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Outline of the highly polluted evacuation areas by the severe accident of the Fukushima Daiichi Nuclear Power Station

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1. Outline of the accident and the purpose of report

Fukushima Daiichi Nuclear Power Station is located on the Pacific shore about 200 km north of Tokyo, and about 100 km south of Sendai (Fig.1). Three nuclear reactors among six in total were working when the mega earthquake occurred at 14:46, March 11. The emergency shut-down system started at once, and three reactors stopped safely. But huge tsunami with the height of 13～15m struck at whole plant about four minutes later, which stopped all of emergent power supplies, resulting all of the cooling facilities for every nuclear reactors were lost. Such accidental conditions caused a series of vents and hydrogen explosions for each of three power plants from 12th to 15th, March, each of which time huge amount of the highly concentrated radioactive materials exhausted in the air and dispersed broadly in the environment. Much of radioactive materials were also flew out to the sea.

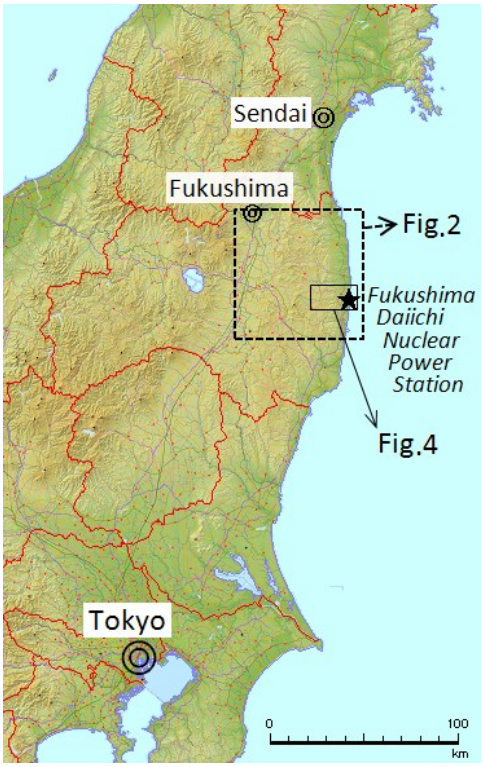

Fig. 1 Location of Fukushima Daiichi Nuclear Power Station

Through this serious event, total amount of radioactive materials dispersed to the air was estimated to reach more than 37×10^{12} Bq, and the level of nuclear accident was rated as the worst of 7th in terms of International Nuclear Event Scale. Most of the 80,000 residents inside of 20～30 km circular area from the power station were obliged to evacuate from their hometown before grasping the damage of earthquake and tsunami. Their situation as evacuee has not changed yet for nine months. It is feared that the significant amount of people could never return to home in their lifetime.

The purpose of this brief report is to describe the regional characteristics of highly contaminated evacuation areas around the Fukushima Daiichi Nuclear Power Station, that is how the region is/was like in term of the industrial basis. The author will also report on the distribution of lower level of pollution observed by accumulation of cesium, which suggests the behavior of the air flow when the accidents took place.

2. Designation of the evacuation and controlled area

In this unprecedented situation, national government pronounced a "no entry" evacuation directive to the area within 20 km sphere from the nuclear power station (Fig.2) on March 12, and the "staying-indoor" control implemented to the 20～30 km zone was terminatedtaken out on March 15.

In addition, a progress of actual observation of the contamination of radioactive materials clarified that the high-concentration area where yearly accumulative dose might reach 20mSv had spread northwestward (Fig.2). It was considered to mainly be conveyed by the wind at the time of the hydrogen explosion on the morning of March 15 and the influence of rain after that. On April 21, national government designated "planned evacuation area" which urge the residents to evacuate in one month for these area, i.e., Iitate-mura, Katsurao-mura, Tsushima district of Namie-machi, Yamakiya district of Kawamata-machi, and southwestern area of Minamisoma city (Fig.2 and 3).

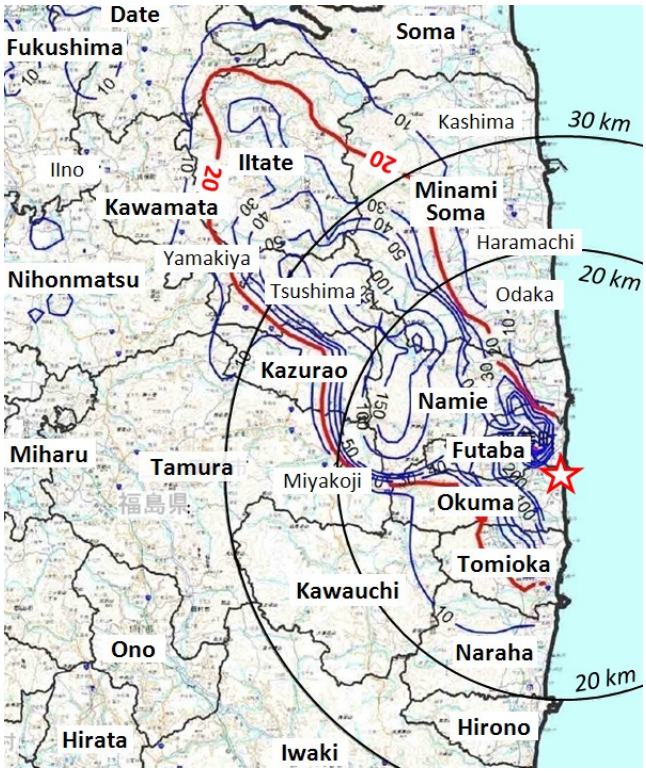

Fig. 2 Yearly accumulative dose (mSv) estimated by the real value observed from 11, March to 21, April (http://www.mext.go.jp)

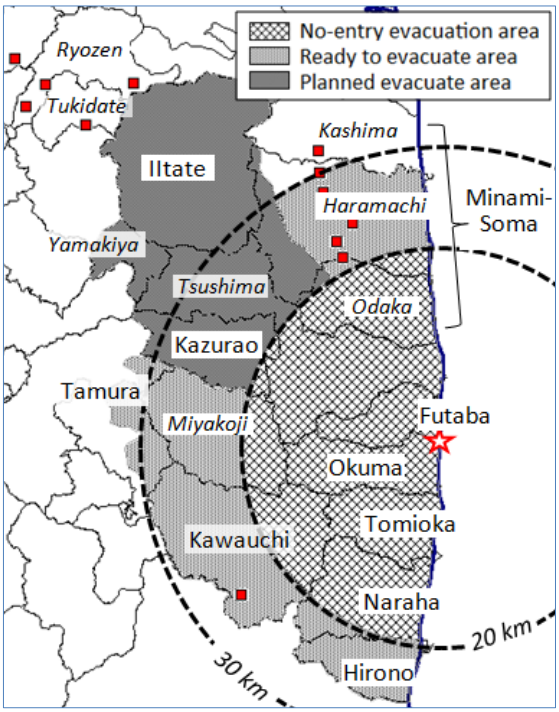

Fig. 3 designated areas

At the same time, 20～30km zonal area under the "staying-indoor" control was designated as "ready to evacuate area" in possible emergent case, where children, pregnant women, and handicapped person were needed to evacuate.

Furthermore, several spots of highly contamination where yearly accumulative dose was estimated to reach 20mSv were discovered outside those designated areas, then the measure of "evacuation recommended" areas were

designated in such places since June 30. The number of the areas reached to 12 settlements, most of which were located in the northwestern and northeastern parts along the 20mSv line shown in Fig 2 and 3, with 282 households in total by November 26.

3. Regional characteristics of the designated evacuation areas

1) Physical Setting

Geomorphology of the designated areas to evacuate and ready to evacuate is typically shown in Fig.4. The areas can be divided clearly into such three geomorphologic parts as below from east to west along Pacific shore:

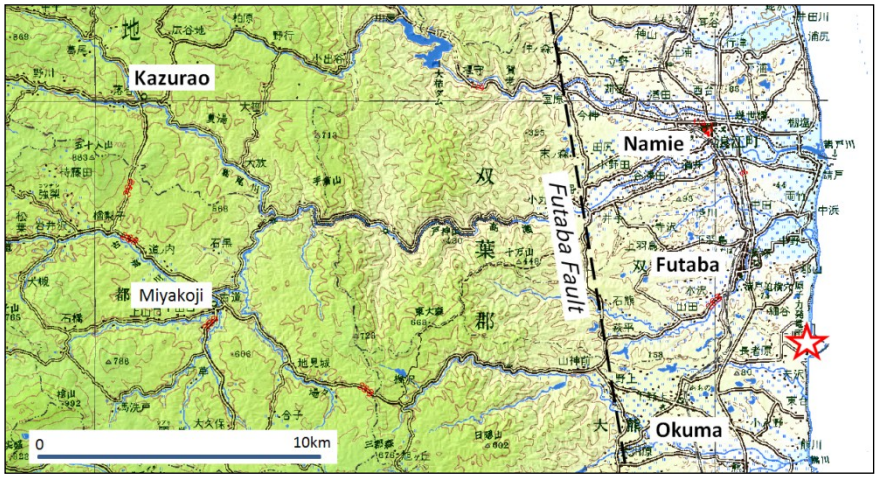

Fig. 4 typical geomorphology of the designated area

i) coastal area called as "Hamadori" consisting of such two sub parts as the table lands with the altitude of 20～50m and the narrow plains along small rivers flowing down cutting the table lands to the Pacific Ocean,

ii) steeply sloped area along the Futaba fault being cut by some deep valleys,

iii) Abukuma Highland with the altitude of about 500m.

Many settlements in the coastal plains were flooded out by the tsunami after the mega-quake of March,11. By the meteorological observation when the hydrogen explosion happened on March 15, most of the radioactive materials was estimated to disperse northwestward along one of the deep valleys between the coastal area and the Abukuma Highland.

2) Population

Population distribution in the municipalities to which the designated areas belong is shown in Fig.5. Many of

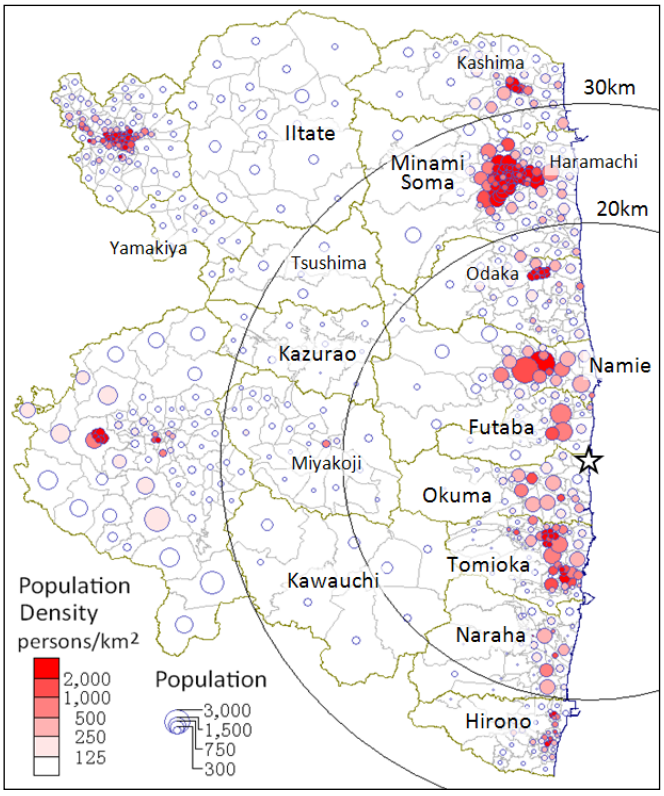

Fig.5 distribution of population (2005)

the residents in this areas live in the coastal area, and the population density is rather low in the sloped area and Abukuma Highland. The number of population and households for each designated zone and area are shown in Table 1.

Table 1 estimated population of each evacuation zone

	population	households
20 km zone	72,891	23,204
30 km zone	133,053	43,078
planned evacuation area	11,229	3,033

Entire population in the "no-entry" 20km zone and the most of population in "planned evacuation area" were obliged to evacuate to another places. The situation in which up to 84,000 persons are obliged accidentally to evacuate would be the situation Japan has never experienced in the past. But a fact that most of population resides in the narrow corridor both side of which are the sea and the thinly inhabited mountainous land as shown in Fig.5 could not had been the worst situation.

3) Industries

In the designated areas shown in Fig.3, most of the economic activities stopped, and when they can restart is unclear even after nine months passed. Table 2 shows the census data for the manufacturing and commercial industries by municipal district shown in Fig.3. The shadowed districts are containing heavier polluted areas by radioactive materials. According to the table, about 2,400 establishments, 20,000 persons' business opportunities, and 402 billion yen of industrial outputs was lost for a year.

Table 2 Manufacturing and Commercial Industries by municipal district (2004)

		location	manufacturing			wholesaling			retailing		
			factories	workers	output*1	shops	workers	sales*1	shops	workers	sales*1
coastal area	Haramachi	20～30 km	154	4,261	73,809	137	1,082	43,373	600	3,332	55,681
	Odaka	10～20 km	46	969	17,914	19	122	5,913	156	597	7,933
	Namie	5～30 km	55	1,134	37,128	48	304	8,956	283	1,504	22,155
	Futaba	～10 km	13	310	7,300	6	46	2,622	96	375	5,871
	Okuma	～10 km	15	639	18,538	8	48	2,142	107	593	7,715
	Tomioka	～10 km	21	391	4,922	40	184	6,079	178	1,311	18,197
	Naraha	10～20 km	27	849	18,410	4	15	895	84	358	4,147
	Hirono	20～30 km	23	831	19,352	6	19	407	66	233	3,312
highland	Iitate	30 km～	16	400	4,570	3	7	35	63	183	2,326
	Yamakiya*2	30 km～	10	145	－			－	13	35	－
	Kazurao	20～30 km	4	57	225	2	9	x	15	37	x
	Miyakoji	15～30 km	10	108	728	3	11	74	36	81	690
	Kawauchi	10～30 km	8	136	500	1	2	x	49	121	x
	Total		402	10,230	203,395	277	1,849	70,496	1,746	8,760	128,027

*1: million yen, *2: data year is 2001, retailing contains wholesaling. －: no data, x: confidential
source : http://www.e-stat.go.jp

Distribution of the commercial industries is like as the population distribution shown in Fig.5, that is, regional center city of Haramachi is the biggest and sub-centers of Namie and Tomioka are the second and third biggest commercial places. As for the manufacturing industry are

located rather evenly in the coastal area. Such industries are few in Abukuma Highland area. As for the type of manufacturing industry, Haramachi's data in 2004 manufacturing census is only usable. According it, "electronic components", "machinery instrument", "rubber commodity", and "clothes and textiles" are the four major manufacturing sections. Generally speaking, these sections are the "labor-intensive" types.

Although this area is not prosperous industrial region in Japan, the industries shown in Table 2 provided important employment opportunities for the residents. Long term evacuation and stoppage of industrial operation are unavoidable, which will be one of the difficulties for recovery of this area.

4) Agriculture, Livestock farming, Forestry

Radioactivity materials dispersed from the nuclear power station polluted the farmlands, forests, rivers and sea, which gave serious damage to the primary industries in this area. Because the detailed facts will be described in the following section, the authors will give here an outline of the primary industries in the designated areas.

Table 3 Primary Indutries by municipal district

		location	agriculture			livestock		forestry	
			workers	ciltivated land (ha)	output (million yen)	milk cow	beef cattle	workers	forest area (ha)
			2005	2004	2004	2005	2005	2000	2004
coastal area	Haramachi	20～30 km	2,613	3,770	4,810	121	442	126	11,386
	Odaka	10～20 km	1,600	2,300	2,870	392	322	141	4,628
	Namie	5～30km	1,925	2,750	3,590	183	188	113	16,021
	Futaba	～10km	674	929	880	0	70	80	3,003
	Okuma	～10km	829	1,220	1,830	0	168	96	4,975
	Tomioka	～10km	882	1,110	2,180	0	261	69	4,047
	Naraha	10～20km	756	841	870	37	139	63	7,756
	Hirono	20～30km	390	365	300	0	0	98	4,382
highland	Iitate	30 km～	1,466	2,270	3,900	0	740	271	17,259
	Yamakiya	30 km～	436	421	–	127	320	26	–
	Kazurao	20～30 km	462	617	1,540	126	212	31	6,906
	Miyakoji	15～30km	623	803	2,750	115	383	123	10,074
	Kawauchi	10～30km	583	925	1,480	81	201	118	17,208
Total			13,239	18,321	27,000	1,182	3,446	1,355	107,645

source : Annual Report of Fukushima Statistical Office (2004), Agriculture Census (2005), Forestry Census (2000)

Some basic statistics of agricultural, livestock and forestry by the municipal district are shown in Table 3. From the table, we can grasp firstly the fact that about 13,000 farmers produced the value of 27 billion yen from 18,000 ha of arable lands. Especially, Namie town and Iitate village which belong to the densely polluted zone are main agricultural areas in the region. In the second, we can know that many of cattle raising and forestry activities were operating in Abukuma Highland.

Fig 6 shows the composition of major crops planted by statistical unit named "shuraku" that is a kind of agricultural community. Rice is the major crop for the most part of the region especially in the coastal area. "Industrial crops" including mainly tobacco in this case are prominent in the western edge of the region. Vegetables are also major crops in the northwestern part. The communities one of whose major crops is the "millet" including mainly buckwheat in this case are shown in some parts.

Average acreage of the cultivated land per a farmer is 1.46 ha in this region, which is rather larger than Japan's average. But the crops with higher productivity such as garden products or greenhouse crops are very limited. In addition, feeding crops for domestic livestock are contained to the average acreage. So to speak generally, agriculture in this region cannot be said as intensive one.

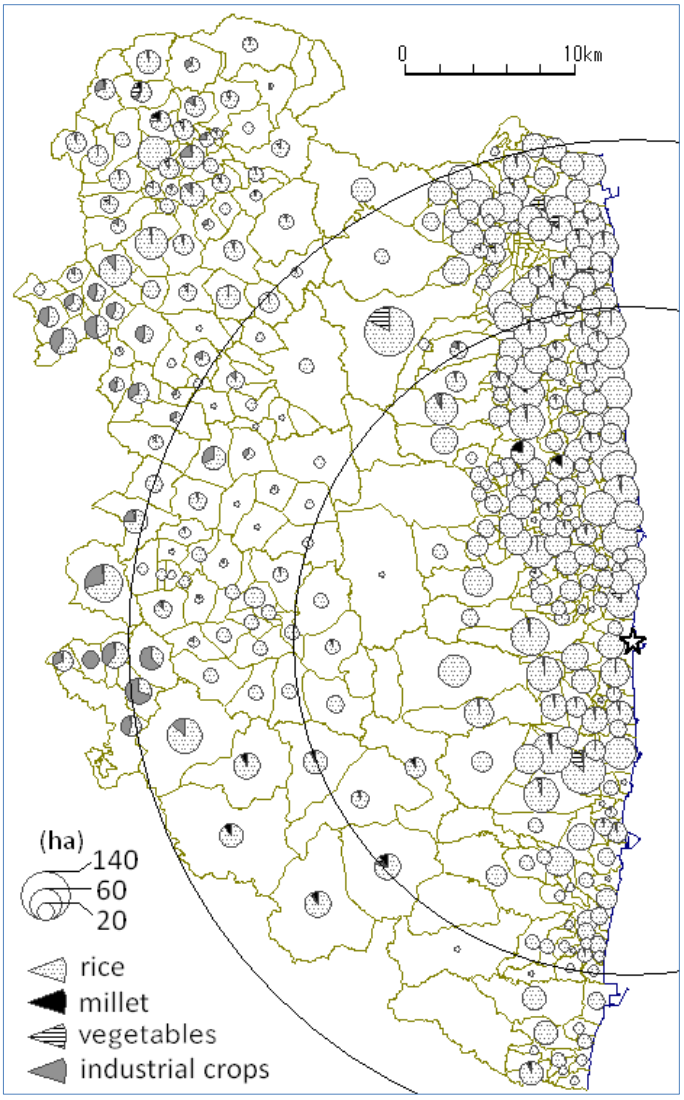

Fig.6 area (ha) and composition of major crops planted by agricultural community (2005)

On the other hand, there contains a village famous for cattle raising such as Iitate, whose beef is well known brand in Fukushima Prefecture. "Shiitake" mushroom farming belonged statistically to the forestry industry is widely operating mountainous area especially in Abukuma Highland. In addition, nurturing forestry and timber production are well-known local industry in Miyakoji village.

5) Fishery

Although this region faces Pacific Ocean, fishery industries cannot be said so thriving as Sanriku Coast which suffered serious damages by tsunami. According to 2008 Fishery Census, 166 fishery workers and 108 fishing boats were registered in this region. Most of them belongs to Uketo fishing port in Namie, at the location about 6 km north of the nuclear power station. Main types of fishery are the drawing net, gilling net and rod fishing by small boat mainly less than 5 ton. Main catches are such small fishes as sand lance or young sardine and stable

flatfishes including flounder.

Fukushima Prefecture prohibited the fishery operations for at least one year in fear of the diffusion of radioactive contamination to the sea. Actually the periodic sampling of marine products indicated that the contamination of marine creatures was tending to increase with time, which will be shown in more detail in the following section.

In the rivers flowing from Abukuma Highland down to Pacific Ocean, many salmon are coming upstream every autumn. In 30km zone from Fukushima Daiichi Nuclear Power Station, River Fishery Cooperatives are organized in five rivers, and manage the artificial hatching and stocking activities. Especially the number of salmon catches in Kido river in Naraha town was one of the most thriving salmon rivers in Honshu island. Every incubation facilities in these rivers were entirely destroyed by the earthquake and tsunami, and four rivers among five are located in "no-entry" 20km zone from the nuclear power station.

4. Diffusion of the lower level of polluted area

The radioactive material spread widely beyond the evacuation areas. Japan's Ministry of Education, Culture, Sports, Science and Technology published radiation dose and accumulation of Cesium several times. Fig.7 shows the accumulation amount of Cesium 134 and 137 in land surface estimated by November 5. According to it, the way of the diffusion of radioactive materials is considered to reflect wind direction and rain when the explosion happened and after, and geomorphologic features. That is, the concentrated radioactive materials were at first carried northwestward from the power plant across Abukuma Highland to Fukushima Basin, and they were turned southward along the Abukuma river basin where lower level of pollution

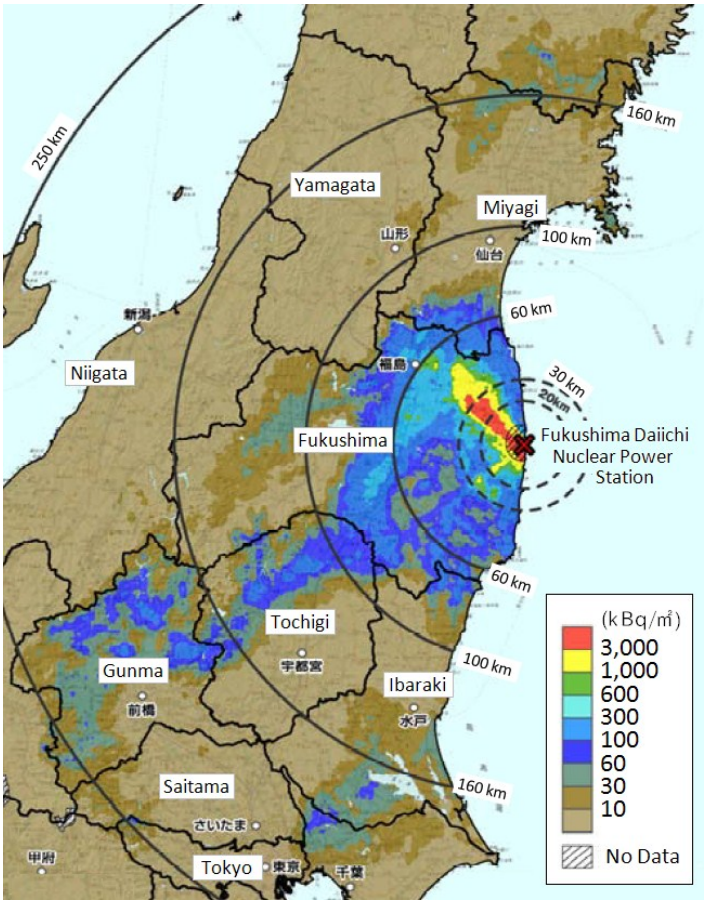

Fig.7 Accumulation of Cs-134 and Cs-137 in land surface Estimated by November 5
(http://radioactivity.mext.go.jp/ja/1910/2011/12/1910_1216.pdf)

came. lower level of pollution went then to the northern Kanto district and partly to just eastern neighbors of Tokyo.

In contrast to it, such place as western half of Fukushima Prefecture (Aizu region) and northern neighboring area in Miyagi Prefecture escaped from the flow of contaminated air, resulting in the lower level of accumulation in spited of their nearer distance.

A kind of "barrier effect" of the geomorphology can be observed in northern part of Kanto area and boundary area between Miyagi and Iwate prefectures. A flow of the contaminated air seemed to be interrupted here by the mountain ranges and fall to the ground with the rain. In addition, it was a likely situation that the dividing range of Ou mountains in the middle of Fukushima Prefecture interrupted the air flow into Aizu region.

5. Prospects

Though the situation of evacuated people has not changed even nine months after the accident, the efforts to restoration of the evacuated areas has been continued. It is necessary to eliminate the radioactive materials from the contaminated areas. National government decided that elimination activities in the areas where accumulative dose could reach more than 1 mSv were responsible for national budget, and pronounced the those areas which contained 102 municipalities in eight prefectures. But the first decision of stock yard for the polluted materials bearing radioactivity has became a problem hard to make consensus in the inhabitants.

December, 16, 2011, national government stated three broken nuclear reactors reached safe and stable situation with enough low temperature, and the countermeasures for the accident shifted to the next stage containing the long time effort to abolish the broken reactors. And needless to say the unprecedented difficult process will be needed to restore the everyday lives of the inhabitants and their communities.