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Comparison of the Chernobyl and Fukushima Nuclear Power Plants Accidents and their Consequences

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Abstract: This work compares the radioactive consequences due to the Chernobyl and Fukushima NPP accidents. Due to non-homogeneous features of the fallouts of radioactive isotopes in the both cases the comparison of radioactive contamination density was compared for similar administrative units – in Russia (Bryansk region, Novozibkov subregion) and in Japan (Fukushima prefecture, Namie municipality). We also estimated and compared both external and internal radiation doses for population during the acute accidental period – the first year. This work also considers the long-term dynamics of exposure doses in Russia which illustrate the Russian experience on countermeasures to protect the population.

Keywords*:* Fukushima accident, Chernobyl accident, radioactive release, radiation dose, countermeasure.
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INTRODUCTION

In 25 years after Chernobyl catastrophe again nearly the whole North hemisphere was affected by radioactive release because of an accident at Fukushima NPP 11 of March 2011. The both accidents contaminated the vast territories by radionuclides and affected on the population by radiation. IAEA ascribed the both accidents to the highest class of radiologic accidents. Nevertheless the absolutely different causes of accidents, different types of reactors, the difference in the catastrophic processes the radioactive releases due to these accidents and their influence on the population and environment are comparable and even similar in many aspects. The main goal of this study is to consider whether post-Chernobyl experience can be adapted to improve of the radiological situation in Japan.
The fallouts due to the both releases show non homogeneous features. Usually it is caused by influence of varying weather conditions. For the Chernobyl case it was due to local difference in precipitation. The general characteristics of fallouts were studied for different degrees of ranges; down to municipalities and even single farms. The comparison shows high similarity in surface contamination features (after ^{137}Cs). But, to compare the consequences some differences in agricultural activities at the territories should be considered.
The significant importance in analysis of the consequences of a radiation catastrophe deals with exposure doses obtained by the population both during the acute accidental period and later. We estimated and compared both external and internal radiation doses for population during the first year. The main source of radiation during the first post-accident days is iodine isotopes. They influenced through an external exposure and an inhalation in the Fukushima case and as an internal exposure of the Thyroid and an external exposure due to the fallouts in the Chernobyl case.

This work also considers the Russian experience on countermeasures to protect the population. We studied the dynamics of population exposure and application of a set of countermeasures.

1. RELEASE

The processes of the both radiologic accidents has a common point – uncontrolled fuel overheating. In the Chernobyl case the overheating took place in the functioning reactor, and thus it occurred within several seconds. As a result nearly all fuel was thrown out of the reactor’s body with the most part of it being dispersed to a size of UO_2 corn. At the Fukushima NPP there were two different scenarios. At the first, second and third blocks overheating took place at the stopped reactors with the minimal flows of neutrons. As a result uncovering of the fuels’ pellets and melting of the core was continuing during several days. The similar situation took place at the storing reservoir of the forth block containing the extracted fuel. Here the energies were even lower and the heating processes were slower. Thus, during the Fukushima accident the fuel rest where it was, only dividing products were released to the environment.

The scientific discussions on the point of how many and what radioactive substances succeeded to get out of the production territory are not finished yet. For the Chernobyl case the most of discussions concerned the hotmelting elements, for the Fukushima case the discussions considered the release of caesium and iodine isotopes. It is proposed for the both cases that all inert radioactive gases collected in the reactors till their uncovering were released to the environment.

As to Chernobyl release of ^{137}Cs, its amount was estimated by direct integration of surface fallouts to the earth surface. It took nearly 10 years to obtain the estimate with reasonable accuracy. The estimate of ^{131}I release was performed by analysis of the spatial distribution of the fractioning coefficients, it also took years. The reasonable accuracy of these estimates was due to the fact that during the accident were released approximately 30÷35 % of stored in reactor ^{137}Cs and approximately 60 % of stored in reactor ^{131}I.

In the Fukushima case the amount of injected to the environment ^{131}I and ^{137}Cs were only around a unit percents of the stored in the reactors amount. It caused the lower level of accuracy in their estimates, and the error below 100 % is not likely to be probable as the significant amount of radionuclides is drawn in the Pacific Ocean. The mathematical models fitted to monitoring data seem to be the main approach for reconstruction of the Fukushima release. But the most scientists suppose that Fukushima ^{131}I release in percents to ^{137}Cs was higher than in the Chernobyl case. Table 1 presents the most likely estimates concerning the releases for the both accidents [UNSCLEAR 2000, Stohl et al. 2011, IRSN 2011].

Table 1. Releases to the environment of the radioactive substances due to Chernobyl and Fukushima nuclear power plants accidents and their percent from the one stored in the reactors

Nuclide or group of r/n	Chernobyl [UNSCLEAR 2000]		Fukushima [IRSN 2011]	
	pBq	%	pBq	%
^{133}Xe	6500	≈100	12600	≈100
^{131}I	1800	≈60	250÷1000	4÷16
^{137}Cs	85	32	12÷60	0.9÷4
hotmelting	200	3.4		<<0.03

2. FALLOUT

All regional maps on surface contamination of Russia due to the Chernobyl accident are systemized and published in Atlas, [2009]. They were built by application of geostatistics on raw monitoring data with results of air gamma survey as additional information. Also short-range maps were corrected by using data on monitoring of the agricultural and forest areas.

First data on contamination of the Fukushima prefecture’s territory were obtained by an air gamma survey after USA Department of Energy [NISA, 2011]. Later they were performed by geostatistical methods basing on multiple dose power measurements and soil samplings. Figure 1 presents maps of the distribution of ^{137}Cs in Bryansk region and Fukushima prefecture based on data from [Atlas 2009, MEXT]. The maps are presented in the same spatial scales and use the same legend on contamination levels for comparison purposes.

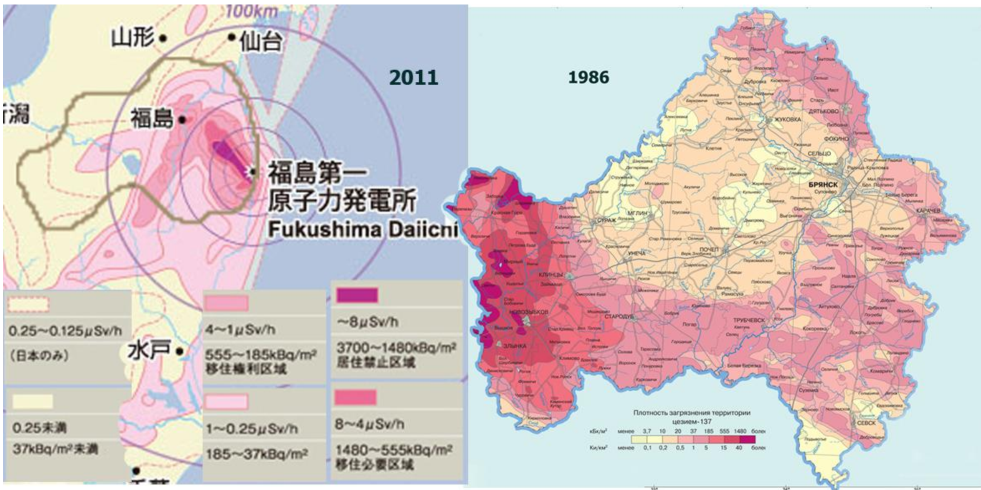

Figure 1. Spatial distribution of ^{137}Cs density in Japan and Bryansk region at the fallout moment [Atlas 2009, MEXT]

Geostatistical approach gives analysis of local uncertainties. The uncertainties in estimation of surface contamination of Bryansk region and Fukushima prefecture territories are rather similar and allow analysis of exposed doses.

The both territories present significant nonhomogeneity of ^{137}Cs distribution especially at more remote from the source territories caused by meteorological conditions influencing precipitation of the radioactive substances. For dose analysis the territories with the level of ^{137}Cs contamination about 0.3÷2 MBq/m^2 present the most interest. Such level of contamination leads to external exposure till the end of the year of an accident higher than 20 mSv and consequently requires some measures on population protection [Recommendations 2007].

Thus, as the territories of the most interest were selected Novovibkovsky subregion (Russia) and municipality Namie (Japan) with the average contamination on fallout moment of 0.83 MBq/m^2 and 1.3 MBq/m^2 correspondingly. Table 2 presents the main parameters of these administrative units.

Table 2. Base parameters on administrative units and their radiological situation

Parameter, its measuring unit	Namie	Novozibkovsky subregion
Area,km^2	223.1	991.7
Population, number	21615	63269
Population density, number/km^2	96.9	63.8
Area under population sites, km^2	~63	~50
Integrated ^{131}I contamination, PBq	3	4.6
Integrated ^{137}Cs contamination, PBq	0.3	0.8
Minimal ^{137}Cs contamination density, kBq/m^2	40	200
Maximal ^{137}Cs contamination density, kBq/m^2	3600	2300
Average ^{137}Cs contamination density, kBq/m^2	1300	800
Maximal concentration of ^{131}I in milk, kBq/l	5	200

Due to its lower territory the Namie municipality has lower integrated contamination than the Novozibkovsky subregion. On the other side Namie surface contamination presents stronger non homogeneity with much higher values at single locations, what can be seen through higher value of the average contamination. Nevertheless, one can consider these territories as rather similar according to radioecological parameters.

Dose power in the open space can be either measured or estimated. Still it is always used within estimation of dose exposure. Dynamics of the dose power mostly depends by the nuclear composure of the fallout, what allows to make corresponding estimates. Also it depends by type of underlying surface. Table 3 visualizes the dependence from the underlying surface. It presents measurements in Noviye Bobovichi – a population site from the Novozibkovsky subregion, which has rather homogeneous surface contamination with an average ^{137}Cs contamination density of about 1.05±0.26 MBq/m^2. For the comparison Table 3 also presents dose power dynamics for one monitoring point in Namie due to the North-West tail. The slower decreasing of the dose power in Namie is due to relatively higher content of ^{134}Cs in the Fukushima release.

Table 3. Radiation in Noviye Bobovichi and sample point 32 in Namie (μGy/h)

Date / Underlying surface type	26.04.86 D+0	01.09.86 D+126	01.09.87	01.09.90	01.09.2005
Grass lawn	130	5	3.1	1.3	0.48
Hard road, centre	100	2	1	0.47	0.18
Yard	130	5	2.5	0.77	0.3
Vegetable garden	160	4	2	0.6	0.4
Undisturbed zone	170	6	4	1.8	0.6
Date / Underlying surface type	15.03.2011 D+0	19.07.11 D+126			
Undisturbed zone	130	12			

Usually, average power dose over different underlying surfaces around several housings characterizes an agricultural population site.

3. ANALYSIS OF YEARLY DOSES OBTAINED BY POPULATION

Population exposure dose forms from external and internal parts. External part bases on the contamination density of separate radionuclides for considering time. Realistic estimate takes into the account people movements, influence of deepening of radionuclides to the soil, protective properties of screens and buildings. To illustrate the difference of external dose's estimates let us consider already mentioned above population site Noviye Bobovichi. The most conservative estimate of external dose during the first after accident year (248 days) of it was 19 mSv. After considering of the deepening in soil and snow coverage the dose decreased to 15.3 mSv. The more realistic model considering people movements and protective effect of buildings gives an estimate of 8.2 mSv, two times lower than the first estimate. But still because of the conservative habits of radioecologists the official dose indicated in proof-books on contamination issued in 1987 is 18.6 mSv.

Table 4. Estimates of average external exposure doses for people in Noviye Bobovichi in 1990

Place	Average dose power, μGy/h	Dose, mSv
Inside house	0.28	0.932
Yard	0.77	0.164
Household buildings	0.42	0.087
Garden, vegetable garden	1.01	0.491
Street	0.585	0.264
Office	0.3	0.422
Total		2.36

The detailed analysis of external doses was performed in Noviye Bobovichi in 1990 when the average contamination density was already 1 MBq/m^2. For this purpose were performed samplings in every individual hosting. Table 4 presents dose powers and external doses obtained by an adult person in different places according to an average time of spending there considering different seasons [Panchenko et al, 2003]. Only departure from the site was not considered. The obtained realistic estimate appears nearly 1.9 times lower than the official for the 1990 value from the proof-books (4.4 mSv).

Estimates of internal dose are even more uncertain than the external one. Internal doses are mostly connected with the contaminated food. Estimation of internal dose bases on the local food priorities and seasoning. The calculations also use models of ^{137}Cs metabolism.

Table 5 presents results of the internal dose's estimates for several population sites in the Novozibkovski subregion performed using different approaches. Countermeasures such as limitation of consuming local contaminated products were both considered (with CM) or ignored (no CM) [Konstantinov et al, 1987]. Also Table 5 presents dose estimates reconstructed later (in 1999) after modification of coefficients [Risk & Radiation, 1999] basing on additional study of population.

Table 5. Estimates of the internal doses (mSv) during 1986 for population sites of the Novozibkovski subregion

Population site	Contamination density, MBq/m^2	Conservative approach		Realistic approach		Reconstructed, 1999
		No CM	With CM	No CM	With CM	
St.Vishkov	1.5	207	84	67	5.3	3.2
Svyatsk	1.5	77	31	73	4	3.2
Veretshaki	0.7	128	53	32	5.2	4.4
Katichi	0.64	98	40	46	4.1	4

Special attention is usually paid to analysis of thyroid exposure dose as it is a well-known storage of radionuclide ^{131}I if preventive actions weren't performed. Within Novozibkovski subregion the most part of ^{131}I was obtained through milk. The average estimate of thyroid exposure for an adult is 80 mGy, for a baby – 560 mGy.

To model exposure doses for Namie population the first step was to reconstruct the contents of radionuclides in the fallout. It was performed using dynamics of dose power in monitoring points and single samples of soils within north-west tail. Soil samples provide information on relative contents of radionuclides allowing to estimate fractional coefficients. The curve describing dynamics of the dose power allows to estimate concentrations of the short-living nuclides ^{136}Cs, ^{131}I, ^{132}I at the fallout moment. Figure 2 illustrates such reconstruction on an example of the monitoring point 32. Table 6 presents reconstructed concentrations of radionuclides in the atmosphere just above the surface for the monitoring point 32 and their contents for the dose from the radioactive puff.

Table 6. Concentrations of radionuclides and exposure dose from the puff at monitoring point 32

Isotope	Integrated concentration in the air, $Bq \cdot c/m^3$	Dose coefficient, $(Sv/c)/(Bq/m^3)$	Exposure dose from the puff, nSv
^{129m}Te	$3.5 \cdot 10^8$	$1.55 \cdot 10^{-15}$	545
^{132}Te	$1.8 \cdot 10^9$	$1.03 \cdot 10^{-14}$	18330
^{131}I	$1.1 \cdot 10^9$	$1.82 \cdot 10^{-14}$	20817
^{132}I	$1.8 \cdot 10^9$	$1.12 \cdot 10^{-12}$	199315
^{133}I	$2.9 \cdot 10^8$	$2.94 \cdot 10^{-14}$	8561
^{133m}Xe	$1.9 \cdot 10^9$	$1.3 \cdot 10^{-15}$	2658
^{133}Xe	$1.2 \cdot 10^{11}$	$1.55 \cdot 10^{-15}$	187477
^{134}Cs	$2 \cdot 10^8$	$7.5 \cdot 10^{-14}$	15224
^{136}Cs	$4.6 \cdot 10^6$	$1.06 \cdot 10^{-13}$	4898
^{137}Cs	$2.1 \cdot 10^8$	$2.88 \cdot 10^{-14}$	6118
TOTAL			463943

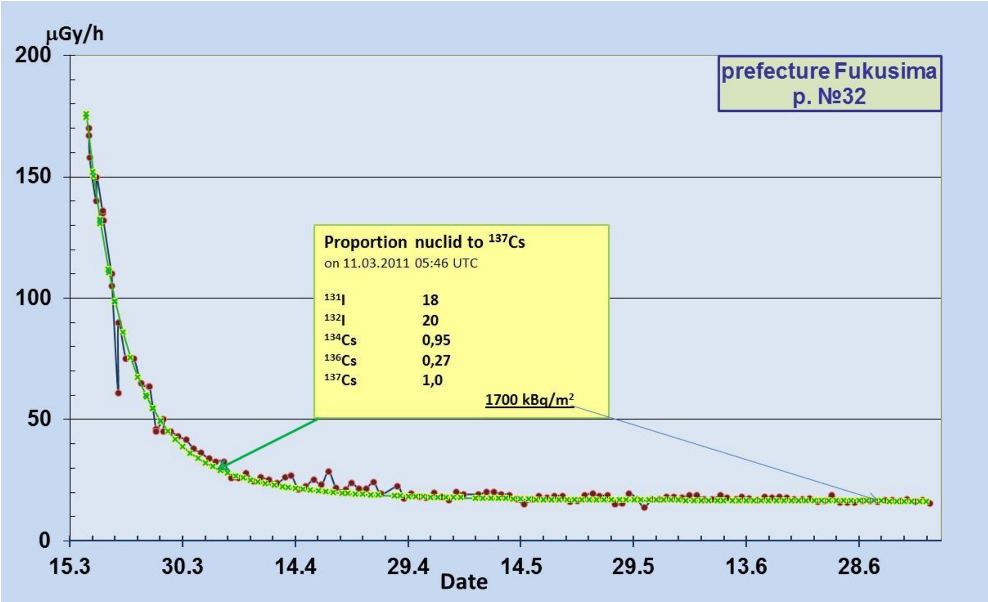

Figure 2. Reconstruction of the ^{137}Cs contamination density and radionuclide contents for monitoring point 32

The exposure dose was calculated under assumptions that: 10% of ^{131}I was in the form of aerosol and 90% is the molecular iodine; not all inertial gases were extracted from the fuel before the accident. According to calculations external exposure dose from the plume near point 32 is about 0.4±0.1 mSv. The dose on the thyroid of an adult being outside during the plume passing due to inhalation of iodine and tellurium is about 120 mSv. An external dose till the end of the year due to surface radiation taking into the account protection of the buildings is 70 mSv.

To compare exposure doses for Noviye Bobovichi and a population site in Fukushima prefecture during the first year we shall consider the equal time interval (248 days). The both population sites have similar ^{137}Cs contamination density (1.05 MBq/m^2). Table 7 presents calculations of different contents of the exposure dose for comparative analysis.

Table 7. Exposure doses (mSv) for Noviye Bobovichi and a population site from Namie municipality

Dose type	Noviye Bobovichi	PS from Namie
From the plume (no protection)	<0.1	0.3
From the surface	8.2	40
On the thyroid of an adult	80	70
On the thyroid of a baby	560	75
Internal exposure (without thyroid)	3±2	<1

The strongest difference between this two population sites is in the exposure dose from the surface, it is about in 5 times. It can't be explained only by the difference in the contents of ^{134}Cs. It seems that estimate for Namie's site is too conservative. Also as too conservative can be considered estimates concerning thyroid exposure in Namie, as there was nobody found with a dose higher than 50 mSv. Real internal exposures (including the thyroid) were lower because contaminated food was absolutely not consumed in Japan and normative regulations for food stayed at the normal values. Japan authorities do not apply accidental regulation norms. Nevertheless in general dose exposure structure can be considered as similar.

4. LONG-TERM EXPOSURE DOSE ANALYSIS AND COUNTERMEASURES

Dynamics of yearly exposure doses and calculations of more long-term doses is possible only for Chernobyl data. But taking into the account already observer similarity, some expectations on Japanese situation can be made.

As it was already mentioned above different approaches for dose estimation provide strongly different results. The conservative estimate was usually fixed as an official one. Such situation continued till 2011, when in [Russian National Report, 2011] more realistic estimates were published as an official version.

At all population sites in Russia with ^{137}Cs contamination density above 1 MBq/m^2 took place a great set of countermearsures with a total number of items more 100. The most important among them were: desactivation of buildings by changing roofs and somewhere walls and changing coverage of streets; total monitoring of local food production; change of grain cultures to potatos; strong recultivation and mineralization of fields; changes in the structure of cows norishment; etc. The serious activity was devoted to people information concerning utilisation of contaminated production, as an example milk with ^{137}Cs concentration slightly higher than regulation norms allows to produce butter or cheese clean according to regulation norms. Also lots of proof-books and atlases were published outlining properties of wild forest mushrooms and berries to consume radionuclides. All measures led to faster decreasing yearly exposure doses, but real doses seem to be decreasing even faster.

Here we consider estimates for population site Noviye Bobovichi. Figure 3 presents dynamics of yearly doses according to official data. They are conservative but still use some countermeasures according to their application dynamics.

The calculations of the storage doses for the 20 years period also suffer from uncertainty due to different approaches. The estimate of a cumulated dose for Noviye Bobovichi simply by adding the yearly official doses (from Figure 3) provides a value of 98.4 mSv. The estimate based on the official approach to obtain yearly doses and their summation provides a value of 73 mSv. Summation of yearly doses according to more realistic approach gives the value of 42.4 mSv. The most recent official document [Russian National Report, 2011] gives the most realistic estimate: the average over all population sites with initial ^{137}Cs contamination density within the interval 0.56 – 1.5 MBq/m^{2}of the 20 year cumulated dose is 39.6 mSv.

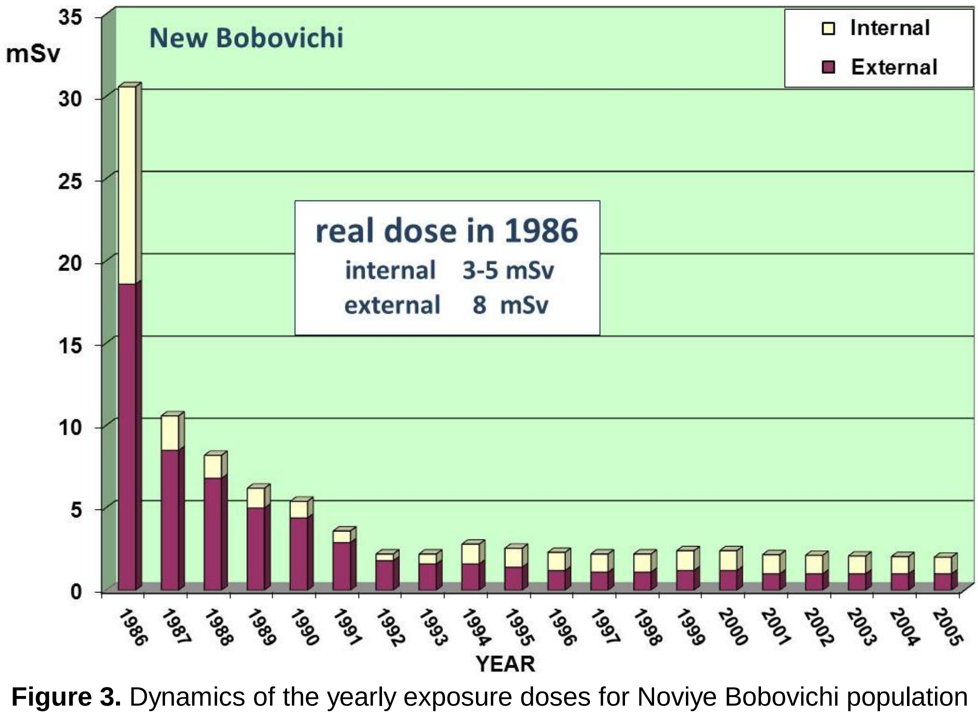

Figure 3. Dynamics of the yearly exposure doses for Noviye Bobovichi population according to official data

According to Japanese officials agricultural territories and population sites within contaminated territories were covered by the whole spectrum of countermeasures according to obtained consultations: decontamination, limitation of the consumption of local products, education of population. Thus one can expect for the Japan more optimistic results in overcoming the radioecologic accident consequences.

CONCLUSION

1. Nevertheless very similar structure of the fallout population exposure due to the Fukushima accident is lower, and long-term consequences are expected to be less great because of in-time performed countermeasures.
2. At the acute phase of the radiation catastrophe the most dangerous are iodine isotopes. Their importance is higher if the nuclear fuel has a low distraction. In about a month grew the importance of caesium isotopes. Only within catastrophic events with dispersion of fuel (as Chernobyl case) hotmelting elements induce real input in dose exposure outside the technical zone and during a year after an accident.
3. In the case when such measure as evacuation is not used internal exposure doses can be rather simply decreased, and the exposure of the population is only due to radioactive fallout.
4. Real external exposure doses for the first year appear to be significantly lower than calculated values, which are used for developments of countermeasures for the acute phase.

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