The estimated amount of radioactive materials released into the air by Fukushima Daiichi NPS accident

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Profile

- **Name**
  Junichi TAIRA

- **TOKYO ELECTRIC POWER COMPANY**
  - Radiation Protection & Environment Group
  - Project Planning Department Fukushima Daiichi
  - Decontamination and Decommissioning
  - Engineering Company

- **Date of joining TEPCO**
  4.1.2005～

- **Work (After the accident)**
  - Environmental assessment
    - monitoring plan
    - estimations of the release rate from reactor
  - Designing facilities to reduce the effect of additional release from reactor

12. July. 2013 at Fukushima Daiichi
Background

- After the accident, radioactive material was released from Units 1~3.
  - Venting and building explosions
  - Continuing releases of radioactive material to the atmosphere from buildings after the building explosions.

- The monitoring posts and stack monitors was lost due to the earthquake and tsunami.

- Monitoring cars were posted around the power station
  - To measure the air dose rate, meteorological data and other data in an effort to ascertain the status of radioactive material release.
1. Fukushima-Daiichi site map
2 Measured air dose rate data

Measured by monitoring car in power station

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3.1 Image of estimation

**Diagram Description:**
- **Input:**
  - Reactor building
  - Stack monitor
  - Air dose rate
  - Weather data
  - Wind direction
  - Wind speed
- **Output:**
  - mSv/h
  - Bq/h
  - Release rate
  - mSv/h

**Steps:**
1. **STEP1:** Input vs. time
2. **STEP2:** Release rate
3. **STEP3:** Adjustment
4. **STEP4:** Equal data?
   - If equal, release rate is determined
   - If not equal, proceed to STEP2
5. **STEP5:** Output

**Key Data Points:**
- Green: Measurements data
- Purple: Estimations data

**Legend:**
- Monitoring car
- Dispersion
- Stack monitor

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3.2 weather data & DIANA

- **weather data**
  - **the wind direction** & **wind speed** (measured by monitoring car)
  - **precipitation** (by the Japan Meteorological Agency)

- **DIANA**
  - **DIANA**: Dose Information Analysis for Nuclear Accident
  - **assessment domain**:
    - 30km on the **land** side × 50km north-to-south line
    - 20km on the **sea** side × 50km north-to-south line
  - **calculation step**: 10-minutes intervals
  - **release point**: one point
  - Capable of assessing **the air dose rate** and **the amount of deposition on soil** at a specified location and time by inputting the release rate of **0.5 MeV-equivalent virtual particle and weather data**.
3.3 Flowchart for Estimation

**STEP 1: Estimation of released amount**

- **Input data**
  - Weather data
  - Air dose rate data
  - Composition of nuclides in the plume obtained from the air dose rate data

- **Calculation code** (DIANA)

- **Assumption of a release rate**

- **Agreement with measured values**
  - YES
  - NO

- **Repeat the above estimation during the assessment period**

**STEP 2: Comparison of deposited amounts**

- **Input data**
  - Verification data
  - Soil sampling data obtained by the Ministry of E.C.S.S&T (Deposited amount)
  - Rainfall taken into account

- **Calculation code** (DIANA)

- **Total deposited amount in the limits covered by the analysis (50km × 50km)**
  - Deposited amount of Cs (Bq)

- **Deposited amount on the land side (30km)**
  - (Bq)

- **Deposited amount on the sea side (20km)**

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3.4 Estimation of release of each nuclide [1/3]

- Contamination of observation area are caused by deposition of iodine and cesium.
- Deposition of iodine and cesium increases the background dose rate around the observation area. (main contributor is cesium)
- The deposited iodine and particulate nuclides decay according to their half life period.
- To estimate the portion of noble gas, iodine and cesium in the plume, we varied the ratio and calculated by DIANA until we could reconstruct the curve of the measured dose rate.
3.4 Estimation of release of each nuclide

- Ratio of Susceptibility of Radioactive Nuclides to Release
  - noble gas : iodine : cesium = 100 : 2 : 0.2

![Graph showing air dose rate (μSv/h) over time (DAY) with main gate and DIANA estimation markers.](image)
3.4 Estimation of release of each nuclide

- Ratio of Susceptibility of Radioactive Nuclides to Release
- **noble gas : iodine : cesium = 100 : 1 : 0.1**

![Graph showing air dose rate (μSv/h) vs. day with main gate and DAINA estimate markers]
3.4 Estimation of release of each nuclide

**Ratio of Susceptibility of Radioactive Nuclides to Release**

noble gas : iodine : cesium = 100 : 10 : 1

![Graph showing air dose rate vs. day](image)
3.4 Estimation of release of each nuclide

- \[ R(t) = Q'(t) \left( 100C_1 X(t) + 10C_2 Y(t) + C_3 Z(t) \right) \]

- \( R(t) \): 0.5MeV-equivalent virtual particle release rate (Bq/s) calculated backwards using DIANA from the air dose rate
- \( X(t) \): Noble gas inventory at time \( t \) (Bq)
- \( Y(t) \): Iodine inventory at time \( t \) (Bq)
- \( Z(t) \): Cesium inventory at time \( t \) (Bq)
- \( C_1 \): Coefficient converting the noble gas inventory to 0.5MeV-equivalent value
- \( C_2 \): Coefficient converting the iodine inventory to 0.5MeV-equivalent value
- \( C_3 \): Coefficient converting the cesium inventory to 0.5MeV-equivalent value
- \( Q'(t) \): Coefficient for converting a certain released amount (0.5MeV-equivalent value) to a release rate determined from the air dose rate. (1/s)

- The values except for \( Q'(t) \) are determined for each time \( t \).
  \[ \rightarrow Q'(t) \text{ is determined.} \]

- From the above equation, the release rate for each nuclide at time \( t \) is as given below.
  - Noble gas : \( 100C_1 Q'(t) X(t) \text{ Bq/s} \)
  - Iodine : \( 10C_2 Q'(t) Y(t) \text{ Bq/s} \)
  - Cesium : \( C_3 Q'(t) Z(t) \text{ Bq/s} \)
4. Result of Investigations on FP release volume

<table>
<thead>
<tr>
<th></th>
<th>noble gas (0.5MeV)</th>
<th>I-131</th>
<th>Cs-134</th>
<th>Cs-137</th>
</tr>
</thead>
<tbody>
<tr>
<td>approx.</td>
<td>500PBq</td>
<td>approx. 500 PBq</td>
<td>approx. 10 PBq</td>
<td>approx. 10 PBq</td>
</tr>
</tbody>
</table>

(PBq = 10^{15} Bq)

The value estimated by our company is rounded off to one decimal place, being a figure in Bq at the time of being released.

![FP release volume graph](image)

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## 5. FP release volume  【vent & explosion】

<table>
<thead>
<tr>
<th>unit</th>
<th>time</th>
<th>event</th>
<th>release volume (PBq)</th>
<th>noble gas</th>
<th>I-131</th>
<th>Cs-134</th>
<th>Cs-137</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.12 14:00～</td>
<td>vent</td>
<td>4</td>
<td>0.7</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td></td>
<td>3.12 15:36</td>
<td>explosion</td>
<td>10</td>
<td>3</td>
<td>0.05</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.13 09:00～</td>
<td>vent</td>
<td>1</td>
<td>0.3</td>
<td>0.005</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.13 12:00～</td>
<td>vent</td>
<td>0～0.04</td>
<td>0～0.009</td>
<td>0～0.0002</td>
<td>0～0.0001</td>
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<tr>
<td></td>
<td>3.13 20:00～</td>
<td>vent</td>
<td>0～0.003</td>
<td>0～0.001</td>
<td>0～0.00002</td>
<td>0～0.00002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.14 06:00～</td>
<td>vent</td>
<td>0～0.003</td>
<td>0～0.001</td>
<td>0～0.00002</td>
<td>0～0.00002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.15 16:00～</td>
<td>vent</td>
<td>0～0.003</td>
<td>0～0.001</td>
<td>0～0.00002</td>
<td>0～0.00002</td>
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<tr>
<td></td>
<td>3.16 02:00</td>
<td>vent</td>
<td>0～0.003</td>
<td>0～0.001</td>
<td>0～0.00002</td>
<td>0～0.00002</td>
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<tr>
<td></td>
<td>3.17 21:00</td>
<td>vent</td>
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<td>0～0.001</td>
<td>0～0.00002</td>
<td>0～0.00002</td>
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<td></td>
<td>3.18 05:00～</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>3.20 11:00</td>
<td>vent</td>
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<td>0～0.001</td>
<td>0～0.00002</td>
<td>0～0.00002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.14 11:01</td>
<td>explosion</td>
<td>1</td>
<td>0.7</td>
<td>0.01</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>vent  &amp; explosion</td>
<td></td>
<td>approx.20</td>
<td>approx.4</td>
<td>approx.0.09</td>
<td>approx.0.06</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>between March 12 and March 31</td>
<td></td>
<td>approx.500</td>
<td>approx.500</td>
<td>approx.10</td>
<td>approx.10</td>
<td></td>
</tr>
</tbody>
</table>

Majority of FP release is considered to be due to uncontrolled release from Reactor Buildings (not from venting or explosion.

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6. Deposition Cs-137

Survey Data | 1PBq
---|---
DIANA estimation | 1PBq

Deposition Cs-137
PBq/(50km × 30km)

Soil sampling data & range of DIANA estimation
# 7. Estimation results of other Organization

<table>
<thead>
<tr>
<th>Organization</th>
<th>release volume unit : PBq</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>noble gas</td>
</tr>
<tr>
<td>TEPCO</td>
<td>approx.500</td>
</tr>
<tr>
<td>JAEA 8.22.2011</td>
<td>-</td>
</tr>
<tr>
<td>JAEA 3.6.2012</td>
<td>-</td>
</tr>
<tr>
<td>NISA 4.12.2011</td>
<td>-</td>
</tr>
<tr>
<td>NISA 6.6.2011</td>
<td>-</td>
</tr>
<tr>
<td>NISA 2.16.2012</td>
<td>-</td>
</tr>
<tr>
<td>IRSN</td>
<td>2000</td>
</tr>
</tbody>
</table>

JAEA : Japan Atomic Energy Agency  
NISA : Nuclear and Industrial Safety Agency  
IRSN : Institut de Radioprotection et de Sûreté Nucléaire
Air dose rate showed rapid increase around 10:00 am on 3/15 but there were no plant operation like venting.

This picture shows the steam release from Unit 2 around 10:00 am on 3/15.
8. Cause of Contamination of NW region 【2/3】

These pictures indicate that the plume released from Unit 2 on 3/15 located NW region from evening to midnight.
8. Cause of Contamination of NW region 【3/3】

According to the weather radar, around NW region it was raining from evening to midnight on 3/15.

We concluded the main cause of the contamination of NW region was the uncontrolled release from Unit 2.
9. Conclusion

- Comparison with the estimation results of other organization, it can be said that **TEPCO’s estimation about Cs is almost adequate.** But the amount of Iodine is too large. So, we think that **farther investigation is required.**
- The process of the main release is **uncontrolled release from Reactor Buildings.**
- **S/C venting is effective** to decrease the FP release to the air.
- Main Cause of the contamination of NW region is **uncontrolled release from Unit2 (potential impairment of torus).**

<table>
<thead>
<tr>
<th>process of release</th>
<th>noble-gas</th>
<th>I-131</th>
<th>Cs-134</th>
<th>Cs-137</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venting</td>
<td>approx.5</td>
<td>approx.1</td>
<td>approx.0.02</td>
<td>approx.0.01</td>
</tr>
<tr>
<td>Hydrogen Explosion</td>
<td>approx.10</td>
<td>approx.3</td>
<td>approx.0.07</td>
<td>approx.0.05</td>
</tr>
<tr>
<td>uncontrolled release from Reactor Buildings</td>
<td>approx.500</td>
<td>approx.500</td>
<td>approx.10</td>
<td>approx.10</td>
</tr>
<tr>
<td>Total</td>
<td>approx.500</td>
<td>approx.500</td>
<td>approx.10</td>
<td>approx.10</td>
</tr>
</tbody>
</table>