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# Technical Issues in Source Term Estimation in the Real Radiological Emergency of Nuclear Power Plant

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## 1. Introduction

Radionuclides are released to the environment, which are called source terms, from Kyshtym, Windscale, TMI, Chernobyl and Fukushima accidents. Kyshtym accident is an explosion in a waste storage tank occurred in 1957 in Mayak nuclear complex in former Soviet Union. Windscale, TMI, Chernobyl and Fukushima accidents are occurred in real nuclear power plants. Windscale accident occurred in 1957 in a gas cooled reactor in United Kingdom. The TMI accident occurred in 1979 in a PWR in Pensylvania in USA. The Chernobyl accident occurred in 1986 in RBMK reactor in Ukraina (at that time Soviet Union). All four accidents except Kyshtym are occurred in power reactors, but they are all different reactor types. Major release radionuclide in Kyshtym accident is strontium because Kyshtym is not a nuclear power plant but a liquid nuclear waste storage facility.

## 2. Methods

ORIGEN2 code [1] is developed in Oak Ridge National Laboratory to estimate radionuclide inventories in nuclear power plant. MELCOR [2] and MAAP [3] codes are developed in USA to predict the release amount of radionuclides to environment based on the detailed thermal hydraulics of reactor vessel and core slumping down phenomena. RASCAL code is also developed in US NRC for the emergency preparedness in nuclear power plants. But the main target reactor types are PWR and BWR. RASCAL code [4, 5] estimates radionuclide release amount to environment based on simple plant conditions.

Radionuclide release to atmosphere from the Chernobyl and Fukushima accidents are summarized in UNSCEAR 2008 [6] and 2013 [7] reports, respectively. Core inventory is estimated from ORIGEN code with burnup history. Atmospheric releases are estimated by a reverse or inverse method. Airborne and deposition activity to soil are measured after accidents. Using the meteorological data together with activity or dose measurement data the radionuclide release amount from nuclear power plant to environment are estimated. Severe accident codes developed in all over the world including MELCOR code, which is developed in USA, are used to estimate the radioactivity release to atmosphere in the OECD/NEA BSAF project [8, 9] for Fukushima accident by the forward accident progression method.

Many countries prepares for the situation of real accident occurrence. For instance they developed SPEEDI and WSPEEDI computer codes in Japan [10], however, they are not used appropriately in deciding emergency action levels in Fukushima accident. In the emergency situation, the fast and reasonable estimation (prediction) of released timings, what kinds of and the released amount of radionuclides would be very important with very limited information on the nuclear power plant accident. RASCAL [4, 5] and HotSpot [11] codes are prepared in USA for the fast and reasonable estimation of source term release to atmosphere to be used in real accident situations. MACCS2 code is used in USA for Level 3 PSA (Probabilistic Safety Assessment).

Availability of the meteorological data is also one of the most important information in estimation of accident source term. The right chose or utilization of the method of atmospheric transport and dispersion of radionuclides is also very important. There are models such as straight-line Gaussian plume model, Gaussian puff model and Lagrangian trajectory model, etc [5]. Depending on the magnitude of deposition on the ground in annual expectation, the emergency action levels such as evacuation, sheltering, temporary moving are decided usually. Therefore, the speed and accuracy are very important in decision making in real situation of radiological emergency occurrence.

## 3. Results

What kinds of radionuclide are released would be a main concern in the real accident situations. Main radionuclide will be strontium in the liquid waste tank explosion as occurred in Kyshtym accident. Major concern in the nuclear power plant accident, however, is interested in the estimation of iodine and cesium. I-131 has half life of 8 days and Cs-137 has half life of 30 years. So the release fraction of iodine depend on the accident progression timings.

In the Chernobyl accident, a fire sustained during 10 days and plume released to all around Europe during these 10 days release. The radioactivity release to atmosphere maintained during almost 1 month in the Fukushima accident. The plume release directions are almost all the 360 degrees during this one month release. Thereafter oceanic release of radioactivity was there inevitably. In the Chernobyl accident some actinides (about 3 % of core inventory) were released to atmosphere due to the core fire during ten days. In the Fukushima accident, however, there was almost no actinide release to atmosphere.

SPEEDI, RASCAL, and MELCOR codes are used to estimate source terms in Fukushima accident. Fig. 1 shows Cs-137 release to atmosphere estimated by SPEEDI by Chino (2012), Terada (2012), and Katata (2015). It is estimated from 9 PBq to 14 PBq of Cs-137 released to environment. Fig. 2 shows RASCAL 4 estimate of the cumulative I-131 and Cs-137 release for the Fukushima Accident [4]. It is estimated that about 22 PBq of Cs-137 released to the environment at 120 h after reactor shutdown. It is estimated that approximately 20, 5, and 10 PBq of Cs137 are estimated to be released to the environment from Unit 1, 2, and 3, respectively based on MELCOR code simulations. Total 35 PBq is released to the environment during 500 hours. (Fig. 3).

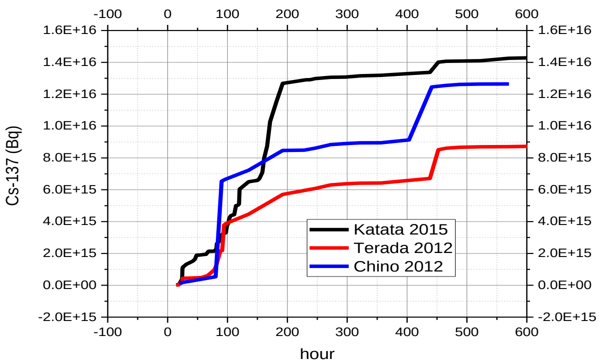


Fig. 1. Cs-137 Release to atmosphere estimated by SPEEDI by Chino (2012), Terada (2012), and Katata (2015)

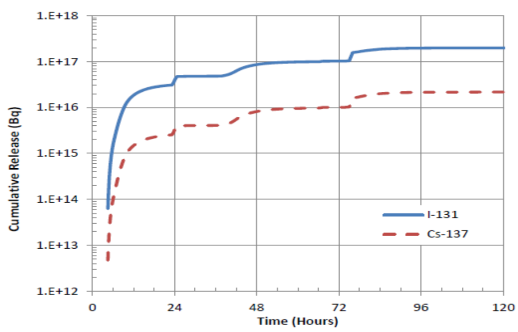


Fig. 2. RASCAL 4 estimate of the cumulative I-131 and Cs-137 release for the Fukushima Accident [5]

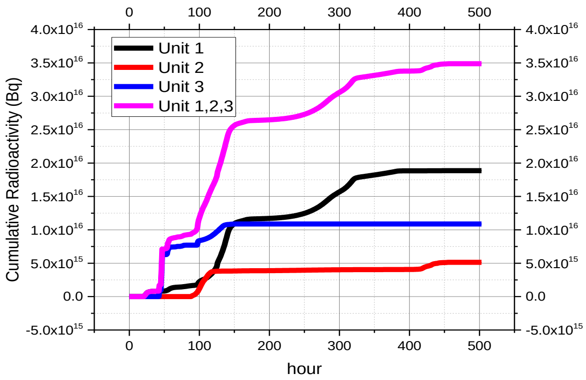


Fig. 3. Cumulative Released Activity (PBq) of CS137 from Fukushima Units 1, 2 and 3 estimated by MELCOR code by T.W.Kim et al at BSAF Project Phase II [9]

It is estimated that 9, 13, 14, 22 and 35 PBq of Cs-137 is released to the atmosphere from the Fukushima accident. These numbers are the same as reported in UNSCEAR 2013 report [7] in the range of 9 to 36 PBq. Therefore it can be concluded that SPEEDI, RASCAL and MELCOR estimates on Cs-137 release in Fukushima accident looks reasonable. It can be also concluded that the development of similar programs and computing tools are necessary in Korea.

## 4. Conclusions

It is reviewed in this paper that there are many technical issues which should be reviewed in preparing and responding to real emergency situations of nuclear power plant. One of them is to prepare software to predict of source term in fast and accurately. The second one is to simulate of the potential radiation release accident to environment and to provide training of the severe accidents based on the simulation results.

## ACKNOWLEDGEMENT

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