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Development of emergency planning zone for high temperature gas-cooled reactor

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ABSTRACT

Emergency planning zone (EPZ) is a basic element of nuclear emergency planning, whose architecture is mainly determined by the characteristics of early light water reactors (LWRs) at present. As a candidate of Gen IV reactors, high temperature gas cooled reactor (HTR) is required to consider the issue of EPZ in current regulation framework of nuclear emergency. The issue we discussed here is based on high temperature gas cooled reactor pebble-bed module (HTR-PM) being constructed at Shidao Bay, Shandong Province, China. Since HTR is much different from LWRs in design concept, system configuration and accident characteristics, the emergency planning developed for HTR can be simplified comparing to the current LWR-based emergency planning. HTR, like HTR-PM, implements inherent safety features and ensures the elimination of severe core damage and large release of radioactive material. So that EPZ needs to be adjusted to match the safety features of HTR to reduce the cost of construction and operation, and enhance the feature of good neighbor. The commonly used technical framework introduced in NUREG-0396, which is documented by Nuclear Regulatory Commission (NRC) is adopted as base to discuss the EPZ issue. The accidents need to be considered during EPZ development, including the design basis accidents (DBAs) and emergency reference release categories (ERRCs), are firstly confirmed according to the accident characteristics of HTR-PM. We conclude that radii of EPZ for plume exposure pathway and ingestion exposure pathway can both be the same as exclusion area boundary, which supports the further simplification of nuclear emergency of HTR.

1. Introduction

At present, the emergency planning of nuclear power plants (NPPs) is developed mainly based on the accident characteristics of early LWRs (NRC, 1978; CNNAEO, 2008). However, the technology development of source term analysis (NRC, 1995) and the improvement of reactor safety (NRC, 1990), especially the gradual construction of advanced reactors, support the re-discussion on emergency planning. For example, the Utility Requirements Document (URD), which was established by American Electric Power Research Institute (EPRI), asks for a competitiveness emergency planning for advanced LWRs to achieve the good neighbor policy (EPRI, 1992). In addition, the European Utility Requirements (EUR), which was developed by major European power producers jointly, also request the simplification of emergency planning for future LWRs and give out some specific targets that future LWR NPPs should strive to achieve (EUR, 2002). Except these utility requirements, there are also some studies on the EPZ evaluation for advanced reactors (Lee, 2004; Huang et al., 2011) supporting the reduction of EPZ from technical view. This trend or requirements to reduce the scope of EPZ for LWR NPPs seems being abandoned since Fukushima, but the case is different for small modular reactor, like HTR.

For HTR, the thermal power of single module is much smaller than most commercial LWRs. In addition, the design concept, system configuration and accident characteristics of HTR are also much different. Taking HTR-PM for instance, its features of negative temperature feedback for whole scope, special designed pebble fuel and passive heat removal ensure the elimination of severe core damage and large release of radioactive material (Zhang et al., 2016). This results in much difference in accident characteristics, which allows more emergency response time before the release of accidents. As a consequence, the corresponding requirements to emergency preparedness and response should also be reappraised based on the characteristics of HTR-PM. The

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EPZ, which is considered as an essential element of emergency planning, where preparedness should be carried out (NRC, 1978) will be detailedly discussed in this paper.

The early practice of EPZ development for HTR was carried out on the Modular High-Temperature Gas-Cooled Reactor (MHTGR) designed by U.S. Department of Energy. NRC reviewed the safety of MHTGR and suggested that the emergency planning should be based on the design features of advanced reactor. Specifically, the ability of preventing large release of radioactive material and more response time before the release of accidents in MHTGR should be taken into account (Williams et al., 1989). Apart from the practice in MHTGR, the current emergency planning regulation, Section 50.47 of 10 CFR Part 50 (NRC, 2016a), also clarifies that the EPZ of HTR should depend upon the particular design of the plant.

This paper will conduct a detailed study on EPZ issue of HTR-PM. During the calculation, special attention will be paid to the unique design characteristics and accident features of HTR-PM and finally gives out the scope of EPZ from technical perspective. At the same time, this work will support the emergency planning development on the first demonstration plant of HTR-PM being constructed in China.

This paper is organized as follows. Section 2 outlines the principles and methodology of EPZ development for HTR-PM. Section 3 is a detailed introduction of the selected emergency planning reference accident sequences for HTR-PM. The calculation results are given in Section 4. This paper is concluded in Section 5 with a discussion about the potential influence of the resulted EPZ to the emergency planning of HTR.

2. Principle and methodology

The principles for EPZ development define the EPZ structure, the rule for choosing basis accidents and the dose criteria to determine the EPZ scope. The methodology refers to the technical framework used to manage and carry out the calculation. Since there are no ready-in-hand principles and methodology for HTR-PM, the stipulation and practice ~~for~~ in other reactors will be taken as references.

IAEA updates the EPZ for LWRs after The Fukushima Daiichi Accident and suggests four areas which need to be identified in advance during the preparedness stage around the NPPs to ensure the prompt implement of protective actions and other response actions. The four areas are precautionary action zone (PAZ), urgent protective action planning zone (UPZ), extended planning distance (EPD) and Ingestion and commodities planning distance (ICPD) (IAEA, 2013). Their suggested sizes (shown in Table 1 below for reactors with different thermal power) and requirements are also updated compared to the given values in IAEA safety guidance No.GS_G_2.1 (IAEA et al., 2007) and technical document IAEA-TECDOC-935 (IAEA, 2003). It can be known that EPZ in IAEA is protective action oriented.

In the United States, EPZ is defined for exposure pathways. One is for plume exposure pathway and named as plume emergency planning zone (PEPZ), the other is for ingestion exposure pathway and named as ingestion emergency planning zone (IEPZ). This EPZ structure was defined in NUREG 0396 and then written in 10CFR Part 50.47 by NRC. NRC developed EPZ by the conservative consequence of DBAs and the best estimated consequence of Class 9 accidents, which was weighted by the meteorological distribution and frequency of scenario occurrence.

Table 1
Suggested sizes for emergency zones and distances – IAEA.

Emergency zones and distances	Suggested maximum radius (km)	
	≥1000 MW (th)	100–1000 MW (th)
PAZ	3–5	
UPZ	15–30	
EPD	100	50
ICPD	300	100

In China, the principles and methodology for EPZ development of LWRs are published in the national standard GB/T17680.1 (CNNAEO, 2008), in which the technical framework introduced by NUREG-0396 is adopted. The EPZ is also defined for exposure pathways and the accidents considered include DBAs and more serious accidents sequences.

Table 2 below lists the type and size of EPZ in some countries (Zhao and Qiu, 2003).

Although the suggested LWRs-based EPZ size given in GB/T17680.1 is not applicable for HTR-PM, the EPZ structure, the rules for choosing reference accidents, the dose criteria and the corresponding estimation method in it are generally applicable for all types of NPPs. The rules and criteria are outlined below:

(1) The accidents that are required to be considered for developing EPZ shall include DBAs as well as severe accidents. But for the severe accidents with very low occurrence frequency could be excluded to avoid the unreasonable cost.
(2) The size for PEPZ should fulfill the following two requirements: (a) when the most serious accident sequences occur, the maximum possible projected dose to an individual outside the PEPZ shall not exceed the intervention levels stipulated in *Basic Safety Standard 115* (IAEA et al., 1996). (b) The projected doses corresponding to the specific protective actions for all considered DBAs and severe accident sequences should be lower than the generic intervention levels stipulated in *Basic Safety Standard 115* beyond the PEPZ.
(3) The size of IEPZ should satisfy that the contamination level of food and drinking water outside the IEPZ for the considered severe accident sequences shall not exceed the generic intervention levels stipulated in *Basic Safety Standard 115*.

The EPZ calculation and analysis method for HTR-PM also follows the current general framework of LWRs. Firstly, the emergency planning reference accident sequences are determined for HTR-PM. Then, source terms are estimated for these selected emergency planning reference accident sequences. After that, the radiological consequence and contamination level of food and drinking water are evaluated using appropriate weather sequences, dispersion model and dose evaluation method. Finally, the size of EPZ for HTR-PM is determined from the technical perspective by comparing to the dose criteria listed above.

3. Emergency planning reference accident sequences

In this section, the principles for the determination of emergency planning reference accident sequences will be explicated. Then, these reference accident sequences will be figured out from all the accidents of HTR-PM. Finally, the source term estimation will be conducted for the release information needed in Section 4.

3.1. Principle

One of the most fundamental part of emergency planning is to decide the scope of accident sequences, i.e. the emergency planning reference accident sequences.

For LWRs, U.S. considers the accidents classification in the Appendix D of 10 CFR Part 50 (NRC, 2016b), in which the accidents are divided into nine classes: the Class 1 to 8 include anticipated operational events and DBAs, while the Class 9 refers to those that