Development and application of a refinement model for data related to radiation protection

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Abstract. Background/Objectives: Human errors can occur while deducting correct data in reported data related to radiation protection. To prevent human errors and construct more correct base data, we aim to develop a refinement model for reported data.
Methods/Statistical analysis: The reported data maintained by the regulatory body are stored in Excel format. This study developed an initial refinement model for data related to radiation protection using a macro in Excel. To do this, we wrote the visual basic for application (VBA) code to execute the macro for each step after the establishment of a step for deducting the information needed by each reported data.
Findings: Before developing the refinement model, to confirm the factors related to radiation risk assessment, we needed to check the data one by one and input the modified data while refining the data. Problems arising during the corresponding processes were resolved by developing a refinement model. Subsequently, we analyzed the reported data related to radiation risk assessment in the Republic of Korea for 2016–2017. As a result, we predicted that the average exposure dose and safety management performance scores were pertinent to the workplace environment. This study was limited to factors related to the radiation risk assessment model for the non-destructive testing field. Furthermore, if we develop the VBA codes to determine the factors are involved in the radiation risk assessment model for each field that uses radiation, we expect that these VBA codes can be used as fundamental data for any field.
Improvements/Applications: Using the refinement model for data related to radiation protection, the time to refinement was shorter than the current refinement time, and human error did not occur. Therefore, we expect to construct more precise fundamental data related to radiation risk assessment.

Keywords: data refinement, refinement model, macro, VBA, radiation protection, human error

1. INTRODUCTION

The number of radiation workers is increasing with the increase in the use of radiation in various fields, such as medicine, education, academia, and industry[1-3].In addition, government organizations that receive and keep radiation protection reported data differ depending on the field in which radiation is used[4-6]. However, most institutions report radiation protection data to the Nuclear Safety and Security Commission (NSSC) through the Korea Institute of Nuclear Safety (KINS), the Korea Institute of Nuclear Nonproliferation and Control (KINAC), and the Korea Foundation of Nuclear Safety (KoFONS). Radiation protection data comprises radiation workers' protection records (exposure dose, medical surveillance, and education and training), the data on the workers with personal dosimetry problems, and report data for the daily workload[7-11]. KINS performs the radiation safety management assessment and maintains the data [7-11].The target of the radiation safety management assessment is an institution that performs periodic inspections annually. However, the availability of radiation protection data is not high because only the exposure dose data are used to achieve radiation protection.

In addition, risk assessment for radiation work has been performed in foreign countries [12]. However, there is no risk assessment model for radiation work in the Republic of Korea. Therefore, we expected that the radiological risk of the non-destructive testing (NDT) field would be the highest because the average exposure dose of the NDT field is the highest. We developed a risk assessment model for the NDT workplace after selecting for a risk assessment model factor through expert advice and question investigation in previous studies [13-17].The factors of the risk assessment model for the NDT workplace are listed in Table 1. To confirm the factors of the risk assessment model for the NDT workplace, we need to secure the following data: 1) data on the exposure dose, 2) data for workers with personal dosimetry problems, 3) assessment report for radiation safety management, and 4) reported data on the daily workload. To deduce the factors using the reported data, we deleted unnecessary data and refined inaccurate data. Human errors can occur during the deletion and refinement processes because the user directly refines the reported data. The types of human error according to the reported data are shown in Table2. In the present study, we aimed to develop a data refinement model that automatically arranges the reported data related to radiation risk assessment to prevent human error.

2. REPORTED DATA RELATED TO RADIATION RISK ASSESSMENT

Reported data related to radiation risk assessment include 1) data on exposure dose, 2) report data for daily workload, 3) data on the workers with personal dosimetry problems, and 4) data on the radiation safety management assessment. The contents of each reported data and factors that can be confirmed in each report are discussed below.

2.1. DATA ONTHE EXPOSURE DOSE

According to the Nuclear Safety Act, all nuclear energy-related business operators must report the exposure dose of radiation workers to KINS within one month after each quarter[7].Data on the exposure dose submitted to KINS include the institution name, worker numbers, monthly exposure doses, and total exposure doses. Based on these data, we can deduce the following factors related to the risk assessment model for the NDT field using the method shown in Table 3.

Table 1: Main factors of the risk assessment model for the NDT workplace

Factors	Sub-factors
Radiation sources	The most frequently used radiation source
Exposure dose	- Average exposure dose (including the record level[1]) - Average exposure dose (excluding the record level[1]) - Gap between maximum dose and average dose - Collective dose
Workplace management	- Number of workers per working group - Workload per hour
Workers with personal dosimetry problems	- Number of workers exceeded the dose limit - Number of workers who required follow-up
Periodic inspection	- Number of corrective measures suggested by the regulatory body - Number of comments pointed out by the regulatory body - Score for safety management performance by the regulatory body - Number of delayed/lost notifications

[1] Record level is 0.1 mSv; NDT, non-destructive testing

Table 2: Types of human error according to the reported data

Reported data	Types of human error
Data on the exposure dose	- While changing the exposure dose of workers with personal dosimetry problems, we may alter the exposure dose of other workers, or we may not confirm the total exposure dose of the corresponding workers. - While deducting the factors for the risk assessment model based on the data of the NDT companies, we may include the exposure dose of other companies or omit the exposure dose of the corresponding company.
Data on the radiation safety management assessment	- While calculating the number of corrective measures and comments, each score may be divided by the wrong value[1]. - We may obtain incorrect counts while calculating the number of delayed/lost notifications.
Report data for the daily workload	- While deducing the factors for workplace management, we may use incorrect data[2]. - We may select incorrect radiation sources because we can miscount the number of radiation sources used.
Data on the workers with personal dosimetry problems	- We may incorrectly classify workers with personal dosimetry problems.

[1]The number of corrective measures is obtained by dividing the corrective measures score by 10, and the number of comments is obtained by dividing the comments score by 5.

[2] We may miscalculate the work time or the number of workers per working group.

Table 3: Risk assessment model factors related to data on the exposure dose

Factors	Methods of calculation
Average exposure dose (including the record level)	- Confirmation of the average exposure dose among all radiation workers engaged in the corresponding company
Average exposure dose (excluding the record level)	- Confirmation of the average exposure dose among radiation workers whose exposure dose exceeded 0.1 mSv and engaged in the corresponding company
Gap between maximum	- Confirmation of the exposure dose among radiation workers whose exposure doses

dose and average dose	were the highest - Subtraction of the average exposure dose (including the record level) from the highest exposure dose
Collective dose	- Summing the exposure doses among all radiation workers engaged in the corresponding company

2.2. REPORT DATA FORTHE DAILY WORKLOAD

To create a safe work environment in the NDT field, KINS receives the report data for the daily workload including 1) workload and daily average workload, 2) information on the work environment according to the specific working day (e.g., work time, workplace, workload, inspection object, and radiation sources used),and 3) reasons for overwork[11].The institution that submits the reported data for the daily workload is the same one that that requests that the NDT company performs the work for more than a month. Reported data for the daily workload submitted to KINS are reported according to the specific working day and contain 1) the worker numbers, 2) work time, 3) work load, 4) radiation source used, 5) workplace, 6) object of the work, and so on. Using these data, we could deduce the following factors related to the risk assessment model for the NDT workplace using the method shown in Table 4.

Table 4: Risk assessment model factors related to reported data for the daily workload

Factors	Method of calculation
Number of workers per working group	- Confirmation of the number of radiation workers per working group by working day - Confirmation of the average number of radiation workers per working group in the corresponding company
Workload per hour	- Confirmation of the total work time (using the start/end times of work) - Confirmation of the workload divided by the total work time - Confirmation of the average workload per hour for the corresponding company
The most frequently used radiation source	- Confirmation of the frequency of use of radioisotopes and radiation generators in performing the NDT work - Selection of the most frequently used radiation sources in the corresponding company - According to the radiological risk, change the name of the radiation source to the corresponding value (radiation generator (1), Am-241 (2), Se-75 (3), Ir-192 (4), Co-60 (5))

2.3. DATA ONTHE WORKERS WITH PERSONAL DOSIMETRY PROBLEMS AND DATA ON THE RADIATION SAFETY MANAGEMENT ASSESSMENT

According to the Nuclear Safety Act, workers with personal dosimetry problems are defined as follows: 1) Persons whose dose limits have been exceeded, 2) Persons whose exposure doses were illegible due to loss and damage of personal dosimetry devices, and 3) Persons who submitted personal dosimetry data after more than two months based on the periodic replacement of personal dosimetry devices.[8] If workers with personal dosimetry problems are engaged at the institution, the nuclear energy-related business operator should promptly report to the relevant institution (KINS or NSSC). In addition, the relevant institution needs to confirm the exposure dose if the exposure dose of the radiation workers cannot be confirmed. Data on the workers with personal dosimetry problems submitted to KINS include 1) the institution name, 2) worker numbers, 3) reasons for the occurrence, and 4) verified dose. Using these data, we could deduce the following factors: 1) the number of workers exceeding the dose limit and 2) the number of workers who require follow-up apart from those exceeding the dose limit.

According to the permissible amount of radioactive material and radiation generators, the regulatory body periodically inspects the institution using radiation based on a constant cycle (one year, five years, and ten years)[7].However, institutions with a constant cycle of periodic inspection spanning one year can be exempted from periodic inspection through the radiation safety management assessment[10].The scoring criteria for exemption from periodic inspection is 70 points, and the contents of the radiation safety management assessment are shown in Table 5[10]. The data on the radiation safety management assessment contains the following data: 1) score for corrective measures by the regulatory body (high relation to the work environment), 2)a score for comments that are pointed out by the regulatory body (high relation to the work environment), 3) safety management performance scores provided by the regulatory body, and 4) number of delayed/lost notifications for each reason (quarter, transportation, production, or sales) (verification of the degree of sincerity of radiation safety manager).We need to deduce the number of corrective measures and comments by dividing the score of corrective measures and comments by a constant value(Table 2). In addition, we need to deduce the total number of delayed/lost notifications through a process that sums all numbers of delayed/lost notifications for each reason.

Table 5: Contents of the assessment tool for radiation safety management

No.	Contents
1	Items of corrective measures assessed during periodic inspection or unannounced inspection by the regulatory body
2	Items related to comments made by the regulatory body during periodic inspection or unannounced inspection
3	Excellence (preparation or inspection) of the attitude of the manager during periodic inspection or unannounced inspection
4	The occurrence of accidents related to loss or theft of radioactive materials or radiation generators
5	Exceeding the dose limit in a radiation worker

6	The occurrence of workers with personal dosimetry problems as a result of the exposure dose measurement
7	History of permission for change
8	History of a change of radiation safety manager
9	Exceeding the deadline for the report or notifications

3. DEVELOPMENT OF A REFINEMENT MODEL FOR REPORTED DATA

The amount of data on the workers with personal dosimetry problems is small because the annual occurrence of workers with personal dosimetry numbers is low. Thus, we did not develop a refinement model for the corresponding reported data. A refinement model for exposure dose contains processes that reflect the verified dose of workers with personal dosimetry problems in the data on the exposure dose. The code and development processes used in the refinement model for reported data other than data on the workers with personal dosimetry problems are discussed next.

3.1. USED CODE

As KINS maintains the reported data related to radiation risk assessment in a Microsoft Excel format, we produced Visual Basic for Applications (VBA) code for each process to refine the data using the macro function in Excel. The macro performs a series of tasks upon entering one key while avoiding repetitive work[18].In addition, VB Aisa programming language that records macros in Microsoft Office application programs [18].

3.2. REFINEMENT MODEL FOR DATA ON THE EXPOSURE DOSE

The purposes of this model are: 1) to reflect the verified dose in the existing exposure dose data by inputting the information for workers with personal dosimetry problems and 2) to deduce the factors related to the exposure dose of the radiation risk assessment model for the NDT workplace. To accomplish these, we produced a VBA code related to the following process. The process reflecting the verified dose of the workers with personal dosimetry problems and the work process for this model are shown in Figures 1 and 2, respectively.

Step 1: Designate the worker number range in the exposure dose data (Purpose: To search for the worker number of the workers with personal dosimetry problems).

Step 2: Input the information of workers with personal dosimetry problems (worker number, month in which the exposure dose needed to be modified, verified dose).

Step 3: Within the range of the worker numbers, select the specific cell(1) that contains the worker number of the workers with personal dosimetry problems.

Step 4: Input the verified dose in a specific cell (2) that moved three columns from the specific cell (1) specified in step 3 (Reason: The distance between the worker number column and that of the exposure dose for January is three columns).

Step 5: Modify the exposure dose for the month in which the exposure dose needed to be modified.

Step6: Input the sum function (Excel function) after range designation of the total exposure dose (Purpose: To confirm the total exposure dose as reflected in the verified dose)

Step 7: Deduce the company names.

Step 8: Deduce the total average value and company value of the factor related to exposure dose in the radiation risk assessment model for the NDT workplace.

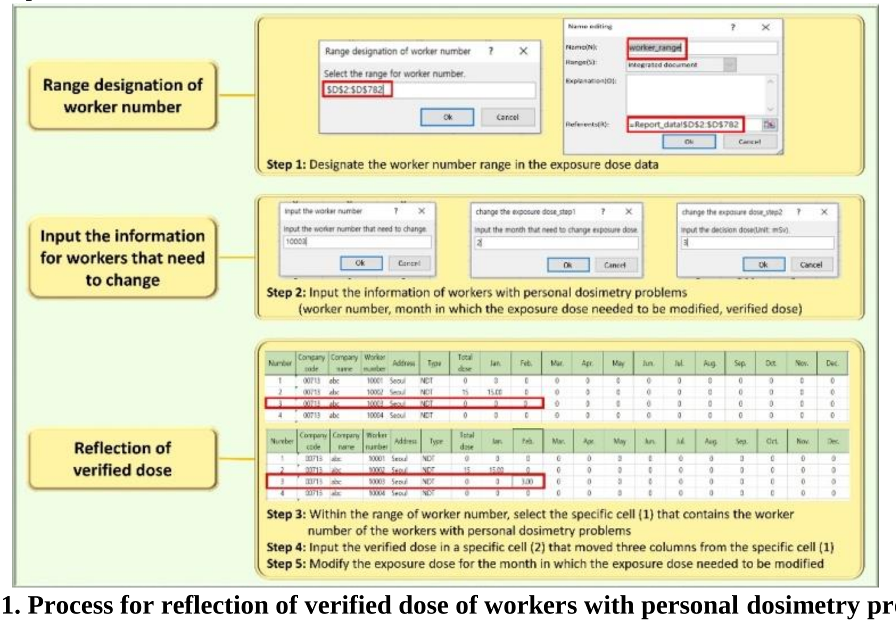

Figure 1. Process for reflection of verified dose of workers with personal dosimetry problems

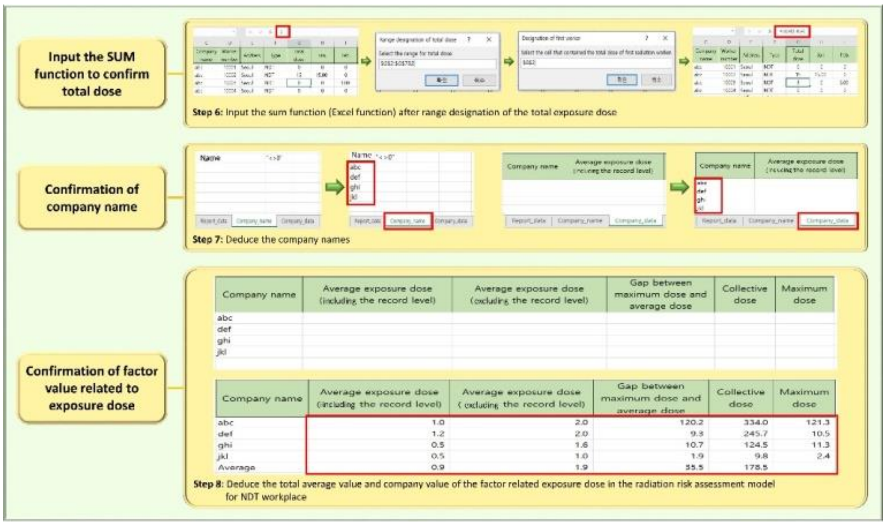

Figure 2. Work process for the refinement model for data on the exposure dose

3.3. REFINEMENT MODEL FOR DATA ONTHE RADIATION SAFETY MANAGEMENT ASSESSMENT

The purpose of this model is to deduce the factors related to the periodic inspection of the radiation risk assessment model for the NDT workplace. To accomplish these, we produced a VBA code related to the following process. The steps in this model are illustrated in Figure 3.

Step 1: Change the corrective measures and comments scores to the number of corrective measures and comments after adding a column for the number of corrective measures and comments.

Step 2: Confirm the total number of delayed/lost notifications after adding a column for the number of delayed/lost notifications (Reason: There is no total number of delayed/lost notifications because the number of delayed and lost notifications is fractionated in quarter, transportation, production, and sales).

Step 3: Deduce the company names.

Step 4: Deduce the total average value and company value of the factor related to periodic inspection of radiation risk assessment model for the NDT workplace.

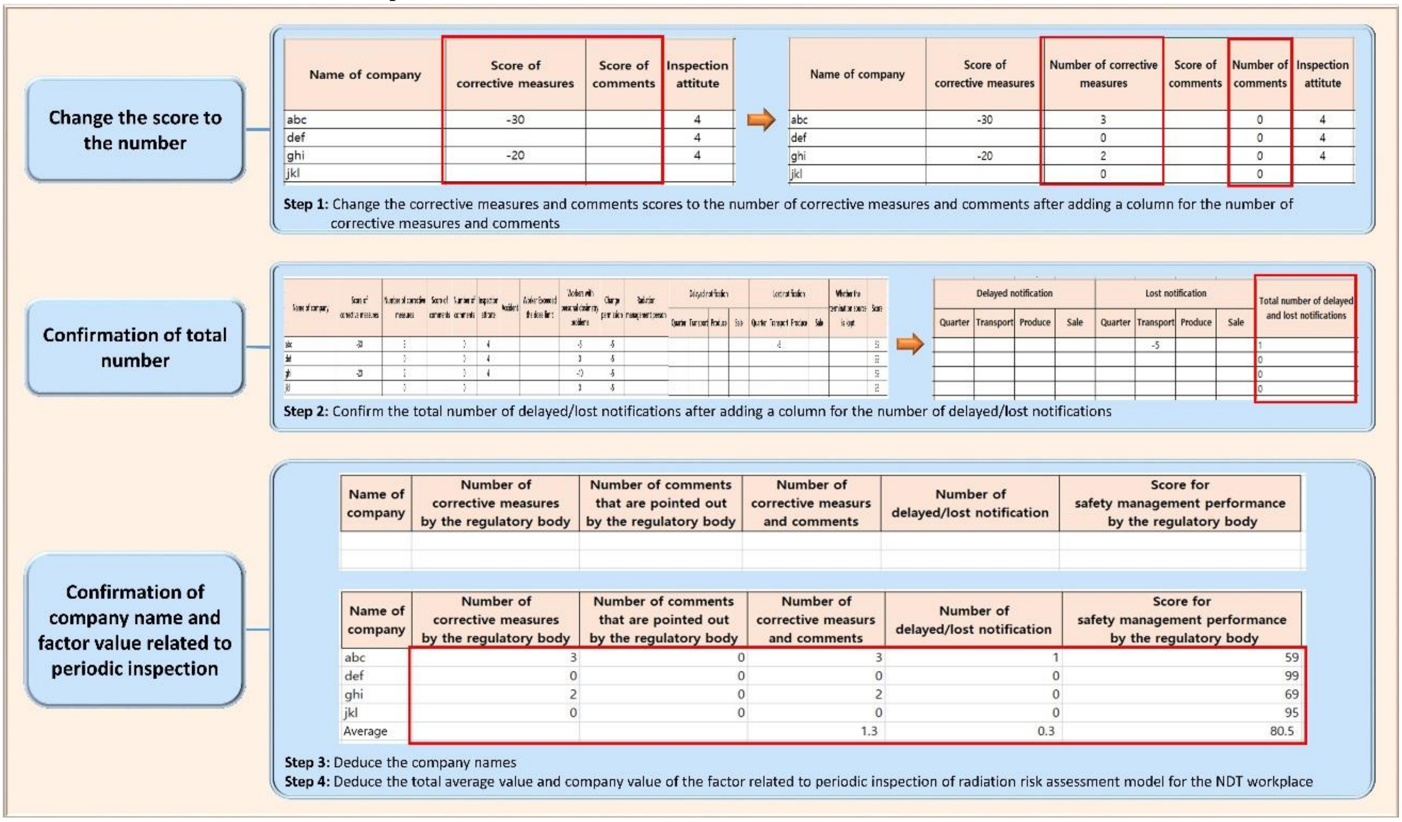

Figure 3. Work process for the refinement model for assessing reported data on radiation safety management

3.4. REFINEMENT MODEL FOR REPORTED DATA ON DAILY WORK LOAD

The purpose of this model is to deduce the factors related to the radiation source and workplace environment of the radiation risk assessment model for the NDT workplace. To accomplish these, we produced a VBA code related to the following process. The process of this model isillustrated in Figure 4.

Step 1: Delete some data (such as address and code of workplace, the object of work, information for workplace notification) other than data related to radiation risk assessment (Purpose: To minimize the file size).

Step 2: Add columns for the number of workers per working group, total work time, and workload per hour.
Step 3: Delete the corresponding row after inputting the "No workload" in the column on work leader (Purpose: To confirm the row that does not input the workers per working group because of no workload).
Step 4: Delete the corresponding row after inputting "0" in the column on workload (Purpose: To confirm the row that inputs the workers per working group but does not input the workload).
Step 5: Delete the corresponding row that does not input the start time, end time, and radiation sources used.
Step 6: Deduce the number of workers per working group using the Excel function.
Step 7: Deduce the workload per hour (workload divided by total work time) after deducing the total work time using the method shown in Table 6 (Assumption: Because the work time input method differs for each company, we assume that the work time ranges from 0 hours to 24 hours).
Step 8: Delete the corresponding rows in which the total work time exceeds12 h.
Step 9: Deduce the company names.
Step 10: Deduce the total average value and company value of the factor related to the radiation source and workplace environment of the radiation risk assessment model for the NDT workplace.

Table 6: Method of calculating the total work time

Comparison of the start and end times	Method of calculation[1]
Start time = End time	Assuming that the work time is one hour
Start time <End time	Subtract the start time from the end time
Start time >End time	Sum up the end time after subtracting the start time from 24

[1]If the company operated for 24 hours, we expected that the total work time would range from 8 to 12 hours because the worker is at work in day/night shifts or three shifts. We adjudged that a total work time exceeding 12 hours was not possible. Thus, we deleted corresponding rows that exceeded 12 hours of work time.

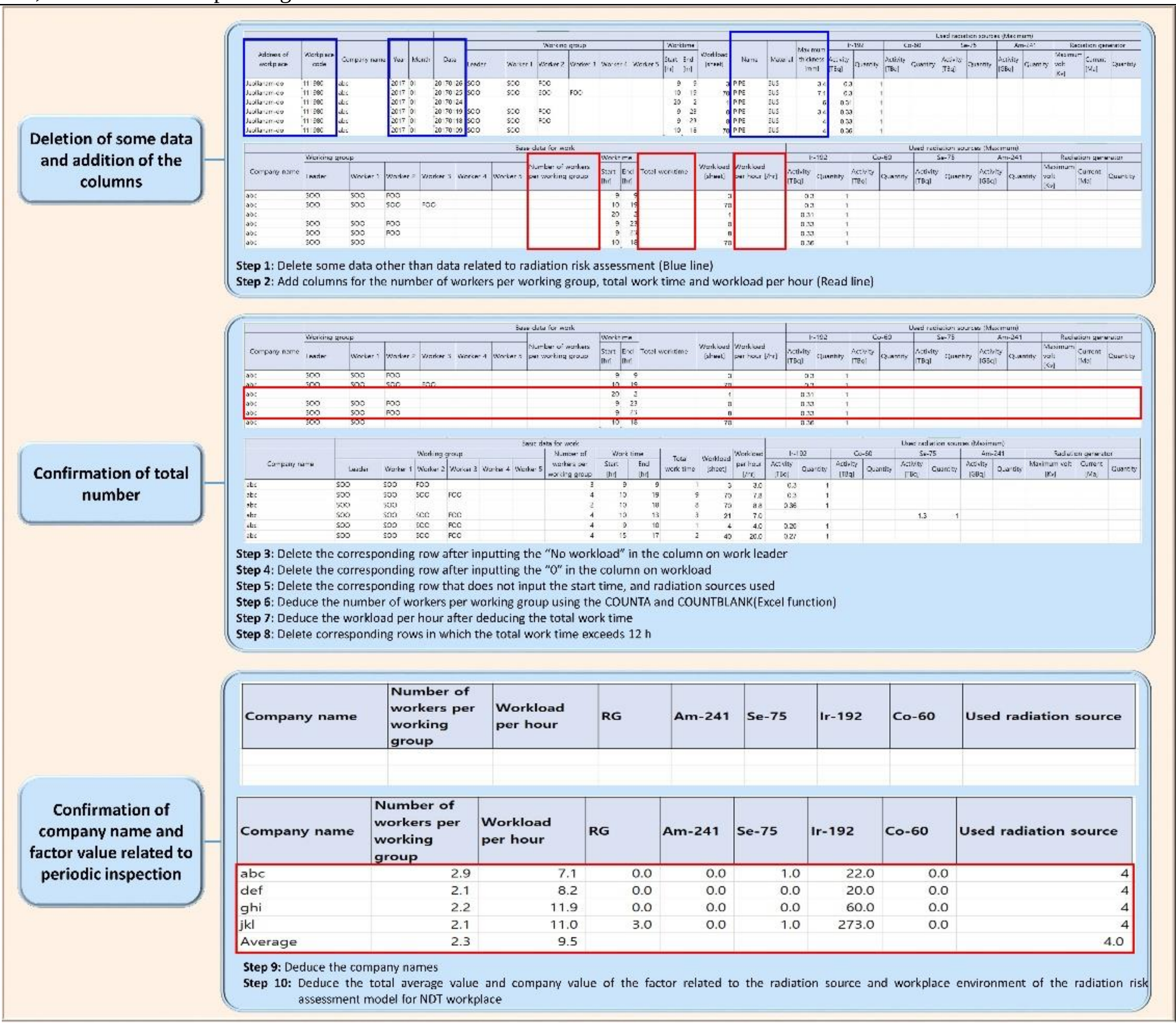

Figure 4. Work process for the refinement model for reported data on daily workload

3.5. PLAN OF APPLICATION OF REFINED DATA

To confirm the change in the NDT workplace environment, we used reported data related to radiation risk assessment in the Republic of Korea for 2016–2017. Using the refinement model for data related to radiation protection, we deduced the factors related to risk assessment and analyzed the contents of Table 7. The average values for each item are listed in Table 8.

Table 7: Contents of analysis of data deducted from the refinement model

No.	Contents
1	According to the score for safety management performance provided by the regulatory body (standard: 70 points), we calculated the average value of factors related to exposure dose and workplace management
2	According to the existence of corrective measures and comments, we calculated the average value of factors related to exposure dose and workplace management
3	Based on the average number of workers per working group for each year, we calculated the average value of factors related to exposure dose
4	Based on the average workload per hour for each year, we calculated the average value of factors related to exposure dose

Most NDT companies in the Republic of Korea use Ir-192, and the average exposure dose does not exceed the dose limit. Also, there was little change in the number of workers per working group(2016: 2.5 persons per working group, 2017: 2.4 persons per working group) and the workload per hour(2016: 13.5 /hour, 2017: 15.4/hour). After analyzing the data from 2016, we found the following:

1. Companies whose safety management performance scores provided by the regulatory body were above 70 points had a high average exposure dose and average number of workers per working group; however, the average workload per hour was low.
2. Companies whose corrective measures and comments did not exist had a high average exposure dose; however, the average number of workers per working group and average workload per hour were low.
3. Companies whose average number of workers per working group was higher than the average for all companies had a low average exposure dose.
4. Companies whose average workload per hour was lower than the average of all companies had a low average exposure dose.
5. Also, after analyzing the data from 2017, we found the following:
6. Companies whose safety management performance scores provided by the regulatory body were above 70 points had a high average number of workers per working group; however, the average exposure dose and average workload per hour were low.
7. Companies whose corrective measures and comments did not exist had a high average number of workers per working group; however, the average exposure dose and average workload per hour were low.
8. Companies whose average number of workers per working group was higher than the average of all companies had a low average exposure dose.
9. Companies whose average workload per hour was lower than the average of all companies had a high average exposure dose.

Table 8: Average values of contents of the data analyzed

Contents	Value (2016)	Value (2017)
For companies whose safety management performance score provided by the regulatory body were above 70 points		
Average exposure dose (including the record level)	1.33	0.73
Average exposure dose (excluding the record level)	2.15	1.57
Number of workers per working group	2.54	2.44
Workload per hour	12.71	14.93
For companies whose safety management performance score provided by the regulatory body were less than 70 points		
Average exposure dose (including the record level)	0.79	1.56
Average exposure dose (excluding the record level)	1.44	3.15
Number of workers per working group	2.53	2.40
Workload per hour	16.13	16.61
For companies whose corrective measures and comments did not exist		
Average exposure dose (including the record level)	1.38	0.79
Average exposure dose (excluding the record level)	2.24	1.68

Number of workers per working group	2.51	2.51
Workload per hour	13.42	13.27
For companies whose corrective measures and comments existed		
Average exposure dose (including the record level)	0.82	1.15
Average exposure dose (excluding the record level)	1.45	2.37
Number of workers per working group	2.62	2.34
Workload per hour	13.53	17.75
For companies whose average numbers of workers per working group were higher than the average of all the companies		
Average exposure dose (including the record level)	0.71	0.75
Average exposure dose (excluding the record level)	1.33	1.59
For companies whose average numbers of workers per working group were lower than the average of all the companies		
Average exposure dose (including the record level)	1.80	1.10
Average exposure dose (excluding the record level)	2.79	2.30
For the companies whose average workload per hour was lower than the average of all companies		
Average exposure dose (including the record level)	0.94	1.02
Average exposure dose (excluding the record level)	1.66	2.06
For the companies whose average workload per hour was higher than the average of all companies		
Average exposure dose (including the record level)	1.65	0.81
Average exposure dose (excluding the record level)	2.54	1.88

4. CONCLUSION

The NSSC receives various reports related to radiation work and radiation protection. Various reports have been accumulated for many years; however, the following problems have come up: 1) the inclusion of inaccurate data (omissions and some incorrect reporting input), and 2) low utilization in terms of radiation protection. As the amount of reported data is large, we expected that it would take a long time to delete inaccurate data, and there is a high probability of human error during the refinement of reported data in the future. To prevent human errors, we developed a refinement model for each reported data using the macro function in Excel. We then analyzed the two-year data using a refinement model. Based on the results of the two-year analysis, the NDT workplace characteristics in the Republic of Korea were as follows:

1. The higher the safety management performance score provided by the regulatory body, the higher the number of workers per working group and the lower the workload per hour. Moreover, the relationship between the safety management performance score and the average exposure dose was not constant. Therefore, we predicted that the safety management performance score is highly pertinent to the workplace environment.
2. The larger the number of workers per working group, the lower is the average exposure dose. However, the relationship between the average workload per hour and average exposure dose was not constant. Therefore, we predicted that the average exposure dose would be highly pertinent to the number of workers per working group.

To confirm the more precise relevance of the analysis contents of data deduced using the refinement model, we need to analyze the data for multiple years. Also, if we develop a risk assessment model for each radiation field in the future, we can deduce the factors of the risk assessment model for each radiation field by modifying the existing VBA code resulting from this study and developing new VBA code. Finally, if we can use the refinement model in the analysis of statistical data for radiation protection in the future, we expect to construct more accurate fundamental data than existing data.

5. ACKNOWLEDGMENT

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6. REFERENCES

1. Nuclear Safety and Security Commission(NSSC), Korea Institute of Nuclear Safety(KINS), Korea Institute of Nuclear Nonproliferation and Control(KINAC). 2017 Nuclear Safety Yearbook. Republic of Korea: NSSC, KINS, KINAC; 2018. p. 265.Available from: https://www.kins.re.kr/nsic.do?menu_item=library/magine/yearbook. Korean
2. Nuclear Safety and Security Commission(NSSC), Korea Institute of Nuclear Safety(KINS), Korea Institute of Nuclear Nonproliferation and Control(KINAC), Korea Foundation of Nuclear Safety (KoFONS). 2018 Nuclear Safety Yearbook.

Republic of Korea: NSSC, KINS, KINAC, KoFONS; 2019. p. 260. Available from: https://www.kins.re.kr/nsic.do?menu_item=library/magine/yearbook. Korean

3. Nuclear Safety and Security Commission(NSSC), Korea Institute of Nuclear Safety(KINS), Korea Institute of Nuclear Nonproliferation and Control(KINAC), Korea Foundation of Nuclear Safety (KoFONS). 2019 Nuclear Safety Yearbook. Republic of Korea: NSSC, KINS, KINAC, KoFONS; 2020. p. 263. Available from: https://www.kins.re.kr/nsic.do?menu_item=library/magine/yearbook. Korean
4. Nuclear Safety and Security Commission (NSSC). Nuclear Safety Act. Republic of Korea: NSSC; 2020.Available from: https://elaw.klri.re.kr/kor_service/lawView.do?hseq=51533&lang=ENG
5. Ministry of Health and Welfare (MOHW). Medical Service Act. Republic of Korea: MOHW; 2019.Available from: https://elaw.klri.re.kr/kor_service/lawView.do?hseq=53532&lang=ENG
6. Ministry of Agriculture, Food and Rural Affairs (MAFRA). Veterinarians Act. Republic of Korea: MAFRA; 2019.Available from: https://elaw.klri.re.kr/kor_service/lawView.do?hseq=51818&lang=ENG
7. Nuclear Safety and Security Commission (NSSC). Enforcement Regulations of the Nuclear Safety Act. Republic of Korea: NSSC; 2019.Available from: https://www.law.go.kr/LSW/lsInfoP.do?efYd=20210304&lsiSeq=230045#0000
8. Nuclear Safety and Security Commission (NSSC). Enforcement Decree of the Nuclear Safety Act. Republic of Korea: NSSC; 2019.Available from: https://elaw.klri.re.kr/kor_service/lawView.do?hseq=49909&lang=ENG
9. Nuclear Safety and Security Commission (NSSC). Regulation on assessment and management of personal exposure dose (Notification of the NSSC, No. 2019-20). Republic of Korea: NSSC; 2019.Available from: https://www.law.go.kr/admRulSc.do?menuId=5&subMenuId=41&tabMenuId=183&query=%EA%B0%9C%EC%9D%B8%ED%94%BC%ED%8F%AD%EC%84%A0%EB%9F%89#liBgcolor0
10. Nuclear Safety and Security Commission (NSSC). Regulation on exemption of periodic inspection for permitted user and business agency of radioactive isotopes (Notification of the NSSC, No. 2017-48). Republic of Korea: NSSC; 2017.Available from: https://www.law.go.kr/admRulSc.do?menuId=5&subMenuId=41&tabMenuId=183&query=%EC%A0%95%EA%B8%B0%EA%B2%80%EC%82%AC#liBgcolor19
11. Nuclear Safety and Security Commission (NSSC). Regulation on technical standards for radiation safety control, etc (Regulation of the NSSC, No. 25). Republic of Korea: NSSC; 2020.Available from: https://www.law.go.kr/admRulSc.do?menuId=5&subMenuId=41&tabMenuId=183&query=%EB%B0%A9%EC%82%AC%EC%84%A0%20%EC%95%88%EC%A0%84#liBgcolor3
12. Radiation Protection Management: Official Web site of the University of Edinburgh [Internet]. Risk Assessments: Information, templates and guidance for preparing a suitable and sufficient Radiation Risk Assessment; [updated 2021 Feb 01; cited 2021 Apr 27]. Available from: https://www.ed.ac.uk/health-safety/radiation-protection/radiation-protection-management/risk-assessments
13. Bae YJ. Study on the Risk Assessment Method at Workplace of Radiation Facilities according to Occupational Radiation Exposure [dissertation on the Internet]. [Republic of Korea]: Daegu Catholic University; 2016.Available from: http://www.riss.kr/link?id=T13972738
14. Gwon DY. Development and Application of a Risk Assessment Model for the Non-Destructive Testing Field [dissertation on the Internet]. [Republic of Korea]: Daegu Catholic University; 2020. Available from: http://www.riss.kr/link?id=T15663756
15. Bae YJ, Kim BS, Gwon DY, Kim YM. Multidimensional Model for Assessing Risks from Occupational Radiation Exposure of Workers. J Korean Soc Radiol. 2017 Dec;11(7):555-64. DOI: https://doi.org/10.7742/jksr.2017.11.7.555
16. Gwon DY, Han JY, Bae YJ, Kim BS, Kim YM. A Study on the Selection of the Main Factors of Radiation Risk Index Model for assessing risk in Non-destructive testing workplace. J Korean Soc Radiol. 2018 Aug;12(4):459-66. DOI: https://doi.org/10.7742/jksr.2018.12.4.459
17. Han JY, Gwon DY, Kim BS, Kim YM. Risk Analysis of Radiographic Testing Companies using Radial Scale Analysis Model. J Korean Soc Radiol. 2018 Nov;12(6):745-53. DOI: http://dx.doi.org/10.7742/jksr.2018.12.6.745 Lee DS. Excel 2016 Macro&VBA Thoughtlessly imitating. Republic of Korea: Gilbut; 2016. 564. Korean