Estimation of radiation exposure of the public during normal operation of NPP

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Task:

To show the methodology used by RIRAE for radioecological assessment in the observation zone of NPPs (certain example – Beloyarsk NPP):

Predictive assessment of radiation doses and risks for population resulted from atmospheric releases of radionuclides associated with the launch of a new unit at Beloyarsk NPP. Assessment of potential contamination levels of agricultural products and components of agroecosystems.

Assessment of radiation doses and risks from technogenic radioactive background for members of public in the observation zone of Beloyarsk NPP based on radioecological monitoring data.
The only nuclear power plant in Russia with a commercial fast breeder reactor BN-800.

Location: Sverdlovsk Region. 3 km to satellite city of Zarechnyy; 45 km to the region capital - Yekaterinburg.

Beloyarsk NPP named after I.V. Kurchatov was the pioneer of large-scale nuclear power production in the USSR, and Russia’s only nuclear plant running power units of different types.

The electrical power produced by Beloyarsk NPP amounts to about 10% of total electric power in the Sverdlovsk power grid.

The plant was built in three phases: phase 1 was Power Units No. 1 and 2 with an AMB reactor, phase 2 built Power Unit No. 3 with a BN-600 reactor and power unit No. 4 with a BN-800 reactor was built in 2014. After 17 and 22 years in operation, Power Units No. 1 and 2 were shut down in 1981 and 1989 respectively, and now remain in long-term conservation with defueled reactors; in terms of international standards, they are at Stage 1 of decommissioning.

Beloyarsk NPP has power unit BN-800 now in work. This is the world’s largest power unit with a fast-neutron reactor. The fast neutron reactor BN-800 rated for capacity 880 MW.
Methodological aspects:

Long-term assessment (forecasting) of radioecological situation in the vicinity of NPP:

Methodology:
- Safety Report Series No. 19
- CROM CODE - Screening Model for Environmental Assessment
- ERICA Tool

Input data:
- Annual release activity
- Meteorological conditions
- Environmental conditions, diet, etc.

Results:
- Radiation doses and risks for long-term period of NPP operation
- Exposure and contamination levels of agricultural crops, animals and foodstuff

Assessment of radiation doses and risks for population at current radioecological situation in the vicinity of NPP:

Methodology:
- MR 2.6.1.0063-12 “Control of radiation doses of population, residing in the vicinity of radiation facility during its operation and radiation emergency”

Input data:
- Monitoring data on concentrations of radionuclides in different components of environment and foodstuff
- Environmental conditions, diet, etc.

Results:
- Radiation doses and risks for population at current radioecological situation
Methodological aspects: Prognostic assessment of radioecological situation via atmospheric releases

Use of CROM Code and ERICA Tool for assessment

Input data:
- Annual activities of radionuclides released into the atmosphere, Bq/a;
- Meteorological parameters
- Release conditions (height, type of underlying terrain, etc.)

Pathways:
- Inhalation
- Cloud immersion
- Ingestion with foodstuff and water
- Soil surface exposure

Outputs:
- Annual average effective dose to public during the 1st and 30th years of operating NPP
- Lifetime risk to public during the 1st and 30th years of operating NPP
- Concentrations of radionuclides in foodstuff and annual intake by humans
- Radiation impact to the components of agroecosystems in 30-km zone around the NPP
Assessment results: Prognostic assessment of radioecological situation via atmospheric releases

Total effective dose from artificial radionuclides for:
- the 1st year of NPP operation $3.96 \times 10^{-2} \mu Sv/a$
- the 30th year of NPP operation $4.54 \times 10^{-2} \mu Sv/a$

Dose criteria:
- 1 mSv/a

Quote for radiation dose for atmospheric releases during NPP operation:
- 10 µSv/a

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>1st year of operation</th>
<th>30th year of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>3.53E-06</td>
<td>3.53E-06</td>
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<tr>
<td>C-14</td>
<td>9.38E-04</td>
<td>9.38E-04</td>
</tr>
<tr>
<td>Ar-41</td>
<td>8.90E-04</td>
<td>8.90E-04</td>
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<tr>
<td>Xe-133</td>
<td>7.85E-06</td>
<td>7.85E-06</td>
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<tr>
<td>Xe-135</td>
<td>3.81E-05</td>
<td>3.81E-05</td>
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<tr>
<td>Kr-85</td>
<td>1.76E-04</td>
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<td>Kr-85m</td>
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<td>Kr-87</td>
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</tr>
<tr>
<td>Kr-88</td>
<td>9.58E-05</td>
<td>9.58E-05</td>
</tr>
<tr>
<td>I-131</td>
<td>1.14E-04</td>
<td>1.14E-04</td>
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<tr>
<td>Co-60</td>
<td>6.03E-04</td>
<td>6.03E-04</td>
</tr>
<tr>
<td>Cs-134</td>
<td>1.47E-03</td>
<td>6.23E-03</td>
</tr>
<tr>
<td>Cs-137</td>
<td>1.47E-03</td>
<td>6.23E-03</td>
</tr>
</tbody>
</table>
Assessment results: Prognostic assessment of radioecological situation via atmospheric releases

Contribution of pathways to the dose, adults, µSv/a

1st year of operation
- Inhalation: 49.26%
- Cloud immersion: 1.07%
- Ingestion: 44.97%

30th year of operation
- Inhalation: 42.99%
- Cloud immersion: 8.09%
- Ingestion: 9.66%
- Exposure to soil surface: 40.29%
**Assessment results:**

Prognostic assessment of radioecological situation via atmospheric releases

**Total risk:**

\[ Risk = E \cdot r \]

- \( E \) – average annual effective dose, Sv;
- \( r \) – risk coefficient;

Radiation risk from artificial radionuclides for adults:

- the 1\textsuperscript{st} year of NPP operation \( 1.66 \times 10^{-9} \)
- the 30\textsuperscript{th} year of NPP operation \( 1.91 \times 10^{-9} \)


- \( 4.2 \times 10^{-2} \) Sv\(^{-1} \)

Lifetime risk criteria:

- \( 5.0 \times 10^{-5} \)
Assessment results: Prognostic assessment of radioecological situation via atmospheric releases

### Concentration of $^{137}$Cs in foodstuff

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>Concentration, Bq/kg</th>
<th>Sanitarian and hygienic standards (SanPiN 2.3.2.1078-01), Bq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruits</td>
<td>$1,07 \times 10^{-4}$</td>
<td>40</td>
</tr>
<tr>
<td>Potatoes</td>
<td>$1,37 \times 10^{-4}$</td>
<td>120</td>
</tr>
<tr>
<td>Milk</td>
<td>$4,00 \times 10^{-4}$</td>
<td>100</td>
</tr>
<tr>
<td>Meat</td>
<td>$2,00 \times 10^{-3}$</td>
<td>200</td>
</tr>
<tr>
<td>Vegetables</td>
<td>$7,65 \times 10^{-5}$</td>
<td>120</td>
</tr>
</tbody>
</table>

### Annual intake of radionuclides

<table>
<thead>
<tr>
<th>Radionuclides</th>
<th>Annual intake by human organism with air, Bq/a</th>
<th>Annual intake limit with air, Bq/a</th>
<th>Annual intake by human organism with food, Bq/a</th>
<th>Annual intake limit with food, Bq/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$H</td>
<td>$4,00 \times 10^2$</td>
<td>$3,7 \times 10^6$</td>
<td>-</td>
<td>$2,1 \times 10^7$</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>$5,71 \times 10^{-1}$</td>
<td>$1,0 \times 10^5$</td>
<td>-</td>
<td>$6,3 \times 10^5$</td>
</tr>
<tr>
<td>$^{131}$I</td>
<td>$2,85 \times 10^{-5}$</td>
<td>$1,4 \times 10^4$</td>
<td>$4,31 \times 10^{-3}$</td>
<td>$5,6 \times 10^3$</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>$1,33 \times 10^{-5}$</td>
<td>$8,3 \times 10^4$</td>
<td>$7,36 \times 10^{-1}$</td>
<td>$3,7 \times 10^4$</td>
</tr>
<tr>
<td>$^{134}$Cs</td>
<td>$3,75 \times 10^{-5}$</td>
<td>$1,5 \times 10^3$</td>
<td>$3,26 \times 10^{-2}$</td>
<td>$5,3 \times 10^4$</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>$1,38 \times 10^{-4}$</td>
<td>$2,2 \times 10^5$</td>
<td>$2,79 \times 10^{-1}$</td>
<td>$7,7 \times 10^4$</td>
</tr>
</tbody>
</table>
Assessment results: Prognostic assessment of radioecological situation via atmospheric releases

Dose rates for agroecosystem components in 30-km zone of NPP, $\mu$Gy/h
Methodological aspects: Dose assessment at current radioecological situation

Pathways:

External exposure:
- Radionuclides in soil and on soil surface
- Radionuclides in air

Internal exposure:
- Inhalation
- Ingestion
Methodological aspects:  
Dose assessment at current radioecological situation

External dose assessment: 
\[ E_i^{ext} = \sum_{k=1}^{N} \left[ R_i \cdot (e_{i,g}^k \cdot \sigma_k + e_{i,c}^k \cdot C_{k,a}) + C_{k,w} \cdot (e_{w1}^k + e_{w2}^k) \right] \]

- \( R_i \) – total factor of dose reduction at external exposure of representatives of group \( i \) of population in the anthropogenic environment;
- \( \sigma_k \) – deposition density of radionuclide \( k \), Bq/m\(^2\);
- \( C_{k,a} \) – annual average concentration of radionuclide \( k \) in surface air, Bq/m\(^3\);
- \( e_{i,g}^k \) – effective external dose coefficient for radionuclide \( k \) from surface deposits, Sv/a per Bq/m\(^2\);
- \( e_{i,c}^k \) – effective external dose coefficient for radionuclide \( k \) from cloud immersion, Sv/a per Bq/m\(^3\);
- \( C_{k,w} \) – annual average concentration of radionuclide \( k \) in water, Bq/m\(^3\);
- \( e_{w1}^k \) – effective external dose coefficient for radionuclide \( k \) from water submersion or at locating on water surface (boat, etc.), Sv/a per Bq/m\(^3\);
- \( e_{w2}^k \) – effective external dose coefficient for radionuclide \( k \) from sediments on tidal flats, along river banks and while using contaminated water for irrigation, Sv/a per Bq/m\(^3\).
Methodological aspects: Dose assessment at current radioecological situation

Internal dose assessment.

Ingestion:
- $e_{i,ing}^k$ – committed effective dose coefficient for ingestion, Sv/Bq;
- $S_{kj}$ – annual average concentration of radionuclide $k$ in foodstuff $j$, Bq/kg;
- $V_{ij}$ – consumption rate for foodstuff $j$ by population group $i$, kg/a.

\[
E_{i,ing}^{int} = \sum_{k} \sum_{j} e_{i,ing}^k \cdot V_{ij} \cdot S_{kj}
\]

Inhalation:
- $C_{k,a}$ – annual average concentration of radionuclide $k$ in surface air, Bq/m$^3$;
- $Br_i$ – inhalation rate, m$^3$/a;
- $e_{i,inh}^k$ – inhalation dose coefficient, Sv/Bq;
- $F_i$ – annual fraction of time during which the representative of population group $i$ is indoors;
- $0,3$ – stated ration of radionuclide concentrations in air indoors and outdoors.

\[
E_{i,inh}^{int} = \sum_{k} C_{k,a} \cdot Br_i \cdot e_{i,inh}^k \cdot [(1 - F_i) + 0,3 \cdot F_i]
\]
Two types of population were considered: urban and rural.

Total effective dose from artificial radionuclides for:
- adults from urban area amounts $8.98 \times 10^{-2}$ mSv/a
- adults from rural area amounts $1.33 \times 10^{-1}$ mSv/a

Dose criteria:
- $1$ mSv/a
Methodological aspects: Risk assessment for exposure to artificial radionuclides

Total risk:

\[ \text{Risk} = E \cdot r \]

- \( E \) – average annual effective dose, Sv;
- \( r \) – risk coefficient;

General issues:

- Different age groups of population;
- Urban and rural members of public are considered;
- Risks for internal and external exposures are calculated. Pathways:
  - Inhalation
  - Ingestion with foodstuff and water
  - External exposure to radionuclides contained in soil

Risk for external irradiation

\[ R_{\text{ext,si}} = r_{\text{ext,si}} \cdot T_{\text{stay}} \cdot C_{\text{soil},i} \]

- \( R_{\text{ext,si}} \) – lifetime radiation risk from external exposure to soil contaminated with radionuclide \( i \) during a year;
- \( r_{\text{ext,si}} \) – risk coefficient for inhalation of radionuclide \( i \), kg/Bq;
- \( T_{\text{stay}} \) – annual fraction of time spent outdoors without shielding (assumed as 1), rel. unit;
- \( C_{\text{soil},i} \) – concentration of radionuclide \( i \) soil, kg/Bq
Methodological aspects: Risk assessment for exposure to artificial radionuclides

Risk for internal irradiation

\[ R_{\text{inh},i} = r_{\text{inh},i} \cdot I_{\text{inh}} \cdot C_{\text{air},i} \]

- \( R_{\text{inh},i} \) – lifetime radiation risk from breathing in of the radionuclide \( i \) during a year;
- \( I_{\text{inh}} \) – inhalation rate, m\(^3\)/a;
- \( C_{\text{air},i} \) – concentration of radionuclide \( i \) in air, Bq/m\(^3\);
- \( r_{\text{inh},i} \) – risk coefficient for inhalation of radionuclide \( i \), risk/Bq.

\[ R_{\text{ing},i} = r_{\text{ing},i} \sum_p C_{i,p} \cdot I_{\text{food},p} \cdot B_p \]

- \( R_{\text{ing},i} \) – lifetime radiation risk from ingestion of foodstuff \( p \) contaminated with radionuclide \( i \) during a year;
- \( C_{i,p} \) – concentration of radionuclide \( i \) foodstuff \( p \), Bq/kg;
- \( I_{\text{food},p} \) – consumption rate for foodstuff \( p \), kg/a;
- \( r_{\text{ing},i} \) – risk coefficient for ingestion of foodstuff \( p \) contaminated with radionuclide \( i \), risk/Bq.

\[ R_{\text{water},i} = r_{\text{water},i} \cdot I_{\text{water}} \cdot C_{\text{water},i} \]

- \( R_{\text{water},i} \) – lifetime radiation risk from water ingestion of the radionuclide \( i \) during a year;
- \( I_{\text{water}} \) – consumption rate for water, l/a;
- \( C_{\text{water},i} \) – concentration of radionuclide \( i \) in drinking water, Bq/m\(^3\);
- \( r_{\text{water},i} \) – risk coefficient for water consumption of radionuclide \( i \), risk/Bq.
Two types of population were considered: urban and rural.

Total lifetime risk from artificial radionuclides for:
- adults from urban area amounts 7.12×10^{-7}
- adults from rural area amounts 9.42×10^{-7}

Lifetime risk criteria:
- 5.0×10^{-5}
Conclusions

Assessment:
- Radiation doses and risks for population resulted from atmospheric radioactive releases were calculated. The calculations show that the values do not exceed regulative criteria.
- Concentrations of radionuclides in foodstuff, annual intake of radionuclides by human organism and radiation doses to components of agricultural ecosystems were estimated.
- Radiation doses and risks for population in the observation zone of Beloyarsk NPP displaying the current radioecological situation in the observation zone of Beloyarsk NPP were calculated with use of monitoring data. The values obtained show the radiation doses from technogenic radiation background, and relevant radiation risks.

Methodology:
- Monitoring data used are mostly appropriate to make the screening assessments for radioecological situations on reference radionuclides due to lack of information on concentrations of radionuclides in different environmental components, whereas program codes allow to obtain a broad picture of probable impact.
- These methodologies can be a tool for environmental analysis for confirmation whether the NES facilities will meet national regulatory standards.
- Assessment can be conducted both for public and non-human biota. Reference biota species can also be considered.
Thank you for your attention!