TM on the Harmonization of Reference Levels for Foodstuff and Drinking Water Contaminated Following a Nuclear Accident

8 - 12 September 2014, Vienna

IAEA Safety Standards for Emergency Preparedness and Response: *Focus on criteria for radionuclides in food, milk and drinking water*

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• Fundamentals

GS-R-2
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IAEA Safety Standards
Fundamental Safety Principles

Preparedness and Response for a Nuclear or Radiological Emergency

Arrangements for Preparedness for a Nuclear or Radiological Emergency

Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency

Public Communications in EPR (DS475)

Termination of an Emergency (Transition) (DS474)

GSR PART 7 (2015)
Safety Standards in EPR (2)

• In the context of criteria for radionuclides in food, milk and drinking water: **GSG-2** published 2011 (Co-sponsored by FAO, IAEA, WHO, PAHO, ILO) and **GSR Part 7** (2015)
Guidance and Tools in EPR
Generic criteria (GC)

- In terms of **projected dose** or **received dose**

**Concern**
- Severe deterministic effects
- Possible increase in stochastic effects

**Generic Criteria**
- Dose in hours
- Dose in days
- Dose in year

**Actions**
- Precautionary undelayable actions
- Urgent protective actions
- Early protective actions
Dosimetric quantities

- Intake, $I$ [Bq]
  - Radiation fluence, $\Phi$, [cm$^{-2}$]
  - Absorbed dose in tissue or organ $T$, $D_T$ [Gy]
  - Equivalent dose in tissue or organ $T$, $H_T$ [Sv]
  - Effective dose, $E$ [Sv]

- RBE Weighted absorbed dose in tissue or organ $T$, $AD_T$ [Gy]

- Evaluation of deterministic effects

- Evaluation of stochastic effects

- Evaluation radiation detriment
## GC to Reduce the Risk of Stochastic Effects (1)

### Urgent protective and other response actions

<table>
<thead>
<tr>
<th>Dosimetric quantity</th>
<th>Projected dose in the first week and set of urgent actions for protection strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective dose</td>
<td>100 mSv</td>
</tr>
<tr>
<td>Equivalent dose in fetus or embryo</td>
<td>100 mSv</td>
</tr>
<tr>
<td>Committed equivalent dose in thyroid</td>
<td>50 mSv</td>
</tr>
</tbody>
</table>

- Sheltering, evacuation, decontamination, restrictions on food, milk and drinking water…
- Iodine thyroid blocking
**GC to Reduce the Risk of Stochastic Effects (2)**

<table>
<thead>
<tr>
<th>Dosimetric Quantity</th>
<th>Projected Dose in the First Year and Set of Early Actions for Protection Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Dose</td>
<td>100 mSv</td>
</tr>
<tr>
<td>Equivalent Dose in Fetus or Embryo (for period of <em>in utero</em> development)</td>
<td>100 mSv Temporary relocation, decontamination, restrictions on food, milk and water ...</td>
</tr>
<tr>
<td>Effective dose</td>
<td>Equivalent dose in embryo or foetus</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>10 mSv per annum</td>
<td>10 mSv for the full period of <em>in utero</em> development</td>
</tr>
<tr>
<td>10 mSv per annum</td>
<td>10 mSv for the full period of <em>in utero</em> development</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Aim: To mitigate the economic impact on international trade

<table>
<thead>
<tr>
<th>Effective dose</th>
<th>Equivalent dose in embryo or foetus</th>
<th>Response action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mSv per annum</td>
<td>1 mSv for full period of <em>in utero</em> development</td>
<td>✓ Restriction on food, milk, drinking water and other commodities traded internationally</td>
</tr>
</tbody>
</table>
Important notice

- Restrictions on essential food, milk and drinking water may cause severe malnutrition, dehydration or other severe health effects.

- Restrictions on food, milk and drinking water based on the generic criteria are implemented only if these are not essential and if replacements or other alternatives are available!
Operational Criteria

GENERIC CRITERIA

- Observables/Indicators
  - Conditions on-scene

- Emergency Action Levels (EAL)
  - Abnormal facility conditions

- Operational Intervention Levels (OIL)
  - Field and laboratory measurements

ACTIONS
Operational Interventional Levels

OILs – a predetermined level of a measurable quantity (by a field monitoring instrument or determined by laboratory analysis) to trigger appropriate actions that corresponds to generic criteria.

- Dose rate above the ground
- Food and water concentrations
- Dose rate from skin contamination
# Default OILs in GSG-2

<table>
<thead>
<tr>
<th>OIL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OIL1</td>
<td>Measured value for ground contamination to indicate where urgent protective actions (e.g. evacuation) are warranted</td>
</tr>
<tr>
<td>OIL2</td>
<td>Measured value for ground contamination to indicate where early protective actions (e.g. relocation) are warranted</td>
</tr>
<tr>
<td>OIL3</td>
<td>Measured value of ground contamination to indicate where immediate restrictions on food, milk and drinking water are warranted</td>
</tr>
<tr>
<td>OIL4</td>
<td>Measured value of skin contamination to indicate when decontamination or providing instructions for self-decontamination and for limiting inadvertent ingestion are warranted</td>
</tr>
<tr>
<td>OIL5</td>
<td>Measured values of radionuclide concentration in food, milk or drinking water to indicate where restrictions on food, milk and drinking water are warranted</td>
</tr>
</tbody>
</table>

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Default OILs for food, milk and drinking water restrictions based on sample’s analysis

Samples from food, milk and drinking water destined for immediate human consumption (i.e. not dried or concentrated foods)

- **OIL5**: Gross beta and alpha measurements of samples
  - $\beta$: 100 Bq/kg
  - $\alpha$: 5 Bq/kg

- **OIL6**: Radionuclide specific measurement of samples [Bq/kg]

Table 10 (GSG-2)
### OIL6: Extract from Table 10, GSG-2

- For more than 300 radionuclides

#### Table 10. Default Radionuclide Specific OILs for Food, Milk and Water Concentrations from Laboratory Analysis

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>OIL6 (Bq/kg)</th>
<th>Radionuclide</th>
<th>OIL6 (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>$2 \times 10^5$</td>
<td>Sc-44</td>
<td>$1 \times 10^7$</td>
</tr>
<tr>
<td>Be-7</td>
<td>$7 \times 10^5$</td>
<td>Sc-46</td>
<td>$8 \times 10^3$</td>
</tr>
<tr>
<td>Be-10</td>
<td>$3 \times 10^3$</td>
<td>Sc-47</td>
<td>$4 \times 10^5$</td>
</tr>
<tr>
<td>C-11</td>
<td>$2 \times 10^9$</td>
<td>Sc-48</td>
<td>$3 \times 10^5$</td>
</tr>
<tr>
<td>C-14</td>
<td>$1 \times 10^4$</td>
<td>Ti-44</td>
<td>+</td>
</tr>
<tr>
<td>F-18</td>
<td>$2 \times 10^8$</td>
<td>V-48</td>
<td>$3 \times 10^4$</td>
</tr>
<tr>
<td>Na-22</td>
<td>$2 \times 10^3$</td>
<td>V-49</td>
<td>$2 \times 10^5$</td>
</tr>
<tr>
<td>Na-24</td>
<td>$4 \times 10^6$</td>
<td>Cr-51</td>
<td>$8 \times 10^5$</td>
</tr>
</tbody>
</table>
If OIL6 is exceeded:

- Stop consumption of non-essential food, milk or drinking water
- Replace essential food, milk and drinking water as soon as possible or relocate the people if replacements are not available
- For iodine contamination consider providing iodine thyroid blocking if replacement of essential food, milk or water is not immediately available
- Estimate the dose of those who may have consumed food, milk and drinking water from the area where restrictions were implemented to determine if medical actions are warranted
Basis for deriving these default OILs

- **Generic Criterion**
  - $E_{\text{ing}} = 10 \text{ mSv per annum}$
  - $1/10$ of the GC for early protective actions

- **Exposure pathway**
  - Ingestion (simple)
Ingestion rate

• A single conservative ingestion rate of contaminated food, milk and water of 500 kg per year (an average of 0.057 kg/h) is assumed

• This is about 100% of all the total food, milk and water typically consumed by an infant (representative person)
Representative person

• ICRP Publication 103:
  ➢ It will get a dose representative of the highest doses reasonably expected to be received by any member of the public during an emergency
  ➢ During an actual emergency no individual would receive a dose exceeding that calculated for the representative person

• The most sensitive members of the public considered
## Characteristics of the representative person

<table>
<thead>
<tr>
<th>Type of exposure</th>
<th>External</th>
<th>External</th>
<th>External</th>
<th>Internal</th>
<th>Internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source of exposure</td>
<td>Ground deposition</td>
<td>Adjacent source</td>
<td>Distant source</td>
<td>Ingestion</td>
<td>Inhalation</td>
</tr>
<tr>
<td>Dose of consideration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total effective dose</td>
<td>10 years old reference person</td>
<td>Adult reference person</td>
<td>Adult reference person</td>
<td>Reference infant(^{(a)})</td>
<td>Adult reference person</td>
</tr>
<tr>
<td>Total dose(^{(b)}) in foetus or embryo</td>
<td>Adult reference person</td>
<td>Adult reference person</td>
<td>Adult reference person</td>
<td>Adult reference person</td>
<td>Adult reference person</td>
</tr>
<tr>
<td>Committed dose(^{(b)}) in thyroid</td>
<td>NA(^{(c)})</td>
<td>NA(^{(c)})</td>
<td>NA(^{(c)})</td>
<td>Reference infant(^{(a)})</td>
<td>Adult reference person</td>
</tr>
<tr>
<td>RBE weighted dose in soft tissue</td>
<td>NA(^{(c)})</td>
<td>Adult reference person</td>
<td>NA(^{(c)})</td>
<td>NA(^{(c)})</td>
<td>NA(^{(c)})</td>
</tr>
<tr>
<td>RBE weighted dose in skin derma</td>
<td>NA(^{(c)})</td>
<td>Adult reference person</td>
<td>NA(^{(c)})</td>
<td>NA(^{(c)})</td>
<td>NA(^{(c)})</td>
</tr>
<tr>
<td>Total dose(^{(b)}) in other organs or tissues</td>
<td>15 years old reference person</td>
<td>Adult reference person</td>
<td>Adult reference person</td>
<td>Reference infant(^{(a)})</td>
<td>Adult reference person</td>
</tr>
</tbody>
</table>
Assessment of effective dose
Example:

Assessment of equivalent or RBE weighted absorbed dose in embryo or foetus

Diagram:

- **ATMOSPHERIC RELEASE**
  - GROUND DEPOSITION
    - VEGETATION & WATER
    - SOIL
    - SURFACE, SKIN, CLOTHES
    - GROUND
    - AIR
  - INHABITATION
  - EXTERNAL EXPOSURE
  - CONTACT EXPOSURE
  - INADVERTENT INGESTION
  - INGESTION
    - ANIMAL
      - Behavior data
      - Dose model of Reference person
    - Behavior data
  - Behavior data

**TOTAL DOSE in FOETUS/EMBRYO** of Representative person

**INDIVIDUAL**

- Adult
- Pregnant woman
Assessment of equivalent or RBE weighted absorbed dose in thyroid
Assessment of equivalent or RBE weighted absorbed dose in organs other than thyroid, embryo or foetus
Organ dose calculations

Controlling from among all organ doses:

- **Committed equivalent dose to the thyroid** \( (HF_{thy,ing}) \) and **committed effective dose** \( (EF_{eff,ing}) \) to the representative person following intake by ingestion.

- **Committed equivalent dose to the fetus** \( (HF_{fetus,ing}) \) following intake by ingestion by the pregnant woman.
## Examples

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>HF$_{\text{thy,ing,i}}^a$ (mSv/Bq)</th>
<th>HF$_{\text{fetus,ing,i}}^b$ (mSv/Bq)</th>
<th>EF$_{\text{eff,ing,i}}^c$ (mSv/Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Te-132$^{+e}$</td>
<td>3.6E-04</td>
<td>1.4E-04</td>
<td>3.2E-05</td>
</tr>
<tr>
<td>I-125</td>
<td>1.1E-03</td>
<td>2.5E-04</td>
<td>5.7E-05</td>
</tr>
<tr>
<td>I-129$^{f}$</td>
<td>4.3E-03$^{f}$</td>
<td>1.1E-03$^{f}$</td>
<td>2.2E-04$^{f}$</td>
</tr>
<tr>
<td>I-131</td>
<td>3.6E-03</td>
<td>1.1E-03</td>
<td>1.8E-04</td>
</tr>
<tr>
<td>Cs-134</td>
<td>NA$^d$</td>
<td>1.1E-05</td>
<td>1.6E-05</td>
</tr>
<tr>
<td>Cs-137$^{+e}$</td>
<td>NA$^d$</td>
<td>7.2E-06</td>
<td>1.2E-05</td>
</tr>
</tbody>
</table>
Resulting in conservative approach

- The most restrictive age dependant dose conversion factors and ingestion rates (i.e. infant) are used

- The persons exposed are the most sensitive members of the public (i.e. infant or pregnant woman)
Additional considerations (1)

- The food, milk and drinking water are initially contaminated to the OIL concentrations and are consumed for a full year.
- The population lives/behaves normally and no protective actions are taken to reduce the dose during the exposure period.
- The contributions of the progeny are included with that of the parent:

  ➢ Example: For 1 Bq of $^{52}$Fe it is assumed that there will also be 1 Bq of $^{52m}$Mn present.
Additional considerations (2)

• Maximum dose factors for ingestion from amongst those provided for different chemical and physical forms are used.

• Instrument response accounted:
  - For example, reduced instrument count rate associated with monitoring under emergency conditions.

• Need to consider all radionuclides expected (Conservative approach, i.e. resulting in the lowest OIL).
Below the default OILs – no observable radiation induced health effects

IAEA default OILs

Safe for consumption

Careful consideration needs to be given if a State decides to take actions below these default OILs in order to ensure they are **justified** (i.e. do more good than harm) and **optimized**
For large release from a NPP

- Specific OILs for LWRs:
  - **OIL3** → Ambient gamma dose rate at 1m above ground
  - **OIL7** → Concentrations of marker radionuclides 131-I and 137-Cs in food, milk and drinking water samples

- To be used for promptly assessing the need for immediate restrictions on food, milk and drinking water
Exposure pathways (OIL3)

Ingestion of contaminated:
7a. Local produce
7b. Rain water
7c. Milk from grazing animals
Specific considerations

✓ Physical and chemical behavior of radionuclides - factors to account for:
  • Vertical migration into soil
  • Transfer from soil to plant/milk/water
  • Fixation

✓ …
Technical basis to be provided soon within EPR series

\[ OIL3(t) = DC_{OIL3}(t) \times \sum_i (I_i(t) \times *HF_{\text{grad},i}) \]

\[ DC_{OIL3,\text{ground}}(\Delta s, t) = \frac{CG_{s,\text{eff}}(\Delta s)}{\omega_{\text{bg,ing}}(\Delta s, t) + \omega_{\text{milk,ing}}(\Delta s, t)} \]

\[ \omega_{\text{bg,ing}}(\Delta, t) = Q_{f,v,i} \times \phi_2 \times F_f \times \sum_i (EF_{\text{eff},\text{ing},i} \times \Delta_{\text{eff,i}} \times RF_i \times I_{f_p,i}(t)) \]

\[ \omega_{\text{milk,ing}}(\Delta, t) = Q_{f,m,i} \times \phi_1 \times F_f \times U_{\text{cow}} \times F_{\text{cow}} \times \sum_i (EF_{\text{eff},\text{ing},i} \times \Delta_{\text{eff,i}} \times RF_i \times F_{m,i} \times I_{f_p,i}(t)) \]

\[ RF_i = \exp(-\lambda_{R,i} \times \Delta_U) \times PF \]

\[ \Delta_{\text{eff,i}} = \frac{1 - \exp(-\left(\lambda_{\text{w}} + \lambda_{R,i}\right) \times \Delta_A)}{\left(\lambda_{\text{w}} + \lambda_{R,i}\right)} \]

\[ OIL3_{\alpha}(t) = DC_{OIL3}(t) \times UC \times \sum_i (I_i(t) \times \theta_{\alpha,i}) \times CF_{\text{Field},\alpha} \times W_{\text{Baseline area}} \]

\[ OIL3_{\beta}(t) = DC_{OIL3}(t) \times UC \times \sum_i (I_i(t) \times \theta_{\beta,i}) \times CF_{\text{Field},\beta} \times W_{\text{Baseline area}} \]
Thank you for your attention...

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