Risk assessment of
radiation-induced thyroid
cancers in Belarus

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Abstract The paper presents results of a qualitative assessment of the morbidity and mortality in thyroid cancers by the Belarusian population caused by the Chernobyl accident. In the period of 1986-1998 about 3,851 radiation-induced thyroid cancers appeared in Belarus: about 615 cancers by children and about 3,236 cancers by adolescents and adults. The number of lethal thyroid cancers in this period of time in Belarus is assessed as about 167 cases. The excessive absolute risk (EAR) of the morbidity in the thyroid cancer assessed for the period of 1986-1998 on the basis of given data on the morbidity is about 1.7 per 10^4 PYGy. The excessive absolute risk of mortality is assessed as about 0.075 per 10^4 PYGy. These values agree quite well with analogous risk coefficients established for other groups of people in other epidemiological studies.

Introduction
As a result of the Chernobyl accident a large amount of radioactive substances escaped from the destroyed reactor. Especially high release was in the case of volatile radionuclides. So according to the existing assessments about 50-60 per cent of the ^131I isotope inventory came into the environment (Güntay et al., 1997). This caused the radioactive contamination of many countries of the Northern Hemisphere. However, Belarus was affected by the accident most of all. Practically the whole territory of Belarus was contaminated with different radionuclides (Matveenko et al., 1997). This resulted in irradiation of the whole Belarusian population. In the early stage of the accident the radiation situation was determined mostly by short-lived radionuclides. A very important role at this time was played by iodine isotopes. They caused irradiation of thyroid glands of children, adolescents and adults of the whole Belarus. However, the highest doses to the thyroid glands were delivered to inhabitants of Gomel and Brest oblasts (regions). For example, the arithmetic mean thyroid dose in the age group 0-6 years by children living in settlements settled in the 30km zone was about 4.7 Gy and maximal doses were about 50Gy (Gavrilin et al., 1999). For inhabitants of this settlement aged 7-17 years at the moment of the accident the thyroid dose was about 2.1Gy and for adults about 1.6Gy. The extensive irradiation of the thyroid gland by the Belarusian population caused very soon after the accident a significant increase in the incidence in thyroid cancers. This effect was especially very pronounced for children, who are more sensitive to irradiation and that received much higher doses than adolescents and adults.
The first reliable data on a sharp increase in the thyroid cancer morbidity by children of Belarus after the Chernobyl accident were published in 1992 (Kazakov et al., 1992). However, specialists met these data with great scepticism (Ron et al., 1992). There were serious reasons for this scepticism. First, the published data on the incidence of thyroid cancers have shown an unusual short latent period of about two to three years. Second, no similar data about the increase in the incidence of thyroid cancer by children of the affected areas of the Ukraine and Russia were known at that time. And this was very strange because all specialists believed that the Ukraine was affected by the Chernobyl accident much more than Belarus. It is now clear that such assumption was totally incorrect.

In order to explain an unusually high incidence of thyroid cancer in the children of Belarus some specialists proposed the idea that this increase was caused by the improved screening in Belarus (Ron et al., 1992).

This situation changed only after the first international conference on the radiological consequences of the Chernobyl accident held in Minsk in 1996 from 18-22 March. At the conference new data on the thyroid cancer incidence in Belarus (Demidchik et al., 1996a) as well as similar data on the increase in the thyroid cancer incidence by children of the Ukraine (Tronko et al., 1996) and Russia (Tsyb et al., 1996) were presented. Data on the thyroid cancer morbidity by children of these two countries differed only quantitatively from the Belarusian data.

At the Minske conference an amount of evidence was given which shows that the increase in the incidence of thyroid cancer in the children and adolescents of Belarus, the Ukraine and Russia had its origins in radiation.

So it was shown that, in Belarus, thyroid cancer has mainly appeared in children irradiated as a result of the Chernobyl accident. Out of the total number of 390 thyroid cancers registered by children of Belarus in 1986-1994 and first seven months of 1995, 380 cases were diagnosed by children born before the Chernobyl accident, six cases by children born at the time of the accident and only four cases by children born after full disintegration of radioiodine (Demidchik et al., 1996a). Another very important finding relates to the histological types of thyroid cancers in countries affected by the Chernobyl accident. For instance, more than 90 per cent of thyroid cancers in Belarus and the Ukraine were papillary carcinoma as compared with 68 per cent in England and Wales (Williams et al., 1996). Within the papillary carcinoma, over 70 per cent of thyroid cancers in the countries affected by the Chernobyl accident were of the solid follicular type, compared to only 40 per cent in England and Wales.

At present practically all specialists are sure that the sharp increase in the incidence in thyroid cancer established by the children of Belarus, the Ukraine and Russia after the Chernobyl accident has its origins in the radiation.

It is noticeable here that many specialists, especially in Western countries believe that besides radiation-induced thyroid cancers in the children of Belarus, the Ukraine and Russia no other medical effect was caused by the Chernobyl accident in these countries. Such an assumption is incorrect, at least for Belarus.
where an increase in the incidence of thyroid cancer in adolescents and adults was also registered after the accident. Existing assessment (Malko, 1998a) shows that in the period 1986-1997 about 2,708 additional thyroid cancers were manifest in adolescents and adults of Belarus in comparison with 562 cases of children. As can be seen from these data the number of additional thyroid cancers manifest in adolescents and adults of Belarus in the period 1986-1997 is five times higher than that for children. This fact indicates that assessment of the real harm of a radiological accident of the scale of the Chernobyl accident requires consideration of all irradiated groups of the affected population.

One of the tasks of this report is the assessment of the total number of additional thyroid cancers manifest in Belarus in the period 1986-1998, as well as finding arguments that show a positive association between these additional thyroid cancers and irradiation of people as a result of the Chernobyl accident.

It seems that assessment of the excessive absolute risk (EAR) of the radiation-induced thyroid cancer can provide such arguments. This task is solved on the basis of data established in Belarus because the population of this country received the highest thyroid doses (Malko, 1998b). Due to this fact a clearer manifestation of the irradiation effects may be expected in Belarus. It is also important that the epidemiological data established in Belarus are more comprehensive and accurate than in Russia and the Ukraine.

**Materials and method**

Assessment of the morbidity in thyroid cancers by children, adolescents and adults of Belarus after the Chernobyl accident was carried out on the basis of published data of the Scientific Center for Thyroid Cancer of Belarus (Demidchik *et al.*, 1996a; 1996b; Demidchik, 1998; Demidchik, 2000) as well as published data of the Belarusian Cancer Registry (1999).

These centers collect all information about thyroid cancers in children, adolescents and adults registered in all regions of Belarus. This monitoring of the manifestation of thyroid cancers was carried out from the 1960s.

Analysis of publications of the Scientific Center for Thyroid Cancer of Belarus and of the Belarusian Cancer Registry shows that they give practically the same data on the incidence of thyroid cancers in children, adolescents and adults of Belarus. The only one difference is that the Center publishes the absolute numbers of thyroid cancers and the Registry gives the crude incidence rates as well as age standardized morbidity rates. The Registry gives also information about mortality from thyroid and other cancers.

The excessive absolute risk was assessed in the paper on the basis of the following expression:

\[
\text{EAR} = (O - E \cdot c)/(H^{\text{coll}} n),
\]

(1)

where:

- \(O\) = observed number of cases;
- \(E\) = expected or spontaneous number of cases;
EMH 11.5

\[ c = \text{coefficient allowing for the screening effect;} \]
\[ H^{\text{coll}} = \text{collective dose of the thyroid gland irradiation;} \]
\[ n = \text{number of years under observation.} \]

The value of the coefficient \( c \) in the present work was taken equal to 1 because no correct information about a contribution of the screening effect to the incidence in thyroid cancers by children, adolescents and adults of Belarus before and after the Chernobyl accident is known.

In the case of children, as an expected number of thyroid cancers, 1 case per year was taken as follows from data of the Belarusian Thyroid Cancer Center (Demidchik et al., 1996b). So according to these data in 1966-1985 (or during 20 years before the Chernobyl accident) only 21 cases of thyroid cancer were registered by children of Belarus. This gives one case of thyroid cancer per year as a spontaneous morbidity in the thyroid cancer for the Belarusian children. The average number of children (less than 15 years old) in Belarus in the pre-accidental period was about 2.5 million (Public Health, 1997). As can be calculated from this figure the spontaneous morbidity in thyroid cancer by children of Belarus before the Chernobyl accident was approximately 0.4 cases per million. This value is very close to the spontaneous morbidity in thyroid cancer in children of England and Wales (Williams et al., 1966), that is approximately 0.5 cases per million.

The expected numbers of thyroid cancers in adolescents and adults of Belarus were assessed on the basis of the formula (Malko, 1998a):

\[ E_j = E_0 \cdot (1 + a)^j, \]  \hspace{1cm} (2)

Here:

\[ E_0 = \text{spontaneous morbidity of adolescents and adults in 1977 (121 cases);} \]
\[ a = \text{is a constant showing the annual increase in the incidence of the thyroid cancer, it is about 0.2 (2 per cent increase annually);} \]
\[ j = \text{is a number of the consequent year beginning with } j = 0 \text{ for 1977 (} j = 1 \text{ for 1978 and so on);} \]
\[ E_j = \text{spontaneous morbidity of adolescents and adults in the } j\text{th year.} \]

The last expression was established by using observed incidence in thyroid cancers by adolescents and adults of Belarus before the Chernobyl accident (Demidchik et al., 1996a). In the present paper it was used for calculation of expected thyroid cancers in this group of population after the Chernobyl accident. Results of calculation together with observed data (Demidchik et al., 1996a) are presented in Table I. Here are also given observed and expected numbers of thyroid cancers by children of Belarus in 1977-1985.

As can be seen from Table I, observed (Demidchik et al., 1996a) and expected numbers of thyroid cancers in children, adolescents and adults of Belarus in
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1977-1985 tally quite well. For example, the difference between numbers of observed (1,131 cases) and expected (1,180) thyroid cancers in adolescents and adults of Belarus in this period of time is only 49 cases or about 4.3 per cent. This means that our assumption about the spontaneous morbidity of thyroid cancer in Belarus before the Chernobyl accident is quite correct. Data in this table show that the largest difference in observed and expected numbers of the thyroid cancer in the case of adolescents and adults took place in 1978 and 1979. It is about 25 per cent. It resulted possibly from underestimation of observed thyroid cancers in 1978 and 1979. By using for these years data calculated with the expression (2) as observed data, the difference in total amounts of observed and expected numbers of thyroid cancers manifest in adolescents and adults in the period 1977-1985 decreased by up to 0.16 per cent. Observed numbers of thyroid cancers in adolescents and adults of Belarus corrected in this way are given in the sixth column of Table I.

### Results and discussion

Table II and Figure 1 show observed data (Demidchik, 1998) on the thyroid cancer morbidity of children of Belarus after the Chernobyl accident. Data in Table II demonstrates an increase in the incidence of the thyroid cancer manifest in children of all regions of Belarus. However, the largest increase

<table>
<thead>
<tr>
<th>Year</th>
<th>Children Observed</th>
<th>Children Expected</th>
<th>Adolescents and adults Observed</th>
<th>Adolescents and adults Expected</th>
<th>Adolescents and adults Corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>2</td>
<td>1</td>
<td>121</td>
<td>121</td>
<td>121</td>
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<td>1978</td>
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<td>97</td>
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<td>123</td>
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<td>101</td>
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<td>1980</td>
<td>0</td>
<td>1</td>
<td>127</td>
<td>128</td>
<td>127</td>
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<td>1</td>
<td>1</td>
<td>132</td>
<td>131</td>
<td>132</td>
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<td>1982</td>
<td>1</td>
<td>1</td>
<td>131</td>
<td>134</td>
<td>131</td>
</tr>
<tr>
<td>1983</td>
<td>0</td>
<td>1</td>
<td>136</td>
<td>136</td>
<td>136</td>
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<tr>
<td>1984</td>
<td>0</td>
<td>1</td>
<td>139</td>
<td>139</td>
<td>139</td>
</tr>
<tr>
<td>1985</td>
<td>1</td>
<td>1</td>
<td>148</td>
<td>142</td>
<td>148</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>9</td>
<td>1,131</td>
<td>1,180</td>
<td>1,182</td>
</tr>
</tbody>
</table>

### Table II.

Thyroid cancer in children of Belarus after the Chernobyl accident

<table>
<thead>
<tr>
<th>Year</th>
<th>Brest</th>
<th>Vitebsk</th>
<th>Gomel</th>
<th>Grodno</th>
<th>Minsk</th>
<th>Mogilev</th>
<th>Minsk-city</th>
<th>Belarus total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1987</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1988</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1989</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1990</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1991</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1992</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1993</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1994</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1995</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1996</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1997</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Cases: 459
appeared in the Gomel and Brest regions. The geographical distribution of thyroid cancers by Belarusian children correlates with levels of contamination by $^{131}$I isotope in Belarus (Matveenko et al., 1997).

The summary data from Table II were also used to construct Figure 1, which shows the temporary trend in the thyroid cancer incidence in children of Belarus in the time from 1986 up to 2004. Here numbers of thyroid cancers registered by children in 1986-1999 (Demidchik et al., 1996a; Demidchik, 1998; 2000) and data forecast for 2000-2004 are presented.

As can be seen from Table II and Figure 1, the incidence of thyroid cancer in children of Belarus reached the maximum in 1995 and then began to decrease. The reason for this decline is very easily explained. It was explained on the basis of a transition model (Malko, 1998a). All official data on the cancer morbidity in Belarus are given for two groups. The first group includes data for those people for which any cancer, as well as the thyroid cancer, was diagnosed when they were less than 15 years old. The second group includes all people who are older than 15 years. Thus, when a person reaches 15 years at the time of the thyroid cancer diagnosis this person will be considered as a person belonging to the group of adolescents and adults. This means that the observed decline in the morbidity in thyroid cancer in children of Belarus originates from the method of medical registration used in Belarus.

The last children with thyroid glands irradiated as a result of the Chernobyl accident will pass into the category of adolescents and adults in 2001. To this group belong children irradiated in-utero and born some months after the explosion of the Chernobyl reactor. Thus the incidence of thyroid cancer in children of Belarus in 2002 has to change to the spontaneous rate that was assessed in this paper as one case per year for the whole of Belarus.
By forecasting of numbers of thyroid cancers for 2000-2004 the following simplified procedure was used. A total 54 cases of thyroid cancers in 1998 and 49 in 1999 by children of Belarus were registered (Demidchik, 2000). Linear extrapolation between 49 cases in 1999 and one case in 2002 gives for the years 2000 and 2001, 32 and 16 thyroid cancers respectively. The total number of thyroid cancers in the Belarusian children that can manifest in the period from 1986 up to 2002 will be then equal to 725 cases. Subtracting from this number the number of spontaneous thyroid cancers that have to appear in 1986-2001 (15 cases) will give the total number of thyroid cancers in children of Belarus that will be caused as a result of the Chernobyl accident, equal to approximately 710 cases.

Data on the number of thyroid cancers registered by adolescents and adults of Belarus in 1986-1997 given in the second column of Table III were taken from the report (Demidchik, 1998). The number of thyroid cancers in this column for 1998 were calculated on the basis of the morbidity rate (Belarusian Cancer Registry, 1999) of thyroid cancer of the whole Belarusian population.

According to report of the Belarusian Cancer Registry (1999) this rate was 7.5 cases per 100,000 people in 1998 and the total number of people in Belarus was 10.2 million. By using these data one can calculate the total number of thyroid cancers registered in Belarus in 1998 as being equal to 765 cases. This number is a sum of thyroid cancers established by children and adolescents and adults. Subtraction of the number of children’s cancers (54 cases in 1998) from this value gives 711 cases as a number of thyroid cancers registered in 1998 by adolescents and adults. This number is shown in Table III.

The third column of Table III gives numbers of spontaneous thyroid cancers in 1986-1998 calculated by using the expression (2). The fourth column of this table presents the numbers of additional thyroid cancers manifest in

<table>
<thead>
<tr>
<th>Year</th>
<th>Observed</th>
<th>Expected</th>
<th>Observed-expected</th>
<th>Sir</th>
<th>95 per cent CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>162</td>
<td>145</td>
<td>17</td>
<td>1.12</td>
<td>0.95-1.30</td>
</tr>
<tr>
<td>1987</td>
<td>202</td>
<td>147</td>
<td>55</td>
<td>1.37</td>
<td>1.19-1.57</td>
</tr>
<tr>
<td>1988</td>
<td>207</td>
<td>150</td>
<td>57</td>
<td>1.38</td>
<td>1.20-1.58</td>
</tr>
<tr>
<td>1989</td>
<td>226</td>
<td>153</td>
<td>73</td>
<td>1.48</td>
<td>1.29-1.68</td>
</tr>
<tr>
<td>1990</td>
<td>289</td>
<td>157</td>
<td>132</td>
<td>1.84</td>
<td>1.64-2.06</td>
</tr>
<tr>
<td>1991</td>
<td>340</td>
<td>160</td>
<td>180</td>
<td>2.13</td>
<td>1.91-2.36</td>
</tr>
<tr>
<td>1992</td>
<td>416</td>
<td>163</td>
<td>253</td>
<td>2.55</td>
<td>2.31-2.81</td>
</tr>
<tr>
<td>1993</td>
<td>512</td>
<td>166</td>
<td>346</td>
<td>3.08</td>
<td>2.83-3.36</td>
</tr>
<tr>
<td>1994</td>
<td>553</td>
<td>169</td>
<td>384</td>
<td>3.27</td>
<td>3.01-3.56</td>
</tr>
<tr>
<td>1995</td>
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<td>358</td>
<td>3.07</td>
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<td>568</td>
<td>176</td>
<td>392</td>
<td>3.23</td>
<td>2.97-3.51</td>
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<tr>
<td>1997</td>
<td>641</td>
<td>180</td>
<td>461</td>
<td>3.56</td>
<td>3.29-3.85</td>
</tr>
<tr>
<td>1998</td>
<td>711</td>
<td>183</td>
<td>528</td>
<td>3.89</td>
<td>3.61-4.18</td>
</tr>
<tr>
<td>Total</td>
<td>5,358</td>
<td>2,122</td>
<td>3,236</td>
<td>2.52</td>
<td>2.46-2.59</td>
</tr>
</tbody>
</table>

Table III. Thyroid cancer in adolescents and adults of Belarus after the Chernobyl accident
adolescents and adults of Belarus in this period. The fifth column shows the standardized incidence ratio and the sixth column gives the confidence intervals estimated for SIR on the basis of the Poisson distribution.

The data of Table III show that the incidence of thyroid cancer in adolescents and adults of Belarus increased after the Chernobyl accident at least by a factor of two to three in comparison with the incidence before the accident. This increase resulted in the number of additional thyroid cancers equal to 3,236 cases. It is clear that the accuracy in the assessment of additional thyroid cancers depends very strongly on the accuracy in determination of the background morbidity before the Chernobyl accident, because the background morbidity in this period of time is used in the present paper for assessment of expected thyroid cancers after the accident. It is also evident that underestimation of the morbidity in thyroid cancers will be important only when after the accident a significant improvement in screening has taken place. This effect or the effect of improved screening is especially important in case of adolescents and adults because of a rather elevated increase in the incidence of thyroid cancers in this group of population after the Chernobyl accident. The effect of improved screening is not so important in the case of children because of a very large increase in the incidence in thyroid cancers by them.

Unfortunately, at the present time there is no such information for Belarus that could be helpful by answering the question what contribution to the assessed numbers of additional thyroid cancers by adolescents and adults gave the effect of improving in screening after the Chernobyl accident. However, it seems unreasonable to explain the evident increase in the incidence of thyroid cancers in adolescents and adults of Belarus after the accident exceptionally on the basis of the idea of improved screening. At least partly this increase has to be a real effect because of the transition from the group of children into the group of adolescents and adults. It should also be noticed here that a marked increase in the incidence of thyroid cancers in adolescents and adults was registered in 1987-1989, when there was no necessity for radical improvement of medical screening in Belarus. It is well known that in the former USSR only some areas in the northern Ukraine were considered as affected by the accident during the first three years after the accident. The first official and realistic information about radiological problems of Belarus caused by the Chernobyl accident appeared only three years after the accident. This was the time of aggravation of the economic situation in Belarus as well as in the whole USSR. So there was also no economic base for a significant improvement in screening of thyroid cancer in Belarus at all. Relating this problem, one needs also to notice that the incidence of the thyroid cancer in Belarus before the Chernobyl accident was practically the same as in some counties of the UK and in some other European countries. Calculation on the basis of corrected observed numbers of thyroid cancers (see the sixth column of Table I) gives, for the period 1978-1982, the mean age standardized (world standard) value of the morbidity rate of thyroid cancer for Belarusian population equal to 1.1 per 100,000 people. Practically the same standardized values were determined in
1978-1982 in different counties of the UK, as well as in different areas of Poland, Romania and other European countries. This agreement shows that the level of medical screening in Belarus before the Chernobyl accident was the same as in other European countries. Thus it is unreasonable to believe that the increase in the incidence of thyroid cancers in Belarus in the period 1986-1998 results from the improvement in the screening.

The total number of additional thyroid cancers in children, adolescents and adults of Belarus in 1986-1998 calculated on the basis of the data discussed above is equal to 3,851 cases. The collective thyroid dose of the Belarusian population according to the assessment (Malko, 1998b) is about $12.7 \times 10^5$ man-Sv. By this assessment a conversion coefficient $0.72$Sv/Gy was used. Considering this fact one can calculate the collective thyroid dose of the Belarusian population also as $17.6 \times 10^5$ man.Gy. Inserting this value and the number of additional thyroid cancers that was assessed in this work (3,851 cases) into the expression (1) one can estimate the EAR of the radiation-induced thyroid cancers caused in Belarus by the Chernobyl accident as being equal to $1.7$ per $10^4$ PYGy.

This value tallies completely with the excessive absolute risk of radiation-induced thyroid cancer that was established for the period 1990-1997 for those inhabitants of the city Kiev and Ukrainian regions closest to the Chernobyl NPP (Chernigov, Kiev and Zhytomir regions) that were 0-18 years old at the time of the Chernobyl accident (Likhtarev et al., 1999). In 1997 they were 11-31 years old. For this fraction of the affected Ukrainian population the value of the EAR equal to $1.7$ per $10^4$ PYGy was established.

The EAR value that was assessed in the present work agrees also very well with EARs established in other studies. For example, the value of EAR that was established for the period 1958-1987 by atomic bomb survivors is $1.6$ per $10^4$ PYSv with 95 per cent CI $0.78-2.5$ per $10^4$ PYSv. By transforming to other units these values gives the EAR equal to $1.1$ per $10^4$ PYGy ($95$ per cent CI = $0.55 - 1.75$). In the study of inhabitants of the Marshall Islands that had a strong internal irradiation of the thyroid gland with $^{131}$I the EAR was estimated as $1.1$ per $10^4$ PYGy (Robbins and Adams, 1989). Study of consequences of the Utah $^{131}$I fallout (Kerber et al., 1993) gave the value of EAR equal to $3.3$ per $10^4$ PYGy. According to the pooled analysis of Ron et al. (1995), the excessive absolute risk of the acute external irradiation of thyroid glands by people aged less than 20 is $4.4$ per $10^4$ PYGy (95 per cent CI = $1.9 - 10$).

Agreement between the values of EAR established in this and other works permits a number of conclusions, which are the following. First, one can believe that the number of additional thyroid cancers that was assessed in this work is quite reasonable. It means that, in the period of time 1986-1998, in Belarus about 615 radiation-induced thyroid cancers appeared in children and about 3,236 thyroid cancers in adolescents and adults. Second, this agreement reveals the correctness of the assessed collective thyroid dose of the Belarusian population (Malko, 1998b) used in the present paper by estimation of the excessive absolute risk. It is clear that a reasonable value of the excessive
absolute risk can be achieved only in case of having quite accurate data on the numbers of radiation-induced cancers and on the collective thyroid dose of the irradiated group of people. Third, the early manifestation of radiation-induced thyroid cancers in Belarus shows clearly that the latent period of the thyroid cancer, at least in Belarus, is less than five years. This is not surprising. Such a possibility was forecast a long time ago (Gofman, 1981). It was proposed that the latent period of any cancer had to depend on the number of people in the group under study. In the case of a small group a very long time can be needed in order to get a provable difference within a control group. By contrast, in the case of a very large group of irradiated people, the provable difference can be reached in a very short time. Such a situation is realized in Belarus where thyroid glands of approximately 10,000,000 people were irradiated.

The similar procedure as in the case of the thyroid cancer incidence can be used for assessment of a number of people in Belarus that died from the thyroid cancer caused by the Chernobyl accident.

Figure 2 shows the dynamic in the crude mortality rate resulting from the morbidity in thyroid cancers. These data were taken from reports of the Belarusian Cancer Registry (Public Health Ministry of the Republic of Belarus, 1997; Tsyb et al., 1996; Williams et al., 1996). They give the mortality in thyroid cancers of the whole Belarusian population (children, adolescents and adults). The upper (solid) line gives the observed mortality rates. The lower (dotted) line shows the “spontaneous” mortality rates as determined by us. Using these data as well as data on a number of people in Belarus in 1986-1998 (it is about 10 million people) gave approximately 167 fatal cases resulting from the radiation-induced thyroid cancers for this period of time.
The excessive absolute risk of mortality resulting from the radiation-induced thyroid cancers calculated on the basis of this number and the collective thyroid dose of the Belarusian population is equal to $0.075\times 10^4$ PYGy. This value is comparable with the excessive absolute risk of mortality from radiation thyroid cancers by atomic bomb survivors. For this cohort of people the value of EAR equal to $0.016\times 10^4$ PYSv (95 per cent CI $= -0.04 - 0.24$) was estimated for the period 1950-1987 (Ron et al., 1994). In other units the excessive absolute risk of mortality by atomic bomb survivors is $0.011\times 10^4$ PYGy (95 per cent CI $= -0.028 - 0.168$). As can be seen from these data, there is an overlapping in values of the excessive absolute risks of mortality from radiation-induced thyroid cancers estimated in the present paper and by atomic bomb survivors. This permits the conclusion that the number of people who have already died in Belarus from radiation-induced thyroid cancers caused by the Chernobyl accident is assessed in the present paper quite correctly.

Conclusions

- The morbidity and mortality from radiation-induced cancers in Belarus as a result of the Chernobyl accident has been assessed for the period of time 1986-1998. According to this assessment about 615 radiation-induced thyroid cancers in the children of Belarus appeared in 1986-1998. The total number of children’s thyroid cancers that will manifest in 1986-2001 can be about 710 cases. The number of the radiation-induced thyroid cancers manifested by adolescents and adults of Belarus in 1986-1998 as a result of the Chernobyl accident was assessed as approximately 3,236 cases. The total number of radiation-induced thyroid cancers appearing in this period of time is about 3,851 cases. The number of people that died in Belarus in 1986-1998 from radiation-induced cancer was assessed as about 167 cases.

- The excessive absolute risk, EAR, of the radiation-induced thyroid cancers manifested in Belarus after the Chernobyl accident is assessed as $1.7\times 10^4$ PYGy. This value agrees with EARs established in other studies of the morbidity in thyroid cancers as a result of irradiation.

- The excessive absolute risk of mortality in Belarus in 1986-1998 from the radiation-induced thyroid cancers was assessed as $0.075\times 10^4$ PYGy in accordance with data established in other studies.

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