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Consideration of the Impact of COVID-19 Crises on Radiation Safety: Focus on Regulatory Systems and Related Activities

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ABSTRACT

Background: The radiation safety regulation system, characterized by its critical and domestically tailored features, encountered unexpected challenges due to coronavirus disease 2019 (COVID-19). Accordingly, each country implemented diverse measures to ensure the continuous efficacy of its regulatory system. This study investigates the responses of five institutions concerning radiation safety, collecting data aiming to enhance preparedness through systematic procedure.

Materials and Methods: The data were extracted from official documents or websites of respective regulatory bodies (RBs) that discussed their responses to the radiation safety regulation system from COVID-19. From this data, it was observed that each country responded uniquely based on its specific conditions.

Results and Discussion: Due to the repercussions of COVID-19, the regulatory system faced challenges, particularly regarding on-site inspections. In response, many countries published COVID-19 annual reports, with a few set up dedicated websites addressing its impact on the radiation regulatory frameworks. This data observed the distinct and situation-specific approaches adopted by each country in response to the pandemic. Notably, several nations introduced digital technologies into their regulations, including remote systems and online methods, while also customizing their regulatory systems according to respective circumstances.

Conclusion: A variety of responses from the national RB regarding the radiation safety regulation system after the outbreak of COVID-19 highlight the importance of crisis preparedness and indicate that the current regulatory system could be enhanced.

Keywords: Regulatory Body, Radiation Safety Regulation System, COVID-19, Pandemic, Remote System

Review

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Introduction

The radiation safety regulation system is a critical component that must operate even during inevitable crises to ensure the safe handling of radiation. Each country's regulatory body (RB) operates a system tailored to its national conditions, often employing diverse methods. For instance, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), an Australian RB, utilizes a methodology that establishes regulatory priorities (RPs) for facilities and radiation sources to determine minimum inspection frequencies [1]. In the USA, the Agreement State and federal agencies, such as the

Environmental Protection Agency and the Food and Drug Administration, share responsibility for radiation protection, with a primary focus on the USA's RB, Nuclear Regulatory Commission [2]. Consequently, radiation safety regulation systems function differently depending on each country's unique characteristics.

However, the unexpected outbreak of the coronavirus disease 2019 (COVID-19) pandemic has had far-reaching consequences for countries worldwide, leading to widespread restrictions to combat this virulent coronavirus disease. The radiation safety regulation system was not exempt from its impact, although not in direct physical ways [3–5]. Instead, the pandemic significantly affected the safety management procedures in the system. With the implementation of social distancing measures to prevent virus transmission, the radiation safety regulation system, which relies heavily on on-site activities, faced challenges. In response to COVID-19, the International Atomic Energy Agency (IAEA) provided extensive support to numerous countries, offering technical guidance, webinars, and safety equipment [6]. In 2020, the IAEA conducted a survey and an online meeting to gather feedback on the challenges faced by each RB due to the pandemic [4].

Interestingly, despite previous infectious disease outbreaks such as severe acute respiratory syndrome (SARS) in 2003, Middle East respiratory syndrome (MERS) in 2012, and COVID-19 in 2019, it appears that some countries had not adequately prepared manuals or contingency plans for handling pandemic situations. In contrast, Canada, having experienced the SARS outbreak, developed robust business contingency plans for the nuclear sector, enabling its RB to maintain regulatory operations during the COVID-19 crisis [7]. Hence, the importance of formulating systematic procedures tailored to each country's conditions becomes evident, ensuring that the radiation safety regulation system can function as normally as possible during emergencies like COVID-19 [4]. Objective comprehension of each country's situation and the establishment of a foundation for introducing new regulatory measures are crucial in preparing these systematic procedures.

The objective of this study is to compile fundamental data to assist each RB in preparing its radiation safety regulation system to tackle crises effectively. To achieve this, the regulatory responses of several institutions, including the IAEA and RBs in Repulic of Korea, Canada, Australia, and France were investigated through their annual reports, official websites, and relevant documents.

Materials and Methods

To assess the impact of COVID-19 on radiation safety related activities and regulation systems, including Republic of Korea, data were collected and compared from 2019 to the recent year 2023. First of all, the initial response of national RBs to COVID-19 was identified using the survey report published by the IAEA in 2020 [4]. A total of 127 countries provided feedback on the impact of COVID-19, with 123 countries responding to questions specifically related to the influence of the pandemic on RBs. The survey respondents covered a wide geographic distribution, including 27 RBs from the Americas, 37 RBs from Europe, 33 RBs from Africa, and 26 RBs from Asia-Pacific region.

Information about Republic of Korea's radiation safety regulation system was obtained from the "Radiation Safety Information System (RASIS)" website, which is dedicated to radiation safety management [8]. Additionally, the nuclear safety yearbooks published from 2020 to 2023 were referenced for comprehensive content related to radiation and nuclear safety, including the latest developments in this domain [5, 9].

Several countries, following the onset of the COVID-19 pandemic, established special websites or dedicated sections to document their response in the field of radiation or nuclear safety. For example, the Canadian RB created the "Canadian Nuclear Safety Commission (CNSC)'s response to COVID-19 [7]" webpage, which records monthly responses to the pandemic. This webpage contains records from March 2020 to December 2020, with additional updates in November 2021.

Many countries publish annual reports encompassing the themes of radiation protection and nuclear safety. Some countries such as Canada and France, have designated COVID-19 as a keyword in these reports and have provided insights into its impact and RB's responses. In addition, the Australian RB further enhanced transparency by preparing both quarterly and annual reports, documenting on-site inspection progress, and comparing the results with the pre-COVID outbreak. These annual reports, which were also available before the pandemic, have been serving as an effective means of sharing current conditions and best practices.

Results and Discussion

1. IAEA's Comprehensive Approach: Adapting to the COVID-19 Situation in Radiation Safety

The IAEA responded proactively to the challenges posed

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by the COVID-19 pandemic by implementing effective safeguards and alternative measures. They developed revised guidelines and measures to mitigate COVID-19's impact on radiation safeguard activities. The alterations to various guidelines included radiation safety standards and nuclear security guidance [6]. As part of these measures, RB staff were directed to work at home, except for critical staff members. Additionally, conferences, meetings, or workshops were either suspended or conducted online [4, 7, 9].

In this respect, the IAEA undertook several additional tasks. Firstly, the agency hosted a meeting that allowed participation from diverse countries. The purpose was to ensure continued information and experience exchange during the pandemic. For instance, the Emergency Preparedness and Response Standards Committee (EPReSC) meeting was organized so that organizations could share lessons they learned during the pandemic [6]. Secondly, the IAEA developed a technical report [10], which recommended that RBs prepare systematic measures that are suitable for specific situations. In addition, the agency published a document that outlined effective ways to implement regulatory inspection during the pandemic. Lastly, the IAEA surveyed each radiation safety regulator to assess the repercussions of the COVID-19 pandemic on the radiation safety regulation system [6, 11].

In the IAEA survey [4], 97 out of 123 (79%) countries responded that their regulatory activities had been affected by COVID-19. Moreover, 85 out of 123 (69%) countries were not able to fully implement their regulatory programs during the pandemic. These results highlight the need for preparation and planning to ensure the availability of radiation protection technical services [4].

Each RB attempted to respond to restrictions on radiation-related activities due to the pandemic in its own way. Among them, several common methods were adopted by many RBs to overcome these limitations. Typically, RBs revised their schedules to reduce the number of staff members working on-site and established streamlined online systems to enable remote work and efficient communication from their homes. These remote systems included information and communication technologies, and some countries utilized information technology tools to facilitate information exchange. Some RBs also provided regulatory relief or deviations from legal regulation in certain circumstances [4].

The ability to assess the response to the COVID-19 situation also varied by country. For example, while one RB continued inspections solely for medical facilities, others postponed the inspection of such facilities to alleviate demands on resources against COVID-19. This severity of the disease also prompted various changes in the inspection format. During the pandemic, inspections were conducted through document reviews or by utilizing remote systems, and novel graded approaches were adopted. This approach allowed RB to prioritize the inspection of critical infrastructure such as medical centers, amidst the challenges posed by the pandemic [4].

The feedback from this IAEA survey feedback is particularly meaningful as it allows for a comprehensive examination of the initial responses of RBs worldwide after COVID-19. Although the pandemic was initially perceived as an ongoing crisis, several RBs took advantage of the opportunity to develop advanced inspection techniques or strengthen radiation regulation legislation. These advancements were not limited to emergency responses but could also be utilized for effective routine inspections even after the pandemic subsides [4].

2. Present Condition in the Radiation Safety Regulation System of Republic of Korea

Korea's regular inspection period is classified as 1, 3, and 5 years, depending on the type and riskiness of its radiation facility [12]. These inspections are conducted using either an on-site inspection or a documentary examination method, with the latter based on the self-inspection report's results [9]. Facilities with a 1-year inspection period that demonstrate a high level of self-management safety over the past years can be exempted from regular inspections [13]. However, facilities facing safety management issues may be subjected to unexpected on-site or frequent inspections [9].

Since 2020, the COVID-19 pandemic and social distancing measures have significantly impacted the regular inspection of radiation facilities in Republic of Korea, mainly due to the high proportion of on-site inspections. In 2019, before the pandemic, 330 out of 555 (59%) inspections were planned and implemented with an on-site method. In the same year, documentary examination and exemption of inspection were planned and implemented with 18% and 23%, respectively [14].

In the 2020 schedule of regular inspection, only the changes in the start time of the on-site inspection were considered, with the provisional delay due to the COVID-19 pandemic. The inspection targets remained unchanged. However, in May 2020, a few facilities, such as medical facilities sensitive to the virus, were granted exemptions or postponements

Table 1. Comparison of the Planned and Actual Number of Regular Inspections in Republic of Korea (2020)

2020 Total institutions subject to regular inspection (n=635)	No. (%)
Plan	
On-site inspection	289 (45.5)
Documentary examination	213 (33.5)
Exemption of inspection	
Licensed users	125 (19.7)
Business agents	8 (1.3)
Actual	
On-site inspection	167 (26.3)
Contactless inspection	60 (9.4)
Postponement of inspection	62 (9.8)
Documentary examination	213 (33.5)
Exemption of inspection	
Licensed users	125 (19.7)
Business agents	8 (1.3)

from inspection due to the spread of COVID-19. Table 1 shows the number of planned and actual inspections in 2020, which demonstrates the decrease in the on-site inspection ratio, unlike the original plan [9, 15]. Compared to the 2019 ratio of on-site inspections, the 2020 on-site inspection rate decreased by 33.2 percentage point from 59.5% to 26.3%. This shows that the proportion of on-site inspections significantly decreased due to the impact of COVID-19.

In response to the prolonged COVID-19 situation, the Korea Institute of Nuclear Safety (KINS), the Korean RB, prepared a new outline for the 2021 regular inspection. The revised schedule took into account the lessons from the 2020 regular inspection and ongoing social distancing measures. Anticipating constraints on the on-site situation, KINS established a plan to prioritize improved documentary examinations from the beginning of the year [5].

Previously, the documentary examination for regular inspection only required a self-inspection report. However, the new documentary examination in 2021 was improved to include a radiation source management inspection report and a facility site video [16]. Notably, in addition to facilities with 3-year or 5-year inspection periods, those that received exemptions or postponements in the previous year among facilities with a 1-year inspection period were also included in the 2021 documentary examination target [5, 16].

In addition, KINS introduced a new "contactless inspection" method. This contactless inspection follows the same process as the revised documentary examination in 2021, but the target of the inspection is different. Some facilities with a 1-year inspection period and those that received exemptions from regular inspections are required to submit a self-inspection report, a radiation source management inspection report, and a facility site video for contactless inspection [17]. Facilities with a 1-year inspection period are considered high-risk, and originally, those receiving exemptions were to undergo on-site inspections that year. However, in 2021, some on-site inspections were replaced with contactless inspections due to COVID-19 social distancing measures.

As the COVID-19 situation improved, many conferences and meetings resumed in person [18]. Furthermore, in 2023, the Korean RB launched a new type of inspection called "remote inspection," and some facilities were inspected using this method. The remote inspection is a form of remote inspection that utilizes video conferencing platforms like ZOOM (Zoom Video Communications). Similar to other inspections, licensees are required to submit requested documents, and the inspectors can ask questions or require them to observe the facility in person [8]. While only a few facilities were inspected using the remote inspection in 2023, if it proves feasible, there is potential for an increase in the use of this type of inspection.

Despite the absence of new technology introductions or a complete overhaul of the regulatory methods since COVID-19, the Korean regulatory system demonstrated flexibility by adapting to its unique characteristics and field conditions during this period. Notably, the postponement of regular inspections for medical facilities directly treating COVID-19 patients exemplifies this adaptability. In order to ensure the safety of KINS employees during the pandemic, they adopted a shift-based work-from-home approach. The use of digital systems, including video or pictures, was also employed in inspection to maintain the quality of regulation [8, 9].

The steady progress in developing the radiation safety regulation system represented the outcome of "remote inspection" and demonstrated the clear commitment of KINS to continuously improving the system. These ongoing efforts by the Korean RB showcase their understanding of the overall conditions within facilities handling radiation sources and their determination to strengthen domestic radiation safety regulation methods for the future as well as for the pandemic situation.

3. Present Condition in the Radiation Safety Regulation System of Canada

After SARS swept through Canada in 2003, the CNSC, a

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Canadian RB, took proactive measures to prepare for potential disruptions to normal operations. These preparations enabled them to respond effectively to the COVID-19 pandemic. Licensees in Canada gained valuable experience and established "what-if" plans to anticipate various scenarios, along with ensuring sufficient personal protective equipment. CNSC staff members also focused on critical facilities or activities, even during abnormal situations, by adhering to strong and rigorous regulatory guidelines to maintain a safe radiation environment. During the height of the COVID-19 pandemic, on-site inspections were halted from March 16 to May 4 [7]. However, Canadian RB developed an alternative inspection protocol to resume inspections. As the pandemic receded, CNSC has made ongoing efforts to improve inspection processes by researching a hybrid approach involving both on-site and remote inspection by undertaking a self-assessment of the inspection process [19, 20]. This continuous research and adaptation demonstrate the commitment of CNSC to ensuring effective regulatory oversight and safety in the post-COVID-19 era.

As the first case of community transmission of COVID-19 in Canada occurred in March 2020, CNSC responded immediately with plans to address the pandemic's impact. In line with efforts to reduce social contact, CNSC activated only its critical staff from March 16 of that year to ensure effective regulatory oversight, while others were directed to stay home. Throughout April and May 2020, CNSC continued its comprehensive responses to the COVID-19 pandemic [7].

To accommodate the challenges posed by COVID-19, CNSC established an internal communication infrastructure to facilitate convenience for staff members working at home. Simultaneously, measures were taken to provide convenience and support to licensees across Canada. CNSC introduced the "new e-consultation platform [21]" to offer fast and accurate feedback on regulatory documents to licensees, ensuring streamlined communication. In addition, CNSC prioritized facilities that provided essential services to society, such as hospitals, radioisotope producers, and sterilization facilities. These essential facilities received priority attention to ensure their needs were met during the pandemic. For other facilities, CNSC implemented flexible regulatory approaches to ease the oversight burden. New guidance for on-site inspections was also tailored on a case-by-case basis to meet specific challenges [7, 19].

During the pandemic, several conferences and commissions in Canada were postponed. To adapt to the situation, CNSC hosted its first virtual conference in June 2020, utilizing webcast technology. Recognizing the significance of multilateral collaboration, CNSC actively sought information from 19 member countries and engaged in an exchange of pandemic response strategies. In its role as the chairman of the IAEA's Commission on Safety Standards, CNSC actively participated in meetings and delivered presentations to share experiences in transitioning back to the normal workplace [7]. These conferences and workshops continued, and in 2020–2021, CNSC and the Nuclear Energy Agency jointly hosted a virtual workshop on innovative regulation [19]. These initiatives aimed to foster continuous learning and cooperation during the pandemic, ensuring the advancement of nuclear safety and regulatory practices.

Canada's effective response to the pandemic included active use of digital tools and cooperation with other organizations. CNSC took advantage of various digital platforms to provide technical information to licensees and promptly answer users' questions through various social media. Moreover, since 2018, both RB and licensees have been actively making reports to disseminate radiation regulatory information to the public by uploading it to the CNSC website. This commitment to transparency continued to grow in 2020 and 2021, with even more accessible information (994 information inquiries were responded to and 2,621 posts were uploaded on social media) provided through the CNSC website [7] and "Open Science and Data Portal" [22]. Physical distancing measures limited movement between regions, prompting CNSC to adopt a collaborative approach with regional colleagues residing in specific areas. For instance, CNSC offered virtual training sessions on environmental sample collection processes to regional colleagues, supporting ongoing environmental monitoring during the pandemic [19].

As time passed since the COVID-19 outbreak, CNSC continued to support managing the member network and reinforcing the integrated communication system, ensuring smooth discussions among the staff members. To further improve the staff's working environment, RB launched the "Reimagine the Workplace Initiative (RWI)" under its working guidelines [20]. Throughout this uncertain period, Canadian RB also faced regulatory oversight challenges but consistently sought innovative solutions to ensure accessibility. The experiences gained during this time will contribute to future development and improvement of Canada's regulatory system.

4. Present Condition in the Radiation Safety Regulation System of Australia

The ARPANSA is one of the RBs that classifies the RP of radiation facilities and radiation sources using detailed criteria. This criterion helps evaluate the hazard level and control level of radiation facilities, and the hazard level of radiation sources. Based on these evaluations, ARPANSA determines each RP and frequency of inspection, leading to the implementation of different inspection methods according to the RP [1, 23].

ARPANSA faced significant disruptions in its regulation schedules due to travel restrictions, as 84% of its staff members are located in Melbourne and the rest in Sydney. As a result, several inspections were canceled on short notice, and alternative approaches were adopted, such as conducting inspections via video or using a combination of video and on-site inspection [24, 25]. To protect its staff from the contagious virus, ARPANSA limited physical visit inspections, requested additional documents from license holders, and transitioned to an electronic data collection environment. During the pandemic, ARPANSA categorized the circumstances as "special circumstances" and introduced alternative arrangements. One such arrangement was the application of "e-inspection" or "desktop review," where the inspection is conducted based on documents and photographs submitted by the license holder. Prior to the COVID-19 outbreak, this type of inspection was mainly limited to license holders with low-hazard sources or those located overseas. However, after the COVID-19 outbreak, ARPANSA focused on using this method for some license holders who could not undergo physical visit inspection. Due to past experience and the adaptation of "e-inspection" during the special circumstances of the pandemic, ARPANSA was able to readily implement inspections with additional reports, such as self-assessment of regulation compliance during a pandemic [1]. As a result, the number of regulatory site visits significantly decreased during the 2019–2020 and 2020–2021 financial years, compared to the previous years, as shown in Fig. 1 [24].

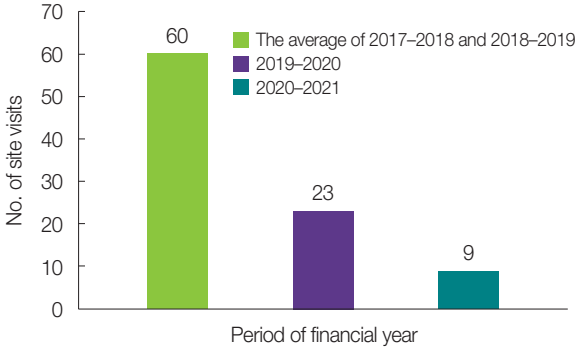

Fig. 1. Number of regulatory site visits in Australia.

During the COVID-19 pandemic, ARPANSA carried out strict measures to protect its staff members from infection, including home-based work. The ARPANSA promptly adopted a virtual collaboration platform to facilitate efficient remote work, which was classified as a "hybrid" arrangement. This virtual means was not only used for internal communication among ARPANSA staff but also extended for international engagement between countries and communication with license holders. The success of a video conference held in May 2020 to exchange information on radiation regulation for license holders demonstrated the feasibility of using virtual methods. Although this hybrid method may not be as efficient as face-to-face engagement, ARPANSA recognized the potential benefits and possibilities of utilizing this method even in the post-pandemic period, based on their experience during the pandemic. Furthermore, ARPANSA has continued to strive to improve the working environment of its staff by upgrading its "platforms and systems (PAS)" project, which are digital systems used in their operation. The aim is to construct a digital platform through a "laboratory information management system (LIMS)" contract, which would stabilize workflow tracking and related data management [24].

The outbreak of the novel virus posed new challenges for ARPANSA in sustaining high-quality regulation during crises. In response, ARPANSA adopted a detailed and practical approach to its inspection system. The agency prioritized the use of "virtual" tools for inspections, and they continuously sought innovative solutions, such as exploring the usage of "fifth generation (5G)" technology to maintain the quality of the inspection. This change was kept even during the disruption caused by the coronavirus. These efforts have been successful in enabling the RB to adapt to shifting epidemic situations effectively [25, 26].

Drawing on the valuable feedback and lessons learned from the COVID-19 pandemic, ARPANSA has taken proactive steps to prepare countermeasures and review its policies and procedures for handling future contingencies. The agency has engaged in various activities with domestic regulatory members to collaboratively develop regulatory measures for potential future crises [25, 26]. These ongoing activities demonstrate ARPANSA's commitment to continuously improving and refining its guidelines to be better equipped to respond

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to emergencies and other challenges in the future. The pandemic has served as an opportunity for Australian RB to evolve and enhance its regulatory framework, ensuring a more robust and adaptable system for future contingencies.

5. Present Condition in the Radiation Safety Regulation System of France

The management of radiation protection and nuclear safety in France involves several agencies, including the French Nuclear Safety Authority (ASN), playing a central role. On-site inspections are carried out by regional divisions dispersed throughout the country. To develop the system of radiation protection and nuclear safety, ASN appoints and operates inspections in three groups: nuclear safety inspectors, radiation protection inspectors, and labor inspectors. Among these, nuclear safety inspectors and radiation protection inspectors are responsible for conducting inspections [27, 28].

ASN employs various types of inspections to ensure compliance and safety. These include routine inspections, reinforced inspections, in-depth inspections, inspections with sampling and measurements, event-based inspections, worksite inspections, and inspection campaigns. Routine inspections, reinforced inspections, and in-depth inspections are the primary inspections conducted regularly by French inspectors. The level of detail and thoroughness of the inspection increases as it progresses from routine to in-depth inspection. During the reinforced inspection, a larger number of inspectors focus on specific topics for examination. In contrast, in-depth inspection involves more than 10 inspectors examining multiple topics over a few days. To verify the actual conditions at a facility site, inspectors may conduct unannounced visits or provide a few days' notice to licensees before the site visits [27, 28]. This comprehensive inspection approach ensures robust regulatory oversight and adherence to safety standards in the field of radiation protection and nuclear safety in France.

As in other countries, the outbreak of COVID-19 presented a significant challenge to ASN, disrupting the regulatory oversight system in France. The country faced a major health crisis, leading to the suspension of on-site inspection by ASN. However, ASN maintained the objective to resume these inspections promptly if necessary [29, 30]. The pandemic highlighted the importance of preparedness and precaution in the regulatory system, prompting ASN to view this challenge as an opportunity to renovate and adapt its existing system by adapting its working methods [27].

To guarantee the continuity of the regulation, ASN took several measures during the COVID-19 period. Regular communication with licensees allowed ASN to quickly identify difficulties faced in their activities, and the agency extended the due date for certain documents to ease the regulatory burden. In the medical sector, ASN streamlined licensing procedures to facilitate the possession and utilization of radiation. In addition, ASN implemented a remote inspection system and converted some inspection types to document examination to sustain the inspection crucial for main infrastructures. ASN's adaptability to COVID-19 was facilitated by its preparedness for remote inspections through the digital transformation plan launched in 2017. This plan includes real-time methods and equipped ASN to handle large-scale remote inspections. During remote inspection, documents submitted by licensees became the primary means of inspection, supported by audio conferences with licensees when necessary. Depending on the situation in France, ASN conducted three types of inspection either on-site, remotely, or through a combination of both methods, including audio conferences with the licensees. In particular, out of a total of 53 inspections performed over the 2 weeks of November 2020, 36% were on-site, 14% were remote, and 50% were a combination of the two, as shown in Fig. 2 [27, 29]. This statistic reflects the significant usage of remote inspection measures during the pandemic, which ASN acknowledges as one of its inspection methods and notes its efficiency in certain sectors [28].

In 2021, 2 years after the onset of COVID-19, ASN continued its efforts to ensure activity continuity and develop plans for future inspection. As part of the digital transformation, France introduced online services for the registration and notification system, catering to licensees of small-scale nuclear activities. This service, which became available in July

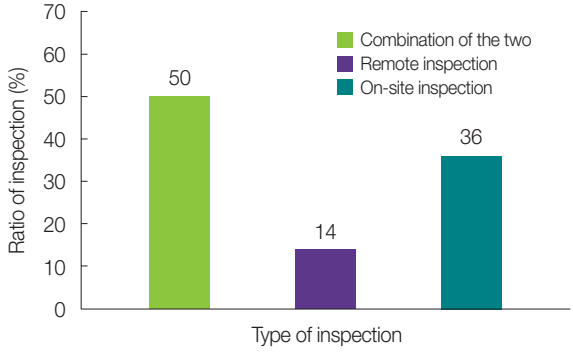

Fig. 2. Ratio of inspection types performed in France for 2 weeks.

2021, simplifies the registration application process, but it does not replace the main on-site inspection. The aim of this digital transformation is to facilitate the submission of registration files through the system, making it easier for licensees to comply with regulatory requirements. ASN also announced the implementation of a new home-working system to support staff members who work remotely [28].

Despite the gradual return to normal operation for some facilities, such as the Aube waste disposal facility, part of the regulation schedule for 2021 had to be postponed due to the ongoing COVID-19 pandemic [28]. ASN plans to continue monitoring developments to maintain the effectiveness of its programs and comprehensive oversight. Throughout the pandemic, various ideas were suggested as substitutes for on-site inspections. However, most of these ideas were aimed at supporting inspections or were not as effective as the traditional on-site inspection method. Despite the challenges posed by the pandemic, ASN prioritizes the safety and regulatory oversight of radiation facilities and sources in France and continues to seek innovative solutions to improve the regulatory framework and ensure continuous operation in times of crisis. The commitment of ASN has played a crucial role in bolstering systematic regulation and marking a significant milestone toward more precise guidelines.

6. Summary of Persistent Adaptations in Radiation Safety Regulation Systems amidst and beyond COVID-19

During the COVID-19 situation, countries faced similar restrictions in executing radiation safety regulation systems. Nevertheless, they strived to conduct regulatory activities steadily by employing alternative approaches. While not covered in this report, other RBs have also invested in introducing new inspection techniques or advanced measures, in-

Table 2. The Summary of Each Regulatory Body Regulation in the COVID-19 Situation

	Passive response	Active response	Home-based work	Feature
Republic of Korea (KINS)	Change the start time of the on-site inspection Give exemption or postponement of inspection to licensees Introduce a 'contactless inspection' in 2021	Implement the improved documentary examination 1) Self-inspection report 2) Radiation source management inspection report 3) Facility site video Launch an 'online inspection' with a remote platform	Take turns with other staff	Invent new regulatory systems with existing technologies and revise existing system →Tried to adjust the regulation according to the facility field condition
Canada (CNSC)	Arrange measures for abnormal situations after the SARS →"What-if" plan Focus on critical facilities with strong and rigorous regulatory guideline Guarantee the needs of essential facilities Provide regulation flexibility for other facilities Exchange regulatory information through reporting (both RB & licensees)	Research a hybrid approach in inspection (on-site inspection+remote inspection) Establish internal communication infrastructure for RB staff members Construct the new e-consultation platform for licensees Use digital tools actively Collaborate with regional colleagues to sustain the facility oversight	Except for critical staff	Interchange pandemic responses with 19 member countries by using virtual tools
Australia (ARPANSA)	Expand the scope of the 'e-inspection' Demand the additional documents to the licensees Implement the video conference to exchange information with license holders	Introduce the digital system 1) PAS 2) LIMS	With the virtual collaboration platform	Find out the solutions that could be used with '5G' technologies
France (ASN)	Contact licensees regularly Delay the due date of some documents for licensees Change the type of inspection to the documentary examination	Prepare the remote inspection system Implement the audio conference to support the documentary examination Provide online services with the digital transformation	With home-working system	Prepare for the huge remote inspection with the digital transformation plan since 2017

COVID-19, coronavirus disease 2019; KINS, Korea Institute of Nuclear Safety; CNSC, Canadian Nuclear Safety Commission; SARS, severe acute respiratory syndrome; RB, regulatory body; ARPANSA, Australian Radiation Protection and Nuclear Safety Agency; PAS, platforms and systems; LIMS, laboratory information management system; 5G, fifth generation; ASN, French Nuclear Safety Authority.

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cluding remote monitoring systems, proving their value during the pandemic. In addition to the countries mentioned above, other countries such as the USA, Poland, Ukraine, and Japan endeavored to maintain their radiation safety regulation systems by introducing remote or new technology systems [31]. In spite of the gradual easing of COVID-19's impact, these efforts persisted, leading to the adoption of novel inspection techniques such as "remote inspection" in Republic of Korea, diversifying the inspection techniques.

In Table 2, the approaches that each RB implemented were categorized into "passive response" and "active response." Passive responses encompassed measures that involved modifying existing regulations, regulatory scope, and objectives. Conversely, active responses entailed introducing new technologies and systems. Furthermore, the characterized features of home-based work and regulatory system in each country were also organized in Table 2.

Conclusion

This study investigated the impact of COVID-19 on radiation-related activities and the radiation safety regulation systems in some countries, including the efforts made by each RB to maintain normal operations during the pandemic. Despite facing similar restrictions, each country adopted different approaches to ensure the continuity of regulatory activities, all while prioritizing the safety of RB members and the radiation environment.

The experiences gained throughout the 4-year pandemic highlight the importance of developing official measures that can be employed in emergencies. Although the situation may appear to have returned to normal, the potential for future pandemics remains, making it essential to be ready for such contingencies. During the pandemic period, RBs introduced various technologies, such as remote systems, and underwent numerous trials and errors in their application to regulatory systems. These experiences have demonstrated the potential for continuous growth and development of the regulatory system in the face of unexpected challenges.

It is crucial for each RB to glean lessons from the pandemic and optimize their regulatory systems, tailoring them to the techniques and conditions of their respective countries. With this preparedness, RB can swiftly respond to unexpected situations without delaying regulatory inspections. Continuous development of new inspection methods and improvements to the regulatory framework are imperative for the long term. By summarizing each RB's key responses, this report aims to positively impact the revision of global radiation safety regulation systems, better equipping them to handle future situations.

However, it is important to note that determining global trends through this study is challenging, as the investigation was limited to only a few countries. Consequently, while the insights provided are valuable, they may not fully represent the global situation.

Overall, the COVID-19 pandemic has challenged the radiation safety regulation system, but it has also presented opportunities for growth and improvement. Prior to COVID-19, there was no readiness for situations in which the regulatory system became hard to operate, leading to delays or cancelations. Particularly, the radiation safety regulation system heavily relied on on-site inspection, and the epidemic was fatal with human contact. Many countries have since learned how to operate the regulatory system effectively, reducing the likelihood of future disruption. These pandemic experiences and lessons can serve as a foundation for developing more resilient and effective regulatory systems capable of adapting to any future challenges.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Author Contribution

Conceptualization: Chung Y. Methodology: Lee E, Kim CE. Data curation: Lee E, Kim CE. Formal analysis: Lee E, Kim CE. Supervision: Chung Y. Funding acquisition: Chung Y. Project administration: Chung Y. Investigation: all authors. Writing - original draft: Lee E. Writing - review & editing: Chung Y. Approval of final manuscript: all authors.

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