site, for real-time monitoring of radiation. However, though three weeks have passed since the incident occurred, this kind of simple system has not been developed, nor NSC (which seems to have absolute authority to command scientists on radiation diffusion issue) did not claim to develop such system.

Fortunately, the dust height is not very high according to the analyses of the past events and trend. Therefore, we can use the surface wind measurement, with no more than 120 degree uncertainty in the direction. This is the second alternative. For example, one can rely on the Automated Meteorological Data Acquisition System (AMeDAS) that monitors the wind at ground in 25km x 25km mesh nearly real-time basis. Considering the Ekman spiral, i.e., that the wind direction gradually rotates clockwise from the ground to around 1 km up, downwind direction stretches from 90 degree clockwise to 30 degree anticlockwise against the wind direction at the ground.

However, AMeDAS is not always available at hand because you need high-speed network. In such a case, one should take the third alternative: existing forecast system. Japanese Meteorology Agency started to give the forecast from 5 April. Problem with such a simulation (prediction) is that the result strongly depends on uncertain assumptions, and it is better to compare with different similar simulations by foreign laboratories are informative. Simulation results of the whole Japan are provided by Dr. Andreas Stohl (an expert of atmospheric pollution simulation) of the Norwegian Meteorological Institute (<http://transport.nilu.no/products/fukushima>), Austria's national meteorological authority (<http://www.zamg.ac.at/aktuell/>), the German Meteorological Agency (<http://www.dwd.de/>), or France's Institute of Radioprotection and Nuclear Safety (<http://www.irsn.fr/EN/Pages/home.aspx>), and so on. For example, this shows where the dust reaches.

As mentioned above, you can see that the agglomerated dust flows a quite long distance with maintaining the shape. The forecast of the Norwegian Meteorological Institute is based on the wind direction forecast of the Norwegian Meteorological Agency (<http://www.yr.no/>) (for example, this is for Tokyo). Please note that all simulations include some sorts of assumptions that make accurate forecasts impossible. In particular, forecasting the destination and density of dust clouds is far more difficult than weather forecasts. For example, changing assumption of the maximum height of the dust will totally change its destination. As a matter of fact the above four simulation results conflict with each other. This is why observed data must be regarded as the most reliable basis. Particularly when sea wind or land wind is prominent (except for the case of soaring dusts such as explosion), mean of past wind records (mainly north-west) must be paid more attention to than wind direction forecast. Ambiguity associated with forecasts or calculations are prominent in quantity. For example, Austria's national meteorological authority forecasts quantity of radioactive substances, but you should not pay too much attention to this sort of simulations as it is common practice to somewhat overestimate (to be mentioned below). What is important is observed value.

Well, what is the level of radioactivity at the Fukushima Daiichi nuclear power plant that should urge us to evacuate indoor? The critical level is 50 milli-Sv/hour for 2 hours even if the radioactive dust that flew quickly strays around residential area due to morning or evening lull. That is, (6) if the radioactivity level exceeds 50 milli-Sv/hour around the nuclear power plant, persons within 100 km downwind should evacuate indoor (if possible under shelter made of concrete: Note 4), and persons outside 100km also need to pay frequent attention to local radioactivity level information (= Red Level). Basically, you do not need to evacuate from your living place. Unless unexpected explosion occurs, decide your action following (1) - (5) according to the situation.

How about the alarming level of radioactivity? In this case, we have to take into account that there is only one monitoring point at the plant. The high radioactive cloud is a local phenomenon and we need to allow a margin of error at the order of one. Accordingly, the alarming level becomes 10% of the critical level, i.e. 5 milli-Sv/hour. However, this level of radioactivity cannot be distinguished from direct radiation from the accident sites. For such a case it is common to use the range of fluctuation. That is, (7) if the radioactivity level at the plant suddenly changes by more than 5 milli-Sv/hour, persons within 100 km downwind should evacuate indoor (if possible under shelter made of concrete: Note 4), and persons outside 100km also need to pay frequent attention to local radioactivity level information (= Yellow Level). In

addition, the same as the measures to smog, (8) if the living place is with Yellow Level, refrain from going out under morning or evening lull (or foggy weather) (= Red Level). Because nobody knows how fast the dust can accumulate. In fact, rainy condition will significantly reduce external exposure risks (unless you are in direct contact with the rain) as rain removes dusts, but it makes soil and water examination necessary.

On the other hand, if some explosion (phreatic explosion or hydrogen explosion) occurs, it is unpredictable how high radioactive dusts would soar. This point is apparent from the fact that first and second hydrogen explosions, which were said “without radioactive substances”, were very likely associated with a huge amount of radioactive dusts. Thus, if explosion occurs at the plant, the downwind area is unconditionally red-signaled. Further, all directions are in danger as the wind direction differs at different altitude. Consequently, (9) if some explosion (phreatic explosion or hydrogen explosion) occurs at the nuclear power plant, persons within 100 km downwind should evacuate indoor (if possible under shelter made of concrete: Note 4), and persons outside 100 km also need to pay frequent attention to local radioactivity level information (= Red Level).

§4: What if non-critical but high level of radiation continues for a long period?

This type of radiation most likely comes from the ground (via fallen-dust) rather than floating dust in the air. In fact, the SPEEDI calculation that was published on 23rd March 2011 assumes all radiation comes from the polluted soil by the radioactive fallen-dust. This is one of the reasons that SPEEDI simulation gave unrealistic values by one order of magnitude off. Furthermore, SPEEDI is not responding any new massive release of the radioactive dust from the nuclear plant. In other words:

(10) System for Prediction of Environmental Emergency Dose Information (SPEEDI) simulation is hopeless for any future event because it calculates the past event only.

(11) Do not take too serious about any simulation result (prediction) because they are very erroneous.

Anyway, the constant high-level of radiation mainly in the north-west region means that the radiation level there will not decrease easily! A rough model using single time-constant exponential decay gives estimate of total dose that would be received from the current level of radiation. By assuming I-131 (8-day time-constant), a 10 micro-Sv/h on the first week of April (average value) gives as much as 40 milli-Sv in total in the worst case. This dose already exceeds the allowance for pregnant or children. A better estimate should wait until the examination of soil is over, and that could be too late. Therefore,

(12) If the daily baseline at the time of first week of April remains at I-131 levels of 15 micro Sv/hour for adult and 5 micro-Sv/hour for children, one should evacuate from the residence.

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Comments and advice on mistakes would be greatly appreciated.

Final comment: Take it easy! Frustration would result in misjudgment.

Note 1: Regarding unit (Gy and Sv)

$$\text{Sv} = Q \times \text{Gy}$$

In most cases, $Q=1$. However, in the case of neutron near the source (such as near nuclear plants and radioactive dust), $Q=10$ (the value depending on energy).

Note 2: The NSC finally proposed “criteria of judgment for the necessity of evacuation and in-house evacuation based on the measurement of the MEXT” on 25th March 2011, and has publicized the results of the measured value since 26th March 2011. Summing up, this gives a Red Level to the value, which the limit value of radiation exposure (set as 10-50 milli-Sv) is divided by 84 hours.

Note 3: The purpose for indoor evacuation is to avoid both external exposure and internal exposure (inhalation of radioactive dusts). According to the questions and answers provided by Disaster Prevention and Nuclear Safety Network for Nuclear Environment under the Nuclear Safety Division, MEXT and page 94 of the document issued by NSC, if windows and doors are properly shut, staying in inside wooden buildings can moderately avoid radioactive dust for a short period of time (reduced by 1/4), but this statement seems overestimated in terms of sheltering effect. However, the same situation cannot prevent from radioactive exposure emitted from the dusts outside the buildings. While estimation of sheltering effect of concrete buildings seems more appropriate: it can reduce the external radioactive exposure by 1/5. The aforementioned sources of information do not provide information on buildings’ capacity to shut down the amount of radioactive dusts over the long period of time (more than one day). It is not realistic to consider that wooden building can reduce the amount of radioactive dust intrusion by 1/4 over an extended time period (The NSC does not make any examination about this matter).