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EVALUATION OF THE NUCLEAR POWER PLANT KOZLODUY IMPACT ON THE POPULATION HEALTH STATE IN THE AREA*

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Abstract. Kozloduy nuclear power plant (NPP) is located in Bulgaria, 11 km away from Gighera, a village of Dolj County. NPP has been working since 1974. It has six Russian WWER reactors, two of them still working. In the area (a semicircle with a radius of 30 km, called Bechet area – according to the name of the biggest community) live about 82,000 inhabitants. We sought to evaluate the health state of this population in comparison with the health state of the Dolj County population (about 630,000 inhabitants), for a period of 18 years (1990-2007). We measured the radioactivity of water and food samples monthly and analyzed the rate of births, the incidence of congenital malformations and of cancer, and the general mortality in both regions. The measurements results have not shown significant differences between the two areas. The birth rate has been decreasing in both regions while cancer incidence and mortality have been increasing. Only the incidence of congenital malformations registered opposite evolutions, decreasing in Bechet area and increasing in the other one. There are no reasons of concern for the public health authorities about the influence of NPP Kozloduy on the population's health state, for the time being.

Key words: nuclear power plant, health, radioactivity.

1. INTRODUCTION

Kozloduy nuclear power plant is located in Bulgaria, only 11 km away from Gighera, a village of Dolj County.

The power plant has been working since 1974. It has six Russian WWER reactors; two of them, WWER 1,000, open in 1988 and 1993, are still working. Their fuel is enriched uranium and they use Danube water to condense the steam in the condensers.

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In 2002, Bulgaria de-commissioned the first two reactors, but avoided closing down the following two 440MW reactors, instead, providing them with an additional condensation system.

These two were closed at the beginning of this year, so only two 1,000 MW reactors are still working.

It is known that normal physiological processes generate a series of toxic oxidising products (free radicals), which are detrimental to health, even mutational, and sometimes with a carcinogenetic potential. Most or all the cells damaged by the oxidising products survive due to their recovering capacity.

Continual exposure to small doses of radiations may induce cell injuries similar to those produced by oxidising products resulted from normal cellular processes. These free radicals or ions can affect the cell functions, including the DNA of the cell nucleus, the genetic „project carrier" for the structure and functions of the cell. The scientific community recognises that this type of DNA affection can cause either cancer or other genetic abnormalities. However, there is no wide scale scientific consensus up till now, regarding the other diseases, except cancer, that may be brought about by exposure to small radiation doses [1, 2].

The absence of a unanimous opinion of physiologists and radiobiologists about the influence of small radiation doses, the impossibility of singling the radiation component out of the multitude of unfavourable factors, and the non-specific action of small radiation doses over the human body with stochastic effects (late consequences), that can appear decades after irradiation, are the main reasons for the necessity of monitoring over a long period the population health state including the early discovery of the negative tendencies and an efficient organisation of social and medical activities [1, 2].

The form of the relation dose-effect is known only for large doses. The effects of the small radiation doses manifest themselves through the non-linear dependence between the injury level and dose, both at the level of the different systems and at the body level. The stochastic effects always appear late. Years or decades may pass between the moment of exposure and the appearance of the effect. At present *there is no method of reducing the probability of appearance of effects for doses already taken in [3, 4]*.

The aim of this study was to delineate the possible effects produced by prolonged exposure to small radiation doses [5].

The study was carried out between 1990–2007.

2. MATERIALS AND METHODS

The data have been obtained by monitoring the radioactivity of the drinking water, and food samples specific for the local population consumption, collected monthly in two localities: Ghighera village, located at 11 km away, and Craiova city, situated at 60 km away from the Kozloduy NPP. Both places are on the main direction of the winds.

The well water in Gighera was collected weekly from the same two wells, one covered and one uncovered. The water in Craiova comes through the pipeline.

The β global measurements and chemical analyses of Sr-90 and Cs-137 have been done with a low background device of the NK-350 type equipped with a Geiger-Muller in anti-coincidence, with an efficiency of 11.5% for K-40, 17.6% for Sr-90, and 16.8% for Cs-137.

In order to calibrate the installation, we chose K-40, as global β radioactivity is mainly given by K-40 radioactivity, and, in the absence of a radioactive contamination, the average annual values should not differ significantly.

Chemical analyses were carried out for Sr-90 and Cs-137 as these have high radio-toxicity, they have a long half time and they concentrate in bones and muscles.

The spectrometric gamma identifications were done with a multi-channel Eurisys-Mesures spectrometer equipped with a super-pure germanium detector. No evidence of the presence of some artificial gamma emitting isotopes was found.

The demographic and health data were obtained from the evidence books of the primary medical assistance, the books of the Oncology Clinic of the Emergency County Hospital and the evidences of the IT and Medical Biostatistics Service of the Public Health Authority-Dolj which refer to the population on the Romanian territory within a semi-circle of 30 km near the power plant, called generically the Bechet zone (after the name of the largest settlement in the area), and the rest of the population in Dolj county (Dolj-Bechet).

Bechet zone comprises 18 localities with a population of about 82,000 inhabitants (13% of the Dolj county population).

We tried to limit the influence of the pollution area, to determine the population exposed to risks, and to get some information about [7, 8]:

– the artificial radioactive pollution of the environment due to the NPP (we calculated the annual and multi-annual average values and the mean standard errors);

– the population structure according to age, birth rate, death rate, etc;

– the incidence in the risk population of congenial malformations and malignant tumours;

– general death rate.

In order to compare the average values, we used the Student test, „t", for equal dispersion [9, 10]:

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sigma\sqrt{\frac{1}{n_1} \pm \frac{1}{n_2}}}, \tag{1}$$

where: $\bar{x}_1$ and $\bar{x}_2$ are the average values;

$$\sigma = \sqrt{\frac{(n_1 - 1)\sigma_1^{\,2} + (n_2 - 1)\sigma_2^{\,2}}{n_1 + n_2 - 1}}\,, \tag{2}$$

σ_1 and σ_2 are the standard errors of the two means; n_1 – the number of samples of a certain type collected in the Bechet zone; n_2 – the number of samples of the same type collected in Dolj county-Bechet;

The computed value for t is compared to the theoretical value. If the computed value is smaller than the theoretical one, for a significant level of 5%, the difference is considered statistically insignificant for a probability of 95% and $p > 0.05$.

The theoretical values for t are:

- 1.96 for a probability of 95% (significance level 5%, thus $p = 0.05$);
- 2.57 for a probability of 99% (significance level 1%, thus $p = 0.01$);
- 3.29 for a probability of 99.9% (significance level 0.1%, thus $p = 0.001$).

For a significance level of 95%, the confidence interval was computed according to the formula [9]:

$$f \pm 1.96\sqrt{\frac{f(1-f)}{n}}\,, \tag{3}$$

where: f – the percentage of affected individuals found in the group (frequency of illnesses); n – the number of individuals in the group.

In order to test the statistical significance of the difference between the trends of the analyzed parameters, the trend for the annual difference between the two series of values has been raised. The 18 annual differences have been leveled using a regression line. The linear correlation coefficient has been most of the times statistically insignificant.

After gathering the data, the dynamics of the indicators studied between 1996 and 2007 has been analysed.

3. RESULTS

Long term analysis of water and food samples has not shown the existence of artificial radioactive pollution because of Kozloduy NPP, the obtained values being comparable both from year to year, and between the two places of collection.

The well water radioactivity is greater than that of pipeline water due to the residue and not to the radioactive contamination made by the NPP. In fact, we could not demonstrate a contamination of the uncovered well water.

The presence of Sr-90 and Cs-137 in all the products is justified by the Cernobyl accident.

The measured values are obviously under the maximum admitted concentrations.

Table 1 presents the average multi-annual values obtained between 1990 and 2007 (abreviation used: M.A.P. = maximum activity permitted; N.D.L. = less than detection limit; M.D.A. = minim detectable activity).

In all tests the result was $p > 0.05$ for all kinds of products both β global and for chemical analyses. The only significantly difference was between the edible well water in Gighera and the pipeline water in Craiova, where the difference was highly significant, $p < 0.001$.

Analysing the population structure in the two areas Fig. 1, we found that the population number is decreasing, the reduction being more evident in the Dolj-Bechet area than in the alleged risk zone.

As for the population distribution, close to the nuclear objective, according to the age, in 2007, we conclude that we are dealing with an ageing population (51.4% over 45, 31.4% between 15 and 44, and 16.92% between 0 and 14).

We notice in Table 2, Fig. 2 a low birth rate all over Dolj county, the Bechet zone being no exception, with values of 11.4‰ at most, along the whole study (in 2007 the birth rate in Romania was 9.9‰ and in the European Union 10.7‰ [13, 14]).

Table 1

Water and food radioactivity in Gighera and Craiova

Type of sample	**Place**	**Global β radio-activity**	**MAP [11]**	**Chemical analyses Sr-90**	**MAP [12]**	**Chemical analyses Cs-137**	**MAP [12]**
Drinking water	Gighera uncovered well	0.46±0.13 Bq/l	1.1 Bq/l	N.D.L. M.D.A. =0.02Bq/l	125 Bq/l	N.D.L. M.D.A. =0.02Bq/l	1000 Bq/l
	Gighera covered well	0.48±0.15 Bq/l		N.D.L. M.D.A. =0.02Bq/l		N.D.L. M.D.A. =0.02Bq/l	
	Craiova pipeline	0.11±0.03 Bq/l		N.D.L. M.D.A. =0.02Bq/l		N.D.L. M.D.A. =0.02Bq/l	
Milk	Gighera	42.5±6.3 Bq/l	-	0.058±0.02 Bq/l	125 Bq/l	0.095±0.03 Bq/l	1000 Bq/l
	Craiova	39.2±6.2 Bq/l	-	0.06±0.016 Bq/l		0.1±0,03 Bq/l	
Chicken meat	Gighera	80.5±10.2 Bq/kg	-	0.053±0.02 Bq/kg	750 Bq/kg	0.3±0.057 Bq/kg	1250 Bq/kg
	Craiova	82.6±11.6 Bq/kg	-	0.056±0.02 Bq/kg		0.32±0.067 Bq/kg	
Potatoes	Gighera	127.3±15.5 Bq/kg	-	0.032±0.01 Bq/kg		0.12±0.03 Bq/kg	
	Craiova	131±16,9 Bq/kg	-	0.028±0.01 Bq/kg		0.14±0.03 Bq/kg	

Table 1 (continued)

Bread	Gighera	38.8±6.2 Bq/kg	-	0.07±0.02 Bq/kg		0.128±0,03 Bq/kg	
	Craiova	41.2±6.8 Bq/kg	-	0.067±0.02 Bq/kg		0.12±0,026 Bq/kg	
Apples	Gighera	33.4±5.6 Bq/kg	-	0.018±0.01 Bq/kg		0.09±0.03 Bq/kg	
	Craiova	31.7±6.3 Bq/kg	-	0.021±0.01 Bq/kg		0.1±0.029 Bq/kg	

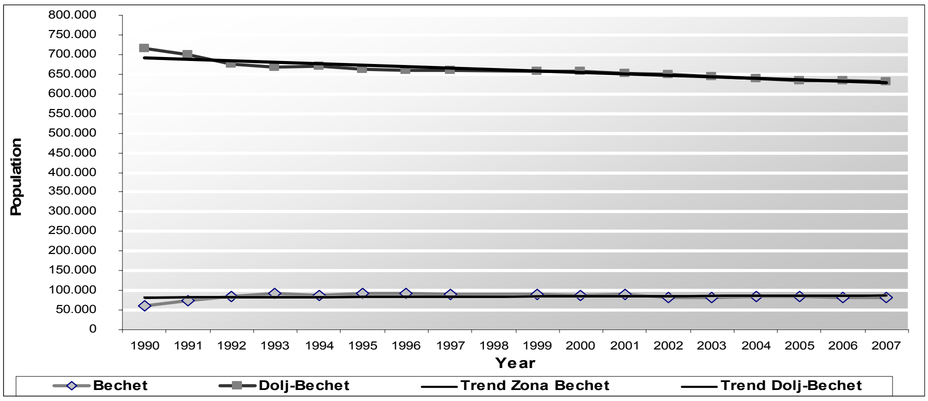

Fig. 1 – Population dynamics in Bechet area and Dolj County, between 1990 and 2007.

Table 2

Birth rate incidence in Bechet zone and Dolj county between 1990 and 2007

Year	**Birth rate**			
	Bechet Zone		**Dolj-Bechet**	
	No.	**$^0/_{00}$**	**No.**	**$^0/_{00}$**
1990	531	8.6	9488	13.3
1991	646	8.7	8358	11.9
1992	785	9.3	8140	12.1
1993	856	9.2	7513	11.3
1994	922	10.4	7671	11.4
1995	940	10.1	7169	10.8
1996	930	10.1	6968	10.6
1997	935	10.4	7258	11
1998	951	10.8	7307	11.1
1999	1011	11.4	7005	10.7
2000	865	9.9	8322	11.4
2001	724	8.1	6676	10.2
2002	832	10.2	6502	10

Table 2 (continued)

2003	742	9.1	6371	9.9
2004	715	8.5	6202	9.9
2005	600	8.5	6383	10.1
2006	631	7.7	6076	9.6
2007	474	5.7	6389	10.1

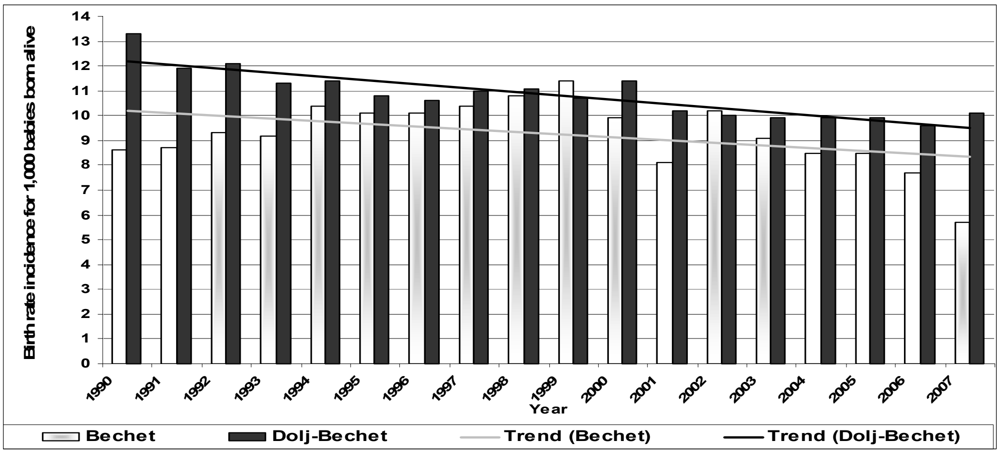

Fig. 2 – Birth rate incidence in Bechet Zone and Dolj-Bechet, between 1990 and 2007.

Table 3 and Fig. 3 present the situation of new-born babies' congenial malformations in the studied area.

The trend is decreasing in both areas, the reduction being more evident in the rest of the county than with the population exposed to risk. The trend difference was tested in order to establish whether the decreasing trend in the Bechet zone is inferior to the decreasing trend in Dolj-Bechet. No significant difference was rendered obvious ($p > 0.05$).

Tabel 3

Incidence of new born babies' congenial malformations in the Bechet Zone and Dolj County between 1990 and 2007

Year	**Congenial malformations incidence**			
	Bechet Zone		**Dolj-Bechet**	
	No.	**$^0/_{00}$**	**No.**	**$^0/_{00}$**
1990	4	7.5±3.7	131	13.8±2.3
1991	8	12.4±2.3	52	6.2±1.6
1992	3	3.8±4.3	46	5.7±1.5
1993	12	14±7.8	38	5±1.5

Table 3 (continued)

1994	14	15±7.8	69	9±2
1995	9	9.6±6.2	53	7.4±1.96
1996	5	5.4±4.6	34	4.9±1.5
1997	4	4.3±4.2	42	5.8±1.5
1998	3	3.2±3.6	33	4.5±1.5
1999	1	0.99± 1.8	191	27±3.7
2000	3	3.5±3.9	143	17.2±2.8
2001	2	2.7±3.8	179	26.8±3.9
2002	2	2.4±3.3	114	17.5±3.2
2003	1	1.3±2.6	113	17.8±3.2
2004	3	4.1±4.7	93	15 ±3
2005	1	1.7±3.3	39	6.1±1.9
2006	2	3.2 ±4.4	63	10.4±2.5
2007	2	4.2±5.8	134	20.9±3.5

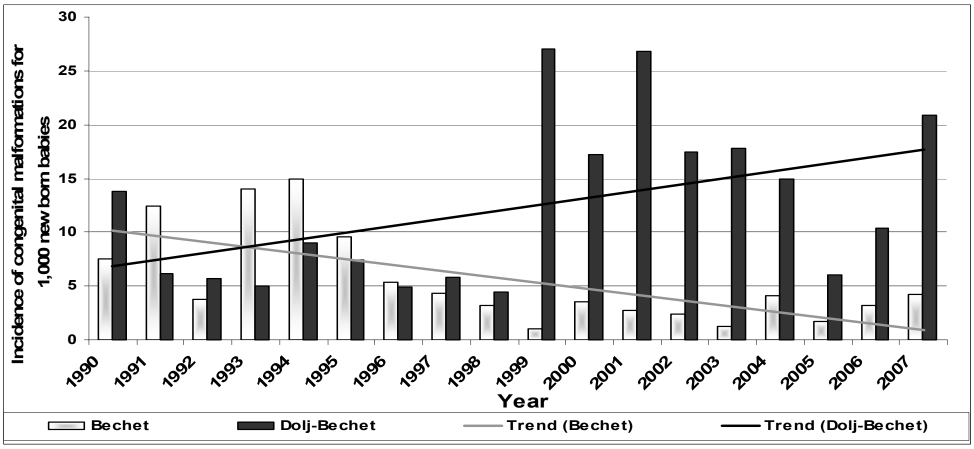

Fig. 3 – Incidence of new born babies' congenial malformations in the Bechet zone and Dolj-Bechet, between 1990 and 2007.

We found out that the incidence of births of new born babies with congenial malformations for 1,000 babies born alive decreased, while in the rest of the county it increased. Their evolution along the period was oscillating each and every year, in both areas, a fact that makes it difficult to compare them from this point of view.

Referring to the deterministic effects of the exposure to ionising radiation, we followed the global frequency of malignant tumours. The data regarding the malignant tumour incidence are presented in Table 4 and Fig. 4.

Tabel 4

Incidence of malignant tumours of the population living close to the nuclear objective and in Dolj County between 1990 and 2007

Year	Malignant tumours incidence			
	Bechet Zone		Dolj-Bechet	
	No.	/100,000	No.	/100,000
1990	49	79.6±7.05	1191	166.2±3
1991	53	71.2±6.1	916	130.9±2.7
1992	95	112.3±7.2	1432	212±3.5
1993	134	144.2±7.7	1181	177.1±3.2
1994	120	136±7.7	1117	166.6±3.1
1995	75	80.3±5.7	1303	196.6±3.4
1996	86	93±6.2	1914	290.1±4.1
1997	36	40.2± 4.2	1677	254.2±3.8
1998	66	74.9±5.7	1842	280.7±4
1999	123	138.4±7.7	1858	282.8±4.1
2000	143	163.7±8.4	1755	267.2±4
2001	128	143.8±7.9	1907	292.1±4.1
2002	124	151.4±8.4	1883	290±4.1
2003	189	231±10.4	1642	255±3.9
2004	190	226.3±10.2	1915	299±4.2
2005	155	184.1±9.2	1914	300.1±4.2
2006	263	322±12.3	1708	269.2±4
2007	230	280.8±36.2	2178	345.8±4.4

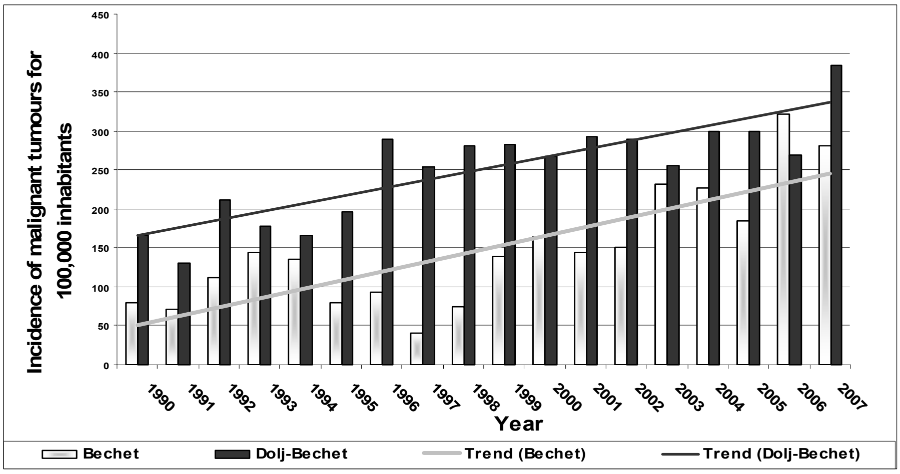

Fig. 4 – Incidence of malignant tumours of the population living close to the nuclear objective and in Dolj County, between 1990 and 2007.

We notice in both areas an increase in the incidence of malignant tumours between 1990 and 2007, but, though the trend is greater for Bechet zone, the incidence stays permanently under the county level. Comparing the two rising trends, we recorded that there is no significant difference between the two areas ($p > 0.05$). The difference of incidence between the two zones has a constant trend ($p > 0.05$).

There have also been recorded data regarding the general death rate, the situation being presented in Table 5 and Fig. 5.

Table 5

General death rate of the population around the nuclear objective and in Dolj County, between 1990 and 2007

Year	General death rate			
	Bechet Zone		Dolj-Bechet	
	No.	$^0/_{00}$	No.	$^0/_{00}$
1990	867	14.1	8837	12.4
1991	940	12.6	8572	12.3
1992	1309	15.5	8952	13,3
1993	1409	15.2	8694	13
1994	1323	15	8770	13.1
1995	1476	15.8	8961	13.5
1996	1531	16.6	9372	14.2
1997	1462	16.3	9403	14.2
1998	1413	16	8982	13.6
1999	1387	15.6	9195	14
2000	1291	14.8	8381	12,8
2001	1219	13.7	8911	14,9
2002	1358	16.6	9533	14,7
2003	1413	17.3	9202	14,3
2004	1395	16.6	8879	13,3
2005	1328	15.8	9040	14,2
2006	1328	16.3	8758	13,8
2007	1259	15.3	8683	13.8

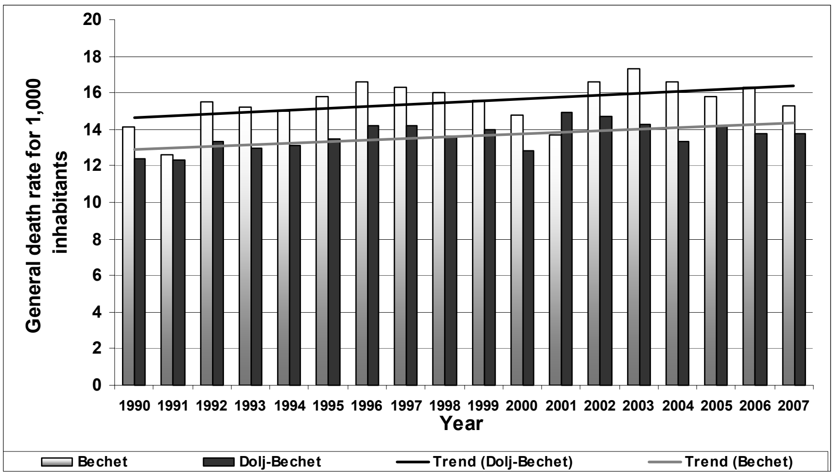

Fig. 5 – General death rate of the population near the nuclear objective and the rest of Dolj County, between 1990 and 2007.

We notice that in both areas, the general death rate has a rising tendency in this period (greater in both zones than the country average of 12‰ or European Union of 9‰ in 2007 [13, 14]). The death rate in Bechet zone was significantly greater than in the rest of the county along the whole period, $p < 0.001$ (99% probability), except for 1991 and 2001.

4. CONCLUSIONS

Following the analysis regarding the correlation between the population health state exposed to risk and the environment radioactivity, we can conclude that:

- the birth rate remains low;
- there are no significant differences between the two zones, in frequency or evolution trend, regarding malformations, malignant tumours or death rate;
- general death rate is greater in the Bechet zone, due to the fact that the population ageing process goes on, in surveyed rural areas.

Analysing the data regarding the population health state in the exposed zone to risk, we conclude that we cannot make a direct causal connection between the impact of the NPP over the environment and, implicitly, over the population health state.

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