Annals of Nuclear Energy 109 (2017) 220–226

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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

Investigation of radiation shielding of the Containment Filtered Venting System for the various operating condition

Minhwa Kim *, Youngsuk Bang, Doo Yong Lee

FNC Technology Co., Ltd., South Korea

ARTICLE INFO

Article history:
Received 23 May 2016
Received in revised form 17 September 2016
Accepted 8 May 2017

Keywords:
Containment Filtered Venting System
Radiation shielding
Source term estimation

ABSTRACT

In order to prevent the uncontrolled large release of radioactive materials to the environment due to containment failure, Containment Filtered Venting System (CFVS) has been considered as the one of effective measure to prevent the containment over-pressurization. Because the filtered radioactive materials are captured and accumulated in the CFVS components, the CFVS becomes the source of the radiation and this radiation should be properly shielded to protect the field workers. In this study, the effect of CFVS operation pressure on the required shielding wall thickness is investigated in various accident scenarios. The accident scenarios considering the type of initial accident and condition of external safety injection besides the CFVS operation pressure were simulated. The source terms were obtained using the MAAP5 and ORIGEN-ARP code calculation. The effective dose rate and required shielding wall thickness were estimated by the MICROSHIELD code. Consequently, the shielding wall was necessary and the CFVS operation pressure affected the required shielding differently depending on the conditions of external safety injection. As a result, the lower operation pressure of CFVS was favorable in perspective with the low demand of shielding wall.

1. Introduction

Containment can be damaged by over-pressurization due to steam and non-condensable gas generation during severe accidents without containment long-term cooling. In order to prevent the uncontrolled large release of radioactive materials to the environment due to containment failure, Containment Filtered Venting System (CFVS) has been considered as the one of effective measure for depressurizing the containment. The main idea is to vent the containment atmosphere to the environment after filtering the radioactive aerosols and vapors using the CFVS. Because the filtered radioactive materials are captured and accumulated in the CFVS components, the CFVS becomes the source of the radiation. This radiation from the CFVS should be properly shielded to protect the field workers who are essential to operate the CFVS and conduct the recovery actions during the accident. The resultant radiation dose which affects the field workers should be as low as possible considering reasonable limits.

The estimation of types and amounts of the radioactive isotopes in the CFVS is important since this is the basis input for the whole shielding analysis. In the past, averaged source terms such as TID-14844 or NUREG-1465 is usually adopted as the license-based source term (Park et al., 2004). However, these source terms are estimated a bit conservative and the operation of CFVS is not considered. When the operation of CFVS is considered, the progress of the accident is additionally changed by reducing the pressure of containment building and affecting the injection of SI, water level of containment etc. Therefore, source terms are needed to be newly estimated considering the operation of CFVS in various accident scenarios. The source term also is expected to be affected by the CFVS operating condition such as the vent starting pressure. Since the recommendation for the reasonable CFVS operating pressure is not established, various CFVS operating pressures are better to be considered in the investigation for the shielding of CFVS.

In this study, the shielding analysis is performed to investigate the radiation shielding for the CFVS operation on the required radiation shielding wall thickness of CFVS. The source terms of various accident scenarios are estimated by analyzing the severe accidents with numerical code. Minimum wall thickness of concrete building to be satisfied the dose limit is achieved from the shielding analysis. Finally, the effect of various CFVS operation conditions on the required shielding wall thickness is investigated. In Section 2, the radiation dose limitation in this study and the analyzing methods are described. The detail modeling of severe accident simulation and the results for the source term estimation are presented in

* Corresponding author.
E-mail address: minhya@fnctech.com (M. Kim).

http://dx.doi.org/10.1016/j.anucene.2017.05.010
0306-4549/

Section 3 and modeling and the results of the shielding analysis are presented in Section 4. In Section 5, the behavior of required shielding due to the various CFVS operation conditions are summarized.

2. Methodologies for shielding analysis

2.1. Limit of radiation dose

The limit of radiation dose during the normal plant operation or design-basis-accident is well proposed while the limit of radiation dose due to the severe accident is not suggested but only the cancer risk from the Level 3 PSA is mentioned. According to the Nuclear Safety and Security Commission, it is allowed that the personnel performing inevitable and vital recovery action can be exposed to the 500 mSv of effective dose and 5 Sv of equivalent dose for the skin. On the other hand, specific limit of radiation dose from the operation of CFVS during the severe accident is presented in the Swiss and Sweden radiation emergency plans as less as 100 mSv for the local operating personnel. Korea Institute of Nuclear Safety also suggested that 100 mSv of effective dose limit for the operating of CFVS (Korea Institute of Nuclear Safety, 2003).

Because the limit of radiation dose for the CFVS is not determined yet, the criterion for the shielding analysis in this study is selected referring previous research as 100 mSv of effective dose which is more conservative than others. The targets to protect from the radiation in this study are the personnel who reside at the plant site. Therefore, the reference point is assumed as 100 m away from the shielding wall. The recovery conducting time is assumed as 10 h for the one personnel considering the on-duty hours and simplicity, and conservatism of calculations. Consequently, the allowable maximum effective dose rate is selected as the 10 mSv/hr at the 100 m away from the shielding wall in this study.

2.2. Shielding analysis method

There are two main steps for the shielding analysis. The radiation source term within the shielding structure should be given or evaluated firstly. For the research of specific source term evaluation, numerical codes for the simulation of severe accident such as MELCORE or MAAP are widely used since the change of core inventory, accident scenarios, plant configuration etc. affects the details of source term. In this study, MAAP5 (MAAP5, 2008) and ORIGEN-ARP (Bowman et al., 2000) were used to simulate the time-dependent amount of radioactive elements in the CFVS. MAAP5 simulates the severe accident and transporting behavior of materials from the core to the CFVS. Since radioactive physics is not considered in MAAP5, the transformation of nuclides is considered using ORIGEN-ARP in parallel to take into account time-dependent variation of radioactive elements composition in the CFVS to obtain more realistic source term. The radiation dose rate at the interesting dose point is evaluated after the estimation of source term. The shielding structure is designed to reduce the calculated radiation dose rate to satisfy the limit. In this study, the simple rectangular concrete building was assumed and the proper wall thickness was deduced. The shielding calculations were performed using MICROSHIELD (Negin et al., 1986) codes which is based on point-kernel method and focus on the calculation the dose caused by gamma ray source because main radiation for the CFVS shielding is gamma ray since other type of radiations are easily shielded with the concrete wall. As a result, necessary shielding wall thickness was induced by MICROSHIELD code.

3. Source term estimation

3.1. Modeling of CFVS operation in severe accident simulation

The severe accident analysis is performed to calculate the source term. In this study, calculation results in the previous research, reference Lee et al. (2015) are utilized. Optimized Power Reactor 1000 (OPR1000) was selected as the subject nuclear plant in reference Lee et al. (2015). OPR1000 is a 1000 MWe PWR nuclear reactor which was developed and has been operating in Korea. Key parameters of OPR1000 are described in Table 1.

The CFVS is not modeled precisely in the severe accident simulations because the released amount of radioactive material is the only a matter of issue in this analysis. The source term of CFVS is determined as the radioactive material released to the environment in the simulation by simply assuming a flow path connecting the annular compartment of the containment and the environment. This means that the 100% of filtration through the CFVS which brings more conservative results in the shielding analysis. On the other hand, the noble gases cannot be captured but only pass through the CFVS. Hence, they are assumed to be just filled in the CFVS with the density in the containment. The density of noble gases in the containment is assumed as the maximum averaged density considering the free volume of containment and maximum mass of noble gases in the containment.

The time-dependent radiation source term in the CFVS is obtained considering release from the core, natural removal in the containment, mass transfer to the CFVS and radioactive decay of nuclides. The time-dependent released mass fractions of radioactive elements to the CFVS are calculated by MAAP5. The released mass of materials categorized into 18 groups in the MAAP5 as shown in Table 2 are obtained. This can be converted as the released mass fraction against the initial inventory mass about each element. It is assumed that the released mass composition in a group is considered to be identical with that of initial core inventory. The release fraction of element which cannot be simulated in MAAP5 such as Br and Se are assumed to be same with that of chemicals which has similar property. For example, Br is assumed to be released with same fraction of I. Each fraction is multiplied with the radioactively decayed mass of each element in the core inventory obtained by ORIGEN-ARP to induce the radioactive element mass in the CFVS considering the radioactive decay. The daughter elements are assumed to be released with same fraction of mother element to simulate the decay of materials in the CFVS simply in this study. Elements with half-life longer than years or with small quantity are ignored.

Since the composition of radioactive nuclides within the CFVS changes in time, time points are selected as every 1/3 time of each venting duration and 100 h after the onset of accident and time point which shows the maximum total decay heat deposited to the CFVS in MAAP5 simulation as shown in Fig. 1. As a result, the time-dependent mass of each isotope is obtained and this can be

Table 1
Key parameters of OPR1000 Plant Characteristics.

Parameter	Value
Reactor thermal power (MW_{th})	2815
Mass of uranium dioxide (lb)	189,900
Mass of zircaloy (lb)	54,327
RCS operating temperature (F)	592.9
RCS operating pressure (Psia)	2250
RCS volume (ft^3)	11,963
Containment design pressure (psig)	57
Containment design Temperature (F)	285
Containment free volume (ft^3)	2.7E+06