Development of Evaluation Methodology for Nuclear R&D Contribution

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1. Introduction

The nuclear safety of Korea can be divided into three areas, basic nuclear safety R&D from the MSIT (Ministry of Science and ICT), regulation and licensing from the NSSC (Nuclear Safety and Security Commission), and nuclear industry from the MOTIE (Ministry of Trade, Industry and Energy). Basic R&D for nuclear safety has mainly been supported by the MSIT for more than 20 years and lots of achievements have qualitatively accomplished, such as the establishment of ATLAS (Advanced Thermal-Hydraulic Test Loop for Accident Simulation), the development of thermo-hydraulic analysis codes, and so on. However, the quantitative analysis between R&D investment and nuclear safety of nuclear power plants (NPPs) has not yet been performed.

Since Fukushima accident in 2011 and GyeongJu earthquake in 2016, the safety of NPPs has been getting more and more attention. Under these circumstances, MSIT has established 'Future R&D strategy for nuclear research' in 2017, focusing on the development of safety technology for nuclear facilities, decommissioning technologies and so on [1]. The role of basic nuclear safety R&D was questionable while setting up this strategy. Therefore, it is necessary to measure quantitatively how to some extent the investment of the basic nuclear R&D contributes to the safety of NPPs. To do this, the basic nuclear safety R&D area was analyzed and identified to evaluate quantitatively its contribution to NPPs.

2. Analysis Methods

2-1. The Analysis of Research and Development Funds

MSIT and NRF have established the comprehensive nuclear energy promotion plan (CNEPP) every 5 years according to the law of nuclear promotion article 9 and also set up the action plan each year based on the national plan. All the action plans has been gathered to analyze the R&D investment of MSIT since 1997. In 1997, six subprograms including nuclear long term program started with the investment of 118 billion won. The annual average R&D investment of MSIT is around 209 billion won, showing the 3.2% growth rate until now [2].

Since then, the name of the program has been changed and some new programs started. Now, ten programs are operated by MSIT (Table 2-1). This paper focuses its R&D on the nuclear safety program as a part of nuclear energy development program.

Table 2-1. MSIT Programs for Nuclear Research

Program	Program period
Nuclear energy development program	1997~2019
Nuclear energy research infrastructure program	1997~2019
Planning & evaluation program for nuclear energy R&D	1997~
Training program for professional human resources of nuclear research	2018~2021
Joint research and development for SMART PPE	2015~2018
Radiation technology development program	1997~2019
Radiation research infrastructure program	2011~
International cooperation program for nuclear energy	1996~
Construction of new research reactor and its utilization facility	2012~2019
Korea heavy ion medical accelerator project	2010~2020
Construction of large scale E-beam irradiation center for corroborative research	2014~2018

MSIT have invested around 4,522 billion won in nuclear R&D since the establishment of the 1st national plan for nuclear research in 1997. Table 2-2 shows that 1,378 billion won was funded by MSIT during the previous 4th national plan and 1,576 billion won will be allocated in the 5th nation plan [3]. MSIT have made an effort to increase the investment of nuclear safety R&D and 157 billion won was invested to nuclear safety program during the 4th national plan, which is 11.4% of total R&D investment. Therefore, the investment pattern to each project within the program and the increase of the TRL (Technology Readiness Level) should be analyzed.

Table 2-2. The investment of MSIT

(Billion won)

The 4th national plan for nuclear research						5th plan
Area	2012	2013	2014	2015	2016	2017~2021
Safety R&D	24	28	31	35	37	245
Total R&D	234	265	292	314	271	1,576

2-2. The Analysis of Element Technologies

MSIT and NRF had operated five committees to establish the 5th national plan for nuclear research in 2016. Nuclear safety committee reviewed and defined 4 major safety areas and 14 detailed element technologies for nuclear safety research (Table 2-3). Researchers related to the defined technologies have evaluated TRL and the utilization of technologies. And then, the end-users of technology and the safety committee had reviewed and reevaluated the increase of TRL and the degree of utilization possibility of each technology if each technology is successfully developed. Also, the committee evaluated the priority of nuclear R&D for each element technology.

Table 2-3. Research Area for Nuclear Safety

Enhancing reliability of operating NPPs	1. Precise evaluation and improvement of nuclear safety 2. Highly reliable monitoring and prediction of NPPs 3. Management of human error and material degradation
Excluding radioactive leak in extreme conditions	4. Development of advanced risk assessment and management technology 5. Development of accident tolerant fuel 6. Isolating technology development of radioactive material from accidents 7. Development of vulnerability analysis for nuclear plant instrument & control
Strengthening the radiation protection system of nuclear facilities	8. Precise evaluation of radiation effects from nuclear facilities 9. Risk assessment and mitigation of radiation accidents 10. Establishment of long-term plan for radioactive contamination after accident
Common technology for the improvement of nuclear safety	11. Development of strengthening seismic technology 12. Fire protection technology of nuclear facility 13. Development of new material for improving the safety 14. Development of intrinsic safety analysis code

2-3. The Analysis of Preceding Research

Many factors can be considered to investigate the relationship between the investment and its result [4]. Firstly, the SCI and patent have been mainly analyzed. The quantitative achievements of papers and patents in nuclear R&D are shown to be relatively lower than other R&D fields [5]. According to the policy report, TRL and technology utilization are shown to be significantly more meaningful to the contribution of nuclear safety through AHP (Analytic Hierarchy Process) analysis than the SCI and patent [6]. Also, the report suggests that there be positive relationship between R&D investment and accident rate of nuclear facilities.

3. Methodology development

Through preceding research and peer review, R&D investment ratio by each governmental department, importance of nuclear policy, TRL and technology utilization can be considered to develop the safety contribution factors as follows. These factors have been articulated through peer review of safety committee.

$$\text{safety index}(\%) = \frac{w_i \times 0.6 + I_i \times 0.4}{2} \times \Delta TRL_i \times u_i \times 100$$

$$w_i = \text{Each technology investment}_i \Big/ \sum (\text{Each technology investment}_i)$$

I_i = Importance of nuclear policy

ΔTRL_i = TRL increase of each technology in 5 years

u_i = the degree of utilization possibility of each technology

This safety index is composed of 4 factors, the R&D investment of an element technology (w_i), importance of nuclear policy (I_i), the increase of TRL in each technology (ΔTRL_i) and the degree of utilization possibility of each technology (u_i). The first three factors were evaluated by nuclear experts, while the investment of R&D was quantitatively calculated. w_i and I_i mean the priorities of technologies and the national policy and act as scaling factors. ΔTRL_i and u_i. show the contribution of technology to nuclear safety.

4. Results

Table 3-1 shows the result of safety index for each element technology.

Table 3-1. The Contribution of Element Technology to Nuclear Safety

No.	Element tech	4th	5th
1	Precise evaluation and improvement of nuclear safety	0.57	0.61
2	Highly reliable monitoring and prediction of NP	0.87	0.81
3	Management of human error and material degradation	0.73	0.46
4	Development of advanced risk assessment and management technology	1.39	1.55
5	Development of accident tolerant fuel	0.93	0.70
6	Isolating technology development of radioactive material from accidents	0.69	0.46
7	Development of vulnerability analysis for nuclear plant instrument & control	0.00	0.00
8	Precise evaluation of radiation effects from nuclear facilities	0.00	0.00
9	Risk assessment and mitigation of radiation accidents	0.00	0.47
10	Establishment of long-term plan for radioactive contamination after accident	0.12	0.00
11	Development of strengthening seismic technology	0.97	1.14
12	Fire protection technology of nuclear facility	0.62	0.67
13	Development of new material for improving the safety	0.26	0.22
14	Development of intrinsic safety analysis code	0.86	0.86

The result shows that development of advanced risk assessment and management technology (No.4) contributes highly to the safety of nuclear facilities. This technology is related to development of advanced multi-unit risk assessment technologies and development of a Level 3 PSA code that can manage the Korean specific site & environmental effects. In contrast, it shows that the development technology of vulnerability analysis for nuclear plant instrument & control (No. 7) and precise evaluation of radiation effects at nuclear facilities (No. 8) are the lowest contribution to the safety. The reason is that MSIT has relatively little invest in these technology compared to MOTIE and NSSC.

Fig. 1 shows that R&D funding of MSIT for last 5 years was shown to totally contribute to 8.02% NPPs safety when safety index of element technology is added. Furthermore, it is expected to 7.94% contribution to nuclear safety through the upcoming 5 years of R&D investment. Particularly, the R&D investment of excluding radioactive leak to extreme conditions has largely contributed to the safety of nuclear power plants. On the other hand, the technology of radiation protection of nuclear facilities has relatively a little effect on the safety and still needs to be more funded. It is expected that the safety contribution index is getting smaller because technology utilization would increase to a saturation point by each year.

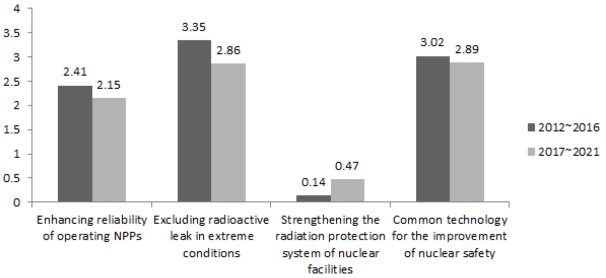

Fig. 1. Safety contribution (past 5 years and future 5 years) of each technology to NPPs

5. Conclusions and suggestions

The quantitative contribution methodology developed in this study shows that basic R&D results from the MSIT have considerably contribute to its final end-users (i.e. the NSSC and the MOTIE) for last five years. Therefore, the safety R&D of the MSIT can be justified in the light of the governmental investment and its role. It is meaningful that the safety contribution factors have drawed and the R&D investment was analyzed by several factors. However, the quite simple methodology were used in this study and therefore, more accurate and elaborate calibration efforts should be pursued.

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