Analysis of the Small Quantity Nuclear Material Transaction Network in the ROK

Seungmin Lee [a, b], Jounghoon Lee [a], and Jae-suk Yang [b*]
[a] *Safeguards Division, Korea Institute of Nuclear Non-Proliferation and Control, Daejeon, 34101*
[b] *Graduate School of Future Strategy, Korea Advanced Institute of Science and Technology, Daejeon, 34141*
[*] *Corresponding author: yang@kaist.ac.kr*

1. Introduction

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) provides the fundamental basis for safeguarding nuclear materials. In compliance with the NPT, the Comprehensive Safeguards Agreement (CSA) was concluded between the International Atomic Energy Agency (IAEA) and the Republic of Korea (ROK) in 1975 [1]. Based on the CSA, the IAEA's safeguards are implemented in all nuclear activities. And the ROK declares the amount and position of whole nuclear material, including small quantity nuclear material (SQNM) which is used in various industries and fields of research.

One kind of SQNM is the shielding material used in radiation non-destructive testing. In the ROK, depleted uranium (DU) is used as a radiation shielding material in steel mills, hospitals, and non-destructive test companies. Another SQNM including uranium or thorium is the spike used for an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) or a Thermal Ionization Mass Spectrometer (TIMS) in the laboratory. The ROK's "Drinking Water Management Act" was amended in 2015 for public safety such that every tap water supplier and drinking water seller have to measure the uranium concentration of their water once a month. It means laboratories using SQNM for analyzing water are increasing rapidly.

The safeguards regulation policy needs to be amended to control the whole SQNM transaction including laboratories for analyzing water as requested by the CSA in the ROK. To date, the Nuclear Safety and Safeguards Commission (NSSC) and the Korea Institute of Nuclear Non-Proliferation and Control (KINAC) have controlled SQNM based on publicity and voluntary reporting by SQNM users. In this paper, we analyze SQNM transaction data over the last 15 years in the ROK using the Network theory. We then suggest reforms to the safeguards policy based on the SQNM transaction Network analysis results.

2. Analysis of the SQNM transaction network and results

2.1 Data collection

KINAC has operated the online system called "The SQNM Reporting System" since 2004 to monitor the transaction of SQNM on the ROK [2]. The SQNM user reports the import, export, movement, consumption, and disposal of SQNM using this online system. For example, the SQNM import company would use the system to report the nucleus, weight, enrichment of nuclear material, the export country, the import date, and so on when they receive the SQNM. When the import company sells the SQNM to a final user, the import company reports the final user name, address, contact and the shipment date. When the final user receives the SQNM from the import company, they use the reporting system to confirm the data, sometimes adding the used/ diluted/consumed the SQNM, or when they exported or returned the SQNM to another country. KINAC inspects the weight, location and so on of nuclear material based on the declaration of the SQNM user.

As of 31 December 2019, 228 SQNM users were registered in "The SQNM Reporting System" with data for 11,801 transactions recorded from 2004 to 2019. Table 1 shows the details according to yearly import, export and domestic shipment.

Table 1. SQNM transaction data (2004-2019)

Year	Import	Domestic shipment	Export	Sum
2004	171		1	172
2005	135	53	4	192
2006	102	91	53	246
2007	303	182	236	721
2008	120	150	23	293
2009	203	235	98	536
2010	308	300	140	748
2011	174	325	69	568
2012	575	980	56	1,611
2013	616	2,170	951	3,737
2014	238	314	350	902
2015	174	257	75	506
2016	97	128	48	273
2017	116	152	60	328
2018	112	213	60	385
2019	210	310	63	583
Total Sum	**3,654**	**5,860**	**2,287**	**11,801**

2.2 Network analysis results

In this paper, we created a network from the SQNM transaction data for each user to a node, and each transaction to an edge. This network was computed using the Gephi open source software [3]. Gephi is a popular network analysis software due to its visualization flexibility and ability to work with various data formats.

From the Gephi, we calculated the Degree distribution of the SQNM transaction network. The resulting network consists of 194 nodes and 841 edges. And the log-log scale plot of the cumulative transaction probability of each SQNM user's transaction exhibits a power-law (Fig. 1).

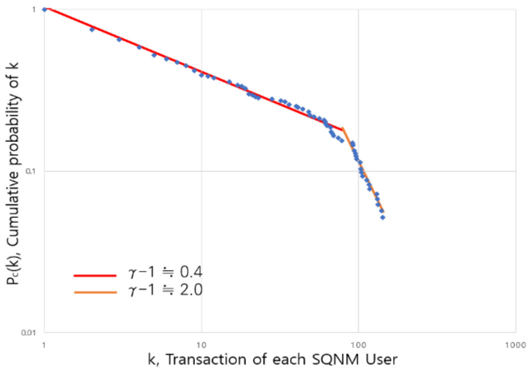

Fig. 1. Cumulative degree distribution $P_c(k)$ for SQNM transaction network. The two straight lines indicate a power-law decay with exponent $\gamma - 1$=0.4 for the red line and $\gamma - 1$=2.0 for the orange line.

This can be explained using the same reasons as preferential attachment presented in the Barabási Albert (BA) model [4]. According to the cited paper, they explained by a preferential attachment mechanism that new nodes tend to link to more connected nodes in the real world. Fig. 1 also shows that a few companies mainly conduct nuclear material import and export transactions. In other words, only a few companies are hubs in the SQNM transaction network.

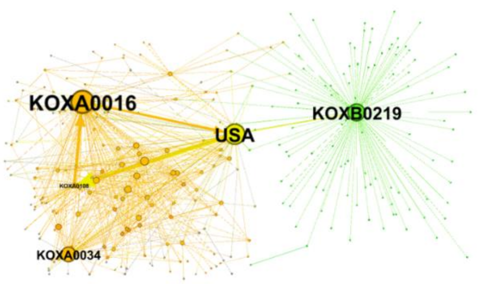

Fig. 2. Network of SQNM transactions (2004-2019)

Fig. 2 shows the image of the SQNM transaction network we obtained from the Gephi analysis. From Fig. 2, we can easily understand that most nuclear materials are imported from the United States. We also see that the SQNM transaction network is divided into two network groups: Green, and Orange. The Green network is the transaction of the spike for ICP-MS and TIMs for analyzing water. The Orange network is the transaction of DU shielding material of such as non-destructive test companies.

In summary, most SQNM are imported from the United States, with only a few companies importing and exporting SQNM. In addition, the spike users tend to buy the spike that contains SQNM from one import company and then use/dilute/consume the spike after receiving it. DU shielding material users also buy the shielding material from a few import companies and return the DU material to import companies for returning to the United States. And since these import companies are hub companies in the SQNM transaction network, they are involved in most domestic and overseas transactions. Transactions by most SQNM users are very few, but the number of transactions by a few SQNM users is very big. In other words, our study confirmed that the transaction of SQNM started from a few companies.

3. Conclusions

Based on the CSA between the ROK and the IAEA, the ROK has to declare the amount and position of nuclear material, including SQNM which is used in various industries and fields of research. But, since these SQNM are exempt from a safety regulatory area, it is difficult to manage whole groups of SQNM and SQNM users for safeguarding reasons. We analyzed these SQNM transactions using the Gephi network analysis software to find a way to reform the safeguards policy. As a result, we found that most transactions of SQNM started from only a few companies such as import and supply companies.

In this respect, the safeguards policy should be amended so that every SQNM import and supply company would have to report the domestic transaction of SQNM to the NSSC and KINAC. The "Nuclear Safety Act" states that the SQNM is subject to safeguarding regulatory agreements, including those of the CSA. However, there is a requirement in the notification that every SQNM import and supply company only report the overseas transaction of nuclear material. Therefore, it is necessary to amend the notification of the NSSC so that SQNM import and supply companies also must report the domestic transaction of nuclear material in addition to the overseas transaction.

REFERENCES

[1] The Agreement of 31 October 1975 between the Republic of Korea and the Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, 1975.

[2] Jeabum Park, Establishment and management of accounting and control system for exempted nuclear material, KINAC/RR-28/2008, 2008.

[3] Bastian, M.; Heymann, S.; Jacomy, M. Gephi: An Open Source Software for Exploring and Manipulating Network. International AAAI Conference on Web and Social Media, North America, March 2009.

[4] Barabási, Albert-László; Bonabeau, Eric. Scale-free Network. Scientific American, 288.5: 60-69., 2003.