Nuclear Engineering and Technology 50 (2018) 494–503

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Necessity of management for minor earthquake to improve public acceptance of nuclear energy in South Korea

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ARTICLE INFO

Article history:
Received 25 July 2017
Received in revised form
30 November 2017
Accepted 30 November 2017
Available online 19 December 2017

Keywords:
Earthquake Measures
Management
Minor Earthquake
Nuclear Energy
Public Acceptance

ABSTRACT

As public acceptance of nuclear energy in Korea worsens due to the Fukushima accident and the earthquakes that occurred in the Gyeongju area near the Wolsong nuclear power plant (NPP), estimating the effects of earthquakes has become more essential for the nuclear industry. Currently, most countermeasures against earthquakes are limited to large-scale disasters. Minor-scale earthquakes used to be ignored. Even though people do not feel the shaking due to minor earthquakes and minor earthquakes incur little damage to NPPs, they can change the environmental conditions, for instance, underground water level and the conductivity of the groundwater. This study conducted a questionnaire survey of residents living in the vicinity of an NPP to determine their perception and acceptance of plant safety against minor earthquakes. The results show that the residents feel earthquakes at levels that can be felt by people, but incur little damage to NPPs, as minor earthquakes (magnitude of 2.0–3.9) and set this level as a standard for countermeasures. Even if a minor earthquake has little impact on the safety of an NPP, there is still a possibility that public opinion will get worse. This study provides analysis results about problems of earthquake measures of Korean NPPs and specific things that can bring about an effect of deterioration of public acceptance. Based on these data, this article suggests that active management of minor earthquakes is necessary for the sustainability of nuclear energy.

1. Introduction

Currently, most countermeasures against earthquakes are limited to large-scale disasters. For that reason, lots of effort has been put into mitigating the effects of earthquakes on the structural integrity of nuclear power plants (NPPs) [1]. As a result, the structural integrity has been further improved, as seen in the Fukushima accident (the structures seemed to be sound even with the strong earthquake of magnitude 9.0). However, these efforts were not likely to improve public acceptance [2].

It has been long believed that the Korean Peninsula is quite stable against earthquakes because it is not located on the boundary of tectonic plates. But the belief seems to have been broken when the Gyeongju earthquake ($M = 5.8$) and its more than 600 aftershocks occurred. The recent occurrence of earthquakes in Korea has become complicated and diversified probably due to the Great East Japan earthquake on 11 March 2011. Gyeongju earthquakes are known to occur due to the movement of the Yangsan fault. Because the Yangsan fault is located near the Wolsong and Kori nuclear sites, public acceptance of nuclear energy in Korea has become worse due to the Fukushima accident and the Gyeongju earthquakes.

Public acceptance of NPPs can be achieved when efforts are made to not only enhance the seismic capacity of NPP buildings but also to engage in more frequent communication between the plant operators and the public, for assurance of plant safety and reliability, even when minor earthquakes occur. In this study, a minor earthquake is defined as a small earthquake of magnitude 2.0–3.9.

This study performed various analyses to emphasize the necessity of appropriate evaluation and measures for minor earthquakes based on the influence of minor earthquakes on residual public acceptance of the Korea nuclear industry. For this purpose, surveys were conducted for residents within 2 km of NPPs, and data were collected. In addition, this study investigated the problems of current earthquake response measurers of NPPs in Korea and analyzed especially if public opinion of Korea's NPPs can be exacerbated by minor earthquakes. Through these analyses, this study tried to suggest policy implications for enhancing the acceptability of NPPs and promoting nuclear energy.

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https://doi.org/10.1016/j.net.2017.11.013

2. Current problems

When an earthquake occurs, plant operator will follow the typical actions as seen in Fig. 1 [3]. If the magnitude of the earthquake exceeds a certain level (OBE: Operating Basis Earthquake [4]), the plant will be automatically tripped. Then, operator walkdown inspection will be carried out to investigate any damage in the plant. If the plant is not automatically tripped and no damage is found, the plant can be continuously operated after immediate operator action and walkdown inspection.

However, even a minor earthquake (magnitude of 2.0–3.9), far below the OBE criteria, when perceived by people, can have an effect on public opinion about NPPs. Therefore, if the appropriate measures are not taken, it is possible to lead to uncertain problems such as changes in nuclear policy and an antinuclear movement. In addition, it is difficult to make a highly realistic and reliable evaluation of the impact of earthquakes on NPP safety only by dealing with relatively large earthquakes that occur less frequently than OBEs.

2.1. Limitations of measures for earthquakes

The earthquake scale normally used in the NPP design is in the range of peak ground acceleration (PGA) of 0.15–0.3 g [5]. PGA design values for Korean NPPs are 0.2 g or 0.3 g; 0.2 g corresponds to an earthquake of magnitude of approximately 6.5, and 0.3 g corresponds to an earthquake of magnitude of approximately 7.0. On the other hand, the Modified Mercalli Intensity (MMI) scale is more related to how people feel earthquakes and how much buildings and structures are damaged. Even with small earthquakes, the MMI scale may be high according to the degree of damage. Therefore, people become more sensitive to the MMI scale. Table 1 shows the relationship between earthquake scales, MMI, PGA, and magnitude. It can be seen in Table 1 that minor

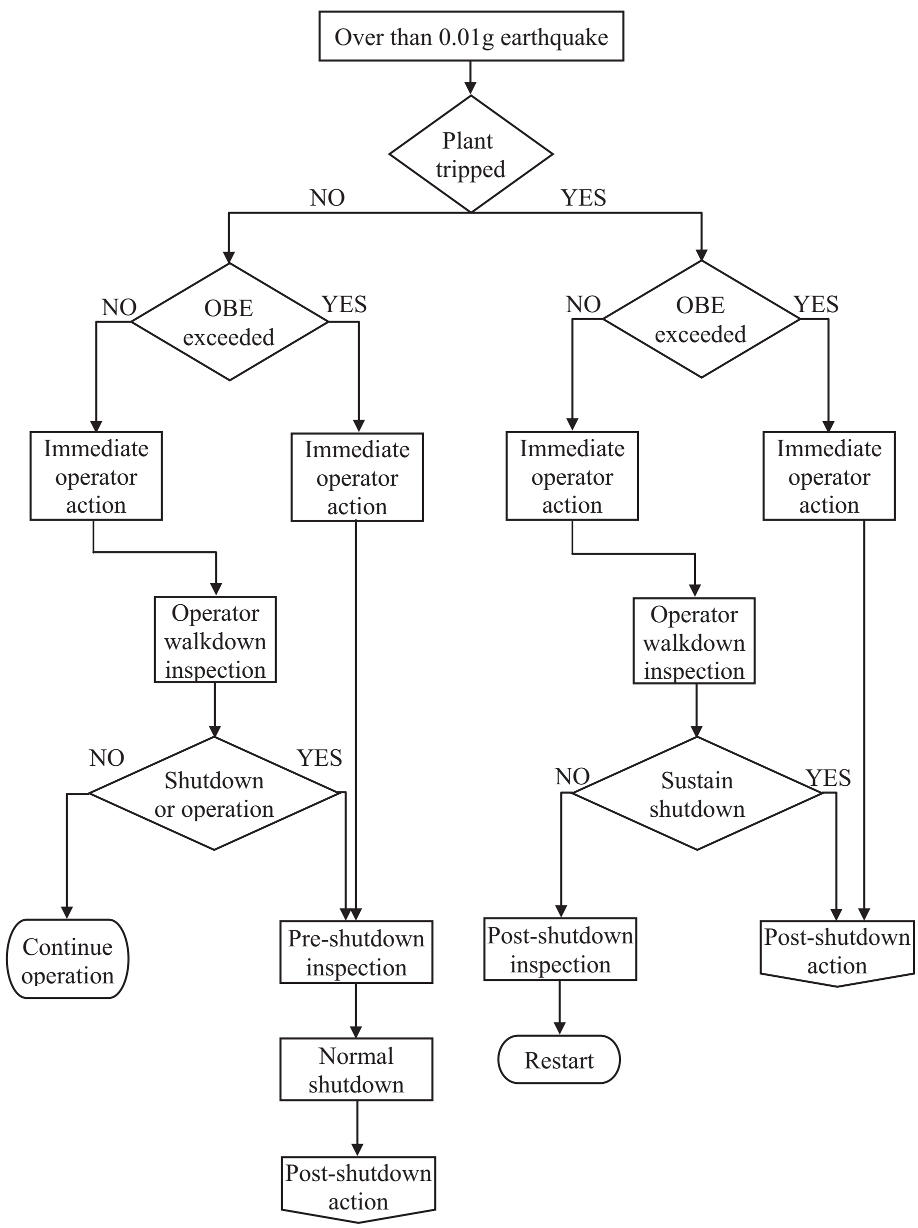

Fig. 1. Flow diagram of actions for more than 0.01 g earthquake (Korea Hydro & Nuclear Power standard procedure).

Table 1
The relationship between earthquake scales (MMI, PGA, and magnitude) (http://www.khnp.co.kr).

MMI Scale	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
PGA(g)					0.01		0.10	0.2	0.3			
OBE&SSE							OBE		SSE			

Richter Magnitude	1	2	3	4	5	6	7	8	9

* Richter Magnitude formula according to MMI scale: M=1+MMI×(2/3)(Gutenberg & Richter, 1956)
* MMI scale formula according to PGA(g): MMI=3logA+1.5(Gutenberg & Richter, 1956)

OBE, Operating Basis Earthquake; PGA, peak ground acceleration; SSE, Safe Shutdown Earthquake.

earthquakes (magnitude of 2.0–3.9) do not affect the safety of NPPs because the magnitude level is far below the OBE level.

In addition, the seismic safety measure standard has suggested that an additional follow-up action is unnecessary at earthquake magnitude of 3.5 or less [5] because, as shown in Table 2, earthquakes of magnitude less than 3.5 cannot exceed OBE level at any site no matter how distant the site is from the earthquake epicenter.

However, these kinds of follow-up action criteria are analyzed only from the point of view of integrity and efficiency of an NPP operation; therefore, they do not consider the environment surrounding the NPP and public acceptance of residents. A report is simply issued to the public through the media about the occurrence and the magnitude of a minor earthquake, consequently resulting in no effects on the safety of NPPs.

2.2. *Limitation of fundamental data for evaluation of earthquake risk*

Earthquake risk is defined as "the degree of risk of earthquakes calculated by collectively analyzing the past record of earthquakes, geology and characteristics of the ground or such, in order to establish earthquake zones which are the base of earthquake-proof design" by the earthquake recovery plan act [6]. Maximum earthquakes and fault activity within 320 km should be investigated to establish evaluation data for earthquakes risk [7]. In addition, records of past earthquakes must be included to apply the most secure seismic design assuming the frequency of occurrence of earthquakes near the NPP. However, while the seismic source area of the NPP regulatory standard in Korea includes earthquake records and fault records for a 320 km range bounding each NPP facility, the seismic source area known to date covers only the land and sea of South Korea. Fig. 2 shows that the whole land of South Korea is included in the 320 km radius from the Wolsong NPP site, including the East Sea as well as the middle northern part of Kyushu in Japan and the southwestern part of Honshu [8]. The Japanese region has experienced a number of minor earthquakes in the past, and it is known that a large number of faults are distributed at sea, even though these have not been surveyed in South Korea. As a result, the predicted earthquake risk was reduced in the NPP in Korea by excluding the data for the East Sea and Japan.

Therefore, seismic design criteria and NPP safety standards for operation that were established with inaccurate maximum earthquake data can possibly be weaker against earthquakes in reality.

3. Distinctiveness of Korean nuclear energy

After the Fukushima accident in 2011, a large number of nations that planned to use nuclear energy, or already had NPPs, entered intense discussions concerning their plans [9]. A serious accident anywhere affects the public's view of nuclear power everywhere [10]. The Fukushima accident has influenced public attitudes toward nuclear energy in Korea. There have been several distinct reasons why public acceptance of NPPs in Korea is sensitive to earthquakes after the Fukushima accident, apart from the geographical factors that are related to Korea's close distance to Japan.

3.1. *Effects of Gyeongju earthquake*

As Table 3 shows, magnitude 5.1 and 5.8 earthquakes occurred in Gyeongju, Korea, where six NPPs are located, on 12th September 2016. These earthquakes recorded MMIs of 5 and 6, with buildings shaken and walls cracked. The unexpected seismic shock attracted much attention and raised concerns about earthquake hazard and risk near NPPs; previously, this was regarded as an area that was relatively safe from large earthquake hazard. In addition, it can be confirmed in Table 4 that more than 600 minor seismic aftershocks occurred afterward. The Korean Peninsula has predominantly been recognized as safe against large-scale earthquakes, but the Gyeongju earthquake has evidence to show that the traditional recognition of earthquakes could be wrong.

After the accident in Fukushima, unease about nuclear accidents spread; the Gyeongju earthquake further increased anxiety about nuclear energy. As shown in Fig. 3, public support for nuclear energy and awareness of the need for NPPs dropped steadily. Six out of 10 people (61.3%) consider that there should be no new construction of NPPs after the Gyeongju earthquake. Moreover, resident acceptance of new NPP construction hit its lowest point of 18.9% (50.5% in 2005, 27.5% in 2010, and 19.6% in 2015). Generally, government policy and general opinion act as important judgment factors for public acceptance because the public has extremely limited knowledge about NPPs. Since the Fukushima accident, policies for nuclear energy around the world are changing. South Korea also permanently stopped Kori Unit 1, which saw its design life expire in June, 2017; Korea also interrupted all procedures for NPPs under construction. If these kinds of policies are cumulative, it will make it impossible to operate NPPs in the future.

Table 2
Distance for excessive of OBE by earthquake magnitude.

Earthquake magnitude	3.5	4.0	4.5	5.0	5.5	6.0	6.8
Distance from origin (km) for exceeding OBE	N/A	5	10	30	60	100	150

OBE, Operating Basis Earthquake.

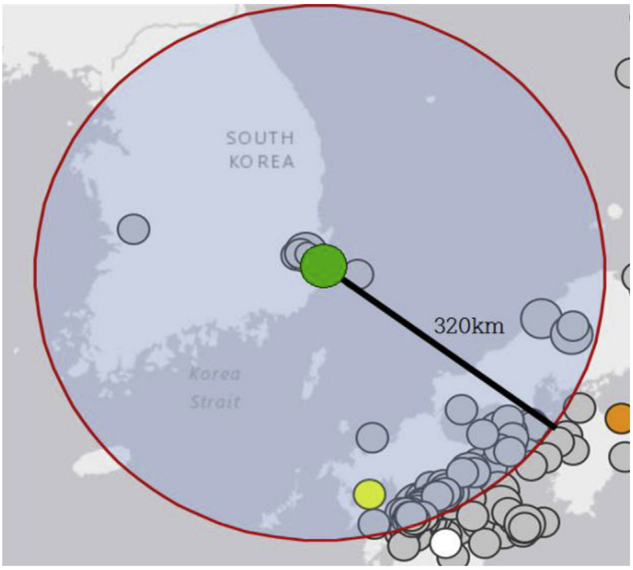

Fig. 2. Minor earthquake (2.0–3.9) status in 320 km range from Wolsong NPP site in Korea from 2010 to 2017 (https://www.usgs.gov).
NPP, nuclear power plant.

Table 3
Gyeongju earthquake (http://web.kma.go.kr).

Earthquake properties	Foreshock	Mainshock
Origin time	2016 Sep. 12 19:44 32 sec	2016 Sep. 12 20:32 54 sec
Epicenter	N: 35.7666°, E:129.1879°	N: 35.7610°, E:129.1878°
Magnitude	5.1	5.8
MMI	V (Gyeongju, Daegu)	VI (Gyeongju, Daegu)

3.2. *High density of NPP complex*

Table 5 shows the results of selecting the top 10 countries with the highest NPP capacity density throughout the world. South Korea operated NPPs with a capacity of 22,505 MW for a total area of 97,202 km^2; the density was 0.2257 MW/km^2. This is the highest density among countries having more than 10 NPPs. Japan's value, the second largest, is 0.1052, half of South Korea's. The population density of NPP sites is more serious in Korea. The Kori NPP has a population of 3.80 million within a radius of 30 km. In addition, Wolsong, Hanul, and Hanbit, all NPPs in South Korea, are among the top ten, making up the world's largest NPP complex, as shown in Fig. 4. This high density of the NPP complex means that the amount of radiation could be large and damage caused by an NPP accident could be much greater. Considering this, Korea's NPP could be far more dangerous than the Fukushima NPPs when calculating “potential risks”. South Korea is less likely to have an earthquake than Japan; however, once an accident occurs, the risk may increase greatly. There are many residents living near the Kori NPP site, within a radius of 30 km—22 times more people than those lived near the Fukushima NPP (about 170,000 people).

The 2011 Fukushima accident raised awareness around the globe that accidents can occur simultaneously in an NPP complex. At that time, three out of the six Fukushima NPPs experienced fuel melting [11]. The government has pointed out that South Korea has a lower probability of earthquakes than Japan; however, fear of earthquakes, with their great uncertainty, directly affects public acceptance, especially after the public witnessed the Fukushima accident in Korea's nearest neighboring country and after the Gyeongju earthquake.

Table 4
FFrequency of aftershock after Gyeongju earthquake (20 June 2017) (http://web.kma.go.kr).

Magnitude	1.5–3.0	3.0–4.0	4.0–5.0	Total
Total	601	21	1	623

4. Materials and methods

Benefits expected through nuclear energy, such as economic development of the country and stable supply of energy, are equally distributed to members of society as a whole; however, the risk of a nuclear accident is a tendency that is unduly popular among local residents in areas near nuclear facilities [12]. Therefore, local residents who have to accept the direct risk of the NPP are more sensitive to the risk than is the general public, and therefore, the acceptability of NPPs can greatly deteriorate, even for small risk factors. In this study, it is assumed that the occurrence of an earthquake, even a minor earthquake, may affect public acceptance of residents who already experienced directly the Gyeongju earthquake and, indirectly, the accident at Fukushima. Based on these circumstances, how public acceptance has changed and how to improve it were considered.

4.1. *Setting up the hypothesis*

In this study, based on the fact that an earthquake of the Fukushima level could have a significant impact on the safety of NPPs and that the public is concerned about NPP accidents caused by earthquakes, we derived the following hypothesis.

- Even a minor earthquake not affecting safety of NPPs can have an adverse effect on public acceptance of NPPs.
  - Study hypothesis 1. In general, the public will not be seriously concerned about nuclear power plant accidents due to earthquakes in the absence of any information on the earthquake.
  - Study hypothesis 2. Information on an earthquake can make the public aware of the potential risk of NPPs, whereby acceptance of nuclear energy can deteriorate.
  - Study hypothesis 3. Even if it is a weak earthquake, vibrating motions that the public can feel may seriously deteriorate resident perception of nuclear safety.

4.2. *Methodology*

This study conducted a questionnaire survey to empirically clarify the relation between the occurrence of a minor earthquake and deterioration of public acceptance of nuclear energy and its grasp of effective countermeasures. Survey was also conducted for local residents, those who live in the Gyeongju area, where the earthquake on September 12 2016 occurred; these residents can represent opinion leaders. The survey is a method of collecting and analyzing data as a questionnaire for respondents selected at specific points in time according to the sample plan; it is a method to analyze the accuracy, generalize the ability, and evaluate the convenience; it can be used as a methodology of social science research and is widely used [13]. Because of these kinds of the characteristics of the questionnaire survey, it is an appropriate method to achieve the purpose of this study. To collect a relatively accurate survey of subjects and results, the survey was conducted through group surveys with the help of the government office (Yangnam-myeon office), from June 12, 2017 to June 23, 2017.

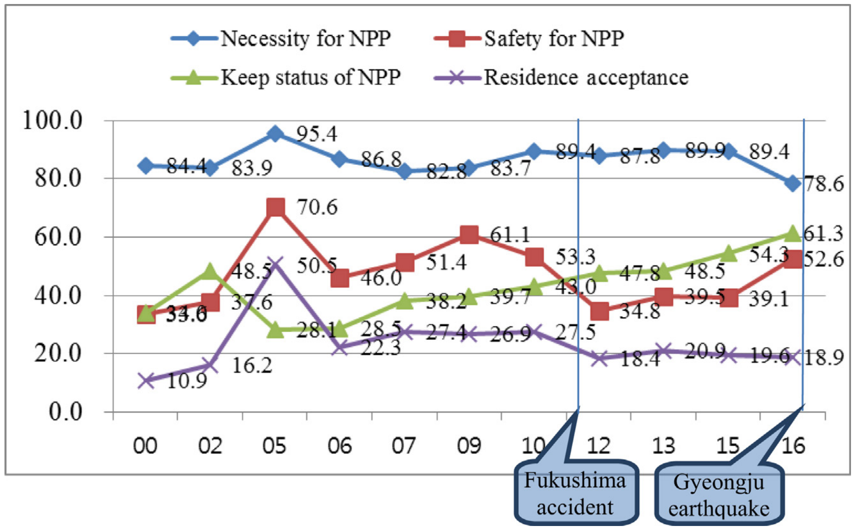

Fig. 3. Public awareness on nuclear power (Jan. 2017) (http://www.knea.or.kr).
NPP, nuclear power plant.

Table 5
Top 10 countries with capacity density of NPP (June 2017).

Rank	Country	Area (km^2)	Capacity (MW)	Unit (EA)	Capacity density (MW/km^2)
1	South Korea	99,720	22,505	24	0.2257
2	Japan	377,915	39,752	42	0.1052
3	France	643,801	63,130	58	0.0980
4	United Kingdom	243,610	8,918	15	0.0366
5	Ukraine	603,550	13,107	15	0.0217
6	Sweden	450,295	9,740	10	0.0216
7	China	9,596,961	32,384	37	0.0038
8	India	3,287,263	6,240	22	0.0019
9	Russia	17,098,242	26,111	35	0.0015
10	Canada	9,984,670	13,554	19	0.0014

NPP, nuclear power plant.

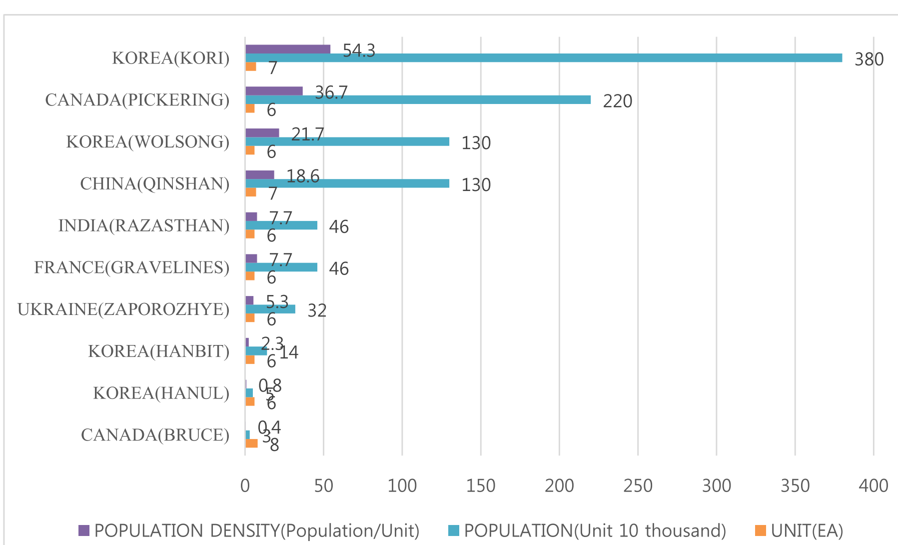

Fig. 4. Top 10 rank of population density in 30 km range from one NPP site (Jun. 2017) (https://www.iaea.org/PRIS/WorldStatistics).

4.3. Research procedure

In this article, to verify the hypothesis based on more accurate data, the research was conducted through the process shown in Fig. 5. First, this article prepared a hypothesis that the earthquake could affect public acceptance of NPPs and derived questions to determine the appropriate information to support that hypothesis. Then, this study selected the appropriate survey subjects to

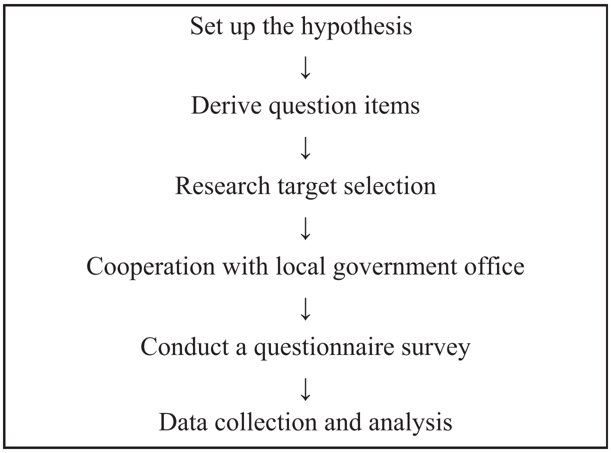

Fig. 5. Research procedure.

Table 6
Demographic characteristics of survey population (Jun. 2017 Yangnam-myeon).

Gender	Male	3,476	53%	100%
	Female	3,086	47%	
Ages	10s and less	857	13%	100%
	20s	717	11%	
	30s	653	10%	
	40s	934	14%	
	50s	1,327	20%	
	60s	1,052	16%	
	70s and above	1,075	16%	

conduct the survey. In addition, it conducted a questionnaire survey through the cooperation of regional offices to ensure accurate and smooth research. The last part was the collection of data that could support the hypothesis and analysis to ensure reliability.

4.4. Characteristics of target population

As mentioned earlier, the survey target is the residents living in the vicinity of an NPP, who have often experienced the minor earthquakes. Therefore, Yangnam-myeon, the nearest area to the Wolsong NPP, was selected for the survey. The statistical distribution of the population around the NPP surveyed in this study is shown in Table 6.

4.5. Sample and sampling method

In this study, to conduct a reliable survey, a questionnaire was used to survey people who could reflect the opinions of local residents. Therefore, those who had a direct interest in nuclear power plants are excluded. In addition, workers working in nuclear power plants or subcontractors were also excluded from the survey. As a result, the questionnaire survey was conducted for people who can represent the local residents of the administrative area, the representatives of small groups, and workers of regional government offices.

Respondents consisted of individuals, as shown in Table 7, whose opinions could be representative of the opinions of locals and who could influence the acceptability of the nuclear power plant.

Respondents selected in this way filled out surveys through periodical meetings conducted by government offices; 112 persons participated in the survey. Data from 109 persons were used in this study, excepting three who answered inappropriately.

4.6. Setting up questions

This study asked questions to prove minor earthquake impact on public acceptance of NPPs and to ask about the necessity of management; it also presented questions that could suggest an improvement plan.

Realizations of the residents about minor earthquakes can be categorized into not knowing at all, knowing only information about the minor earthquake, or directly experiencing the minor earthquake. To investigate the changes of public acceptance of residents about the safety of NPPs in the event of a minor earthquake, the questionnaire consisted of three questions as shown in Table 8. The questions were evaluated using a 10-point scoring method, with "1" point meaning the highest concern, whereas "10" points means no concern at all.

To solve the problem of deterioration of public acceptance, we constructed the questions in Table 9, asking for specific ways to improve public acceptance of nuclear power acceptance by residents. The answers to the questions were made by choosing only one of several options at the individual level.

5. Survey results

To grasp the influence of minor earthquakes on public acceptance of nuclear safety, this study created a graph to sum up the number of persons responding to each step and each question. Analyzing the changes in subsequent graphs, results verified the hypothesis that a minor earthquake can bring about a worsening of residual public acceptance. A total of 112 data sets were collected, and 109 data sets were used for the final analysis, except for three fraudulent responses.

5.1. Data analysis method

To verify the hypothesis, using SPSS (Statistical Package for Social Science) (IBM SPSS Statistics, version 25), this study conducted a reliability survey (Cronbach's α) on questions 1–3 based on the collected data. It is thought that reliability was secured with the value of Cronbach's α being at least 0.6, and the reliability of each variable was verified. Moreover, to investigate the influence of each variable on the hypothesis, in the case in which there is no information on the earthquake (Study hypothesis 1), in the case in which there is limited information on the earthquake (Study hypothesis 2), and when the earthquake was felt directly (Study hypothesis 3), multiple regression analyses were conducted. In addition, regardless of the hypothesis verification, the content of the question used to secure the opinion of the residents measured only standard error using frequency analysis for each question.

5.2. Results of reliability verification and error analysis

In this study, exploratory factor analysis was conducted to explain the correlation of the questions that support the hypothesis based on the collected data. The results are shown in Table 10. Confirming the results of the exploratory factor analysis, the change in perception of nuclear power plant safety due to the minor earthquake has an overall value of 71.275%. In addition, the exploratory factor analysis result for each question is 85.6% for the first question, 93.4% for the second question, and 73% for the third question, so that the explanatory factors for the hypothesis are sufficient. Considering that this research is utilizing variables of 60% or more from the social sciences as the criterion for choosing the number of factors, the results are satisfactory.

Moreover, the reliability for each question was analyzed. As a result, it was confirmed that there were no questions that would

Table 7
Composition of sample respondents.

Variety of respondents	Number of people
Head of village	22
Leader of women's society	22
President of young man	30
President of new village	22
Worker of regional government	21

Table 8
Questions to investigate the changes of public acceptance.

Questions	
1	How much do you think that an NPP is safe when you did not feel a minor earthquake or have not heard any information about the minor earthquake?
2	How much do you think that an NPP is safe when you did not feel a minor earthquake but you are informed of the minor earthquake occurred in the surrounding area?
3	How much do you think that an NPP is safe when you feel the shaking motion of a minor earthquake even it is weak?

Table 9
Questions to investigate the opinion of residents.

Questions	
4	Can you trust the safety of an NPP which was announced through mass media after the minor earthquake?
5	If you cannot trust the announcement of the media, do you think what kinds of information can improve the confidence in the safety of the NPP?
6	Do you think the management of a minor earthquake is necessary, even most NPPs have been designed to withstand against magnitude 7 earthquake?

Table 10
Total variance explained for questions 1–3.

Questions		Variable
1	No information on the earthquake	0.856
2	Limited information on the earthquake	0.934
3	The earthquake was felt directly	0.730
Eigen value		2.138
Variance (%)		71.275
Cumulative (%)		71.275

Kyser-Meyer-Olkin [KMO] = 0.570, Bartlett's x^2 = 134.665 ($p < .001$)

impair the consistency of the results. Table 11 shows the results of the reliability analysis, according to which the reliability of the answers to the questions (question 1–3) used to verify the hypothesis that an earthquake may affect public acceptance had a recorded Cronbach's α of 0.791. As the field of social science believes that a value of 0.6 or more is reliable, the reliability of the results of this research was satisfactory.

In addition, the standard error for each question on improving public acceptance of NPPs is shown in Table 12. The lower the standard error, the more representative the hypothesis is. Therefore, each question for improvement of the residents' acceptance has a high degree of representation.

Table 11
Reliability statistics for questions 1–3.

Cronbach's α	Number of variable
0.791	3

Table 12
Standard error for question 4–5.

Questions		Standard error
4	Reliability for report about NPP after minor earthquake occurrence	0.205
5	Further information you would like to know	0.083
6	The need for weak earthquake management	0.159

5.3. Effect of minor earthquake

According to the results of the data survey and analysis, the change in perception of nuclear safety of residents in response to earthquake occurrence is shown in Fig. 6. If there is no information about the earthquake, 58% of respondents showed a positive response about NPPs (6 points or more). However, if respondents feel the earthquake directly, only 6% of respondents showed a positive response about NPPs. As residents perceive earthquakes more directly, the public acceptance of NPPs decreases sharply.

Potential risks and benefits have the greatest influence among the main elements forming public acceptance of NPPs. Risk perception by the public for nuclear power is a major cause of anxiety and controversy. Public perceptions about energy alternatives, such as nuclear power, are related to the perceived risk and danger [14]. In situations in which a resident's perceptions of potential risks are weakened, it is possible to gain positive recognition from resident due to social economic benefits, political relations, increased employment, and social contribution activities from NPPs. In other words, various activities to improve the public acceptance of NPPs are normally effective for specific groups. However, even in a group that has a positive conception of NPPs, owing to obtaining various benefits from them, when they heard information on a minor earthquake, or felt one, the sense of anxiety about nuclear energy will increase. This result shows that the scale of earthquake that can be felt by a person can greatly influence public acceptance of residents. In addition, the seismic standards of designed nuclear power plants are higher than those of minor earthquakes, but the responses of residents to the need for minor earthquake management are shown in Fig. 7. According to the results, even a small earthquake does not directly affect the safety of nuclear power plants, but most respondents thought that management for a minor earthquake is necessary.

A total of 104 of the 109 (95%) respondents thought that management for a minor earthquake was necessary because the occurrence of the earthquake has a great influence not only on the safety of residents but also on their economic activities. Gyeongju has a long history; its tourism industry is well developed. However, owing to the existence of the NPP and the occurrence of the

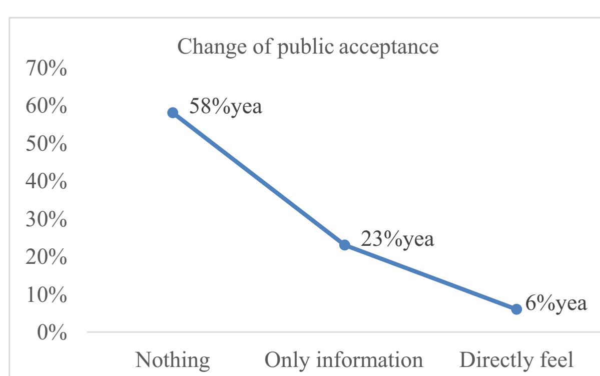

Fig. 6. Change of public acceptance depends on situation.

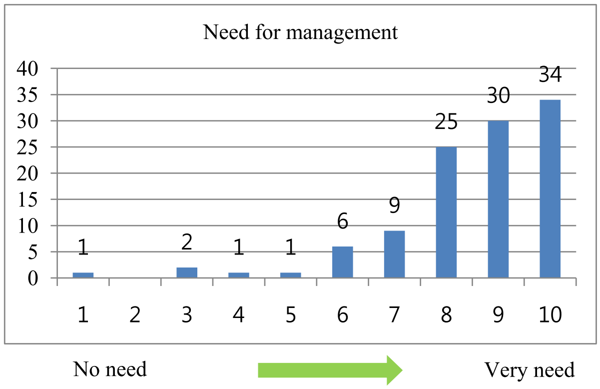

Fig. 7. Need for management of minor earthquake.

earthquake, the number of tourists decreased. According to the "Regional Economic Report" announced by the Bank of Korea in November 2016, as shown in Fig. 8, the number of tourists throughout the Gyeongju area decreased by 47.0% compared with the same quarter of the previous year, to 569,000 people; the total decrease was 740,000 people, or 58.3%, by October. For this reason, residents would like to not only ensure their own safety but also prevent the decrease of visitors by managing minor earthquakes. As a result, most local residents felt that management for minor earthquakes was necessary. Depending on the occurrence of a minor earthquake, deterioration of resident's perceptions of nuclear safety informs the fact that minor earthquakes induce resident consideration of potential risk to NPP and has a large influence on residual public acceptance.

5.4. Measures to improve public acceptance

When a minor earthquake occurs and the public acceptance deteriorates, it is possible to reduce the public concern regarding NPPs only by appropriate measures. Therefore, information that can satisfy the demands of the public must be provided. However, little information has been given to local residents after most minor earthquakes that have occurred. They just can listen to media coverage in which it is said that the NPP is safe. Fig. 9 indicated that 92 respondents among the 109 respondents (84%) considered that reports on the reliability of NPP announced through the media were insufficient to mitigate their anxiety.

Provision of insufficient information could lead to misinformation about the NPP or distrust of NPP safety. To prevent such adverse effects, it is necessary to provide information reflecting opinions that can alleviate the anxiety of residents. Fig. 10 shows the results of the evaluation survey of the agencies providing residents with earthquake-related information when a minor earthquake occurred.

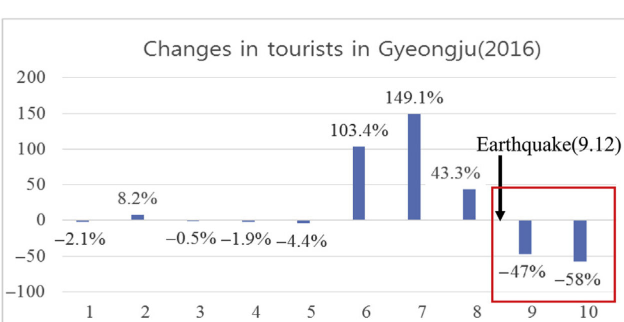

Fig. 8. Changes in tourists in Gyeongju compared with 2015.

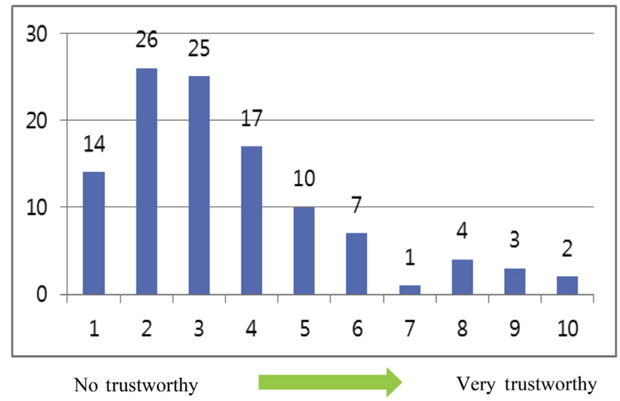

Fig. 9. Reliability for report about NPP after minor earthquake.

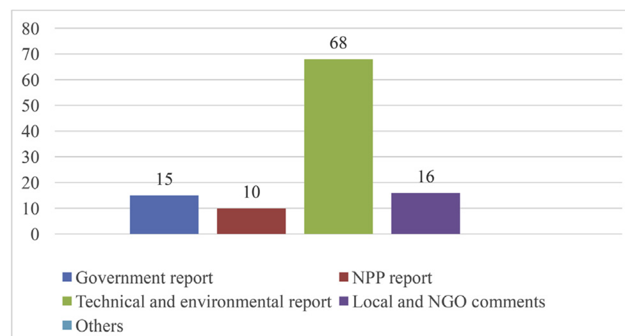

Fig. 10. Preferences for information agencies.
NGO, non-governmental organization; NPP, nuclear power plant.

According to the results of the survey, technical and environmental reports on nuclear safety and the viewpoints of experts are very important factors to increase public acceptance because most local residents lack expert knowledge of NPPs and cannot easily obtain detailed information. Therefore, they want to confirm that the safety of their lives and property is guaranteed through more objective data.

Therefore, research is needed to develop standards related to the safety of NPPs based on various variables caused by minor earthquakes. For example, there is the change in groundwater as one set of objective data that can be used to evaluate the safety of NPP and the potential risk of severe accidents. Table 13 shows that anomalous water level and electrical conductivity changes can be observed by groundwater even under the influence of a minor earthquake of magnitude M 3.1 [15].

The reason that the water level and electric conductivity change of the groundwater is the expansion of ground and the change of the chemical composition of the soil [15]. The stability of the ground and the soundness of the water quality are very important operating conditions of an NPP. Therefore, changes in the operating environment of the NPP caused by minor earthquakes can affect nuclear safety. From this viewpoint, it is necessary to establish more detailed and realistic criteria for evaluating minor earthquakes. In a case in which it is possible to provide information to residents in cooperation with various safety standards of NPPs on many kinds of indicators that change according to the earthquake, it will be possible to reduce the concern of the residents against the earthquake. Therefore, it is indispensable to develop various types of earthquake prediction and evaluation technology, such as

Table 13
Indicates by the effect of the earthquake on the Yeongdeok area (M 3.1).

Monitoring station	Water level		Electric conductivity		Distance from Yeongdeok
	Normal daily variation	Abrupt change	Normal daily variation	Abrupt change	
Gimcheon	±0.03 m/day	0.22 m	±5 μS/cm	80 μS/cm	137 km
Gangjin-Seongjeon	±0.2 m/day	2.5 m	N/A	N/A	333 km
Gongju-Jeongan	±0.02 m/day	0.6 m	±5 μS/cm	40 μS/cm	220 km

methods to conduct measurement of changes in groundwater, chemical conditions of soil, and changes in atmospheric ions, to ensure the earthquake safety of NPPs.

6. Conclusion and discussion

Since the Fukushima accident, public relations concerning nuclear energy policy have entered a new phase to enhance the public acceptability of NPPs. Especially, this is because public opinion, which has shown positive support for NPPs in Korea, rapidly reversed after the Gyeongju Earthquake and the many aftershocks. Public relations and public communication activities, so that the general public can relieve the anxiety about NPPs, can recover their support for NPP [16]. However, there has been a lack of comprehensive research on how minor earthquakes are related to public acceptance of NPPs. While the government and NPP operators have concentrated only on measures for the impact of large-scale earthquakes on NPPs, trust in NPPs was revealed as a factor influencing the acceptance of NPPs; the overall sense of trust can be influenced by recognizing the benefits and risks as well as by providing mediation between these two sources [17].

Public opinion is affected by focusing events [18]. “These are events that are sudden, relatively rare, (and) that can reasonably be defined as harmful” [19]. Earthquakes are the biggest recognized risk that the public can directly perceive. Therefore, this study analyzed the change of resident perception according to circumstances of a minor earthquake and performed surveys to determine whether the minor earthquake virtually influenced resident public acceptance of NPPs. The results of the survey on the relationship between the minor earthquake and public acceptance and the necessity of management are summarized as follows. First, the criteria for earthquake correspondence and evaluation in Korea were made for large-scale earthquakes and constructed on the basis of an insufficient data base. Second, the public recognizes minor earthquakes as potential risks even if those earthquakes cannot affect the safety of equipment and facilities of NPPs. Moreover, not only the experience of earthquakes but also the occurrence information seriously deteriorates public acceptance. Third, management measures for minor earthquakes, using more specific and technical data, are needed to improve public acceptance. This study confirmed that a minor earthquake that had not had a major influence on the operation of an NPP so far has had a large influence on public acceptance among people who can induce a change in nuclear policy. Therefore, to operate NPPs continuously, it is necessary to have a way to improve the people's acceptance more actively. If information that has reasonable technical evidence such as changes of the various environmental indicators, showing that there is no potential risk from a minor earthquake, is given to general people, public acceptance will not worsen when a minor earthquake occurs. For this purpose, it is necessary to develop techniques that can accurately analyze the occurrence of minor earthquakes and the changes in the environment that may occur due to the earthquake, through continuous research and investment. Moreover, based on these data, standards must be established to ensure the safety and integrity of nuclear power plants. Therefore, discussions should be undertaken on policies and methods to more actively share with residents technical and objective data about minor earthquakes related to safety of power plants, to assuage the anxiety of residents around the power plant. The importance of nuclear power plants to adapt to the era of climate change is increasing. Under this circumstance, for sustainable development of nuclear energy, management of earthquakes that can deteriorate public acceptance of NPPs is absolutely necessary. If appropriate technology and a policy plan for minor earthquakes are established and active communication with the public about their anxiety is maintained, public acceptance of nuclear energy can be improved and stable development of nuclear energy can be achieved.

Conflicts of interest

All financial support for writing this paper was supported by KINGS (KEPCO INTERNATIONAL NUCLEAR GRADUATE SCHOOL).

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.net.2017.11.013.

References

[1] C.S. Chung, Structural integrity evaluation of nuclear seismic category IIA 2" globe valve for seismic loads, J. Korea Acad. Ind. Cooperation Soc. 9 (2008) 1500–1505.
[2] J.S. Shim, J.S. Kim, An exploratory study on the effects of conflict frames on the acceptance of nuclear power plant: application of the PLS SEM, Korea J. Pol. Anal. Eval. 25 (2015) 1–27.
[3] Korea Hydro and Nuclear Power, Nuclear Power Plants Standard Procedure against Earthquake, Standard Procedure Abnormal-00, 2013.
[4] U.S Nuclear Regulatory Commission, Earthquake Engineering criteria for nuclear power Plants, 10 CFR 100.23 Appendix S to Part 50.
[5] K.H. Yun, E.J. Jung, Criterion of ground-motion levels for post earthquake procedure based on the seismic intensities of Korean earthquake, J. Earthq. Eng. Soc. Korea 3 (2016) 77–87.
[6] Korea Legislation Research Institute, Earthquake Recovery Plans Act, Earthquake Recovery Plans Act, Chapter I General Provisions, vol. 19, 2014. Article 2 (Definitions), Act No. 12844.
[7] Nuclear Safety and Security Commission, Nuclear Safety Commission Bulletin, Technical Standards for the Location of Reactor Facilities, Nuclear Safety Commission Bulletin 2014-010, 2014.
[8] S.W. Kim, K.T. JO Assembly man office., Policy discussion meeting for safety measures of nuclear power plants, vol. 30, National Assembly Policy Documents, 2016.
[9] E.I. Park, J.Y. Ohm, Factors influencing the public intention to use renewable energy technologies in South Korea: effects of the Fukushima nuclear accident, Energy Pol. 65 (2014) 198–211.
[10] J.R. Vitázková, E. Cazzoli, Common Risk Target for severe accidents of nuclear power plants based on IAEA INES scale, Nucl. Eng. Des. 262 (2013) 106–125.
[11] European Nuclear Safety Regulators Group, EUStress-tests and follow up.
[12] S.K. Jo, A comparative analysis of acceptability of radioactive waste repository policies, Korean J. Public Pol. 13 (2003) 59–77.
[13] K.H. Ahn, B.H. Lim, Social Research Method and Analysis, Hakhyunsa, Seoul, 2005.

[14] T.F. Kwok, C.H. Yeung, Y.A. Xu, Swaying public opinion on nuclear energy: a field experiment in HongKong, Util. Pol. 46 (2017) 48–57.
[15] N.C. Woo, J.Z. Piao, J.M. Lee, C.J. Lee, I.O. Kang, D.H. Choi, Abnormal changes in groundwater monitoring data due to small-magnitude earthquakes, J. Eng. Geol. 25 (2015) 21–33.
[16] D.J. Kim, B.H. Jung, J.H. Jang, A comparative analysis of social and personal level acceptance of nuclear energy, Korean J. Journal. Commun. Stud. 57 (2013) 214–238.
[17] J.S. Sim, Trust in nuclear power plant, perceived risk and benefit, and acceptance, Korean Pol. Stud. Rev. 18 (2009) 93–123.
[18] B.I. Page, R.Y. Shapiro, The Rational Public. Fifty Years of Trends in American's Policy Preferences, University of Chicago Press, Chicago, 1992.
[19] E.W. Latré, T.J. Perko, P.T. Thijssen, Public opinion change after the Fukushima nuclear accident: the role of national context revisited, Energy Pol. 104 (2017) 124–133.