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Radiological Consequences of the Fukushima Event via Water Pathways

Background on dose calculations for fish and seaweed consumption

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Preface

In connection with the accident in Fukushima

- large amounts of highly contaminated water seeped through the structures of the buildings of Unit 2,
- collected on lower levels of the reactor buildings, and
- made their way to rooms on lower levels of the turbine building.

From there, a large amount of the liquid has escaped and made its way to the shore and into the Pacific.

The contamination so reached the sea and spreads there. In the sea, the dissolved radioactive substances, mainly Iodine-131 and Cesium-134/-137, subsequently are enriched in different bio material. Among those are fish and seaweed. As these can be consumed by men, this can cause doses to people.

This paper

- quantifies the data, that is measured by TEPCO, and
- adds calculated doses for selected pathways, and
- draws conclusions from this data and doses in respect to short- and longer term consequences.

1 The sources of the contamination in the Pacific

The water that has collected on the lower levels of the reactor building and the turbine building of Unit 2 stems from different sources, their individual contribution is by now still unknown:

1. Large amounts of water were fed by different means into the reactor core to cool the fuel. If the reactor, the surrounding steel containment, primary coolant pipes and/or the heat exchangers have leaks, part or all of the cooling water can escape. This water would be slightly contaminated, if the fuel is intact or highly contaminated, if the fuel is damaged.
2. Large amounts of water were thrown onto the fourth floor of the buildings, by helicopters and by fire-fighting canons, in order to increase the liquid level of the fuel storage ponds located there to cool and avoid the meltdown of the stored fuel there. Large portions of the water, if not most of the thrown water, did not reach the pool. This water can only take up radioactive substances that were present on the surfaces of the buildings (e. g. activity thrown out during venting and remained on surfaces within the building).
3. Leaks in the spent fuel pools and subsequent water losses from there cannot be excluded. Depending from the state of the fuel in the pool and its grade of damages, the water from that source can be from slightly up to highly radioactive.
4. The pool's water level later was maintained from the outside of the building with a concrete crane. Depending from the visibility during those operations, overtopping cannot be ex-

cluded. Activity concentrations in that case are also depending from the stored fuel's integrity.

5. Other sources of water which increases the total volume are the diverse liquids that are in the facility during normal operation, some of which are slightly or medium radioactive.
6. Rain fall adds to this, but contributes only in the longer term water control in the facilities. Rain fall at the site is only slightly radioactive, but adds to the collected volume and doesn't add much to the concentrations.

The analysis of the liquids in the turbine building of Unit 2 shows the following results.

Table 1: Analysis results for water in the turbine building of Unit 2 of the Fukushima Daiichi Plant

Nuclide	Water in the Turbine Building, in Bq/m³
I-131	1.3E+13
Cs-134	2.3E+12
Cs-137	2.3E+12
Sum	**1.8E+13**

Source: TEPCO file 110327e15.pdf, samples taken 27.03.11, only major and plausible nuclides selected[1]

This concentration is roughly one order of magnitude[2] lower than the IAEA's definition of High Active Waste, and it is in the upper region of Medium Active Waste.

But not only the liquids that have collected underneath the turbine building are radioactive but also the liquids in underground structures called sub drains. Tables 1a and 1b show the results of the analysis, as published so far.

Table 2a: Analysis results for water in the sub drain of the Fukushima Daiichi Plants[3]

Nuclide	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
	Bq/m³					
I-131	4.3E+08	8.0E+07	2.2E+07	n.d.	1.6E+06	2.0E+07
Cs-134	5.2E+06	7.0E+05	1.0E+07	n.d.	2.5E+05	4.7E+06
Cs-137	5.9E+06	6.3E+05	1.0E+07	n.d.	2.7E+05	4.9E+06
Sum	**4.4E+09**	**8.1E+07**	**4.2E+07**	**-**	**2.1E+06**	**3.0E+06**

Source: TEPCO file 110331e18.pdf, samples taken 30.03.11, only major and plausible nuclides selected

[1] After nuclide data had been reported repeatedly wrong and weren't reliable and qualified, TEPCO was urged by the responsible governmental agency to only report on those nuclides for which enough reliability can be guaranteed. As this paper is centred on doses and concentrates on those that contribute relevant to doses, we decided to report only the three relevant ones and not to report and discuss on those nuclides where obvious errors were made.

[2] "One order of magnitude" means a factor of 10, two orders a factor of 100, etc.

[3] Sorry for the readers that didn't follow IUPAC and other international rules, regulations and recommendations and didn't change from Marie C. to Henry B.: 1 Bq = 27 pCi, 1 Sv = 100 Rem, 1 km = 0.62 miles

Table 2b: Analysis results for water in the sub drain of the Fukushima Daiichi Plants

Nuclide	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
	Bq/m³					
I-131	4.0E+08	6.1E+08	3.6E+06	1.7E+07	1.6E+05	1.9E+05
Cs-134	5.3E+07	7.9E+06	1.0E+07	2.7E+06	2.7E+05	2.6E+05
Cs-137	6.0E+07	9.1E+06	1.0E+07	2.7E+06	2.8E+05	2.8E+05
Sum	**5.1E+08**	**6.3E+08**	**2.4E+07**	**2.2E+07**	**7.1E+05**	**7.3E+05**
1b / 1a	**0.12**	**7.78**	**0.57**	**-**	**0.34**	**0.24**

Source: TEPCO file 110414e18.pdf, samples taken 13.04.11

Between the two sampling dates, the concentrations in the sub drains of all Units fell (relation smaller than one), except those in the sub drain of Unit 2. Those rose by roughly a factor of roughly 8.

The most radioactive liquid therefore is the water in the turbine building, followed by roughly four orders of magnitude lower radioactive liquid in the sub drains of Unit 1 and Unit 2, two additional orders of magnitude lower in the sub drains of Unit 3 and another order of magnitude lower in the sub drains of Unit 5 and 6. The differences in many orders of magnitude show that only a small volume leaking from underneath the turbine building into the sub drains can cause a considerable contamination of the sub drain liquids. Five orders of magnitudes difference means that mixing only 1 m³ of the liquid with the high concentration of 1E+13 Bq/m³ with 10,000 m³ of uncontaminated water causes a concentration in the mix of 1E+09 Bq/m³, roughly the highest concentration in the sub drains.

From those concentration profiles, it might well be that the sub drains of Unit 1 to 6 are partially interconnected and that either Unit 1 or Unit 2 (or both) are the only relevant sources for liquid contamination in the other sub drains. The concentration downgrades to Unit 6 by additional non- or lower-contaminated water that adds to the flow from the drains of Unit 1/2. Contrary to that, the concentration in the sub drain of Unit 1 fell between the first and the second sampling, while the concentration in the sub drain of Unit 2 rose. That speaks for Unit 2 or its turbine building as the main source of contamination in the sub drains of all other Units.

If at all, the sub drains of Unit 1 to 6 are not the main sources for contamination in the sea. It is the liquid in the turbine building of Unit 2. The concentration of Cs-137 in the water in one m³ of liquid in the turbine building (see Table 1) corresponds to 1/2 percent of the Cs-137 content of a ton of spent fuel of a lower burn-up, 700 m³ of this liquid correspond to roughly 3 1/2 metric tons of spent fuel (full burn-up) or roughly 2% of the total core inventory of that nuclide (assumed: half burn-up). This liquid was definitely in contact with the reactor core of Unit 2 and with damaged fuel within that core.

As far as is currently known, water from underneath the turbine building has escaped to the sea. Before the crack in the wall of a tunnel was closed, roughly 0.1 m³ of that water was lost per second[4]. That adds up to more than 300 m³ per hour or an inventory of Cs-137 of $5.4*10^{15}$ Bq per

[4] Estimate based on visual expression.

hour released to the sea. A volume of 300 m³ with an inventory of 5.4E+15 Bq can contaminate roughly 54,000,000,000 m³ seawater to a concentration level of 100 Bq/l.

These quantifications show that the inventory that could have escaped to the Pacific could have been very large. All the displayed numbers have a large band of uncertainty with it, but still show the extent to which that source has contributed to what has been found in the analysis of seawater. And what additional risk is faced if the liquids cannot be held back within the turbine building and the sub drains, or cannot be recovered, transported and safely stored in tanks.

2 Activity concentrations in the Pacific

2.1 Sampling points

From the 22nd of March on, TEPCO regularly took seawater samples from the following locations:

(1) Around the discharge canal (south) (approx. 330m south from the discharge canal of Units 1 to 4)

(2) Around the discharge canal (north) (approx. 30m north from the discharge canal of Units 5 and 6)

(3) Around the discharge canal (north) of Units 3 and 4 of Fukushima Daini (approx. 10km from Fukushima Daiichi)

(4) Around Iwasawa coast (aprox. 7000 m south from the discharge canal of Units 1 and 2 Daini) (approx. 16 km from Fukushima Daiichi)

The following locations were included and first sampled on the 5th of April:

(5) Around 15km off shore of Fukushima Daiichi Nuclear Power Station

(6) Around 15km off shore of Fukushima Daini Nuclear Power Station

(7) Around 15km off shore of Iwasawa coast

(8) Around 15km off shore from Hirono Town

(9) Around 15km off shore from Minami-Soma City

(10) Around 15 km off shore from Ukedogawa River

Samples from these locations are only taken, if the weather conditions allow that.

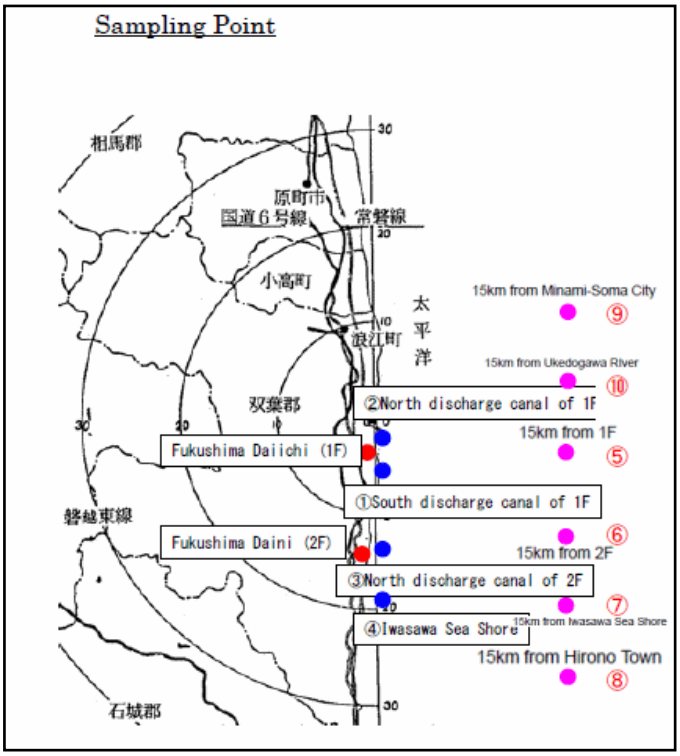
On the 22nd these two locations were sampled additionally:

(-) Southern Discharge Canal (about 100 meters south from 1~4 u discharge canal)

(-) 2 F, at the mouth of Tomioka river (approximately 2.000 meters north of Unit 3, 4 u discharge canal)

The last two locations weren't sampled later on. From the 17th of April on TEPCO added further sampling locations.

The diagram shows the sampling points (1) to (10), for which data is available in more than one case.



Scheme 1: Sampling points around Fukushima Daiichi ("1F"), from: TEPCO, slightly modified

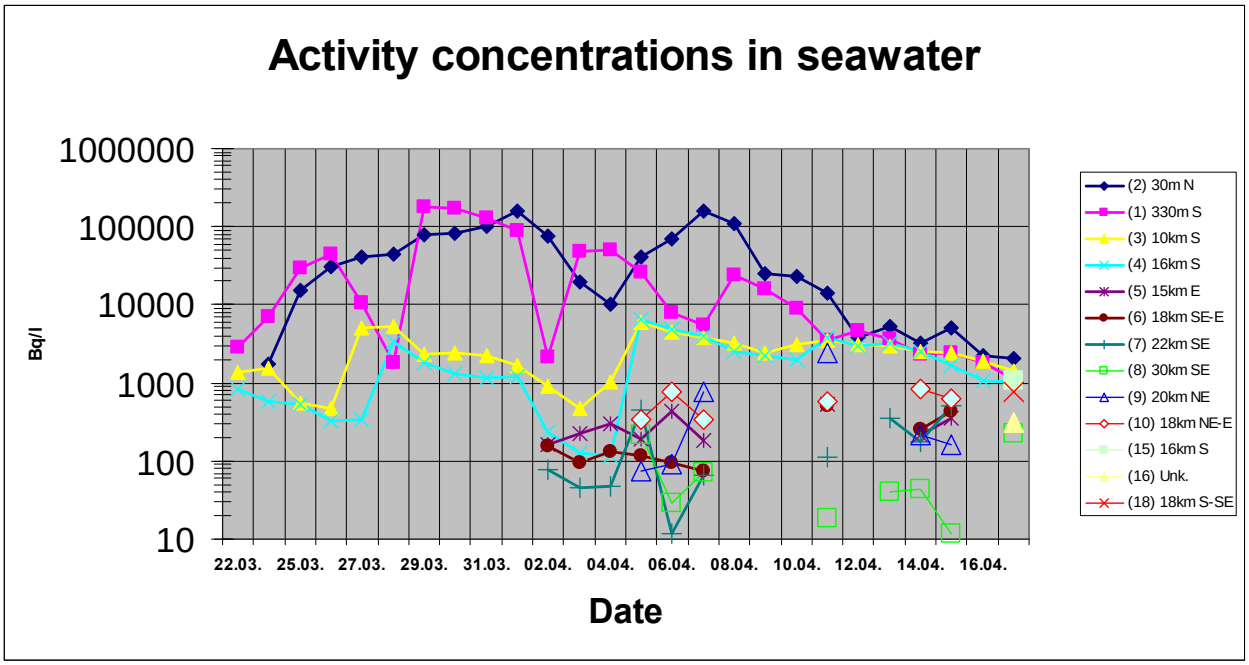
2.2 Measured concentrations

The Diagram 2 displays the results of all the measurements in a single graph. To do that, it is necessary to display these on a logarithmic scale. Numbering of the sampling points is as described in chapter 2.1. Distance to the plant and direction is added for better orientation. Given date is the date of sampling, not the date of the result publication. Only the concentrations of I-131, Cs-134 and Cs-137 were added to the concentration, other nuclides don't play a significant role, neither for the activity nor for any dose calculations.

The points above 10,000 Bq/l[5] are the two nearest sampling points on the coast in 30 and 330 m distance to the plant. Let's call these "the less than 1 km distance" category. After having closed the source for the release, their concentrations fell continuously and finally reached a settling point at roughly 1,000 Bq/l.

[5] Within this text the decimal separator is the dot ("."), the thousands separator the comma (","). As calculation programs have to difficulties with mixed notations, it might be that diagrams in this text are vice versa. In that case it is pointed to in the text.

The 1,000 to 10,000 Bq/l class are the two sampling points on the shore south in 10 km and 16 km distance to the plant. Let's call them "the coastal area beyond 10 km and within 30 km". These sampling points show relatively steady concentrations in that named range and finally declined to the lower boundary of this range.



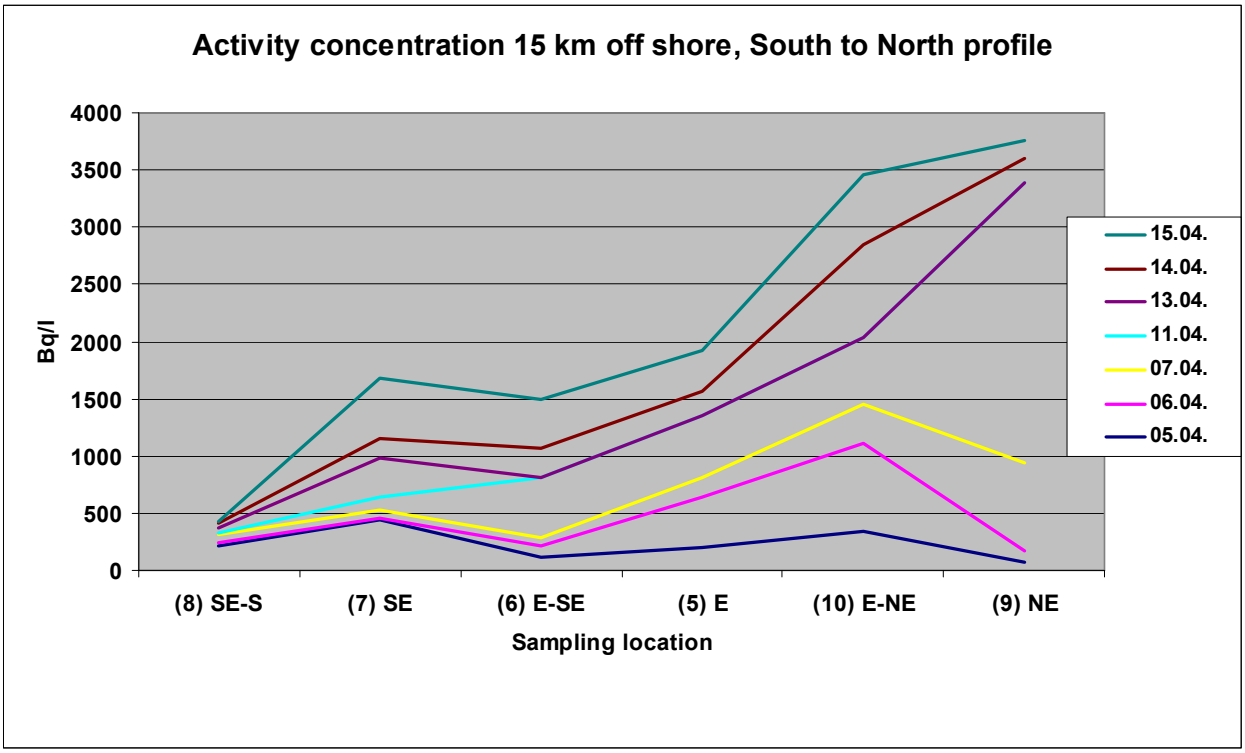
Graph 1: Measured activity concentrations in the sea (coast and off-shore), data from TEPCO

The offshore locations with the shortest distance of 15 km and the longest distance of 30 km from the plant are below 1,000 Bq/l and down to 10 Bq/l (or sometimes below detection limit, but only very seldom). Unfortunately weather conditions don't allow continuous sampling, so no reliable conclusions can be drawn on trends. In general, the north-eastern locations (9) and (10) show elevated concentrations.

2.3 Off shore activity concentration profile

Several of the 10 sampling points are located 15 km off the coast. Those show how the contamination released from the source on the coast distributes to the east and into deeper water levels. Graph 2 shows the profiles of activity concentrations for those days that were sampled so far. The data is sorted and displayed from south to north, directions are characterised.

The distribution in the different directions shows complicated patterns. In the first three of the sampled days the southeast and the east-northeast direction showed the highest concentrations, while the other four sampling days show the significantly highest concentrations in the north-eastern direction.



Graph 2: Measured activity concentrations in the off-shore samples, sorted from the southern to northern sampling locations, data from TEPCO

When interpreting all this data, it must be kept in mind that all sampling by TEPCO is done on the surface. No data is available on complete off-shore profiles over the whole depth in 15 km distance, so “tunnelling” streams underneath the surface would be undetectable. No data on coastal sites to the north of Fukushima Daiichi beyond 30 m from the discharge channel are available, so distribution in the northern direction along the coast is also undetectable. MEXT sampling and measurements[6] closes these two gaps, so no principal errors result from these two blindness’s of the sampling scheme by TEPCO.

3 Doses from fish consumption

As can be seen from the above, contamination in the sea is by no means distributed along easily foreseeable patterns and is by no means homogeneous. If that is so, it will be so even more along the depending bio-pathways. One of the most sensible pathways where contamination moves is fish, because fish can be directly used as food.

Unfortunately the organisms of fishes “enrich” contamination that they are exposed to in the surrounding water. They “filter” large amounts of water for specific micronutrients, and - unfortunately for fish eaters - are very effective in collecting those special metals and elements, if they swim and live in radioactively contaminated seawater. If fish eats fish, he takes up the already

[6] See http://www.mext.go.jp/english/radioactivity_level/detail/1304192.htm for MEXT’s results

accumulated material and accumulates it further. This effect, that the fish concentrates a manifold of certain elements in the water, is called bio-accumulation. Usually the ratio between the concentration in the fish and the concentration in the sea is called concentration factor. Typical concentration factors for Iodine and Caesium in sweet water are 50 and 1,500, in seawater 9 and 100. The latter means a concentration of 1 Bq/l of caesium in seawater corresponds to 100 Bq/kg of fresh fish.

That element-specific “enrichment” means that a Becquerel of Caesium is not equally behaving on that pathway like a Becquerel of Iodine, but a Becquerel of Cesium-134 behaves like that of Cesium-137. With that we can easily predict which contamination fish will have, if we know the contamination of seawater.

Note that the so “calculated fish” can be very different from “measured fish”, because the underlying model assumes constant contaminations over the longer term, that the fish doesn’t move out of the contaminated area and homogeneous concentrations. So, take the calculated results of the concentration in fish as a bandwidth and as course approximation rather than a precise prediction.

If that fish is consumed, the Iodine-131 and Cesium-134/-137 are ingested. This causes radioactive doses for the person that ingested it. Those doses again are depending on a number of properties of the element (e.g. for how long does the element remain inside the human body), the “enrichment” (which organs are accumulating ingested elements more than others) and the decay characteristics (e.g. half life time, decay energy). So, one Becquerel of Iodine-131 causes a dose of 2.2E-08 Sievert (Sv) for an adult person, if ingested, Cesium-134 causes 1.9E-08 Sv and Cesium-137 causes 1.3E-08 Sv per Becquerel ingested. Not much of a difference, but we should calculate it correct. If one needs dose factors for children or babies, these factors are also a bit different. And these dose factors are all for effective doses, to state all things correct. If you need it more precise, you can go that way. We want to keep it simple, and calculate only effective doses for adults.

As you will see, the doses at the same sampling point and the same day are very often varying by a factor of two, so there is no need and it doesn’t make much sense to calculate doses with more accuracy.

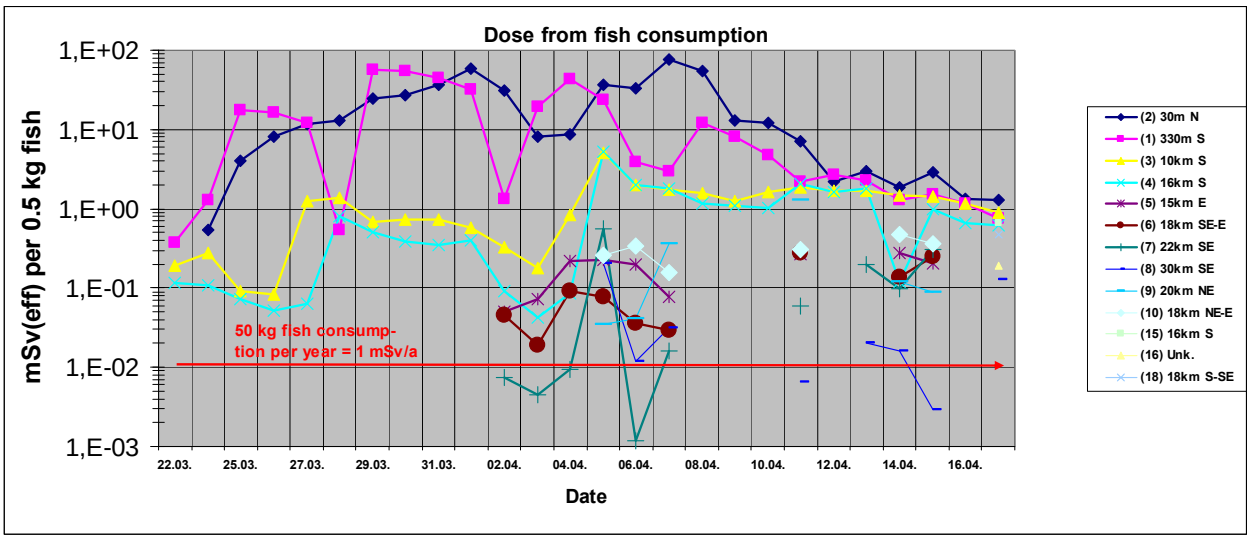
As the current situation varies on a day by day basis, and predictions over a year are pure reading tea leaves, we calculate doses for single meals instead. A 0.5 kg fish meal is our choice, if you prefer larger or smaller meals, it is only following the rule of proportion.

Two values in a single cell show two different measurements on the same day. As can be seen from the listed doses, the variations are very often by a factor of two.

Dose calculation for fish consumption from seawater concentrations, mSv per fish meal															
Location	(2)	(1)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(15)	(16)	(18)
Distance (≈m)	30	330	10000	16000	15000	18000	22000	30000	20000	18000	100	2000	16000	?	18000
22.03.11	n.d.	0,37	0,19	0,12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2,93	0,45	n.d.	n.d.	n.d.
24.03.11	0,54	1,29	0,27	0,11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
25.03.11	4,09	17,39	0,09	0,07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
26.03.11	11,0 | 4,98	10,6 | 22,1	0,08	0,05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
27.03.11	3,46 | 20,4	4,17	1,27	0,06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
28.03.11	14,0 | 11,8	0,60 | 0,50	1,37	0,80	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
29.03.11	24,3 | 24,5	48,7 | 63,6	0,68	0,50	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
30.03.11	29,9 | 24,1	16,6 | 93,8	0,73	0,39	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
31.03.11	23,7 | 50,0	40,9 | 48,6	0,72	0,35	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
01.04.11	71,1 | 46,5	42,2 | 21,4	0,58	0,40	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
02.04.11	38,9 | 24,1	1,82 | 0,86	0,33	0,09	0,05	0,05	0,01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03.04.11	9,19 | 6,87	20,5 | 18,5	0,18	0,04	0,07	0,02	0,00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04.04.11	8,41 | 9,18	18,5 | 68,9	0,84	0,08	0,22	0,09	0,01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05.04.11	46,4 | 27,4	27,9 | 19,3	2,55	2,61	0,14 | 0,09	0,03 | 0,05	0,02 | 0,52	0,10	0,03	0,26	n.d.	n.d.	n.d.	n.d.	n.d.
06.04.11	24,8 | 41,5	3,61 | 4,27	1,98	2,02	0,22 | 0,17	0,07 | 0,00	0,00 | 0,00	0,02 | 0,00	0,08 | 0,00	0,35 | 0,33	n.d.	n.d.	n.d.	n.d.	n.d.
07.04.11	118 | 35,2	2,94 | 3,05	1,76	1,79	0,08	0,02 | 0,03	0,01 | 0,03	0,02 | 0,05	0,36	0,16	n.d.	n.d.	n.d.	n.d.	n.d.
08.04.11	59,4 | 51,0	21,1 | 3,23	1,57	1,18	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09.04.11	16,97 | 9,33	7,55 | 8,60	1,24	1,09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10.04.11	9,15 | 15,07	3,32 | 6,27	1,62	1,01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11.04.11	4,53 | 9,86	2,18 | 2,17	1,89	2,06	0,27	0,25 | 0,29	0,063 | 0,054	0,002 | 0,011	1,31	0,35 | 0,26	n.d.	n.d.	n.d.	n.d.	n.d.
12.04.11	1,49 | 2,95	3,05 | 2,37	1,71	1,62	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
13.04.11	3,21 | 2,78	2,18 | 2,34	1,70	1,77	n.d.	n.d.	0,20	0,02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
14.04.11	2,05 | 1,68	1,20 | 1,40	1,46	1,47	0,322 | 0,228	0,137 | 0,140	0,125 | 0,079	0,018 | 0,015	0,12	0,47	n.d.	n.d.	n.d.	n.d.	n.d.
15.04.11	3,29 | 2,53	1,49 | 1,52	1,52	1,45	0,193 | 0,220	0,144 | 0,356	0,304 | 0,304	0 | 0,006	0,110 | 0,065	0,355 | 0,358	n.d.	n.d.	n.d.	n.d.	n.d.
16.04.11	1,51 | 1,20	1,20 | 1,10	1,15	0,65	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
17.04.11	1,43 | 1,14	0,93 | 0,58	0,88	0,62	n.d.	n.d.	n.d.	0,13	n.d.	n.d.	n.d.	n.d.	0,65	0,19	0,47
Base: measured seawater concentrations by TEPCO; Parameters: seawater concentration factor for water-to-fish; Single meal: 500 g fresh weight of fish; Dominating dose contributions: 80..85% Cs-134/138, 10..15% I-131; "n.d."=not determined, no data; Decimal separator: Komma. Date format: DD.MM.YY. Date is date of sampling.															

Table 3: Doses from fish consumption, mSv per 0.5 kg fish (fresh weight), as calculated from TEPCO data on seawater concentrations

For the people that need graphics to better understand things, the results are also in Graph 3.



Graph 3: Calculated doses from fish consumption, raw data from TEPCO/own calculation

For those who are not familiar with Sievert and what is much and what is small: A dose of 1 Sv and above is the range where deterministic health damages occur, 1/1000th of a Sv or 1 mSv per

year (1 mSv/a) is a common limit for doses from emissions of nuclear facilities to people living downstream, and 0.01 mSv per year can be considered below any concern because the probability for a health damage is too small to count. If the 1 mSv/a-limit is applied for our fish consumption, and if people eat 50 kg per year, a single fish meal should not exceed 0.01 mSv (red arrow line).

As we see in the graph, nearly all samples taken are above this dose level, even those from farer distances to the source such as the 18 km NE (9) or the 22 km SE (7) sampling points. Even the 30 km SE (8) is in most of the samples above those dose criteria. We can clearly state from this that fishing should be banned for at least 20 km to avoid serious health risks, better for 30 km. As we don't have data beyond those distances, and as we have no reliable prediction how long the contamination profile will last in that way over time, this is the least that should be done now. If the profile, as shown in chapter 2.3, is in more NE- and SE-directions, the banned area should reflect this.

As around 80% of the total dose is caused by Cs-134 and Cs-137, the "rapid" decay of I-131 will not relax the situation substantially. Pathways other than fish have smaller or only slightly higher concentration factors than those for fish, so fish consumption is a representative pathway.

4 Doses from seaweed consumption

Unfortunately the latter is not true for seaweed and the various ways this is consumed in Japan. Seaweed plants have a concentration factor of 10,000 for Iodine, roughly 1,000 times higher than for fish. Seaweed products are an enrichment machine for Iodine, one of the reasons why it is so healthy to eat it as supplement in normal times. Unfortunately this changes dramatically when the seawater is contaminated.

We chose to calculate two different consumption cases:

a) the consumption of freshly collected seaweed products, a small portion of these of 100 g per meal, and

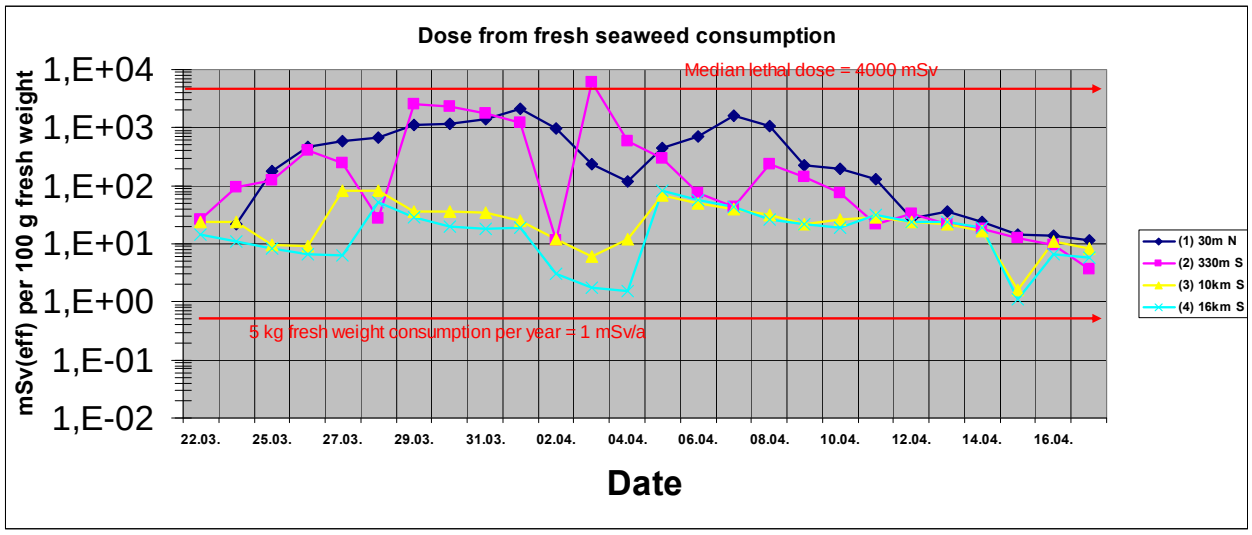
b) the consumption of dried seaweed products, a portion of 250 g fresh weight collected, then dried and consumed after 100 days.

In the latter case, a substantial portion of the I-131 decays. The Graph 4 shows the results for the first case. Only coastal seawater samples were calculated, because off-shore concentrations are irrelevant for seaweed production.

Dose calculation for fresh and dried seaweed consumption from seawater concentrations								
Location	**(2) 30 m North**		**(1) 330 m South**		**(3) 10 km South**		**(4) 16 km South**	
Consumption case	**Fresh**	**Dried**	**Fresh**	**Dried**	**Fresh**	**Dried**	**Fresh**	**Dried**
22.03.11	n.d.	n.d.	26,61	0,08	23,93	0,03	14,47	0,02
24.03.11	21,58	0,05	93,28	0,21	24,25	0,05	11,01	0,02
25.03.11	242,9	0,75	121,76	23,40	9,53	0,02	8,18	0,09
26.03.11	640 | 287	2,18 | 0,96	662 | 170	2,08 | 5,88	9,02	0,01	6,60	0,01
27.03.11	179 | 1014	0,70 | 4,15	242 | 84	0,82 | 0,25	83,69	0,25	6,38	0,01
28.03.11	727 | 595	2,81 | 2,39	31 | 24	0,12 | 0,10	83,72	0,27	52,97	0,16
29.03.11	1080 | 1124	5,01 | 5,03	1080 | 1124	10,04 | 13,13	35,26	0,14	28,64	0,10
30.03.11	1257 | 1036	6,22 | 4,99	706 | 3969	3,45 | 19,50	35,27	0,15	19,41	0,08
31.03.11	992 | 1829	4,97 | 8,37	1631 | 1917	7,20 | 8,19	33,81	2,03	18,40	1,98
01.04.11	2644 | 1653	11,11 | 7,86	1565 | 838	4,44 | 4,02	6,18	0,04	1,74	0,01
02.04.11	1169 | 728	8,45 | 5,23	13 | 10	0,42 | 0,20	11,91	0,07	3,09	0,02
03.04.11	265 | 212	2,01 | 1,49	640 | 552	4,44 | 4,02	6,18	0,04	1,74	0,01
04.04.11	117 | 117	0,92 | 1,01	243 | 905	2,04 | 7,58	12,14	0,09	1,74	0,01
05.04.11	530 | 353	5,15 | 3,02	353 | 243	3,08 | 2,13	68,42	0,56	81,62	0,57
06.04.11	530 | 906	5,53 | 9,26	71 | 82	0,81 | 0,96	48,58	0,44	57,38	0,44
07.04.11	2431 | 707	26,41 | 7,87	49 | 38	0,66 | 0,70	39,76	0,39	44,16	0,40
08.04.11	1105 | 1017	13,35 | 11,41	420 | 42	4,72 | 0,74	30,94	0,35	26,51	0,26
09.04.11	288 | 155	3,83 | 2,11	135 | 155	1,70 | 1,94	22,11	0,28	21,66	0,24
10.04.11	150 | 243	2,07 | 3,41	49 | 100	0,76 | 1,42	26,55	0,37	18,57	0,23
11.04.11	104 | 153	1,01 | 2,23	21,5 | 21,1	0,50 | 0,50	28,78	0,43	30,99	0,47
12.04.11	16,0 | 37,7	0,34 | 0,68	37,7 | 28,8	0,70 | 0,54	24,36	0,39	24,35	0,37
13.04.11	37,7 | 35,5	0,74 | 0,64	21,8 | 21,6	0,50 | 0,54	22,16	0,39	24,37	0,41
14.04.11	28,8 | 18,0	0,467 | 0,386	9,58 | 26,5	0,278 | 0,314	16,64	0,34	18,62	0,34
15.04.11	16,0 | 13,1	0,342 | 0,352	14,7 | 10,7	0,333 | 0,226	1,62	0,03	1,11	0,01
16.04.11	17,1 | 10,7	0,347 | 0,277	10,9 | 8,03	0,277 | 0,256	10,89	0,27	6,66	0,15
17.04.11	14,4 | 8,47	0,331 | 0,265	4,27 | 3,14	0,219 | 0,135	8,44	0,20	5,78	0,14
Consumption cases for a single meal: fresh=100g fresh seaweed, dried=250g fresh seeweed, collected, dried and consumed 100 days after collection. **Dominating dose contributions: fresh >95% I-131; dried: <10%I-131+≈45%Cs-134+≈45%Cs-137** **"n.d."=not determined; Decimal separator: Komma. Date format: DD.MM.YY. Date is date of sampling.**								

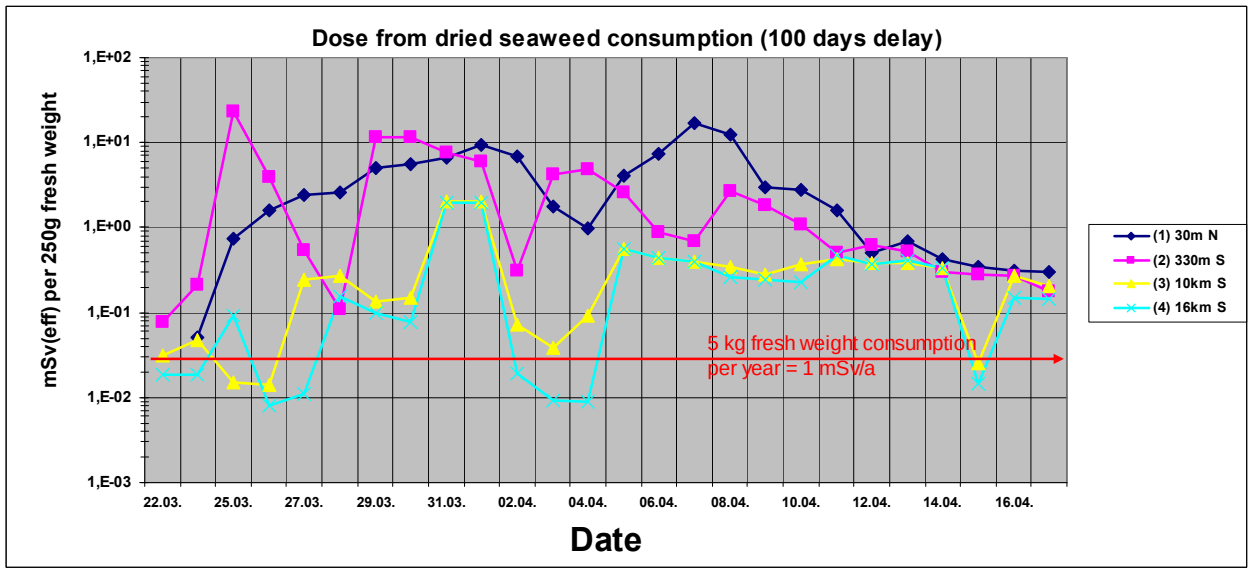
Table 4: Calculated doses from fresh and dried seaweed consumption, data from TEPCO/own calculation

The displayed doses show that the consumption of a single meal of 100 g fresh seaweed in any case leads to doses above 1 mSv (dose limit for a whole year). Samples from closer to the facility reach values where deterministic health damages are to be expected. The mean lethal dose of 4 Sv is displayed with the red arrow line.



Graph 4: Calculated doses from fresh seaweed consumption, raw data from TEPCO/own calculation

For dried seaweed products, the doses are by roughly two orders of magnitude smaller (see Table 4).



Graph 4: Calculated doses from fresh seaweed consumption, data from TEPCO, own calculation

Still the doses are only slightly below 1 mSv per meal, with the doses in the close vicinity on the same level as doses 16 km away from the facility.

From this the following consequences can be drawn:

1. The production and consumption of fresh seaweed products is extremely dangerous and a strict ban should be spoken out for at least a distance of 30 km to the facility.

2. The production and consumption of dried seaweed products should be banned within a distance of 20 km to the north and to the south.
3. Sampling on the coast should at least include the range up to 50 km to the north and to the south.
4. Existing production facilities for fish and seaweed products should have the opportunity to monitor their products closely.