Classification of Nuclear Fuel Cycle-Related R&D Activities using Content Validity Verification

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1. Introduction

Nuclear safeguards are measures that have been in place since the advent of the atomic age to ensure that nuclear materials and technology are only used for peaceful purposes. To this end, nuclear safeguards inspections are conducted regularly by the International Atomic Energy Agency (IAEA) at nuclear facilities in member states worldwide that are signatories of the Treaty on the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty, NPT). Under the NPT, countries that do not have nuclear weapons signed to the treaty must enter into force the Comprehensive Safeguards Agreements (CSA) with the IAEA. Under the CSA, the IAEA has the right and obligation to ensure that all nuclear activities of member states are used only for peaceful purposes.

The IAEA adopted the additional protocol (AP) in 1997 to strengthen the existing safeguards measures system [1]. In order to verify the overall nuclear activities of member states, the AP requires member states to provide information on the nuclear fuel cycle-related research and development (R&D) activities to the IAEA and allows IAEA inspectors to access the R&D facilities. By enabling the IAEA to obtain a comprehensive view of member states' nuclear programs, plans, material holdings, and trade, the AP enhances the IAEA's ability to assure the absence of undeclared nuclear material and activities in member states. However, in the Republic of Korea, it is often challenging for the Korea Institute for Nuclear Nonproliferation and Control (KINAC), the State authority responsible for safeguards, to identify every domestic nuclear research activity and classify nuclear fuel cycle-related R&D activities.

To address this challenge, the current study applied the content validity verification method proposed by Lawshe (1975) and Lynn (1986) to classify nuclear fuel cycle-related R&D activities among the nuclear energy research activities in the ROK [2], [3]. Research data were collected twice from the National Science & Technology Information Service (NTIS) in 2021 and 2022. In addition, experts in implementing safeguards were recruited in this study to determine the relevance of the nuclear fuel cycle. The values of the content validity index (CVI) and content validity ratio (CVR) were used to verify whether the judgments of the experts were valid.

2. Methods and Results

2.1 Data Collection

The Korea Institute of Science and Technology Information (KISTI) operates the NTIS, a comprehensive information system, to manage all R&D projects funded by the government of the ROK. The NTIS provides users access to information on all national R&D projects funded by every ROK ministry. This study used keywords such as 'nuclear', 'uranium', 'plutonium' and 'thorium' to find nuclear-related R&D projects in the NTIS database. Among the numerous R&D projects found through keyword searches, overlapping and medical-related R&D projects were excluded. Finally, a total of 495 R&D projects conducted in 2020 and 430 R&D projects conducted in 2021 were obtained for analysis.

In addition, in this study, a group of safeguards experts consisting of 30 individuals in 2021 and 35 individuals in 2022 was selected to determine whether the R&D projects are subject to declaration under the AP. The expert groups consisted of safeguards inspectors, researchers, and professors researching safeguards. The experts were instructed, "Please determine whether the research topic is related to the nuclear fuel cycle by examining the title and summary of the R&D projects." The experts were asked to respond on a 5-point Likert scale.

2.2 Methods

Among approximately 400 nuclear-related R&D activities, content validity methods proposed by Lawshe (1975) and Lynn (1986) were used to distinguish the nuclear fuel cycle-related R&D activities.

Lawshe (1975) developed a quantitative measure for assessing content validity referred to as the content validity ratio (CVR), which provides information on item-level validity. In addition, Lawshe (1975) proposed the minimum proportion of experts to be evaluated as 'important or necessary questions' when accidental factors were removed in the content evaluation of the question.

Another quantitative measure proposed by Lynn (1986) is the Content Validity Index (CVI). Lynn (1986) presented the ratio of the minimum number of experts judged to be valid and the standard error of the ratio to quantitatively determine the question's content validity.

The proposed CVI and CVR formula are as follows:

$$\mathrm{CVI} = \frac{n_a}{N}$$

$$\mathrm{CVR} = \frac{n_a - \frac{N}{2}}{\frac{N}{2}}$$

n_a = Number of panel members indicating an item 'essential'
N = Number of panel members

CVR values can range between –1 and +1, and the CVR is equal to or above 0 when at least half of the responding panelists indicated an item as 'essential'. In the case of CVR values, the minimum CVR critical varies depending on the number of panelists because questions may be evaluated as 'essential' by chance. A study by Ayre and Scally (2014) showed the minimum CVR critical required for mobilizing 5 to 40 panelists based on the exact binomial probabilities, which are listed in Table 1 [4].

Table 1. Minimum CVR critical required for 5 to 40 panelists

Number of Panelists	CVR critical	Number of Panelists	CVR critical
5	1.00	20	0.50
6	1.00	25	0.44
7	1.00	30	0.33
10	0.80	35	0.31
15	0.60	40	0.30

The CVI can range from 0 to 1, and the CVI cut-off value should be at least 0.78 when the number of panelists is nine or more.

This study determined whether an R&D project was related to the nuclear fuel cycle based on only the CVR value. In other words, for the 2020 R&D project list, if the CVR value was 0.33 or higher, a project was classified as a nuclear fuel cycle-related R&D activity. If the CVR value was 0.31 or higher for the 2021 R&D project list, a project was classified as a nuclear fuel cycle-related R&D activity.

2.3 Results

Tables 2 and 3 show the results of the content validity verification using CVI and CVR. As mentioned above, because the number of R&D projects is 495 and 430, a table representing all the projects cannot be included in this paper. Therefore, only the ten R&D projects with the highest CVR values and those with the lowest CVR values are summarized in Tables 2 and 3.

Among the 495 R&D projects collected in 2021, safeguards experts determined that 29 projects with CVR values exceeding 0.33 were related to the nuclear fuel cycle. In addition, among 430 R&D projects collected in 2022, 53 projects with a CVR value exceeding 0.31 were judged to be related to the nuclear fuel cycle.

3. Conclusions

This study aimed to distinguish nuclear fuel cycle-related R&D activities among the nuclear-related R&D projects listed by NTIS. To this end, a total of 30 safeguards experts examined R&D activities among 495 projects in 2021, and 35 experts examined R&D activities among 430 projects in 2022. The experts' responses were analyzed using the content validity verification method proposed by Lawshe (1975) and Lynn (1986). As a result, 29 nuclear fuel cycle-related R&D activities in 2021 and 53 activities in 2022 were identified.

This study is significant in that it is based on the opinions of a substantial number of experts, which were used to distinguish nuclear fuel cycle-related R&D activities. In particular, in determining whether or not the nuclear fuel cycle activities were related, the experts evaluated the results of each task by calculating the CVR. Through this, objectivity was secured in implementing safeguards measures and regulations. The findings of this study are expected to enable the ROK to fulfill its obligations under international nuclear commitments. In the future, we aim to identify ways to utilize text mining and machine learning with the results judged by the experts in the current study.

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Table 2. The CVR and CVI results of 495 R&D projects collected in 2021

Rank	Title of nuclear-related R&D projects	CVR	CVI
1	Development of Core Technology for Oxide Reduction Process	0.87	0.93
2	Nuclear Fuel Design for Advanced Research Reactor	0.80	0.90
3	Development of Core Technology for Pyroprocessing Head-End Process	0.80	0.90
4	Nuclear Fuel Cycle Analyses for Transmutation Accelerator Driven System and Small Modular Reactor Utilizing Thorium Fuel	0.73	0.87
5	Feasibility Study of Pyroprocessing and Development of Core Technology for Electrochemical Recovery Process	0.73	0.87
6	Core Analysis and Autonomous Operation Technology Development for Innovative SMART	0.67	0.83
7	Development of Pyroprocessing Core Technology for Safety Improvement	0.67	0.83
8	Development of Core Technology for Pyroprocessing Waste Treatment	0.67	0.83
9	Mechanical Element Technology Development For Major Equipment of Innovative SMART	0.60	0.80
10	System Element Technology Development for Innovative SMART	0.60	0.80
…	…	…	…
486	Development of the plasma detonation technology for exploring resource	-1.00	0.00
487	Atomistic design of functional materials	-1.00	0.00
488	Development of defectless chain-based 2D materials and their devices	-1.00	0.00
489	Study on Computational Design of Metal Nanoparticle Based Meta-atom for Improving the Performance of Plasmonic Metamaterial	-1.00	0.00
490	Study on Optical properties of anisotropic SnS by spectroscopic ellipsometry	-1.00	0.00
491	Synthesis of NP-doped organic semiconductor molecules	-1.00	0.00
492	Innovative nanomaterials and nanodevices	-1.00	0.00
493	Novel synthesis of 'Unit Layer Zeolite' and application to gas-phase dimethyl ether carbonylation	-1.00	0.00
494	Development of quantitative imaging profiles for standardized evaluation in digital tomosynthesis system	-1.00	0.00
495	New-Functional Emerging Semiconductor Nano-Architectures	-1.00	0.00

Table 3. The CVR and CVI results of 430 R&D projects collected in 2022

Rank	Title of nuclear-related R&D projects	CVR	CVI
1	Development of Advanced SMR Fuel and Core Concept with Long Fuel Cycle	0.83	0.91
2	New Selective Extraction Process of Heat-dominating, Highly Mobile, and Long-lived Fission Products for Safe Disposal of Used Nuclear Fuel	0.77	0.89
3	Key Technology Development of the Natural Circulation Long-life Molten Salt Fast Reactor Using Low-Enriched Uranium	0.77	0.89
4	Nuclear Fuel Design for New Research Reactor	0.77	0.89
5	Development of fundamental technology for performance evaluation of liquid nuclear fuel in molten salt reactor	0.77	0.89
6	Innovative Super-Deep-Burn Transmutation of PWR TRU Wastes in CANDU Reactor	0.71	0.86
7	Reactor Core Design for New Research Reactor	0.71	0.86
8	A Study on Liquid Fuel-Driven Nuclear Heat Supply Module and Nuclear Species Behavior	0.66	0.83
9	Development of Key Technologies for Conceptual Design of Non-refueling Full-life Micro Reactor for Marine Applications	0.66	0.83
10	Key Technology Development of the Innovative Multi-purpose Natural Circulating Small Modular Molten Salt Fast Reactor Thermal-hydraulic and Passive Safety Systems	0.66	0.83
…	…	…	…
421	Study on Coupling and Propagation of Lower Hybrid Fast Wave on Versatile Experiment Spherical Torus	-0.94	0.03
422	Study on the Biological Effect of Low-dose Radiation Exposure by Radiation Physics Analysis and Experimental Observations: from a Standpoint of Re-evaluating the Linear No-Threshold Model	-0.94	0.03
423	Development of CO-reducing, highly efficiency, and highly reliable nanocatlayst materials scale-up production technology for the production of high purity hydrogen for low temperature fuel cell	-0.94	0.03
424	Development of iron compound catalysts and electrode for platinum alternatives with high detection sensitivity in hydrogen fuel cell	-0.94	0.03
425	Development of radiation-induced photoimmunotherapy using antibody-europium-photosensitizer complex	-0.94	0.03
426	Development of medical imaging system through photon conversion research with gamma-ray emission under the Positronium(Ps) state of captured electron-positron pairs	-0.94	0.03
427	A study on hosting international meetings for strengthening nuclear technical cooperation	-0.94	0.03
428	A study on improving strategic roll of R&D financial support program for nuclear basic research and human resource development	-0.94	0.03
429	Development of Nanostructure Analysis Technique with Mixed Use of the Small Angle Neutron and X-ray Scattering	-0.94	0.03
430	Establishment of Radiation Response Modeling Platform	-1.00	0.00