Lessons Learned from Criticality Accident in Tokai-mura
(1) Outline of the Accident

OKUNO Hiroshi
Japan Atomic Energy Agency*

* Japan Atomic Energy Research Institute (JAERI) and Japan Nuclear Cycle Development Institute (JNC) have been unified and become Japan Atomic Energy Agency (JAEA) on 1 October 2005.
Victims

Nuclear criticality continued for 20 hours!

30 September 1999

2 - 3 GyEq; alive

6 - 9 GyEq; died 210 days later

A 16 - 25 GyEq; died 82 days later

B

C

18.8 wt% enriched U in \( \text{UO}_2(\text{NO}_3)_2 \) solution, 370gU/L
Where is Tokai-mura?

- JCO
- Village Office
- JR Station
- JAPC
- Former JAERI
- Former JNC

Tokai-mura

3 km
30 km
Vicinity of JCO

- Golf driving range
- JCO-Tokai
- Prefectural Road 62
- National Route 6
- Gas station
Main Role of JCO in Nuclear Fuel Cycle

- Uranium Mine
- Mining and Milling Plant
- Yellow cake
- Conversion Plant
- Enrichment Plant
- UF₆
- MOX fuel assemblies
- Fuel Fabrication Plant
- UF₆
- JCO
- Experimental Fast Reactor, JOYO
- MOX fuel assemblies
- UO₂
- Fuel Fabrication Plant
- UO₂
- JCO
- Nuclear Power Plant
- Spent UO₂ fuel assemblies
- Reprocessing Plant
- UO₂
- MOX
- UO₂ fuel assemblies
- Fuel Fabrication Plant
- UO₂
- JCO
- Criticality Accident (1) Outline
Consignment from Former JNC

- To obtain homogeneous uranium nitrate solution from U₃O₈ powder of 18.8 uranium enrichment to make a test fuel for the Experiment Fast Breeder, Joyo of the former Japan Nuclear Cycle Development Institute (JNC).
Simplified Process

**Authorized procedure**  

- **U₃O₈ powder (after refining)**
- **HNO₃**
- **Dissolver**
- **Product solution**
  - **UO₂(NO₃)₂**

**Actual procedure**  
(Sep. 1999)

- **U₃O₈ powder (after refining)**
- **HNO₃**
- **Stainless steel flask (10 lit)**
- **Precipitation tank B**
- **Water**
- **Product solution**
  - **UO₂(NO₃)₂**
What is Induced by a Fission?

http://2012books.lardbucket.org/books/general-chemistry-principles-patterns-and-applications-v1.0m/section_24_02.html
Neutron Dose Equivalent Rate Measured at the Site Boundary

- **Conversion Test Facility**
- **Surveillance Site Boundary**

- **Measured between 19:09 and 19:22 on September 30**

1-4 October 2013  Criticality Accident (1) Outline
Neutron/Gamma Dose Equivalent Rates Measured near JCO

Estimation of Fission Behavior

Burst - Plateau

Total: $2.5 \times 10^{18}$ fis.

2 - $4 \times 10^{17}$ fis. (12%)

2.1 - $2.3 \times 10^{18}$ fis. (88%)
## Radioactivity Discharged into the Atmosphere

<table>
<thead>
<tr>
<th></th>
<th>Released amount (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noble gases</td>
<td>$1.6 \times 10^{14}$</td>
</tr>
<tr>
<td>Iodines</td>
<td>$1.3 \times 10^{10}$</td>
</tr>
</tbody>
</table>
### Emergency Response by JCO

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:35</td>
<td>Gamma-ray area monitors alarmed in JCO.</td>
</tr>
<tr>
<td>10:40</td>
<td>Collected workers on the playing ground and called over.</td>
</tr>
<tr>
<td>10:43</td>
<td>Called 119, telling “Looks like by tenkan*.”</td>
</tr>
<tr>
<td>~11:15</td>
<td>Sent FAX to STA, Ibaraki Pref., Tokai-mura, etc. reporting the event with a comment “nuclear criticality might occur.”</td>
</tr>
<tr>
<td>13:56</td>
<td>Visited Tokai-mura and requested evacuation of the nearby residents.</td>
</tr>
<tr>
<td>14:40</td>
<td>Same as above.</td>
</tr>
</tbody>
</table>

* In Japanese, both conversion and epilepsy are pronounced tenkan.
# Emergency Response by Firefighters

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:46</td>
<td>Arrived at the main gate of JCO.</td>
</tr>
<tr>
<td>11:02</td>
<td>Informed by JCO that the patients suffered radiation exposure.</td>
</tr>
<tr>
<td>11:33</td>
<td>Requested National Mito Hospital (NMH) to accept the radiation casualties.</td>
</tr>
<tr>
<td>12:07</td>
<td>Arrived at NMH.</td>
</tr>
<tr>
<td>13:02</td>
<td>Requested the police helicopters to transfer the casualties to the NIRS.</td>
</tr>
<tr>
<td>13:43</td>
<td>Left the police heliport in Mito.</td>
</tr>
<tr>
<td>15:23</td>
<td>The casualties arrived at the NIRS.</td>
</tr>
</tbody>
</table>
## Emergency Response by Former JNC

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:30</td>
<td>Received a call for help from JCO.</td>
</tr>
<tr>
<td>12:35</td>
<td>Established the JNC Support Headquarters.</td>
</tr>
<tr>
<td>After 14:30</td>
<td>Arrived at JCO and made a plan for counter-measuring the event.</td>
</tr>
<tr>
<td>16:30</td>
<td>Measured the neutron dose level as 0.6mSv/h in the administrative building of JCO.</td>
</tr>
<tr>
<td>19:30</td>
<td>Made gamma screening for JCO workers at Ishigami Community Center.</td>
</tr>
<tr>
<td>Next day</td>
<td>A hundred workers participated in making sand bags and piling them up for shielding.</td>
</tr>
</tbody>
</table>

### Emergency Response by Former JAERI

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:18</td>
<td>Received a call from STA.</td>
</tr>
<tr>
<td>13:10</td>
<td>Established the emergency Headquarters at Tokai Establishment.</td>
</tr>
<tr>
<td>14:10</td>
<td>Dispatched specialists in criticality safety and health physics to STA-Tokai.</td>
</tr>
<tr>
<td>~18:10</td>
<td>Received information on the precipitation tank of JCO.</td>
</tr>
<tr>
<td>~22:00</td>
<td>Estimated that the tank might become subcritical when water would be drained out from the water jacket of the tank.</td>
</tr>
</tbody>
</table>
### Emergency Response by Local Residents

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:30</td>
<td>The residents of Tokai-mura were announced over the community system that they should be stayed indoors, because radiological material was seemingly released from JCO where an accident was occurred at 10:35.</td>
</tr>
<tr>
<td>~15:00</td>
<td>The residents within 350-m-radius area were requested by Tokai-mura to evacuate.</td>
</tr>
<tr>
<td>22:30</td>
<td>The residents within 10-km-radius area were requested by the Governor of Ibaraki-Prefecture to stay indoors.</td>
</tr>
</tbody>
</table>
Lessons Learned (1)

1. The accident was happened where it was not assumed to happen.
   - Not at a nuclear power plant nor at a fuel reprocessing plant!
   - Processing uranium, not plutonium!
   - Nuclear criticality continued!

2. Emergency response can be made within his/her usual habit and ability.
   - Many workers for JCO and some first responders did not carry a personal dosimeter.
   - Criticality calculation was performed by a JAERI researcher who used the code in his research.
3. Information sharing among emergency response headquarters is important.
   - The emergency HQs of Tokai-mura was not informed of the Governor's request.

4. Mass communication, esp. TV broadcast, is a fast publication tool in emergency.
   - JCO workers watched TV during the accident, not knowing what to do.
   - People at the Emergency HQs of Tokai-mura knew the Governor's request through TV news.
   - However, the national broadcast does not join the emergency exercise, because of the independence of mass media.
Appendices

- JAEA/NEAT
- Criticality mass curves
- Drawing for countermeasure
- Memo on calculation results
Emergency Response Structure of the Japan Atomic Energy Agency as a Designated Institute

Japan Atomic Energy Agency

Dedicated staff members of NEAT [50]

- Director
  - Fukui Branch
  - Shift supervisor
  - Controlling group
  - Operational group

Designated experts [110]
who are engaged in research or technical development in normal time

[8 expert fields]
- Environmental monitoring
- Environmental assessment
- Individual dose assessment
- Radiation control
- Criticality/shielding assessment
- Nuclear transport engineering
- Nuclear fuel engineering
- Reactor engineering

Off-site Center, emergency monitoring, etc.
Criticality Mass Curves

Criticality mass curves for uranium nitrate solution

• Outline drawing of the precipitation tank and planning of countermeasures to stop criticality
  1. To draw cooling water outside of tank
  2. To inject neutron absorber into the tank
  3. Is it possible to inject from $\text{NH}_3$ line?

• The paper was faxed to JAERI’s Emergency HQs by the dispatched expert of JAERI.


1-4 October 2013  Criticality Accident (1) Outline
Criticality calculation made for stopping criticality on 30th September

- **Calculation assumptions**
  - Uranium conc.: 370 gU/L
  - Free nitric acid: 1 N
  - Liquid volume: 50 L

- **Calculation results**
  - Infinite multiplication factor $k_\infty = 1.5699$
  - Migration area $M^2 = 35.44 \text{ cm}^2$
  - $k_{\text{eff}} = 1.0442$ w/ water reflector
  - $k_{\text{eff}} = 1.0008$ w/o water reflector