Side Event of IAEA General Conference

Severe Accident Analyses of Fukushima-Daiich Units 1 to 3

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Contents

1. Background

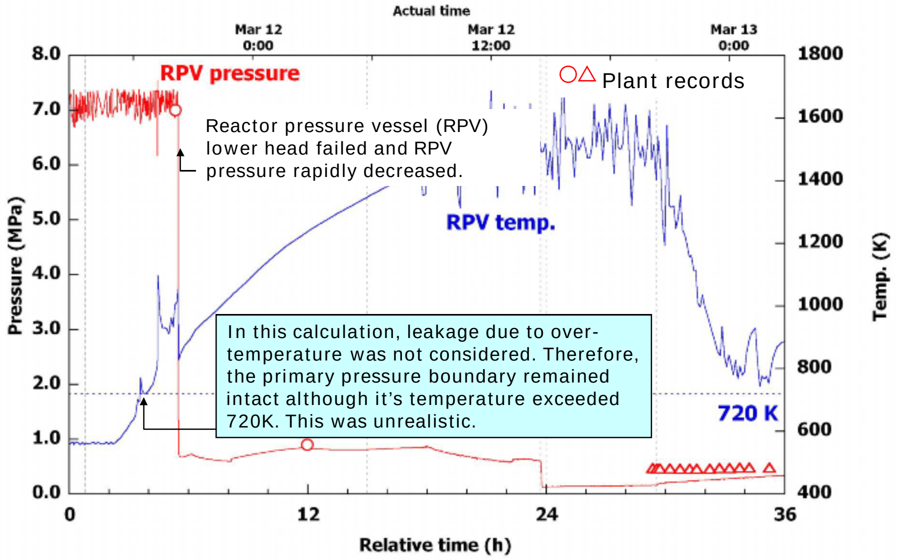
- The SA progression analyses done by TEPCO and JNES were reported to the IAEA Ministerial Conference in June 2011.
- Since then, the analyses have been continuously improved by taking into account new information on, such as:
  - Operation of isolation condensers, RCIC, venting system, etc.
  - Leakage / Failure of primary pressure boundary and containment, etc.
- However, it is still difficult to predict when and how much molten core fell into containment mainly due to large uncertainty in injection water flow rate into the core.
- Very recently, a preliminary analysis of migration and deposition of radioactive materials in the environment by using the radioactive release rates calculated by the SA progression analysis.

2. Accident Progression at Unit 1

Major improvements:

- In the previous analysis, leakage from primary pressure boundary due to over-temperature was not considered. Therefore, the primary system depressurization took place at the timing of lower head failure (melt through). In the present analysis, the leakage due to over-temperature was considered.
- Similarly, the leakage due to over-temperature was considered at the top-head flange of the containment (PCV).

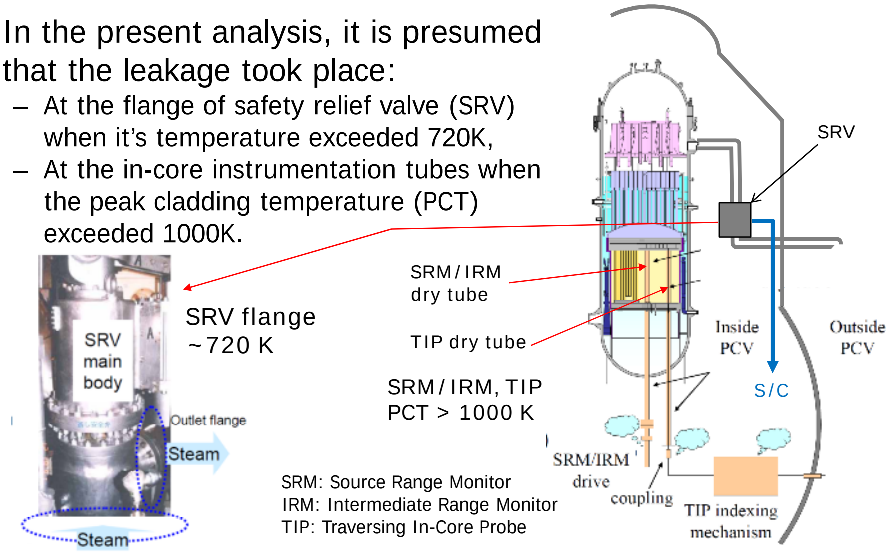
Unit 1 RPV Pressure in Previous Analysis (June 2011)



Reference: Nuclear Emergency Response Headquarters Government of Japan, "Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations - ," June 2011

Assumption of leakage from primary pressure boundary due to over-temperature

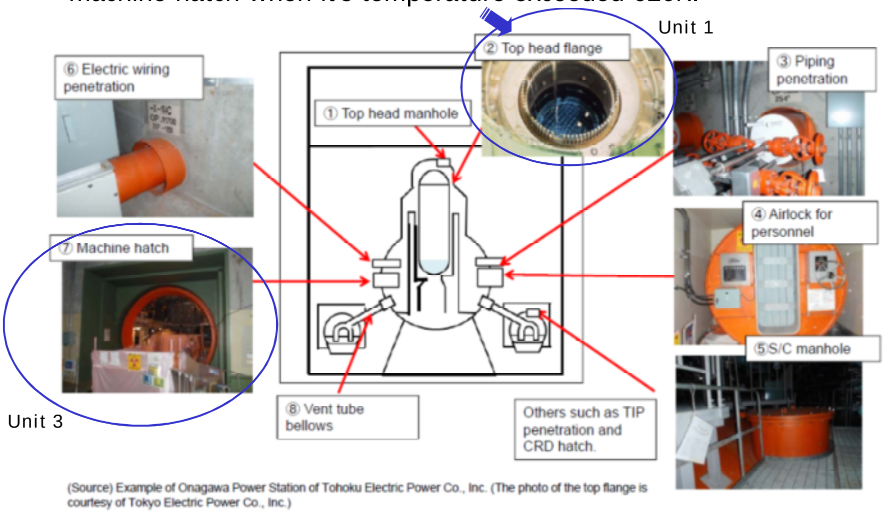
- In the present analysis, it is presumed that the leakage took place:
  - At the flange of safety relief valve (SRV) when it's temperature exceeded 720K,
  - At the in-core instrumentation tubes when the peak cladding temperature (PCT) exceeded 1000K.



Reference: http://www.tepco.co.jp/en/nu/fukushima-np/images/handouts_120312_04-e.pdf

Potential Leak locations of Mark-I Type Containment

- It is presumed that a leakage took place at the top head flange or machine hatch when it's temperature exceeded 620K.

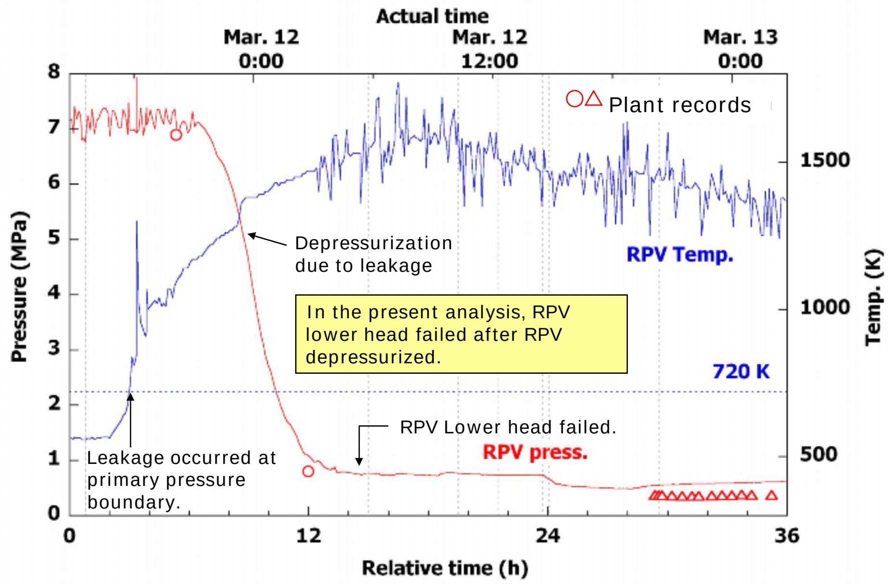


(Source) Example of Onagawa Power Station of Tohoku Electric Power Co., Inc. (The photo of the top flange is courtesy of Tokyo Electric Power Co., Inc.)

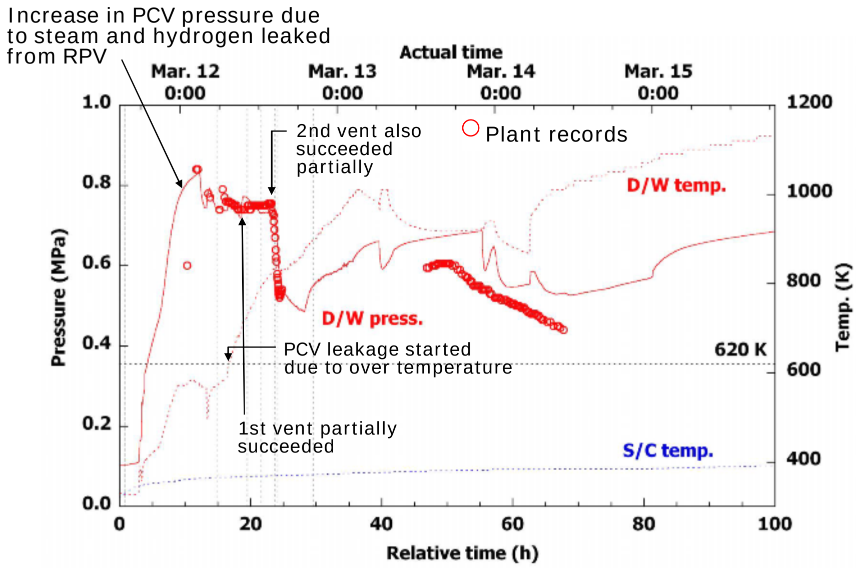
Causes and Countermeasures:The Accident at TEPCO's Fukushima NPS, Masaya Yasui, NISA/METI, March, 2012

RPV Pressure in Present Analysis: Results became more realistic.

Unit 1

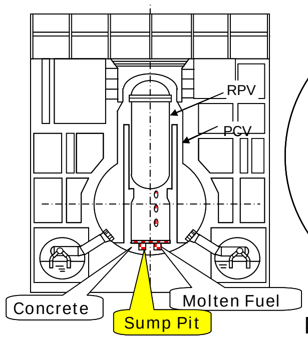


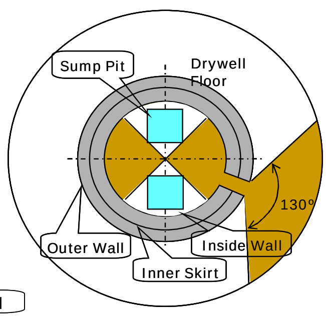
Unit 1 PCV Pressure in Present Analysis: Better agreement was obtained.



Molten Core Concrete Interaction (MCCI)

- JNES performed cross-checking of the calculation done by TEPCO. The assumption applied by TEPCO:
  - It is assumed that the whole molten fuel fell into containment in Unit 1.





Model for distribution of molten fuel on drywell floor

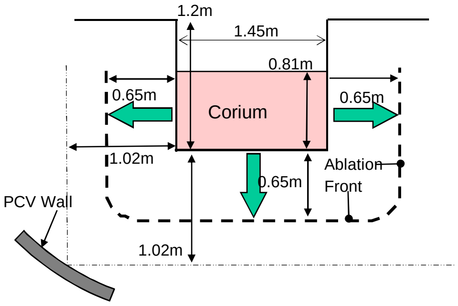
http://www.tepco.co.jp/en/nu/fukushima-np/images/handouts_111130_08-e.pdf

- The amount of molten fuel in a sump pit is determined according to this distribution.

Ablation Profile:
It was confirmed that both results were consistent

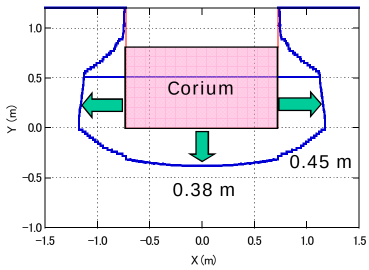
Conservative

By TEPCO
MAAP(DECOMP): 0.65 m



Less conservative

By JNES
COCO Code horizontal: 0.45 m
vertical: 0.38 m



- It is difficult to evaluate the amount of molten fuel that fell into the containment at present.
- It is expected that useful information be obtained through R&D at the Fukushima site for further assessment of MCCI.

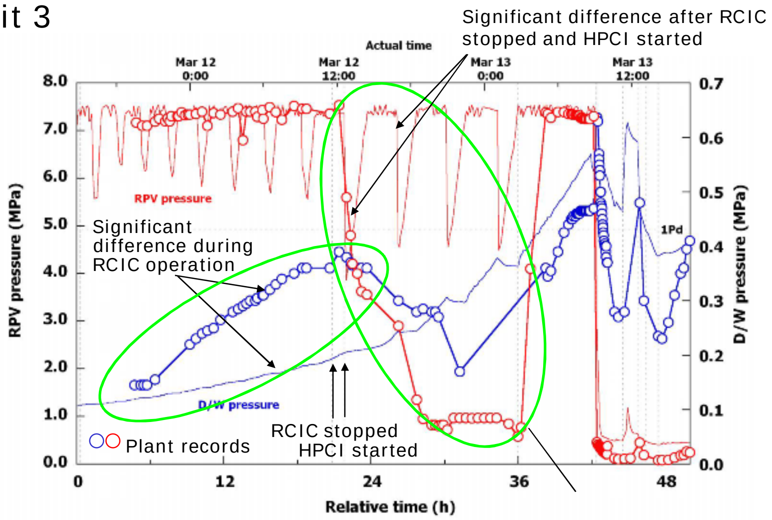
3. Accident Progression at Unit 3

Major Improvements

- In the previous analysis, large decrease in primary pressure just after starting HPCI could not be reproduced.
  - It was reported from TEPCO that HPCI injection flow rate was reduced by using the test line. In the present analysis, this was taken into consideration.
- Also, agreement with the plant data was poor on the containment pressure.
  - In the present analysis, thermal stratification is presumed to take place at suppression chamber (S/C).
  - Operation of containment spray was also considered based on the information from TEPCO.

RPV and PCV Pressures in Previous Analysis: Results show significant differences from plant records

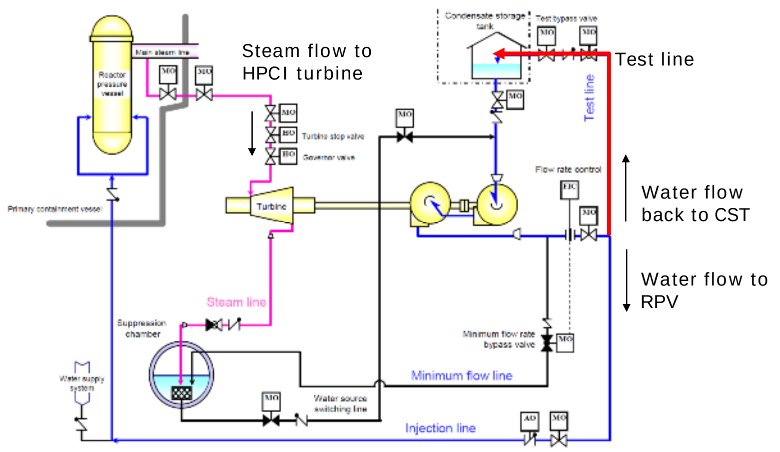
Unit 3



Ref.: Nuclear Emergency Response Headquarters Government of Japan, "Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations - ," June 2011

HPCI Operation Using Test Line

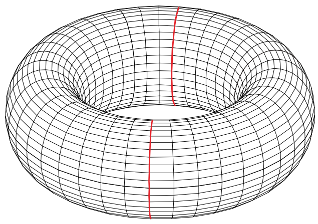
- In the present analysis, the HPCI operation using the test line was modeled. Large steam flow to HPCI turbine caused rapid decrease in RPV pressure.



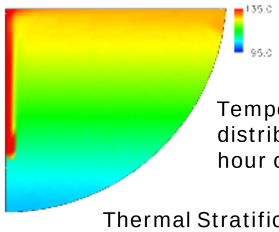
http://www.tepco.co.jp/en/nu/fukushima-np/images/handouts_120312_04-e.pdf

Major Assumptions:

- In order to simulate the thermal stratification at suppression chamber (S/C), the S/C was modeled by two volumes, upper and lower parts, in the present MELCOR analysis.
- A CFD (computational fluid dynamics) analysis was done to estimate the temperature difference between the upper and lower part of S/C (～20K).



Modeling in CFD analysis



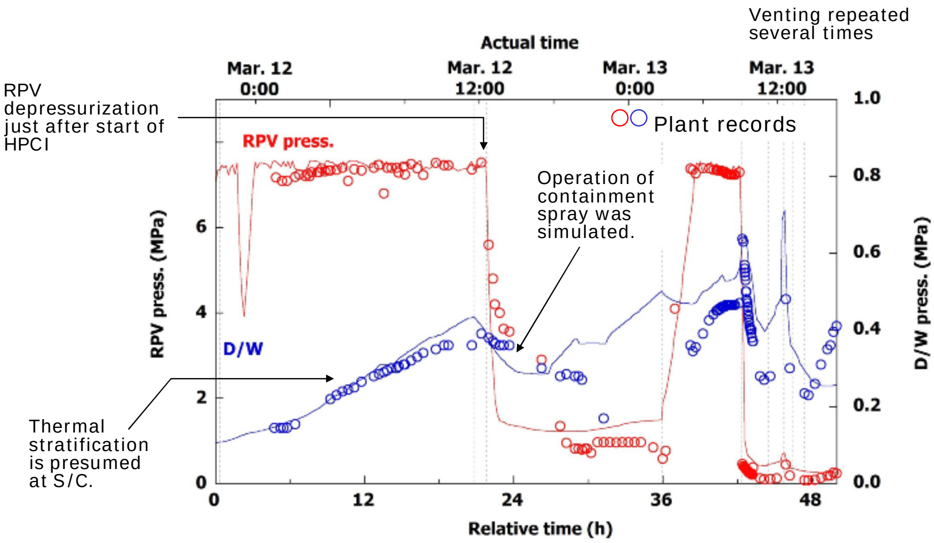
Temperature distribution after 20 hour operation of RCIC

Thermal Stratification

- Operation of containment spray:
  – Flow rate of S/C and D/W spray: 50 m^3/h

RPV and PCV Pressures in the Present analysis: Results were significantly improved

Unit 3



4. Hydrogen Explosions at Units 1 and 3

- Analysis was done with FLUENT, a CFD code, for hydrogen transport and mixing, and AUTODYN for structural analysis of detonation.

Major Assumptions:

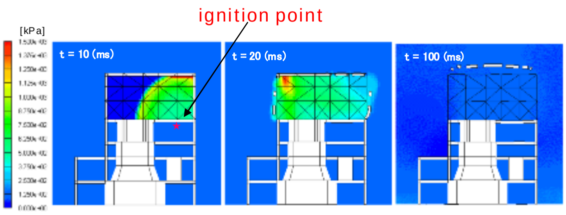
- In Unit 1, Hydrogen of 400 kg was released to the top floor (5F) of reactor building (R/B) and ignited there.
- In Unit 3, Hydrogen of 1000kg was released to the first floor (1F) of R/B and ignited there.

Hydrogen Explosion at Unit 1

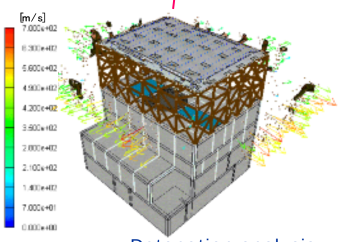
Analysis well reproduced the observed explosion:

- Explosion developed horizontally.
- Walls and roofs of top floor (5F) were largely damaged and debris scattered around R/B.

Potential location of leakage: top head flange of PCV



Propagation of detonation pressure in Unit 1

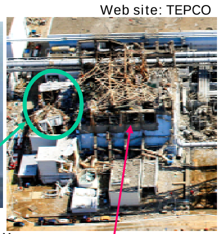


Detonation analysis with AUTODYN:

Hydrogen Explosion at Unit 3

Analysis well reproduced the observed explosion:
- Explosion developed vertically.
- Walls and roofs of top floor (5F) were largely damaged.
- Adjacent low building was also damaged.
- Locally high dose rate was detected at 1st floor.

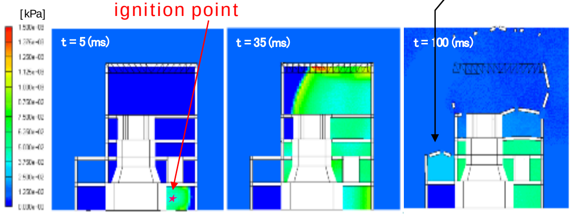
Web site: TEPCO



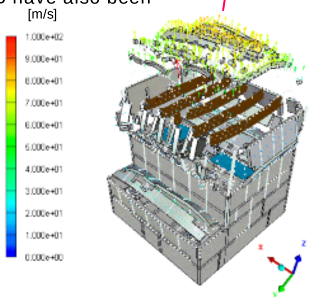
The top of a two-story building next to the R/B have also been damaged.

Potential location of leakage: device hatch

ignition point



Propagation of detonation pressure in Unit 3



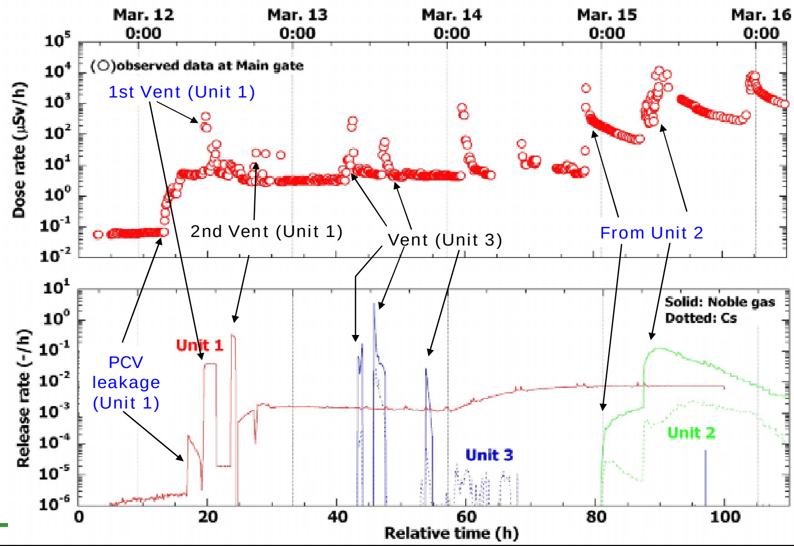
Detonation analysis with AUTODYN:

5. Source Terms

- The radioactive release rates obtained in the present analysis with MELCOR were compared with onsite monitoring data.
- The total amounts of releases were also evaluated by several other organizations:
  - TEPCO, JAEA, JAMSTEC and CREEPI applied “inverse analysis” which evaluated the source terms from the monitoring data and meteorological data.

Comparison between Release Rates Calculated with MELCORE and Onsite Monitoring Data:

- Release timings are relatively in good agreement with the monitoring data



Amount of Releases Evaluated in Several Organizations:

- Results are reasonably consistent with each other

Organization	Amount of Releases (PBq)			Duration	
	I-131	Cs-134	Cs-137		
JNES	250-340	8.3-15	7.3-13	Mar. 11-Mar. 17	Land side only
TEPCO	500	10	10		Land side only
JAEA	120	-	9		Land side only
JAMSTEC			9.7 5.5-5.7	Mar.12-May 6 Mar.21-May 6 To the ocean	Land side only / Sea side only
CRIEPI	11	3.5	3.6	Mar. 26-Sep. 30 To the ocean	Sea side only

(Yellow) Inverse analysis from monitoring data
(Green) Severe accident progression analysis

(1 PBq = 10^{15} Bq)

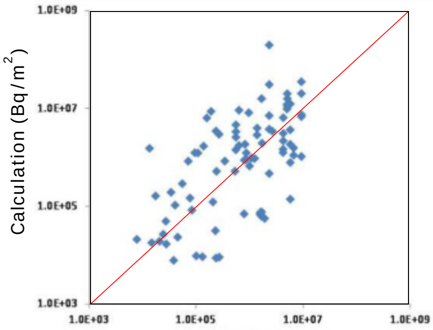
JNES 独立行政法人 原子力安全基盤機構

6. Environmental Consequences

- Very recently, JAEA conducted preliminary environmental consequence analysis with the OSCAAR* code developed by JAEA for level 3 PSA.
- The measured meteorological data were used.
- The source terms calculated by MELCOR, shown in Slide 21, were used.

*: T. Homma, et al, “Uncertainty and sensitivity studies with the probabilistic accident consequence assessment code OSCAAR,” Nuclear Engineering and Technology, 37(3), 245-258 (2005).

Calculated concentrations of Cs-137 in soil are in good agreement with the measured data

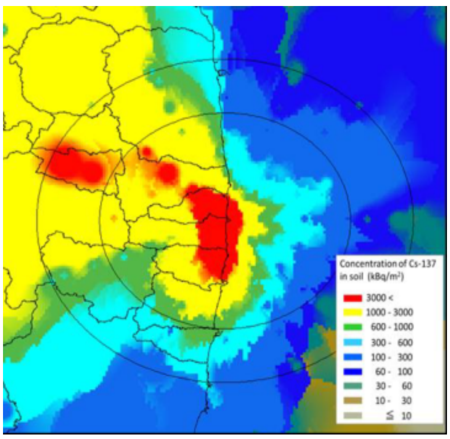


Correlation between measured data and calculation (Cs-137 concentration in soil)

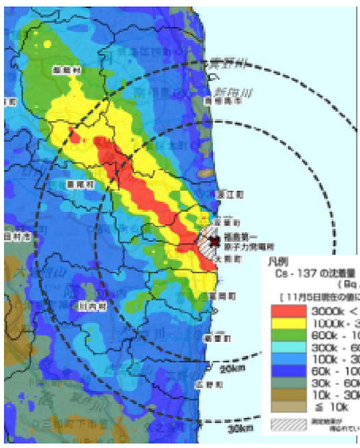
JNES 独立行政法人 原子力安全基盤機構

Preliminary Environmental Consequence Analysis by JAEA/JNES

Concentration of Cs-137 in soil



Environmental consequence analysis by JAEA (OSCAAR) using the source terms by JNES (MELCOR)



Monitoring data by MEXT
(October to Novemer, 2011)

http://radioactivity.mext.go.jp/ja/contents/5000/4901/24/1910_1216.pdf

7. Summary

- Regarding SA progression including source terms, most of the phenomena that took place during the accident have become reasonably well understood by efforts made by various organizations.
- It is still difficult to predict when and how much molten fuel fell into the containment. On this point, it is expected that new information / data will be obtained through R&D activities at the Fukushima site for decommissioning.
- New attempts, such as environmental consequence analysis with using the source terms calculated by SA progression analysis, are expected to be able to obtain better understanding.

Acronyms

AM	: Accident Management
D/W	: Dry Well
HPCI	: High Pressure Coolant Injection
IRM	: Intermediate Range Monitor
MCCI	: Molten Core Concrete Interaction
R/B	: Reactor Building
PCV	: Primary Containment Vessel
RCIC	: Reactor Core Isolation Cooling System
RPV	: Reactor Pressure Vessel
SA	: Severe Accident
S/C	: Suppression Chamber (Suppression Pool)

Organization

CRIEPI	: Central Research Institute of Electric Power Industry
JAEA	: Japan Atomic Energy Agency
JAMSTEC	: Japan Agency for Marine-Earth Science and Technology
TEPCO	: Tokyo Electric Power Company