Large Eddy Simulation of radioactive pollutant dispersion over an open field for time-dependent dose assessment

PUBLIC VERSION

Lieven Vervecken\textsuperscript{1,2} , Johan Camps\textsuperscript{1} , Johan Meyers\textsuperscript{2}

\textsuperscript{1} SCK\textbullet{}CEN, Belgian Nuclear Research Center, Belgium
\textsuperscript{2} Department of Mechanical Engineering, KU Leuven, Belgium

BVS-ABR Scientific Meeting
Brussels, September 19, 2014
Introduction
Transport model
Case study
Ongoing research
Personal background

- Master in Mechanical Engineering (2010)
- Master in Nuclear Engineering (2011)
- PhD program (2011-pres)
60 years of **experience** in nuclear research and technology

Most **recent** knowledge and development

**Innovative** projects

Availability of **large and unique** nuclear installations
Manages all education and training activities – in the broadest sense:

1. Guidance young researchers
   • Thesis (PhD, Master, Bachelor level), post-docs, internships, educational visits

2. Organization of courses
   • Contribution to academic learning
   • Customized training for professionals

3. Policy support
   • Framework programs, H2020, expert groups of IAEA, OECD, ...

4. Research transdisciplinary aspects
   • Scientific/technical + context! (ethical, economical, political, ...)
Accurate modeling results in effective countermeasures

- Release of radioactive pollutants
  - Controlled release
  - Explosion
  - Fire

- Dispersion simulation & dose estimation
  - Link measurements to source term

- Countermeasures
  - Sheltering
  - Evacuate
  - Iodine intake
Existing models not conclusive for the near-range

- Local scale: 500 m
- Meso scale: 50 km
- Long range: 500 km

[TIC at ground level (Bq s m⁻²)

- H_{eff} = 72 m
- Pasquill: D / Bultynck-Malet: E3
- No rain

[Graph showing decay of TIC with distance]

[Camps et al, 2010]
Several applications for this model

Licensing phase
- Building configuration of new installations

Preparedness phase
- Positioning of monitoring stations
- Drawing of evacuation routes

Response phase
- Source term estimation
- Intervention planning
Several applications for this model

- Account for
  - Complex air flow (~buildings, vegetation)
    → Computation fluid dynamics (CFD)
  - Variability due to atmospheric effects
    → Large Eddy Simulation (LES) turbulence modeling

At the near-range, can we use instantaneous or time-averaged gamma dose rate measurements to estimate the skin dose rate or inhalation dose rate?
Pollutant transport model

- Time-dependent advection-diffusion with radioactive decay

\[
\frac{\partial c}{\partial t} + \nabla \cdot (uc) = \nabla \cdot \frac{\nu_{sgs}}{Sc_{sgs}} \nabla c - \lambda c + S
\]

- Assumptions
  - Neutral conditions
  - Non-reactive gas
  - No buoyancy or deposition
CFD simulation of atmospheric boundary layer

- LES turbulence modeling
  - Lagrangian scale-dependent dynamic model
  - Resolve large scales of the flow field → $u$
  - Model small scales → $\nu_{sgs}$

No need for temporal meteorological wind field data

[13]

Radiation model

- **Gamma dose rate**
  - Point-kernel method with buildup factors
  
  \[ \dot{d}_{\gamma,x_0} \sim \phi(x_0, t) \]

- **Beta dose rate**
  - Range of $\beta$ particles in air = limited
  - Local cloud $\sim$ infinite cloud

\[ \dot{d}_{\beta,x_0} \sim c \]

Note: also inhalation dose rate $\sim$ concentration

[Slade, 1968]
[Berger et al., 2000]
Content

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Computational set-up

- **Domain**
  
  - Domain dimensions:
    - $\delta = 750$
    - $N_z = 125$

  - $8\delta = 6000$ m
  - $N_x = 250$

  - $z_0 = 0.01$ m

- **Pollutants**
  
  - Xe-133
  - Released from 75 m at constant rate
  - Observations at 1.5 m height

- **Cluster setup**
  
  - Vlaams Supercomputer Centrum (VSC)
  - 48 CPU
  - +- 4 week of computing

- $3\delta = 2250$ m
- $N_y = 375$
Instantaneous concentration

- Peak concentration near source
- Strong dilution with distance

Color ~ wind speed

Color ~ concentration
Instantaneous observation at $x = 10L$

<table>
<thead>
<tr>
<th>Concentration (a)</th>
<th>Gamma fluence rate (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c^* \approx 0$ most of the time</td>
<td>$\phi \neq 0$</td>
</tr>
<tr>
<td>Large peaks at irregular time intervals</td>
<td>Noisy</td>
</tr>
</tbody>
</table>

![Graph of Concentration](image1)

![Graph of Gamma Fluence Rate](image2)
- Large variation of the beta dose rate
- Limited variability of gamma dose rate
- Time-averaging does not help

**Gamma dose assessment at the near-range is not representative for the skin dose rate and inhalation dose rate**
Content

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Model reduction

- Very long simulation time
  = Not suited for emergency response phase

Faster computation

Accuracy
Case study: Doel Nuclear Power Station
Release from Doel 3

Preliminary results
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SCK•CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSEL
Operational Office: Boeretang 200 – BE-2400 MOL