A survey of methods for estimating the amount of radioactive materials emitted from nuclear power station during severe accident

Dr. Ryohji Ohba (Japan: Nuclear Safety Research Association)

And

Dr. Paul Bieringer (US: National Center for Atmospheric Research)

Today’s reports
1. Summary of J-rapid 2011 program
2. Introduction of the new MEXT 2012-2014 project
## Technical subjects at early phase

<table>
<thead>
<tr>
<th>Difficulties</th>
<th>Countermeasures</th>
</tr>
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<tbody>
<tr>
<td>Shortage of monitoring data</td>
<td>Mobile monitoring by car and airplane</td>
</tr>
<tr>
<td>Unsteady wind and release conditions</td>
<td>Advanced Source Term Estimation method</td>
</tr>
<tr>
<td>Separation of cloud and ground shines</td>
<td>①Filtering technique of data processing&lt;br&gt;②Gamma ray counter with shield cover</td>
</tr>
</tbody>
</table>

![Diagram of cloud and ground shines](image)
# Emergency response systems of each countries (Survey results of J-rapid program)

<table>
<thead>
<tr>
<th>Country</th>
<th>Code name</th>
<th>Organization</th>
<th>Source intensity (Evacuation area)</th>
<th>Reported date</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>RASCAL4 (Simple)</td>
<td>NRC</td>
<td>100% release (50 mile) → 10% release</td>
<td>3/12 9pm</td>
</tr>
<tr>
<td></td>
<td>NARAC (Precise)</td>
<td>LLNL (DOE)</td>
<td>Source term estimation from ground &amp; Aerial sampling On line</td>
<td>1st report 3/12 8pm (US time)</td>
</tr>
<tr>
<td>UK</td>
<td>NAME (Simple)</td>
<td>Met. Office &amp; HPA</td>
<td>10% &amp; 100% release</td>
<td>Reported every 4 hours</td>
</tr>
<tr>
<td>Japan</td>
<td>W-SPEEDI (Precise)</td>
<td>JAEA</td>
<td>Assumption: Unit release Temporal source intensity</td>
<td>3/11 4/12</td>
</tr>
</tbody>
</table>
MEXT 2012-2014 project
Advancement of Source Term Estimation model
at early stage, and exposure model
at intermediate stage for severe nuclear accident

Project leader: Prof. Shinsuke Kato (Tokyo University)
Co-project leader: Dr. Ryohji Ohba (Mitsubishi Heavy Industries)

• Funded by Ministry of Education, Science, Culture, Sports and Technology (MEXT)
• Contracted by Japan Science and Technology Agency (JST)
Emergency response system of US-Laurence Livermore National Lab. (LLNL)

NARAC Conducted Initial Model Refinement as Part of Its Response Activities

- Initial Model Predictions Guide Measurement Surveys
- Measurement surveys and sensor data, e.g., DOE AMS, DOE, DoD, and Japan field data
- Measurement Data transferred electronically to LLNL/NARAC

- Updated predictions using measurement data
- Software used to help select, filter and statistically compare measurements and predictions

Conducted through the MEXT 2012-2014 project
Emergency response system of EU (ARGOS)
(Conducted through the MEXT 2012-2014 project)

Figure 16. ARGOS showing imported nuclear measurements from European stations.

Figure 17. ARGOS monitoring helicopter and diagram showing monitoring principle.
Normal measuring height is about 100 m. 2) Right, results from AGS monitoring survey of Risø DTU, which is the only site in Denmark that had a nuclear installation.

Figure 18. Inspecting the data on a monitoring station.

Figure 22. ARGOS has support for managing measurement routes.
Survey of Estimation Methods for Quantities of Radioactive Materials Emitted from Nuclear Power Station During a Severe Accident

Paul E. Bieringer

National Center for Atmospheric Research (NCAR)

6 March, 2013
Source Term Estimation (STE) for Atmospheric Releases

Chem/Bio Defense Applications

Aviation Safety

http://www.av0.alaska.edu/volcanoes/volcimage.php?volcname=Redoubt

Air Quality Applications

Fukushima Dai-ichi Accident

NEW EXPLOSION AT FUKUSHIMA DAI-ICHI NUCLEAR REACTOR
March 15, 2011: Hydrogen explosion at Unit No. 3 (Topper News Network)
Fukushima Dai-ichi Incident
(Why Source Term Estimation is Important)

• What do we know?
  – Location of radiation source
  – Time release began
  – Limited meteorological information
  – Information regarding operations of power plant
  – Measurements

• What is still not well known?
  – Time varying rate at which the radiation was released

• Why is this important?
  – Accurate source term is needed for SPEEDI downwind hazard predictions

Determining the Source Term is Critical for Making a Timely and Accurate Evacuation Plan

Image Sources: G. Sugiyama – LLNL, Feb-2012 NSF Sponsored Fukushima STE Workshop
NSF Fukushima Radiation STE Workshop

- US National Science Foundation (NSF) funded meeting
  - February 22-24, 2012
  - Assemble leading scientists working on source inversion for atmospheric contaminant releases
  - Japanese participants funded by the J-rapid program

- Goals
  - Characterize the state-of-the science in STE methods
  - Identify and prioritize gaps in knowledge/capabilities/data
  - Provide recommendations for a path forward

- Publish findings in Bulletin of the Amer. Met. Soc.
Workshop Participants
(~40 Experts From the US and Around the World)

Japan
- Japan Atomic Energy Agency
- Kansai Electric Power Company
- Japan Nuclear Safety Research Assoc.
- UK Defense Science and Tech Lab
- Univ. of Paris
- Comprehensive Test-ban Treaty Org.

Europe

United States
- Pacific Northwest National Laboratory
- Lawrence Livermore National Laboratory
- State Univ. of New York, Buffalo
- Harvard Univ.
- Pennsylvania State Univ.
- George Mason Univ.
- Defense Threat Reduction Agency
- Colorado State Univ.
- Univ. of Colorado
- National Center for Atmospheric Research
- US. Air Force Technical Applications Center
Workshop Outcome

- Brought together a diverse group that rarely if ever meets
  - Japanese experts on the Fukushima Dai-ichi incident
  - Atmospheric and transport and dispersion experts
  - STE experts in defense, aviation safety, treaty monitoring, and energy
  - Nuclear power plant operations/safety expertise
  - Radiation measurements

- Collection and consolidation of STE information

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**Bulletin of the American Meteorological Society – Meeting Summary**

**METHODS FOR ESTIMATING THE ATMOSPHERIC RADIATION RELEASE FROM THE FUKUSHIMA DAI-ICHI NUCLEAR POWER PLANT**

By Paul E. Buehler, Steven Harr, George Young, Barbara Kettle, John Holman, and Robb Cline

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**Source Term Estimation Methods for Estimating Atmospheric Release from the Fukushima Dai-ichi Nuclear Power Plant**

- A multiphase group of scientists and engineers from academia, industry, governments, and laboratories in the United States and Japan collaborated to estimate the source term of the Fukushima Dai-ichi nuclear power plant.
- The source term is critical for understanding the potential for radioactive material release and the consequences of the release.
- The estimated source term is used to inform emergency response and to guide risk assessments.

**Research Applications Laboratory | RAL**

**International Workshop on Source Term Determination: Volume for Estimating the Atmospheric Radiation Release from the Fukushima Daiichi Nuclear Power Plant**

http://www.ral.ucar.edu/nsap/events/fukushima/
Workshop Outcome
(Discussion Points From the Meeting)

• Challenges for source term estimation (STE) of the airborne radiation release from the Fukushima nuclear power plant (FD-NPP)
  – Destruction of critical infrastructure
  – Continually evolving incident
  – Fidelity of measurements and available models

• Approaches to solving this problem
  – Inverse model based
  – Forward model based
  – New and emerging approaches

• Conclusions
Common Methods Applied to Source Term Estimation

Inverse and Back Trajectory Model Based

Forward Dispersion Model Based

Non-Gradient Descent

Gradient Descent

Use from One to Many Forward Dispersion Model Simulations in an Algorithm that Attempts to Find the Best Match Between a Dispersion Model and the Observations
Forward Dispersion Model Based Method
(Matching A Dispersion Model to the Observations)

STE First Guess
- Location
- Time
- Release rate

Strengths:
* Can operate with less accurate met data
* Can be a VERY fast running solution
* Is less complicated when only searching for release rate

Weaknesses:
More complicated to implement for multiple dimensions
Can be sensitive to initial guess source term

* Denotes important for nuclear power plant emergency response applications
Conclusions

- Determining source terms for atmospheric releases of hazardous materials is critical for rapid evacuation and public safety.
- Unknown atmospheric conditions can significantly increase the complexity of the STE problem.
- Unfortunately, no single approach provides an all encompassing solution.

This Information Survey Can Inform the Direction of STE Capability Development for Future Disaster Mitigation.
Questions
Appendix
## Comparison of Back Trajectory and Forward Dispersion Model

<table>
<thead>
<tr>
<th>STE Methods</th>
<th>Back Trajectory</th>
<th>Forward Dispersion Model</th>
</tr>
</thead>
</table>
| Computational time | - Simple version is fast  
- Slower if dispersion model is used and numerous observations available | - Can be **VERY** fast (depends on search method used and dimensionality of the problem) |
| Available input data | - Gas concentrations  
- Soil contamination  
- Radiation dose | - Gas concentrations  
- Soil contamination  
- Radiation dose |
| Weakness | - Requires accurate meteorological data  
- Requires numerous forward dispersion simulations | - Is sensitive to first guess  
- Can be difficult to implement for multi-dimensional problems |
| Algorithm | - Invert the winds and follow parcel trajectories from multiple locations  
- Inverse dispersion model | - Residual method (linear scaling of the release mass)*  
- Search algorithm (Simulated Annealing, Bayesian, Gradient descent, etc.) |

*Denotes approach selected for nuclear power plant emergency response applications*
Flow Chart of **Source Term Estimation (STE)**

- **Observation**
  - Meteorological data (Air flow)
  - Concentration
  - Meteorological data (Precipitation)

- **Simulation model**
  - Assumed source intensity
  - Dispersion model
    - Air flow condition
    - Turbulent diffusivity
  - Deposition model
    - Deposition velocity
    - Particle diameter

- **Radiation model**
  - Radiation dose
    - 1) Cloud-shine
    - 2) Ground-shine
    - 3) Sky-shine
  - Distribution of radioactive materials on the ground surface

- **Uncertainty of STE**
  - Availability and Reliability of observed data

Main object of this study: STE
# Examples of STE methods applicable to nuclear accidents

<table>
<thead>
<tr>
<th>Organization name (Code)</th>
<th>Observed data</th>
<th>Simulated data</th>
<th>Release condition</th>
<th>STE METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAEA (SPEEDI)</td>
<td>Dust sampler</td>
<td>Concentration in the air</td>
<td>Quasi-steady with time during 30 min.</td>
<td>Comparison between simulation &amp; observation</td>
</tr>
<tr>
<td></td>
<td>Radiation dose</td>
<td>Cloud, ground &amp; sky-shines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present study</td>
<td>Radiation dose</td>
<td>Cloud-shine</td>
<td>Unsteady with time</td>
<td>Variational technique</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RISO (RIMPUFF)</td>
<td>Radiation dose</td>
<td>Cloud-shine</td>
<td>Unsteady with time</td>
<td>Kalman filter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>LLNL (NRAC)</td>
<td></td>
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</tbody>
</table>
Measurement of radiation dose excluding ground and sky shine

1. Without shield (conventional method)

2. With shield (Improved method)

2-a) Lower shield

2-b) Upper shield

2-c) Lower shield + Check source

• in Tokai nuclear power station
• 2011.12.16
Photos of measurement configurations

2-a）Lower shield

2-b）Upper shield

2-c）Lower shield + Check source
Observation locations near the Tokai nuclear power station

- Inside forest (near monitoring point)
- Beside building (entrance space)
- Open space (storage yard)

- Observation in 2011.12.16
Radiation Dose and Precipitation Observations

a) March/2011

1\textsuperscript{st} peak and dry deposition

Red: gamma radiation dose
Blue: Precipitation

3rd peak and wet deposition

Radioactive decay of I\textsubscript{131}

b) September/2011

Red: gamma radiation dose
Blue: Precipitation

1st peak and dry deposition
# Observed data (μSv/h)

<table>
<thead>
<tr>
<th>Shield condition</th>
<th>Beside building</th>
<th>Open space</th>
<th>Inside forest</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case1</td>
<td>0.10</td>
<td>0.16</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>(No shield)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case2-a</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>(Lower shield)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case2-b</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>(Upper shield)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case2-c</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>(+ 1Check source)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case2-c’</td>
<td>0.04</td>
<td>0.09</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>(+ 4Check sources)</td>
<td></td>
<td></td>
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</tbody>
</table>

- observation in Tokai, 2011.12.16