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Critical issues in emergency planning for nuclear power plant accidents

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Abstract

Accidents at Nuclear Power Plants (NPP) are perhaps the most alarming situations for both the public and emergency services. Nuclear accidents provide us with an opportunity to learn from the experience in order to improve the disaster response system and prevent new tragedies. Experience from past disasters clearly shows that nuclear emergencies can lead to relatively low levels of exposure, but at the same time can cause conflicting reactions among population that are almost impossible to control. We did a review of past NPP accidents including the Three Mile Island (TMI), the Chernobyl, and the Fukushima accidents, to analyze public's evacuation behavior in nuclear accidents and found that absence of people's preparedness to radiological emergency was the main indicator of uncontrolled evacuation. It is therefore necessary to increase knowledge about radiation and convey to people how to choose the right protective measures and effectively control an emergency. To do this, it is important to include special pre-accident programs in the preparation plans and rely on them during a real emergency. We believe that the implementation of such a multidisciplinary concept including engineering emergency planning along with the social aspects, can significantly improve the existing emergency plans. This paper provides policymakers with valuable recommendations to address gaps in terms of nuclear disaster preparedness and assistance.

1. Introduction

Ask yourself how well do you know what to do in case of a nuclear emergency? If so, will you strictly follow all the pre-agreed actions? Today, nuclear power industry is one of the most reliable sources of energy, both economically and environmentally sustainable, and also meets the many challenges of a rapidly developing world. Nuclear energy has proven its effectiveness over many decades, becoming an integral part of the global energy balance (Saidi and Mbarek, 2016). Hovewer, while this greatly improves people's quality of life and contributes to zero carbon emissions, there may be critical safety concerns as most of the substances involved in manufacturing processes are hazardous materials with radiological characteristics. For instance, in the event of a nuclear accident, the subsequent release of radioactive components into the environment often results in serious losses of life and property which usually lasts for years and are difficult to eliminate. Nuclear accidents such as the Three Mile Island (USA, 1979), the Chernobyl (Ukraine, 1986), and the Fukushima (Japan, 2011) led to various serious causalities and environmental damages (Fesenko et al., 2021; Flynn, 1982; Kawaguchi and Yukutake, 2017). To be prepared for a nuclear disaster, the community living near a Nuclear Power Plants (NPP) must have appropriate response and training plans in place (Handl, 2016). Evacuation in case of nuclear accident is considered one of the most effective ways to respond, prevent and mitigate hazards from the disaster. Fast evacuation is needed in order to avoid the harmful impact of radiation. However, evacuation is a complex process that involves either technical or phycological aspects. It includes the removal of the population from risk areas, their shelter, return home or even permanent displacement. In addition, there are such approaches as mandatory evacuation, voluntary evacuation, and recommended evacuation when residents are given a choice to leave or to stay. There is another term for evacuation – a shadow evacuation or "spontaneous" evacuation. The so-called shadow evacuees are a group of people who decide to leave despite being advised to stay (Zhang et al., 2020). Shadow evacuation occurs for a variety of reasons, but it is mainly influenced by the perception that the impending hazard will be hostile,

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whether it is so or not. Therefore, in conditions of urban evacuation, the mobility and responsiveness of people do not always have positive results, but rather can exacerbate the situation. But there were also cases when people delayed the decision to evacuate, exposing themselves to unnecessary risks (Shimada et al., 2018). Evacuation planning and its further implementation should be built on the principle of socio-psychological foundations and rely on the empirical data relevant to mass behavior in such situations. To develop an effective evacuation policy, it is critical to understand how residents respond to evacuation warnings, including their choices of stay or leave, if to leave then when, which routes to take, etc.

The main objective of this research is devoted to the review and analysis of public response and behavior during the evacuation in past nuclear accidents with the aim to identify the major problems in emergency evacuation planning.

2. Overview of evacuation following the past NPP accidents

The extent of the radiological disaster is measured by the so-called International Nuclear and Radiological Event Scale (INES), which has seven levels of severity (Webb et al., 2006). Events are ranked by degree of impact on people and the environment, starting with the first and ending with the seventh. There have been several accidents since the advent of nuclear energy and throughout its history, but only three accidents have been termed as the gravest technological catastrophes. Below are their brief descriptions.

2.1. The Three Mile Island experience

Three Mile Island catastrophe, accident in 1979 at the American NPP, was the most serious in the history of the USA. A series of equipment and technical failures, human mistakes in operating procedures and wrong decisions in the first minutes of the failure led to the partial reactor core, thus assigning the fifth level of accident on the INES scale (Bavelacqua, 2016).

Fortunately, it was concluded that there were no contamination of soil and water and little number of radioactive materials were released into the atmosphere, which had a negligible effect on public's health and environment. Therefore, the emergency response included advisory evacuation on the initial stages and voluntary evacuation in subsequent days. Fig.1 shows the map of evacuation zones around the NPP. On the first day, government announced advisory evacuation within the area of 0-8 km only for pregnant women and pre-school children along with the shelter-in-place for all others within 8-16 km. On the second day, voluntary evacuation was stated for the entire 0-16 km area, and later next day, for the entire 0-32 km zone. Despite no formal evacuation order was done in the first day, more than 100,000 people decided to leave the area. As a result, the total evacuation amounted to 63% from the 0-32 km zone, and only 37% of the entire population within this area preferred to stay. As the questionary surveys showed, the main factors influencing the decision to evacuate were spatial proximity to the station, the inability to assess the risk of danger, as well as initial fear and a sense of not knowing what to expect (Stallings, 1984).

After the accident, the exclusion zone was not established, and after a few months, residents were able to return home.

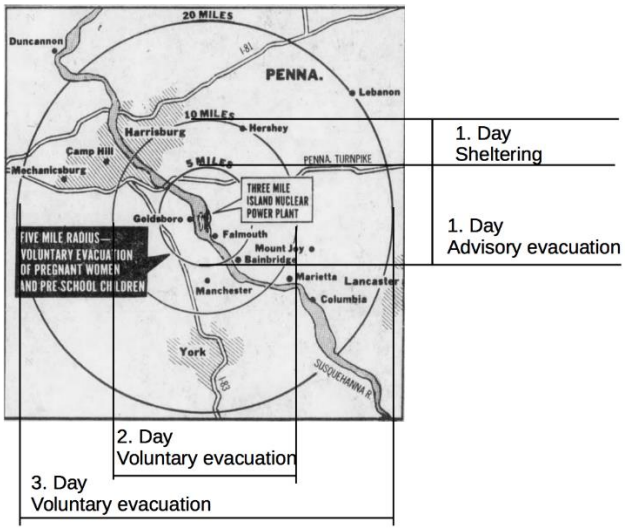

Figure 1. Map of evacuation zones following the Three Mile Island accident (modified from the original source https://www.newspapers.com).

2.2. The Chernobyl experience

The Chernobyl disaster occurred in 1986 in the Ukrainian Soviet Socialist Republic, is still considered to be the worst accident in the history of nuclear power industry having the level 7 of INES (Bavelacqua, 2016). During a technical test, one of the reactors went out of control, which led to an explosion and subsequent fire. As the result, the reactor building was completely destroyed, and large amounts of radiation was released into the atmosphere.

Unfortunately, information about the accident was withheld on the political grounds, residents learned rumors and could not believe that accident was true. Even when officials announced the evacuation, it was said that it would be temporary and implemented as a protective measure in the event of a sudden hazard. However, by that time, all population living in the immediate vicinity of the station had already received the highest doses of radiation. In the long run, all people from the 30-km radius zone were displaced, as well as from other "hotspots" identified over time, which still remain abandoned. Evacuation was carried out only as mandatory and under the strict control of the government. Ukraine still continues to bear – by itself – the main social burden of dealing with the consequences of the Chernobyl disaster.

2.3. The Fukushima-Daiichi experience

The last major accident in the nuclear industry occurred in Japan in 2011 as the result of the Tohoku Earthquake of magnitude of 9.0-9.1 (Bavelacqua, 2016). Earthquake-induced tsunami struck the reactor's building resulting in power loss at the Fukushima-Daiichi NPP. In the absence of power, the cooling systems failed in three of the six reactors, and their cores thereafter

overheated thus, joining Chernobyl to have the level 7 according to the INES.

Post-Fukushima emergency response included mandatory and voluntary evacuations, temporary sheltering, and relocation (The National Diet of Japan, 2012). On the fifth day after the accident, Japanese authorities ordered a compulsory evacuation within a radius of 0-20 km and a simultaneous shelter-in-place within 20-30 km radius (Fig.2). And ten days after this decision, a voluntary evacuation was announced in the radial zone between 20-30 km (what was previously under the sheltering order). However, by the time the order for voluntary evacuation was adopted, almost the entire population in the 20-30 km zone had already left. Risk and a sense of fear led many people to perceive the situation as more critical than it really was. In addition, due to traffic congestions caused by this excessive evacuation, many people accidentally fled to much more polluted areas.

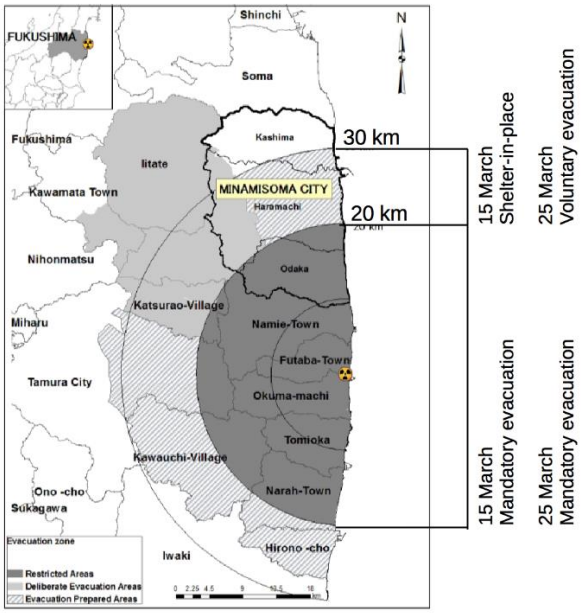

Figure 2. Map of evacuation zones following the Fukushima disaster, 2011 (modified from the original source (Do, 2019).

Table 1. People's returns after the lifting of evacuation orders (Do, 2019).

Region	Date of lifting the evacuation order	Population prior to accident	Population as of 2020
Futaba	March 2020	6,932	0
Katsuaro	June 2016	1,530	420
Kawamata	March 2017	15,569	**12,170**
Kawauchi	October 2014	2,820	**2,044**
Litate	March 2017	6,209	1,318
Minamisoma	July 2016	70,878	**59,005**
Namie	March 2017	20,905	1,923
Naraha	September 2015	7,700	3,710
Okuma	April 2019, March 2020	11,570	847
Tomioka	April 2017, March 2020	16,000	2,128
Tamura	April 2014	40,422	**35,503**

Note: The rate of returns more than 70% are marked in bold. Naraha's returns rate is 48% and all the rest are less that 30%.

Sometime later, owing to the decontamination efforts, Japan managed to recover some of the affected regions and lift the evacuation orders there, allowing people to return home (Table 1). A few chose to return, but the majority refused. Evidence from several cohort studies have shown that the main reason evacuees do not return home is the fear of radiation (Do, 2019).

3. Results and discussions: Issues to which attention should be paid in emergency preparedness

It is clear from the brief overview above that the scale of human response immediately following the nuclear accident can be uncertain. In case of Chernobyl, when the government did not release even sketchy details of the accident and generally tried to minimize its severity, the residents, having no idea what was happening, continued to live their normal lives not even trying to shelter in the safer place. In case of the accidents at the Three Mile Island and the Fukushima-Daiichi NPPs, when local authorities declared an emergency almost immediately after the accident, the population perceived the situation ambiguously. Nevertheless, actual nuclear emergencies have shown a high rate of self-evacuation, especially when residents receive incomplete or unclear information about the accident. Communicating with the public immediately after a disaster, when risk perception is low may result in messages being ignored, and vice versa, a sharp convey of information may lead to public panic, limiting the management of the situation. On the whole, we offer the following recommendations for improving the emergency response:

- It is important to focus on pre-accident communication – to develop an educational program on preparedness actions, where people living near the NPP should receive guidance on how to respond immediately after an accident.
- Residents should understand in advance which action is most appropriate for them, if it is evacuation or shelter.
- Information about the possible consequences of a nuclear accident should be clearly explained and detailed, including situations where non-compliance with government requirments could be dangerous.
- Information should aim to minimize uncertainty among the public by providing the most requested information, including the effects of radiation exposure, the protective measures to be taken first, and the length of time people may need to shelter.
- All information and communications should use basic terminology and plain language, avoiding technical legal terms.
- Information provided in the event of an emergency should sound the same as information presented in pre-emergency communication.

Ultimately, without the proper practice of informing the public about nuclear emergencies, a catastrophic accident could become more serious than we can

imagine. It is imperative that we look for and plan ways to inform the public about protective actions in the event of a radiological emergency.

4. Conclusion

In this study, we examined public response to the decision to evacuate in the radiological accident. As an example, we used three accidents at NPP – the Three Mile Island, the Chernobyl, and the Fukushima-Daiichi accidents, since these disasters are the most serious of all that have occurred. The results of this study directly pointed to the urgent need to improve the nuclear emergency management through an interdisciplinary approach by integrating engineering methods and social disciplines. In our future work, we plan to develop and implement these suggestions.

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