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An Analysis on Risk of Nuclear Materials and Threat of Domestic Nuclear Terrorism

Yeo Ryeong Jeon [a], Yongmin Kim [a], Sunyoung Chang [b*]
[a] *Department of Radiological Science, Catholic University of Daegu., 13-13 Hayang-ro, Gyeongsan-si, Gyeongsangbuk-do,38430, Republic of Korea*
[b] *Korea Institute of Nuclear Nonproliferation and Control., 1534 Yuseong-daero, Yuseong-gu, Daejeon,34054, Republic of Korea*
[*] *Corresponding author: sychang@kinac.re.kr*

1. Introduction

In 2011, the International Atomic Energy Agency (IAEA) issued recommendations on the security of nuclear or radioactive materials that are out of regulation control, and demonstrated guidance on nuclear or radioactive material that has been abandoned, lost, missing, stolen but not reported, or discovered by any means [1]. Recently, there has been a growing interest in nuclear safety accidents and assurance related to spent nuclear fuel processing. In the case of domestic nuclear power plant incidents, all cases are caused by a natural disaster such as an earthquake or technical problems, not out of regulation. As reported IAEA, events involving HEU (High Enriched Uranium) and LEU (Low Enriched Uranium) are sufficient to cause serious effects [2], the malicious use of regulated radioactive materials will have serious implications for many aspects, including health, social, economic and environmental aspects, etc. Therefore, it is necessary to build up a nuclear security system by assessing the risks to prevent nuclear security events in advance.

2. Risk of nuclear and radioactive materials

2.1 Riskiness of nuclear and radioactive materials [3]

2.1.1 Nuclear fuel material

Among the nuclear fuel materials, Uranium-235 only 0.7% present in natural uranium, so it is mainly enriched and used as fuel. Uranium-235 emits much higher gamma energy than Uranium-234 and Uranium-238. If it is inhaled into the body, it will be chemically toxic. And it causes kidney damage. Also, if it is deposited in bone, it caused cancer. This process is the same for all uranium isotopes. When it is a compound, this is not related to the ratio of other isotopes. Therefore, the risk for HEU and LEU is essentially the same. Assuming that 100,000 people are consistently exposed to Uranium-235 with an initial concentration of 1 pCi/g in thick soil, 3 of 100,000 people are expected to cause fatal cancer.

Generally, Plutonium-239 is found in spent nuclear fuel with Uranium-235 and can be used as a nuclear weapon. The half-life is very long (24,110 years). Plutonium dioxide (an oxide of plutonium) is a stable compound that can stay in the lung for a long time and be transported to other parts of the body through the blood. However, it is not absorbed during the passage through the digestive system. So, Plutonium-232 was classified as a high-risk substance.

2.1.2 Radioactive material

Some of the radioactive materials that can be used for RDD are Cobalt-60, Cesium-137, and Iridium-192.

According to US DOE (Department of Energy), Cobalt-60 is one of the most concerned isotopes in terms of environmental management. It is necessary to pay attention to external exposure because it emits two strong gamma rays (1.17, 1.33 MeV). Assuming that 100,000 people are consistently exposed to Cesium-137 with an initial concentration of 1 pCi/g in thick soil, 6 of 100,000 people are expected to cause fatal cancer.

When Cesium enters the body, it behaves like potassium and is evenly distributed throughout the body and excreted quickly. In the case of Cesium-137, the decay product, Barium-137m is collapsed with beta-particles. It has a short half-life (about 2.6 minutes) and emits gamma rays. So, all attention to internal and external exposure is necessary. Assuming that 100,000 people are consistently exposed to Cesium-137 with an initial concentration of 1 pCi/g in thick soil, 6 of 100,000 people are expected to cause fatal cancer.

Finally, among the isotopes of iridium, Iridium-192 is the most concerned isotope based on potential of utilization. It can be used in various fields including medical and industrial fields, and the possibility of loss and stealing may be higher than other nuclides. There is also the risk of external exposure due to strong gamma radiation (0.82 MeV), and as with cesium, it can be absorbed into the body by most ingestion routes. After entering the body, most of it is not absorbed into the blood and is mostly emitted by breathing. Remaining iridium is predominantly deposited in the liver and causes internal exposure.

2.2 Device of using nuclear and radioactive material can be used nuclear security events [3, 4]

RDD (Radiological Dispersal Device) does not result in relatively large doses, but it could be a weapon that can destabilize the local community and can passively distribute radioactivity, such as by hand using this device. The radionuclides used for the manufacture include radioactive waste and various radionuclides such as Cobalt-60, Cesium-137, Iridium-192, Americium-241, Caliphonium-252, Plutonium-238, Radium-226, Strontium-90. High-activity wastes (e.g., from nuclear energy reactors) are well controlled, and the largest volumes of radioactive waste typically contain relatively low concentrations, so these materials are generally considered a secondary concern for RDDs. An alternative device that can be used, RED (Radiation Exposure Device) is just like a leaving radiation source in public place to expose people passing around the device.

IND (Improvised Nuclear Device) is manufactured from nuclear fissile materials such as nuclear fuel materials. It is continuing the fission chain reaction. Nuclear terrorism using IND is a potentially viable scenario. Even on a small scale, IND terrorism could be tremendous consequences and effects of released fissile material for a long time.

3. Case of possible nuclear threat in domestic

In the case of illegal nuclear material trade for the manufacture of IND, there is a possibility of acquiring nuclear material in countries such as Russia and Pakistan, considering security or political vulnerability. Also, there is the possibility of attack by terrorist groups such as North Korea and Islamic militant group in political diplomatic part [5]. However, in the home country where there is experience of participating and holding nuclear security summit meetings and efforts to strengthen nuclear security, it may not be a scenario in which domestic threat groups might be considered to be implemented. A second possible scenario is the possibility of theft or spill of spent nuclear fuel on nuclear fuel cycle facilities where may cause radioactive contamination in the surrounding area. However, the highest probability when considering the level of security and the status of facilities in possession is to steal materials such as cobalt, cesium and iridium, which are relatively easy to obtain, to make RDD and use it to terrorize.

4. IAEA risk assessment method to prevent nuclear security events [6]

In order to assess the risk of nuclear security incidents using the aforementioned nuclear materials, the methodology was presented in IAEA Nuclear Security Series No. 24-G. It constructs event scenario using event tree, fault tree and decision tree, and evaluates the risk by approaching with probabilistic evaluation method.

In Figure 1, we have selected two hostile groups (Adversary A, Adversary B) and considered two types of materials (Nuclear fuel material, Other radioactive material) that they can acquire and some types of devices (IND, RDD, RED) that can be made using them. It also consisted of four targets (Capital city, Tourist City, Celebration, Food/Water) that can be affected by health, economy, environment, and society. In this figure, it is conceivable to combine the possibilities for all path nodes into 48 individual scenarios.

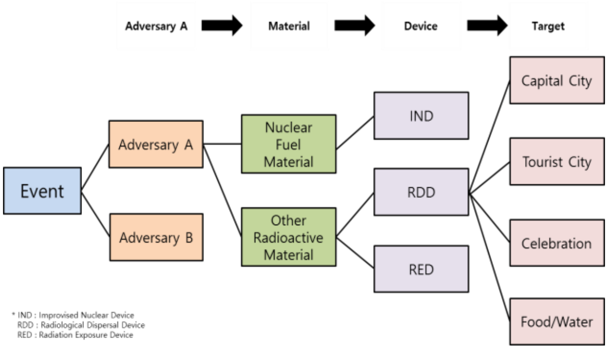
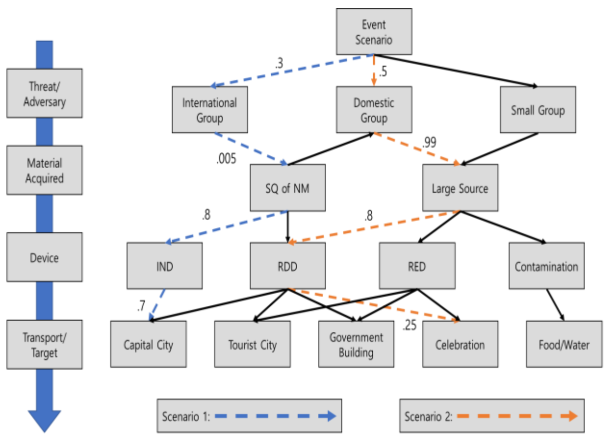


Fig. 1. Example event tree for developing risk scenario



Note: In the example event tree, there are two types of material that may be acquired, a large source (Category 1 source [18]) and a significant quantity of nuclear material (SQ of NM)

Fig. 2. Event tree with two example scenarios highlighted

Figure 2 is an example of constructing an event tree to evaluate the risk of a nuclear security event. The likelihood of an event in a scenario is calculated by multiplying each of the probabilities for the branch points of the tree. Table 1 shows the estimated risk of a nuclear security event in accordance with the scenario of blue dotted line(scenario 1) and orange dotted line(scenario 2).

Table I: Example risk calculations for two scenarios

Scenario 1 : An international group obtain an SQ of NM deploys an IND in the capital city
Likelihood = 0.3 × 0.005 × 0.8 × 0.7 = 0.00084
Scenario risk = 0.00084 × 100 (Normalized consequence rating) = 0.084
Scenario 2 : A domestic group obtains a large radioactive source and deploys and RDD at the celebration
Likelihood = 0.5 × 0.99 × 0.8 × 0.25 = 0.099
Scenario risk = 0.099 × 0.83(Normalized consequence rating) = 0.082

The likelihood of each threat, acquisition material or attack target is relative and uncertain. Each of specific figures should be determined through expert advice or decided on the basis of the results of the pre-implemented threat assessment. Since the likelihood can be specified by the subjective thoughts or prejudices of the experts, it is important to estimate not just the likelihood but uncertainty in the estimated likelihood. Although figure 2 represents a single figure, likelihood should be explained by the distribution.

The 'normalized consequence rating' used in the calculation is the 'value' derived from the threat assessment and reflects the relative severity, such as the number of deaths or social and economic damage. The modification used in derivation is as follow.

$$\text{Value} = \text{Casualties} \times \text{Nominal casualty value} + \text{Economic} + \text{Environmental} + \text{Societal} \quad (1)$$

$$\text{Normalized consequence rating} = 100 \times \text{Value}/\text{Max}(\text{Value}) \quad (2)$$

Comparing the two scenarios, it can be seen almost similar risks.

5. Conclusion

As mentioned above, the nuclear and radioactive materials that can be a threat are diverse, and the risks will vary greatly. If nuclear and radioactive materials used maliciously, it could occur large adverse effects. So, it is necessary to take into account the likelihood and effect of nuclear security events involving these materials. To this end, it can be used for the risk assessment by taking into account the above-mentioned cases of possible threats in domestic and riskiness of nuclear and radioactive materials. For the probabilistic safety assessment, preliminary activities should be carried out, such as assessing threats to identify threat targets, means, and substances as well as assessing the impact of expected nuclear security events, as suggested in main body. Also, the likelihood of the elements constituting the event tree is inherently uncertain, so it should be evaluated.

Risk Informed Regulation, which utilizes the results of probabilistic risk assessment, has been introduced by United States and used actively in the domestic nuclear power plants and nuclear power industry facilities. In order to prevent nuclear security events against nuclear materials in advance, a risk assessment method appropriate to domestic situation is needed.

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